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İTÜ FACULTY of TEXTILE TECHNOLOGIES and DESIGN

INTERNATIONAL ITFC 2023 TEXTILE & FASHION CONGRESS

INTERNATIONAL TEXTILE & FASHION Congress

Proceeding Book

"Innovative textiles and fashion trends tackling global challenges"

16-17 March 2023
ITU Gümüşsuyu Campus
Taksim / Istanbul

www.itfc2023.com

Dalya

International Textile and Fashion Congress ITFC 2023

March 16-17, 2023 / Istanbul

Proceeding Book

Editors, Prof. Dr. Nazan Okur, Prof. Dr. Canan Sarıçam, Assoc. Prof. Dr. İkilem Göcek

Istanbul, 2023

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INVITATION

Dear Colleagues,

It gives me a great pleasure to invite you to the International Textile & Fashion Congress | ITFC 2023 which will be organized in Istanbul -where two continents meet- Türkiye on March 16-17, 2023, hosted by Istanbul Technical University (ITU).

We have organized international & national congresses and R&D days for our community through-out 40 years in irregular sequences up-to-now, neverthless hereafter, our purpose is to commence a new bi-annual international textile congress series at ITU starting from year 2023 for our distinguished community in view of the fact that year 2023 is an extremely significant year for us: 250th anniversary of Istanbul Technical University, 100th anniversary of Turkish Republic and 40th anniversary of Textile Engineering Department, ITU.

In the core of Istanbul, our aim is to organize a meeting point for all textile & fashion/retail researchers as well as fashion designers around the world at the Department of Textile Engineering at Gumussuyu/Beyoglu. We are expecting to strengthen connections with our colleagues, industry members and professionals from across the world, along with sharing our knowledge and experience on innovative textiles and fashion trends tackling global challenges at a new era after pandemics. Thus, we aim to mention the importance of textile in all global struggles that have affected the whole world since 2019 and to witness the latest developments in textile & fashion.

ITFC2023, which is gathered under the six main titles listed below, includes extensive focus areas with numerous sub-titles.

Pandemic & Well-Being
Defense & Security
Climate Crisis & Environmental Pollutions
Digitalization & Management
Fashion & Comfort
Fashion Retailing & Marketing

ITFC2023 will be organized as plenary and parallel sessions according to the topics of the presentations. We invite you to submit your full manuscript prepared according to the guidelines enclosed before the February 15th, 2023. The abstracts that are submitted will be evaluated by the symposium scientific committee and the accepted presentations and the scientific program will be announced. We recommend you to submit the results of your valuable research work at the abstract submission of the "International Textile & Fashion Congress" website platform.

Hope to see you on 16-17th of March 2023.

Yours sincerely,

Ömer Berk BERKALP, Prof.Dr.

ORGANIZATION COMMITTEE

SCIENTIFIC COMMITTEE

Prof.Dr.Abdel-Fattah Seyam North Carolina State, USA	Prof. Dr. Sibel Kaplan Suleyman Demirel University, TURKEY
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Asst.Prof.Dr.Fatma Baytar Cornell University, USA	Prof. Dr. Ziynet Öndoğan Ege University , TURKEY
Prof.Dr.Bülent Özipek Istanbul Technical University, TURKEY	

KEYNOTE SPEAKERS

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Rudolf Hufenus

Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

Rudolf Hufenus has specialized on technical textiles, carrying out research leading to his PhD. In 2003 he initiated Empa's fiber research and development laboratory. Since the installation of a pilot multicomponent fiber spinning plant in 2004, as well as associated polymer processing and analytical equipment, he gained expertise through R&D activities pertaining to extrusion and melt-spinning of different polymer systems and the incorporation of liquids and nanomaterials. He is responsible for numerous completed and ongoing industry-related projects aiming at novel synthetic fibers, and he is involved in projects focusing on fundamental fiber research. He was a visiting scholar at NC State University, and he published over 200 pertinent publications with an h-factor of 25. He is also an active member of The Fiber Society and of the Polymer Processing Society.

Title & Content of Speech at ITFC2023:

"Development and prospect of bicomponent and liquid-core filaments"

Empa's Laboratory for Advanced Fibers focuses on the development of novel synthetic fibers. In the last 80 years, melt-spun filaments became by far the most important fibers for apparel, but even more so for technical textiles, where they spawned a myriad of novel applications. In the development of innovative textiles, product enhancements on the fiber level are most effective. The beauty of bicomponent melt-spinning is that it can combine the chemical and physical properties of two different polymers in a single filament, not only as core and sheath, but also in an impressive number of other cross-sectional configurations. The aim of this presentation is to provide information about the current state of research and development regarding melt-spun bicomponent filaments (BiCoFs). The first BiCoF was already commercialized in the mid-1960s, while melt-spinning a liquid-core filament (LiCoF) in a single processing step is a very elegant alternative that has been developed by Empa rather recently. Here, a capillary injector, which is connected to a high-pressure liquid pump that forces an incompressible liquid into the pressurized polymer melt just before the die exit, yields a melt strand with liquid core that is subsequently quenched and drawn to achieve a filament with high tensile strength. The ability to produce a continuous LiCoF is attractive since post-filling of a fine hollow filament would become increasingly slow at extended lengths. This overview provides insights in bicomponent melt-spinning technology, with a strong focus on novel developments and application prospects.

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Arzu Kaprol

Arzu Kaprol graduated from Mimar Sinan University, Textile and Fashion Design in 1992. She continued her couture education in Paris. In 1995 she received prestigious "Avant-Garde Designer" award from Beymen Academia and founded her design studio at the age of 21. She worked as creative director of Network – Beymen Group of companies, from 2002 till 2012. She participated and performed her shows at Paris Fashion Week, from 2011 till 2015 where she also opened her showroom. Arzu Kaprol collaborated with Vodafone Turkey and realized 3 different technological fashion performances. In 2015 Turkey's first hologram show and, in 2016 Turkey's first Digital Symphony has been realized with a multi-disciplinary approach combining design, music, dance and technology. Same year Arzu Kaprol's digital couture show took place in national and international arena. In 2015 Arzu Kaprol also created one of the first prototypes of contextual smart-wear; a jacket that morphs its shape and functionality with climate change. Arzu Kaprol creates fashion as architecture with unique workmanship in details identified with the designer, timeless design and accessories, which refers to fashion culture of the future.

Title & Content of Speech at ITFC2023:

"An interdisciplinary approach to innovation and sustainability from a human innovation designer perspective"

In the creation process, the cyclical design perspective and methodology are crucial for creating a sustainable textile system. In a sustainable fashion world; there must be a system in which you build a life together on a principle of respect, in which you include everyone, every living thing, every being, starting from the whole. This process is reflected in the design world through the same principles. The purpose of this keynote speech is to inspire the creation of future fashion codes that are correct, sustainable, and appropriate. Our aim is to determine the place of technology and innovation in a sustainable fashion world.

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Alper İlki

ITU Structural Engineering, Turkey

Dr. Alper İlki is a professor of structural engineering at Istanbul Technical University. His research interests include the structural behavior of reinforced concrete and masonry structures. Other main fields of his research interests are large scale structural testing and structural/seismic retrofitting, particularly through innovative techniques and materials. He is the editor of Turkish Journal of Civil Engineering, associate editor or editorial board member of ASCE Journal of Structural Engineering, ASCE Journal of Composites for Construction, Arabian Journal for Science and Engineering and Bulletin of New Zealand Society of Earthquake Engineering. He co-edited three international books published by Springer titled Seismic Risk Assessment and Retrofitting, Seismic Evaluation and Rehabilitation of Structures, and Advances in Assessment and Modeling of Earthquake Loss. Dr. Ilki is an elected member of the IIFC Council, head of Turkish Delegation to fib, chairman of the executive committee of Turkish Earthquake Foundation and a member of the board of Turkish Catastrophe İnsurance Pool. He chaired/co-chaired the organization committees of Smart Monitoring, Assessment and Rehabilitation of Civil Structures International Conference Series and the 10th International Conference on FRP Composites in Civil Engineering, CICE 2020/2021, the official conference of IIFC, as well as the fib Symposium in 2023, among many others.

Title & Content of Speech at ITFC2023:

“Earthquake-resistant carbon fiber reinforced structures”

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Behnam Pourdeyhimi

Wilson College of Textiles, North Carolina State University, USA

Dr. Behnam Pourdeyhimi joined NC State immediately after completing his Ph.D. at the University of Leeds in 1982. Soon, he left for other opportunities, Cornell (2 years), University of Maryland (11 years), and Georgia Tech (4 years) before returning to NC State in 1998-1999 Academic year. Behnam is the William A. Klopman Distinguished Professor of Materials in the Wilson College of Textiles at NC State University and is also an adjunct professor in the departments of Chemical and Biomolecular Engineering and Biomedical Engineering. He also serves as Associate Dean in the Wilson College of Textiles and is the Executive Director of The Nonwovens Institute. Early in his career, he focused on the development of tools for characterizing various materials including nonwovens, medical devices, composite materials, etc. For this body of work, he received the ASTM D-13 Dewitt Smith Medal. In particular, his work on image analysis won him the Fiber Society Distinguished Scientist award in 1994. He also was selected as the Fiber Society Lecturer where he traveled broadly to present his work to industry and academia. He later served also as the vice president, and the president of the Fiber Society. He is best known for his contributions to nonwovens and establishment and the growth of nonwovens at NC State. His work in the area of filtration won him the O' Max Gardner award in 2015 (The Highest award by the University of North Carolina System), and in 2018, he received The Holladay Medal for Excellence (The highest faculty award bestowed by NC State University). In 2020, Behnam was inducted into the National Academy of Inventors as a Fellow. He joined NC State in part to take on a leadership role in the Nonwovens Cooperative Research Center (NCRC). Under his vision, the center morphed into the Nonwovens Institute (NWI). NWI is the largest university-based research institute in the nation across all disciplines. Today, NWI is the world's first accredited academic program for the interdisciplinary field of engineered fabrics. Operating on an “Open Innovation” platform, the Nonwovens Institute engages experts from industry and higher education in building next-generation nonwoven applications while also providing training and guidance to the field's future leaders. He has published several books and monographs, over 375 refereed journal articles, and over 250 conference presentations. He is the recipient of The Fiber Society Young Distinguished Achievement Award (1994) and Fellowship of the Textile Institute (1994). He served as the President of the Fiber Society in 1995. His students have won several awards, including the Fiber Society Best Paper award and the INTC Best Paper Ward. Dr. Pourdeyhimi's research interests are in the area of nonwovens, biomaterials, modeling, image analysis, and filtration. His expertise is recognized by major corporations and leading research bodies around the world. He has acted as a consultant to many bodies and major Corporations.

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Amy Sperber

Fashion Insistute of Technology, New York, USA

Amy Sperber is a highly accomplished fashion designer, consultant, and educator who currently serves as an assistant professor at the Fashion Institute of Technology (FIT) in New York. She holds BFA and MFA degrees from FIT. Her graduate work focused on using body scanning and custom avatar development to create dynamic patterns for adaptable, on-demand fashion design. Sperber is passionate about exploring upcycling and alternative manufacturing systems and is a proponent of 3D printing technology as a tool for fashion customization. With over a decade of experience as a fashion designer for mass-market brands like The Gap, Juicy Couture, and Delias, she has shifted her focus to design that aid consumers and supports healing. She has collaborated with doctors and specialists on several projects and is working on a multi-institution cancer garment set for clinical trials in 2024. Sperber has also launched an open-source fashion avatar database for designers, sponsored by NYSCA and available at www.fashionavatars.org. In her free time, she designs 3D character costumes for a science fiction world of her own creation.

Title & Content of Speech at ITFC2023:

"3D Fashion and Body Diversity: Building an Inclusive Future through Avatar Technology"

This keynote presentation will explore the intersection of 3D fashion, body diversity, and technology. With the rise of 3D design and virtual try-on in the fashion industry, it is crucial to consider the representation of diverse body types in virtual models. This presentation will address the current limitations in the industry and share the grant-funded development of a diverse 3D avatar database as a solution. This free database consists of a wide range of body shapes, sizes, and abilities, allowing designers to create clothing that accurately reflects the diversity of human bodies. By doing so, the fashion industry can become more inclusive and better serve the needs of a broader range of customers. Join me as we explore the exciting potential of diverse 3D avatars in shaping the fashion industry's future.

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SCIENTIFIC PROGRAM

ITFC 2023 — **16 March 2023, Thursday** — Scientific Program

Time	Hall A	Hall B (Main Hall)	Hall C
08:30-09:30	Registration		
09:30-10:30		**Opening Speeches**	
10:30-11:00	Coffee Break		
11:00-11:20		Keynote 1 **Rudolf HUFENUS**, PhD, Empa, Swiss Federal Laboratories for Material Science and Technology, Switzerland	
11:20-11:40		Keynote 2 **Arzu KAPROL**, Innovation Designer, Entrepreneur, Turkey	
11:40-12:00		Keynote 3 **Alper İLKİ**, Prof.Dr., ITU Structural Engineering, Turkey	
12:00-13:00	Lunch		
	Hall A	**Hall B** (Main Hall)	**Hall C**
13:00-14:00	Session 1 **Waste Water Management** Chair: Rudolf HUFENUS	Session 2 **Sustainability in Dyeing and Printing** Chair: Recep EREN	Session 3 **Fashion Retailing and Marketing** Chair: Nesrin TÜRKMEN
13:00-13:15	Color Removal Of Disperse Dyeing Waste Water By Ozone In An Example Dyehause Semiha EREN, **Hüseyin Aksel EREN**, Irem OZYURT, Gizem BAYAÇLI	Investigation Of The Dyeability Of Cotton Fabrics With Bacterial Colorants **Hülya KICIK**, Çağla GÖKBULUT	External Benchmarking Among Private Sale Websites Having Different Retail Business Models **Canan SARICAM**, Nazan OKUR
13:15-13:30	Wastewater Recycling Practices In Textile Industry And Challenges Ahead **Seyedmansour BIDOKI**, Ali DEMIR	Use Of Organic Dyestuffs In Luxurious Fiber Fabric Printing **İsmet Ege KALKAN**, Ayşegül İLKENTAPAR, Figen TEMİZ-DİŞLİOĞLU, Serap ÖZEL, Hamit KAYA, Tuğçe SAVAŞKAN, Elcin EMEKDAR, Umut Kıvanç ŞAHİN	Authentic Fashion Brand Csr Through Effective Social Media Marketing And Branding Communications: A Case Study Approach **Bruce W. Carnie,** Rubab Ashiq, Lucie Pocinkova, Yuri Siregar
13:30-13:45	Separation And Identification Of Microfibers In The Wastewaters Of Textile Finishing Process **Sinem Hazal AKYILDIZ**, Rossana BELLOPEDE, Silvia FIORE, Bahattin YALCIN, Hande SEZGIN, Ipek YALCIN-ENIS	Effects Of Alkaline Conditions On Natural Dyestuff Extraction From Black Carrot And Fabric Performance **Elçin EMEKDAR**, İsmet Ege Kalkan, Umut Kıvanç ŞAHİN, Bensu ÖTEV, Betül Şura ÖZDEM, Yaren MASIR	Exploring Effectiveness Of Celebrity Endorsement: Case Of A Turkish Luxury Fashion Brand **Ege GAZİOĞLU**, Lalın ADIGUZEL
13:45-14:00	Natural Organic Dye Standard (Nods) **Recep KARADAĞ**	Investigation Of Recycled Cotton Dyeing With Rubia Cordifolia And Bio-Mordant Chitosan **Tuba TOPRAK-CAVDUR,** Serkan UYSAL, Raquel BELDA-ANAYA, Jaime GİSBERT-PAYA	The Service Quality Dimensions For Different Type Of Retailers In B2B Industry Zeynep Kavitaş DURGUN, **Sinem BIRSEN**, Canan SARIÇAM
14:00-15:00	Session 4 **Sustainability in finishing** Chair: Dilek KUT	Session 5 **Sustainability** Chair: Hale KARAKAS	Session 6 **Textile Based Composites** Chair: Gaye KAYA
14:00-14:15	The Reduction Of Size Consumption With Novel Pre-Wetting Box **Hasan ÇAKİR**	Development Of Banana Fibers Blended Yarn As An Eco-Friendly Alternative To Cotton Yarns For Clothing **Faheem AHMAD,** Yasir NAWAB, Sheraz AHMAD	Production And Characterization Of Basalt Fiber/Pet Composites **Melis Eldem EKSEN**
14:15-14:30	Effect of UV Treatment on Hydrophilicity and Whiteness Properties of Hemp Fabrics Semiha EREN, **İdil YİĞİT,** Buket MECİR, Ozan Avinç	Sustainable Carpet Design With Rpet/Pan Pile Yarn **Halil Ibrahim ÇELIK**, Mehmet ERDOĞAN, Ismail Emre DOĞAN	Thermal Insulation And Sound Absorption Properties Of Fibrous Layered Structures **Nazan OKUR**, Canan SARIÇAM, Nuray UÇAR, Nevin Çiğdem GÜRSOY
14:30-14:45	Design Of Novel Water Repellent Finish With Low Environmental Impact **Durul Büşra DİLDEN,** Seda KESKİN, Elcin EMEKDAR, Ismet Ege KALKAN, Cansu ESKİTÜRK, Beril YALIN, Umut Kıvanç ŞAHİN	Reducing Microfiber Pollution: Biodegradable Pet Yarn **Melis Eldem EKSEN**	The Effect Of Hemp Waste Reinforcement On Polyurethane Foam Composites Betül KALEBAYIR DAĞPARÇASI, Ömer Berk BERKALP, **Gaye KAYA**
14:45-15:00	An Ecological Softener Application To Chenille Yarn Halil Ibrahim ÇELIK, Ibrahim Halil TEKİN, **Serdar SAYCAN**	Denim Fabric Production With Enhanced Anti-Oxidant Activity **Kübra SABANCI KAPUKAYA,** Cem GÜNEŞOĞLU	Yarn Pull-out and Drop Weight Impact Performance of Shear Thickening Fluid Impregnated Ballistic Fabrics **Canan SARİCAM**, Nazan OKUR
15:00-15:15	Coffee Break		
	Hall A	**Hall B** (Main Hall)	**Hall C**
15:15-16:15	Session 7 **Functional Textiles** Chair: İsmail USTA	Session 8 **Recycling and Life Cycle Analysis** Chair: Hüseyin Aksel EREN	Session 9 **Digitalisation and Industry 4.0** Chair: Ümit Halis ERDOĞAN
15:15-15:30	Ecofriendly Production Of Functional Face Masks **Gülbahar SAAT**, Ali DEMİR	A Case Study For Life Cycle Assessment Of Textiles **Hale KARAKAŞ**, Ebru AKDUMAN	Challenges In The Adaptation Of Clothing Production Companies To Industry 4.0: A Case Study **Abdurrahim YILMAZ**, Engin AKÇAGÜN, Nuray CEVİZ
15:30-15:45	Examination Of Acoustic Properties Of Polymer Coated Nonwoven Textile Samples **Gözdenur ULU**, Ikilem GÖCEK	Chemicals Management In The Textile Industry: Challenges And Possible Strategies For A Transparent And Sustainable Supply Chain **Aslihan MEMİSOGLU**	Future Fashion Factory: Developing An Eco-System To Support Sustainable Change **Kevin Almond,** Susan Rainton
15:45-16:00	Performance Properties Of Firefighter Flame Retardant Underwear Fabrics **Ahmet ORUÇ,** Fatma DEMİRCİ, Kübra ÖZŞAHİN, Hatice ÖZEL, Hatice Kübra KAYNAK	Investigation Of Environmental Load Of Textile Raw Materials In Soil After Final Use In Different Forms And Natural Conditions Sümeyye KES, **Neslihan OKYAY**, Fatih IŞIK	Digitalised R&D And Production In The Textile Industry For Reduced Energy Consumption And Efficient Production Rates **Murphy Murat PEKŞEN**, Cevza CANDAN, F. Banu NERGIS, Bilge KOYUNCU
16:00-16:15		Keynote 4 **Behnam POURDEYHIMI**, Prof. Dr., Wilson College of Textiles, NCSU, USA	Lean Management And Digitalisation In Apparel Manufacturing Process **Bulent KOC**, Selin Hanife ERYURUK
16:35-16:55		Keynote 5 **Amy SPERBER**, Assist. Prof., Fashion Institute of Technology, USA	
19:00	Gala Dinner (Skyview Restaurant)		

	Hall A	Hall B (Main Hall)	Hall C
09:30-10:30	Session 10 **Sustainability in Textiles** Chair: Perrin AKÇAKOCA KUMBASAR	Session 11 **Smart and E-Textiles** Chair: Fatma KALAOGLU	Session 12 **Quality And Performance In Functional Textiles** Chair: Ozer GOKTEPE
09:30-09:45	Quantitative Chemical Analysis Of Poplar And Polyester Blended Nonwovens **Canan USTA**, Alper GURARSLAN	Electrochemical-Mechanical Characterization Of Electrically Conductive Multi-Component Fibers For Textile Displays, Sensors, Actuators And Energy Storages **Simon KAMMLER,** Thomas GRIES	Effects Of Crease Recovery Finishes On Bursting Strength Of Knitted Fabrics **İsmet Ege KALKAN,** Hatice AÇIKGÖZ TUFAN, Elçin EMEKDAR, Umut Kıvanç ŞAHİN, Senem KURŞUN BAHADIR, Cansu BATÇIK GENÇ, Hatice Kübra BAYKAN, Esra ERİCİ, Ersen ÇATAK, Çağla Deniz ŞENTÜRK
09:45-10:00	Physical Properties Of Ring And Air Vortex Yarns Made Of Soybean, Recycled Polyester, Polyester And Viscose **G. Banu GÖKGÖNÜL**, Emel Ceyhun SABIR, Mehmet KERTMEN	Theoretical and Practical Aspects for Flat-Knitted Band-Stop Frequency Selective Surface Ibrahim ÜNER, Sultan CAN, **Banu Hatice GÜRCÜM**, Asım Egemen YILMAZ, Ertuğrul AKSOY, Irfan YOLCULAR	Comparison Of Physical Performances Of Pima Vs Local Cotton Fiber Fabrics **Elçin EMEKDAR,** Hatice AÇIKGÖZ TUFAN, İsmet Ege Kalkan, Umut Kıvanç ŞAHİN, Senem KURŞUN BAHADIR, Cansu BATÇIK GENÇ, Hatice Kübra BAYKAN, Esra ERİCİ, Ersen ÇATAK, Çağla Deniz ŞENTÜRK
10:00-10:15	Investigation Of R-Pet Fibers And Filaments To Be Used In Outdoor Textile Products **Zafer KAPLAN**, Nimet KÖLEOĞLU	The Effect Of Embroidery And Screen-Printing Techniques On The Fabrication Of Band-Stop Fss Ibrahim ÜNER, Sultan CAN, **Banu Hatice GÜRCÜM**, Asım Egemen YILMAZ, Ertuğrul AKSOY	Study On Tensile Properties of Compression Socks Ankle-Cut-Strips at Fixed Extension **Hafiz Faisal SIDDIQUE,** Ahmet Adnan MAZARI, Engin AKÇAGÜN, Abdurrahim YILMAZ
10:15-10:30	Environmentally Friendly Acoustic Panel Design from Curtain Waste **Gamze ACİKGOZ**, Onur AYDIN, Alp Yaman ALTUG, Hande SEZGIN, Ipek YALCIN-ENIS	Effect Of Alkaline Hydrolysis Process On The Physical And Electrical Properties Of Reduced Graphene Oxide Coated Polyester Knitted Fabric **Nergis DEMİREL GÜLTEKİN**	
10:30-10:45	Coffee Break		

	Hall A	Hall B (Main Hall)	Hall C
10:45-11:45	Session 13 **Medical and Biomedical Textiles** Chair: Ali DEMİR	Session 14 **Textile and Clothing Comfort** Chair: Emel ONDER KARAOGLU	Session 15 **Technical Textiles** Chair: Banu NERGİS
10:45-11:00	Synthesis Of Hydrocortisone Loaded Xerogel For Drug Delivery **Hisham Ali Muhammad Ali MOUSSA**, Özlem İpek KALAOGLU ALTAN, Burçak KAYAOĞLU	Increasıng The Fastness Values Of The Sulphur Dyed Woven Fabrics Using Cationic Polymer **İsmet Ege KALKAN**, Hande SAVAŞ, Özlem İNCİ, Elçin EMEKDAR, Umut Kıvanç ŞAHİN	Influence Of Carbon Fıber Non-crimp Fabrics Stitching Parameters On The Out-of-plane Permeability In Liquid Composite Molding Process **Gülnur BAŞER**
11:00-11:15	Design Of Alginate Based Advanced Wound Dressing **Nilay KAHYA**, F. Bedia ERİM, Alper GÜRARSLAN	Moisture Comfort Analysis Of Underwear T-Shirts From Sorption And Moisture Management Properties **Fabien SALAUN,** Adeline MAROLLEAU, Hayriye GİDİK, Daniel DUPONT	Competitive Analysis Of Turkish Composite Industry By Using Five Forces Model: Case Study **Engin AKÇAGÜN**, Nuray Öz CEVIZ, Abdurrahim YILMAZ
11:15-11:30	In Vitro Evaluation Of A Three Dimensional (3D) Knitted Scaffold For Tissue Engineering **Derya HAROGLU**	The Effect Of Alternative Lamination Materials On The Air Permeability Of Automotive Seat Fabric Structures **Semih OYLAR**, Nur Ceyda UYANIKTIR, Selenay Elif İŞLER	Durability Assesment Of Digital Pigment Inkjet Printing On Plasma Pretreated Natural Leather For Car Interior Design **Sanja ERCEGOVIĆ RAŽIĆ**, Martinia Ira GLOGAR, Franka ŽUVELA BOŠNJAK, Anja LUDAŠ, Dario SEJDIĆ
11:30-11:45	Morphological And Mechanical Assessment Of Electrospun Plga Vascular Scaffolds **Suzan ÖZDEMİR**, Janset ÖZTEMUR, Hande SEZGIN, Ipek YALÇIN ENIŞ	The Effect Of Mask Style And Fabric Selection On The Comfort Properties Of Reusable Fabric Masks **Adine GERICKE,** Jiri MILITKY, Mohanapriya VENKATARAMAN, Hester STEYN & Jana VERMAAS	
11:45-13:00	Session 16 **Technical Textiles** Chair: Nihal SARIER	Session 17 **Nanofibers and Nanomaterials** Chair: Fatma GÖKTEPE	
11:45-12:00	A Comperative Study On The Performance Of Side-By-Side Hollow Bicomponent Yarns **Merve BULUT**, Merve KÜÇÜKALI ÖZTÜRK, Cevza CANDAN, Banu NERGIS, Tuğba ZENGIN, Aysun YENICE, Rasim BOYACIOĞLU, Ecenur TOR	Polyurethane Nanocomposite Foams Incorporated With Organoclays **Emel Önder KARAOĞLU**, Nihal SARIER	
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12:15-12:30	Development Of Eco-Friendly Curtain Fabric Using Natural Dyes **Figen EMİR**	The Effect Of Polymer Concentration On Coaxial Electrospinning Of Pvp/Pcl Core-Sheath Nanofibers **Nursema PALA AVCI**, Nebahat ARAL YILMAZ, Banu NERGİS	
12:30-12:45	Natural Jute And Jute-Cotton Fabrics: Functionalized By Flame-Retardant Finish **Most Setara BEGUM**, Abdul KADER, Rimvydas MILAŠIUS	Fabrication And Analysis Of Pcl And Pla Based Coaxial Electrospun Fibrous Surfaces **Janset OZTEMUR**, Suzan OZDEMIR, Hande SEZGIN, Ipek YALCIN-ENIS	
12:45-13:00	Inovenso - Electrospun Nanofiber Based HEPA Filters - An Industrial Scale Production Approach **Busra Nur BULUN**	Sustainability in Textiles: A Case Study from Bossa **Besim OZEK**	
13.00-14:30	Lunch **Poster Session / Exhibition Tour (Textile Machines From Past to the Present)**		

	Hall A	Hall B (Main Hall)	Hall C
14:30-14:45	Session 18 **Clothing Technology** Chair: Cevza CANDAN	Session 19 **Design and Product Innovations** Chair: Sebnem BURNAZ	
14:30-14:45	Innovative Approaches To Pattern-Oriented Design **Birsen ÇİLEROĞLU**, Feride HASRET, Hande Ecem BULUŞ, Gizem TUNABOYLU	Woven Fabric Design With Knitting Seersucker Effect Ayçin ASMA, **Alper BURGUN**, Gizem DEMİREL, Sinem BUDUN GÜLAS	
14:45-15:00	A Design Of A Multifunctional Heated Coat **İsmet Ege KALKAN**, Salih SAFİOĞLU, Nil OKÇUOĞLU, Elçin EMEKDAR, Umut Kıvanç ŞAHİN, Senem KURŞUN BAHADIR	Textile Pattern Generation Using Diffusion Models **Halil Faruk KARAGOZ**, Gulcin BAYKAL, Irem ARIKAN EKSI, Gozde UNAL	
15:00-15:15	3D Garment Simulation As A Tool To Actualize The Design Ideas Of Fashion Students **Evrim BUYUKASLAN OOSTEROM**, Fatma KALAOGLU	Designing And Producing A Women's Underwear Based On Hosiery Knitting Machine **Füsun TAYAN**, Pınar MERİÇ, Belgin GÖRGÜN	
15:15-15:30	Investigation Of The Cracking Behaviour Of Sewing Threads Of Denim And Non-Denim Garments **Ismail İVEDİ**, Sibel TOPBASAN	Examination Of Equestrian Branches And Clothing **Nesligül KILIÇ,** Özgür CEYLAN	
15:30-16:00	Coffee Break **Closing Session (Awards)**		

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INTERNATIONAL TEXTILE & FASHION CONGRESS
ITFC 2023

İTÜ FACULTY of TEXTILE TECHNOLOGIES and DESIGN

Poster Session

P 01 Performance Of Knitted Fabrics Of Conventional And Specially Processed Pa Yarns Intended For Sportswear
Vesna Marija POTOČIĆ MATKOVIĆ, Ivana SALOPEK ČUBRIĆ, Goran ČUBRIĆ, Željka PAVLOVIĆ

P 02 Lettuce Quality Conditioned By Biodegradation Of Nonwoven Textiles From Cellulose Regenerate And Pla Biopolymer
Ivana SCHWARZ, Paula MARASOVIĆ, Ružica BRUNŠEK, Dragana KOPITAR

P 03 Heat Pump Tumble Dryer Drum Revolution Speed Impact On Dimensional Stability Of Jersey Knits
Muhammed Emin ÇOBAN

P 04 Biodegradation Properties Of Natural Fibres From Renewable Resources
Ruzica BRUNSEK, Ivana SCHWARZ, Dragana KOPITAR, Paula MARASOVIC

P 05 Design Of A Nipple Protector Nursing Bra
Ecem ALAGÖZ, Gülşah ŞEN, Naim ŞENER

P 06 The Impact Of Cellulose And Biopolymer Nonwoven Mulches On The Soil Health
Paula MARASOVIC, Dragana KOPITAR, Ružica BRUNŠEK, Ivana SCHWARZ

P 07 Virtual Garment Design: A Case Of Exclusive Fabrics And Trims
Sigla KAYNAK, Evrim BUYUKASLAN OOSTEROM, Fatma KALAOGLU

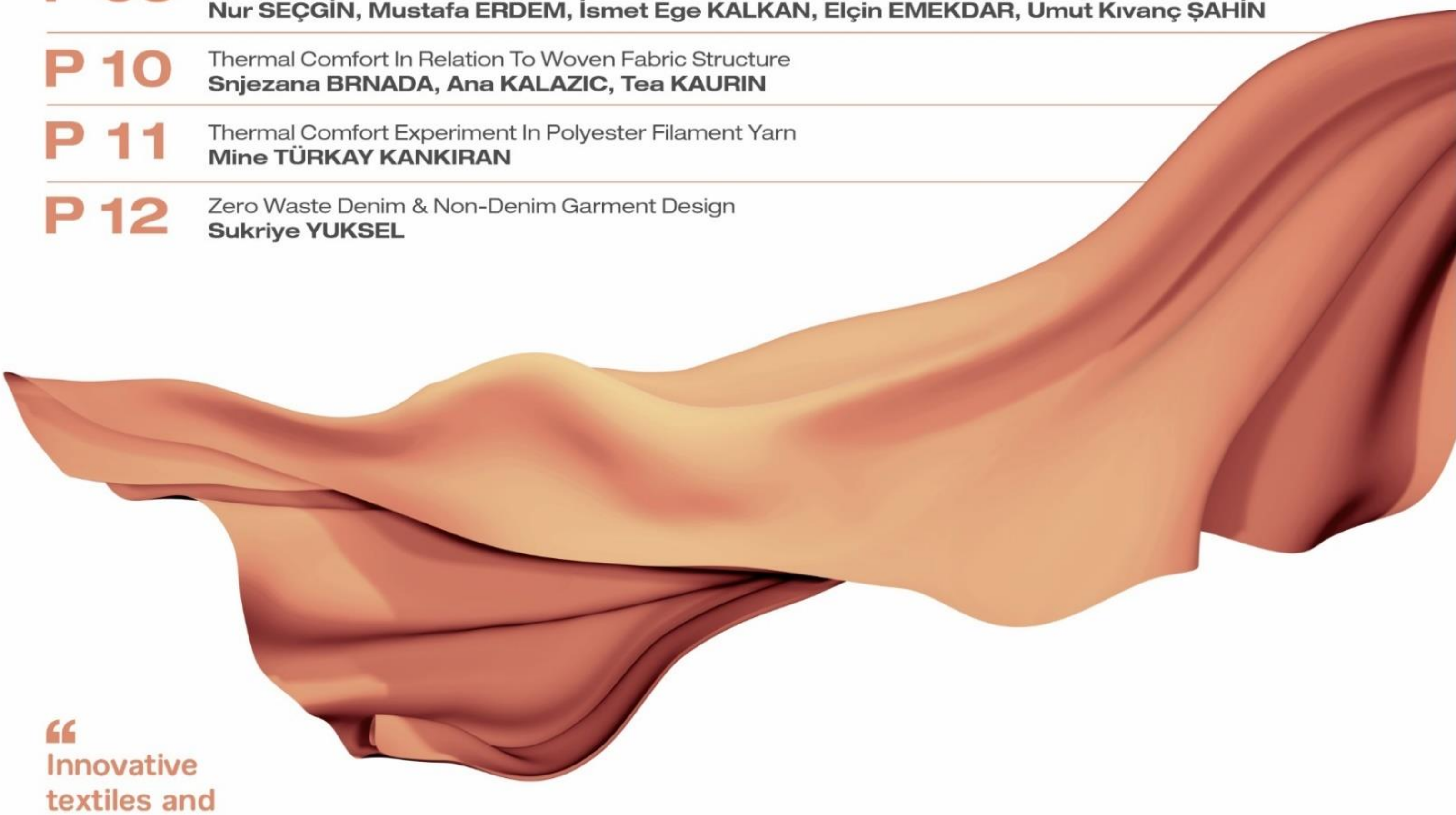
P 08 The Impact Of Micro Climate Under Cellulose And Biopolymer Nonwoven Mulches On The Lettuce Weight
Dragana KOPITAR, Paula MARASOVIC, Ivana SCHWARZ, Ruzica BRUNSEK

P 09 Upcycling Designs Of Women's Denim Trousers With Peinture Method
Derya DASTAN BARSBEY, Elif AKSAN, Demet KITAY, Yunus Emre DENİZ, Şafak DALMAN, Nur SEÇGİN, Mustafa ERDEM, İsmet Ege KALKAN, Elçin EMEKDAR, Umut Kıvanç ŞAHİN

P 10 Thermal Comfort In Relation To Woven Fabric Structure
Snjezana BRNADA, Ana KALAZIC, Tea KAURIN

P 11 Thermal Comfort Experiment In Polyester Filament Yarn
Mine TÜRKAY KANKIRAN

P 12 Zero Waste Denim & Non-Denim Garment Design
Sukriye YUKSEL



“Innovative textiles and fashion trends tackling global challenges”

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ORAL PRESENTATION

INVESTIGATION OF THE CRACKING BEHAVIOUR OF SEWING THREADS OF DENIM AND NON-DENIM GARMENTS

İsmail İvedi[1*], Sibel Topbasan[2]

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ABSTRACT

The appearance of a garment is affected by the quality of the fabrics and sewing threads used in its manufacture, as well as the factors determined by the technology and parameters of the garment manufacturing process. With the increasing use of high-elasticity fabrics in the structure of denim garments in recent years, the properties of the sewing thread that are used in sewing processes have gained more importance.

In this study, an innovative method was developed for measuring the breaking strength of threads used in the sewing processes of denim and non-denim fabrics with different elasticity ratios. Fabrics with 0, 20, 40, and 60% elasticity were sewn with six different sewing thread constructions for non-denim and subjected to piece dyeing process. On the other hand, denim fabrics were sewn with four different sewing thread constructions and subjected to light and heavy washing. The breaking strength of the sewing threads was measured after the finishing processes. The obtained findings were interpreted by yarn, strength, elongation relationship, and one-way analysis of variance. In fabrics with high elasticity, the highest strength values were obtained with sewing threads with a high stretching ability such as corespun.

Keywords: *Thread breaking, Sewing thread, Seam strength, Denim, Non-denim*

1. INTRODUCTION

Cutting, sewing, and ironing processes are applied for turning the two-dimensional fabric into a three-dimensional garment. Sewing threads used during the sewing process affect the product quality as much as the fabric composition [1]. Thread only makes up a small percent of the cost of the finished product, but shares half of the seam responsibility [2]. Since it directly affects the performance of weaving and knitting as well as warp and weft breakages during weaving, the strength of a spun yarn has always been a crucial factor in defining the quality of the yarn [3]. It is necessary to choose the appropriate sewing thread for the fabric used. Denim and piece-dyed non-denim garments are highly preferred due to their comfort and durability. Therefore, in order to continue to meet consumer and brand expectations, it is necessary to raise the quality standards of the developed products [4].

A decrease in thread strength while sewing will result in lower seam strength than anticipated because seam strength depends on thread strength. The role of various machine components or sewing processes must therefore be understood in order to reduce the thread strength drop [5]. Although the stitches in clothing are applied in numerous orientations, the tensile properties of seams are frequently studied experimentally or theoretically for vertical directions. Although a great deal of study has been done on seam strength characteristics, there has been very little done on the strength of seams placed at various angles [6]. In the state of the art, there are "seam strength" tests for seam strength or "seam slippage" test methods for seam opening. The seam opening test method is based on the principle of measuring the peeling in mm, which takes place 14 seconds after the seam breaks, not at the time of breaking. In the seam strength test method, analysis is carried out in two stages (ASTM D 1683/D1683M-22). The seamless sample piece and the stitched sample piece are measured repeatedly. The disadvantage of this test method is that it finishes the test when the fabric breaks, not when the seam breaks [7].

It has been observed that sewing thread cracking occurs as a result of the thread being subjected to parallel force in the warp direction. However, in conventional measurement methods, the breaking strength is measured by stretching the fabrics in the weft direction in the seam areas. Therefore, four different denim and non-denim fabrics with elasticity from 0% to 60% were sewn with sewing threads with polyester, cotton, nylon 6.6, and core-spun composition. According to EN ISO 13935-2:2014 test standard, breaking strength of sewing thread measurements were made by applying force in the warp direction from the seam area [8]. The results were evaluated statistically. It has been observed that the elasticity of the sewing thread should increase in parallel with the elasticity of the fabric.

2. EXPERIMENTAL STUDY

2.1 Materials

Breaking behaviours were investigated on Titan 5 (James Heal, UK) device according to EN ISO 13935-2:2014 standard. Miracle 300 drum device was used for the washing and dyeing processes. (Tolkar, Turkey). Table 1 shows the sewing threads used and their composition. Table 2 shows the fabric compositions and elasticity properties.

Table 1. Sewing threads composition.

Thread Name	Fabric Type	Composition	Bottom Thread No	Upper Thread No
AB	Denim	Polyester/polyester corespun	50	30
Nylbond	Denim	Nylon 6.6	40	30
Epic Ecoverde	Denim	Recycled polyester/polyester corespun	50	30
Epic Rugged	Denim	Polyester/polyester corespun	50	30
ÜB	Non-denim	Cotton	24	20
Tre Cerchi	Non-denim	Cotton	24	20
Dual Duty	Non-denim	Polyester/cotton corespun	50	50
Formos	Non-denim	Polyester/cotton corespun	50	50

Table 2. Fabric composition.

Fabric Code	Fabric Type	Fabric Composition (%)	Fabric Weight (gsm)	Warp and weft density (cm^{-1})	Elasticity (%)
CF	Denim	100 CO	414	26 - 18	0
S.O.	Denim	99/1 CO/EL	350	28 - 20	20
HA	Denim	98.5/1.5 CO/EL	392	31 - 17	40
AX Blue	Denim	92/6/2 CO/T400/EL	372	30 - 22	60
BA	Non-denim	100 CO	320	26 - 16	0
DE	Non-denim	97/3 CO/EL	325	33 – 23	20
SM	Non-denim	77/21/2 CO/PES/EL	285	53 - 32	40
AX	Non-denim	92/6/2 CO/T400/EL	339	30 - 24	60

2.2 Experimental

Denim clothes were subjected to light and heavy washing processes, and non-denim clothes were subjected to piece dyeing processes with reactive dyestuffs. Then, the breaking strength of the sewing threads was investigated by cutting the pieces as shown in Figure 1.

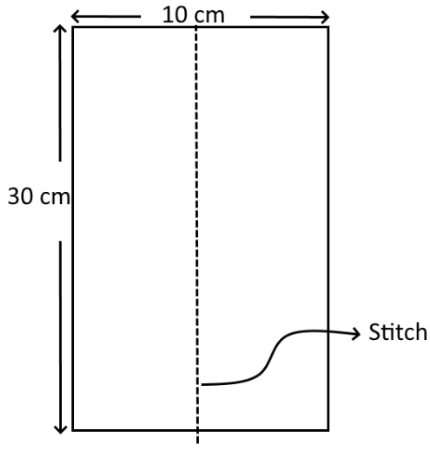

Figure 1. Fabric sample.

The edges of the fabric samples are overlocked. Then, the breaking strength of the sewing threads was investigated by exposing them to warp direction in accordance with the EN ISO 13935-2:2014 standard in the Titan 5 analyzer. The results were interpreted statistically. At the same time, a one-way analysis of variance was performed.

3. RESULTS

One-way analysis of variance and standard error rate between groups are shown in Table 3.

Table 3. Statistical analysis results.

Fabric Code	Mean	Standard Error	Standard Deviation	F value	p-value	F-crit
BA	333,91	64,82	158,78	14,35	3,22E-05	3,098
DE	89,8	32,28	79,07			
SM	39,51	8,71	21,34			
AX	47,36	9,4	23,02			
CF – LW	379,33	7,63	15,26	129,73	2,07E-09	3,49
S.O. – LW	492,55	3,99	7,98			
HA – LW	322,52	4,16	8,32			
AX Blue – LW	209,8	18,32	36,66			
CF – HW	265,3	8,94	17,89	65,1	1,08E-07	3,49
S.O. – HW	345,02	11,98	23,97			
HA – HW	162,39	17,16	34,33			
AX Blue - HW	136,25	7,13	14,27			

Breaking strength and elongation analysis results of BA and DE coded fabric are shown in Figure 2.

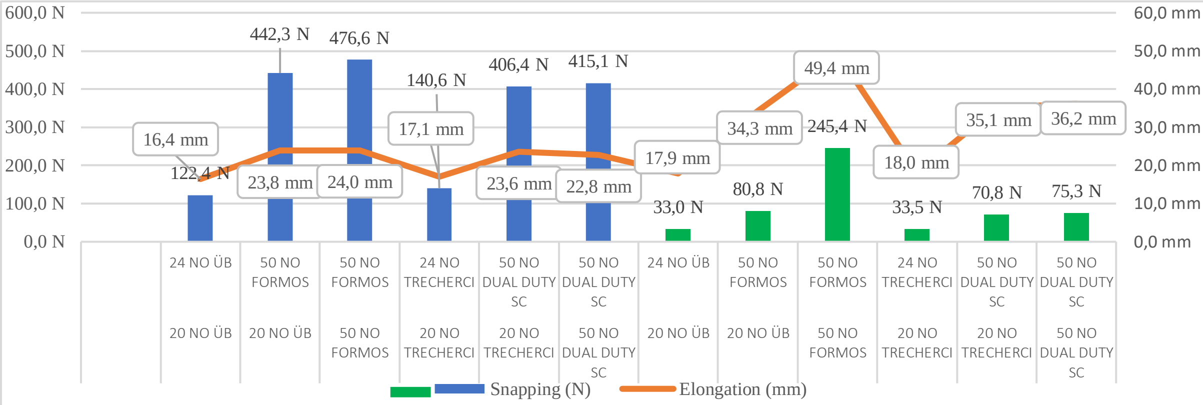

Figure 2. BA and DE coded fabric results.

Breaking strength and elongation analysis results of SM and AX coded fabric are shown in Figure 3.

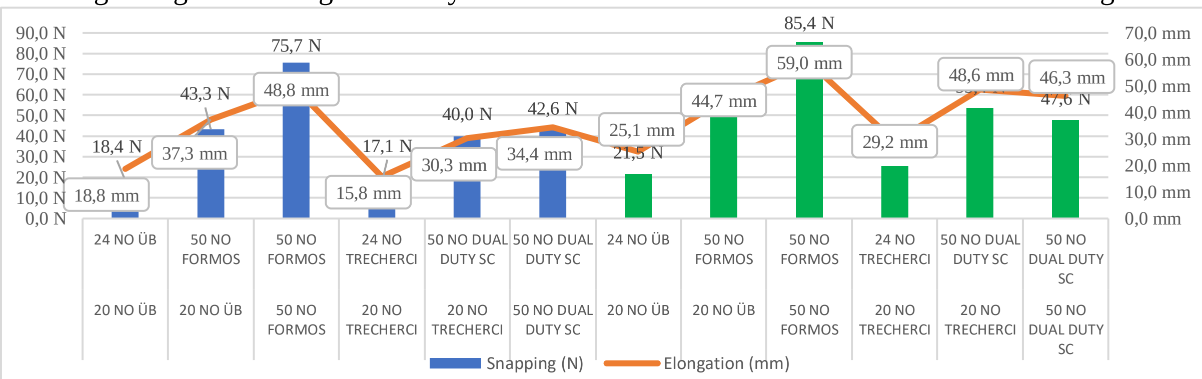

Figure 3. SM and AX coded fabric results.

When the analysis results of non-denim fabrics were examined, it was seen that corespun yarns had higher elongation properties than the others. There is no significant difference between ÜB and Tre Cerchi in terms of breaking strength. As the elasticity of the fabric increased, the strength of the corespun yarns also increased. It is attributed to the fact that corespun yarns contain both cotton and polyester and have high elasticity and strength properties. When corespun yarns are compared among themselves, Formos has 69% to 76% higher tenacity compared to Dual Duty threads.

Figure 4 shows the breaking strength and elongation results of CF coded fabric.

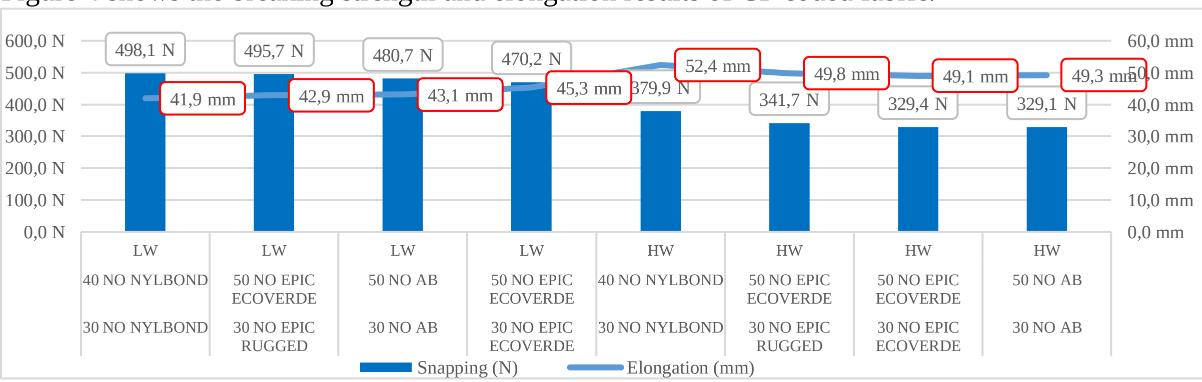

Figure 4. CF coded fabric results (LW: Light wash, HW: High wash).

Figure 5 shows the breaking strength and elongation results of S.O. coded fabric.

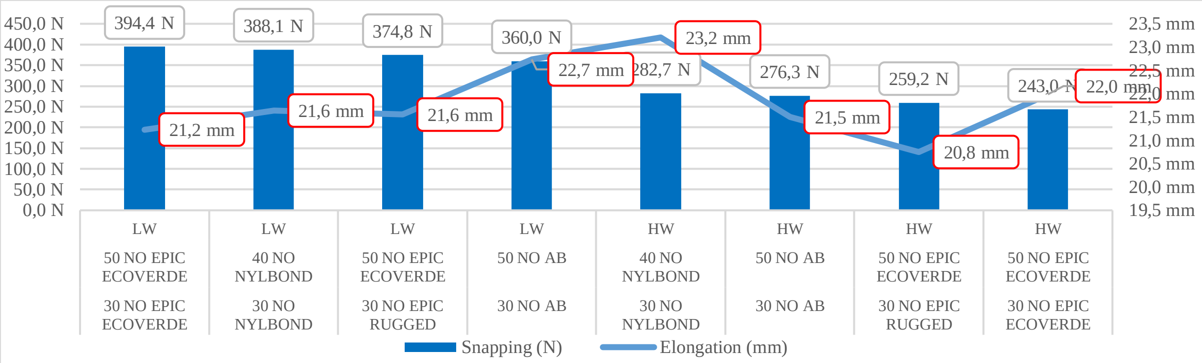

Figure 5. S.O. coded fabric results.

Figure 6 shows the breaking strength and elongation results of HA coded fabric.

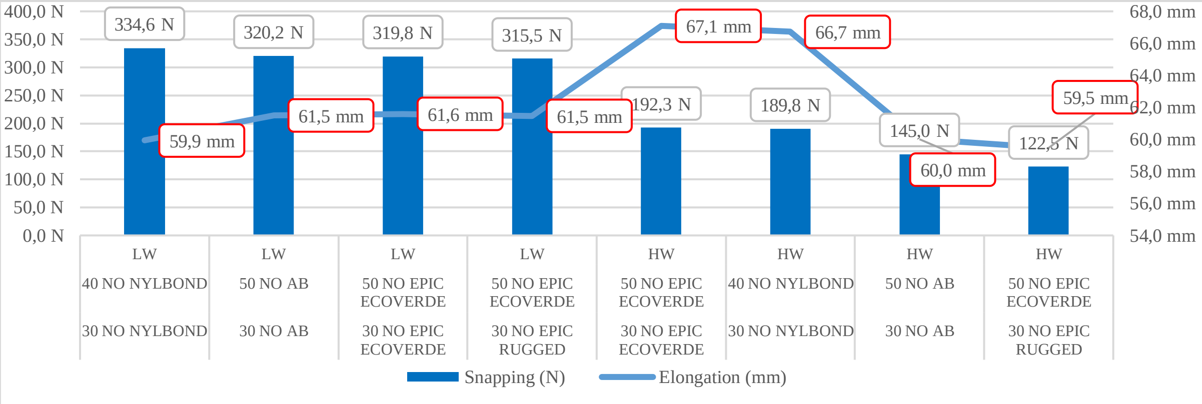

Figure 6. HA coded fabric results.

Figure 7 shows the breaking strength results and elongation results of AX Blue coded fabric.

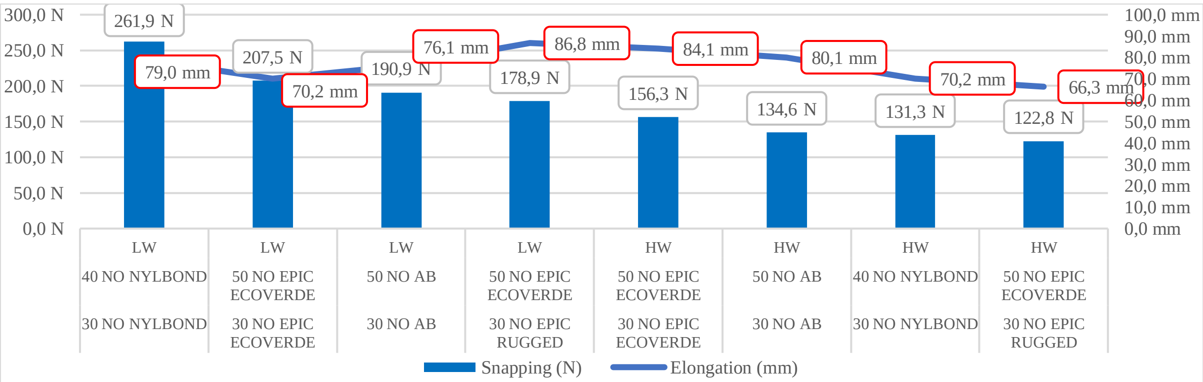

Figure 7. AX coded fabric results.

As expected, bobbin breaking strength test results applied to light-washed denim fabrics have higher strength. In the heavy washing process, it is thought that the yarns weaken because the fabrics are exposed to factors such as pumice stones, sodium hypochlorite, and heat. There is no significant difference was observed between the sewing threads of fabrics with 0% and 20% elasticity, regardless of the washing process. There is no difference between the trials using light washing for 40% elasticity. When the results of the heavy washing process are examined, epic ecoverde has 56% higher tenacity than epic rugged and 32% higher tenacity than AB sewing threads. For fabric with 60% elasticity, it has higher strength in light washing than in nylbond and in heavy washing in epic ecoverde compared to others.

4. CONCLUSION

In this study, the breaking strength behaviours of sewing threads after dyeing non-denim garments and different washing processes of denim garments were investigated. In the aforementioned study, instead of seam strength or seam slippage tests, the sewing threads were placed at right angles to the jaws of the strength measuring device and subjected to force in the warp direction. Operation when the sewing thread cracks measurement is finished. The results were evaluated statistically. When the results of the analysis of variance were evaluated, a statistically significant difference was observed between both non-denim and denim experimental groups. Because the F value is greater than the F-crit value in all results. Also, standard error results support this approach.

As the elasticity of non-denim fabrics increased, higher strength and elongation values were obtained with polyester/polyester or polyester/cotton corespun yarns. In denim fabrics, the highest strength and elongation values were obtained from the yarns with Nylon 6.6 composition and polyester/polyester corespun yarns. When the results were examined, consistency was observed.

The original aspect of this study is the modified test method for the breaking strength of the yarns. As can be seen from the results, it is predicted that it can be used instead of a seam strength test for breaking strength measurement.

In future studies, the test plan should be extended with different fabrics and yarns, and the relationship between the strength results measured by the seam strength method needs to be examined.

REFERENCES

[1] Fan, J., Lau, L., & Hunter, L. (2009). Appearance issues in garment processing. In Engineering Apparel Fabrics and Garments (pp. 131-160). Elsevier Ltd.
[2] Anonymous, (2022, Nov 14). Denim optimizing seam performance. Retrieved from https://www.amefird.com
[3] Ochola, J. R., & Mwasiagi, J. I. (2012). Modelling the influence of cotton fibre properties on ring spun yarn strength using Monte Carlo techniques. Res. Rev. Polym., *3*(3), 84-88.
[4] Zervent Ünal, B. (2011). The prediction of seam strength of denim fabrics with mathematical equations. The Journal of Textile Institute, 103, 744-75.
[5] Trivedi, V., Singh, G. P., & Khanna, S. (2018). Effect of sewing process on tensile properties of sewing threads in denim garment. Journal of the, 260.
[6] Öztaş, H., & Gürarda, A. (2019). Investigation of the effects of different bias angles of stitching on seam performance of wool suits. Autex Research Journal, 19(4), 324-331.
[7] Islam, M. M., Saha, P. K., Islam, M. N., Rana, M. M., & Hasan, M. A. (2019). Impact of different seam types on seam strength. Global Journals of Research in Engineering, 19(J4), 23-25.
[8] Golomeova, S., & Demboski, G. (2017). Investigation of seam performance using two different methods. In 12 Symposium Novel Technologies and Economic Development.

LEAN MANAGEMENT AND DIGITALIZATION IN APPAREL MANUFACTURING PROCESS

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ABSTRACT

Apparel industry has to coordinate the demand of high quality, fast delivery, cost and high flexibility in production to achieve customer satisfaction. Lean manufacturing helps the companies to identify the wastes and design manufacturing processes and methods more efficiently throughout the entire value chain. The introduction of digitalization in the apparel industry provides another competitive advantage to companies since it provides flexibility and agility by the real time data tracking, big data and data analysis techniques. In this study, ITEX PMD which is internet of things (IOT) based on the production tracking module and ITEX software program, will be analysed in the view of the digital lean management. This shop floor and software solution creates another layer of visibility into the factory and reduce non-value added activities and improve efficiency. The ITEX Soft algorithm provides an ideal assembly line layout and a more balanced workload among the work stations with the optimization based on the continuous flow principle in the sewing line.

Keyword: *Apparel Industry, Lean Management, Digitalization, Real Time Production Monitoring, Line balancing.*

1. INTRODUCTION

Low productivity and production delays are common problems in the apparel industry. Especially in small and medium-sized apparel businesses, different types of operations are organized in separate locations and placed in separate departments. There is a need for continuous transportation and work flow planning between departments such as cutting, sewing and packaging. Quality is completely different from production operations and often authorized by a separate department. Once the defect is detected, production is often completed and it is necessary to repair or sort out the defects. Lean processes posses solutions being able to produce in small quantities and quickly in a wide variety of production environments. Lean can be implemented in all types of organizations and processes. It is known as a methodology for maximizing customer value while minimizing waste, i.e. create more output with less input, in order to maintain effectiveness, flexibility, and profitability [1].

Industry 4.0, originated in 2011 from a German government initiative, regarding a high-tech strategy for 2020, meaning changes production processes by using the advancements of the Internet of Things (IoT), information and communication technology (ICT) to integrate digitalization into the production [2]. The main idea behind this term is the digital integration of the physical basic system and software system.

Digitization of lean processes make it possible to trace and measure production. It is possible instantly to monitor basic performance with real-time data tracking, big data and data analysis techniques ITEX PMD, which is an IOT (Internet of Things) based production tracking module, and developed by ITM Tech Soft for instant measurement of operation data. With this module, it has become possible to collect production data from each operation and simultaneously transmit it to the ITEX SOFT cloud network. In this way, it is possible instantly to see the efficiency of each operation, the performance of the operator, the lost time and the amount of defects. ITEX PMD allows employees to have immediate feedback, by this way operators can better pace themselves, evaluate their efficiency and send alerts to their supervisor or mechanic if needed. Giving the operator and team feedback (data) empowers and motivates them to be a part of the goals of the department and company [3].The ITEX Soft algorithm provides an ideal machine layout and a more balanced workload among the work stations with the optimization based on the continuous flow principle in the assembly line.

2. EXPERIMENTAL STUDY

ABC Apparel is implementing a lean transformation supported with digital tools. This factory is using a shop floor control device to monitor all processes in the sewing lines. Thanks to this IOT device, it is possible to follow all work station and measure some KPIs for each single unit of production. In this study, ITEX PMD device and ITEX Software program were used to take needed measurements and data (Figures 1 and 2). The stitching processes of a knitted men's' hoody sweatshirt style will be studied as a case exercise for digital lean implementation (Figure 3). In Table 1 it is presented operation names, machine types, standard times of each task and precedence relations of operations for the hooded sweatshirt style.

Figure 1. ITEX PMD shop floor device.

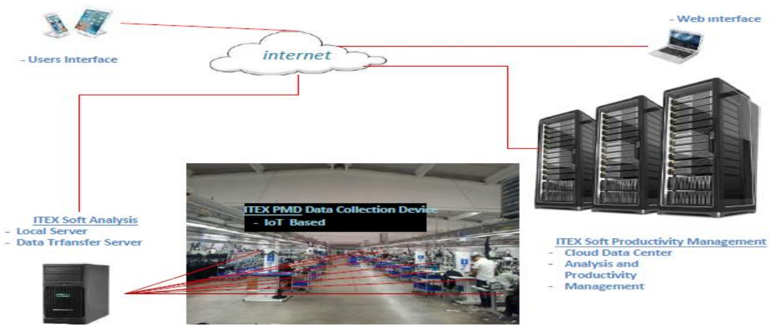

Figure 2. ITEX software management program.

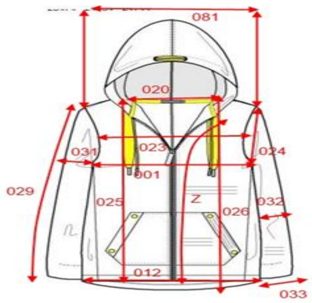

Figure 3. Hoody sweatshirt model.

Table 1. Operation names, machine types, standard times of each task and precedence relations of operations for the sweatshirt style.

Stıtching Line	7			
Style Number	319396			
Task Number	Operation	Machine Type	SMV	Precedence
1	HOOD PARTS ATTACHMENTS	OVERLOCK	0,267	0
2	HOOD LOCK STITCH	LOCK STITCH	0,275	1
3	HOOD LINING ATTACHMENT	OVERLOCK	0,283	2
4	HOOD LINING STITCH	OVERLOCK	0,296	3
5	EYELET MACHINE	EYELET	0,256	4
6	HOOD LOCK STITCH	LOCK STITCH	0,833	5
7	HOOD FIXING	LOCK STITCH	0,550	6
8	HOOD OVERLOCK	OVERLOCK	0,303	7
9	FRONT IRONING	IRON	0,367	0
10	POCKET FUSING	IRON	0,678	0
11	POCKET OVERLOCK	OVERLOCK	0,330	10
12	POCKET LOCK STITCH	LOCK STITCH	0,290	11
13	POCKET PEREPERATION	IRON	0,599	12
14	POCKET UPPER LOCK STITCH	LOCK STITCH	0,460	13
15	POCKER PEREPERATION IRONI	IRON	0,432	14
16	POCKET PART CONTROL	MANUEL	0,207	15
17	POCKET JOIN TO FRONT	LOCK STITCH	0,950	9,16
18	SHOULDER STITCH	OVERLOCK	0,279	17
19	SLEEVE JOINING	OVERLOCK	0,450	18
20	SIDE JOINING	OVERLOCK	0,900	19
21	SLEEVE COVERSTITCH	COVER STITCH	0,633	20
22	HEM LOCK STITCH	LOCK STITCH	0,252	21
23	HEM COVERSTITCH	COVER STITCH	0,317	22
24	HOOD JOIN TO BODY	OVERLOCK	0,366	8,23
25	ZIPPER PIPING	COVER STITCH	0,275	24
26	ZIPPER EDGE FIXING	LOCK STITCH	0,288	25
27	FRONT ZIPPER BABY OVERLO	OVERLOCK	0,550	26
28	FİRST ZIPPER JOIN	LOCK STITCH	0,496	27
29	SECOND ZIPPER JOIN	LOCK STITCH	0,825	28
30	FRONT SOUFFLE STITCH	OVERLOCK	0,314	29
31	ZIPPER COVERING LOCKSTITC	LOCK STITCH	0,667	30
32	NECK PIPING	COVER STITCH	0,463	31
33	NECK PIPING STITCH	LOCK STITCH	0,331	32
34	LABEL JOIN	LOCK STITCH	0,553	33
35	SECOND ZIPPER STITCH	LOCK STITCH	0,369	34
36	FIRST ZIPPER STITCH	LOCK STITCH	0,367	35
37	ZIPPER LOCK STITCH	LOCK STITCH	0,579	36
38	RIVET MACHINE	RIVET	0,311	37
39	CARE LABEL JOIN	LOCK STITCH	0,317	38
40	IN LINE IRONING	IRON	0,366	39
41	IRONING	IRON	1,000	40
42	FINAL CONTROL	MANUEL	0,366	41
			19,010	

2.1. ITEX PMD Data Collection Device:

The data collection device, called as ITEX PMD is defined to each operator and this can be considered as the first step of digitalization in the sewing process. Therefore, it could be possible to collect instant data from machines and operations via the Internet of Things, store these data in the cloud and create the necessary data pool for the appropriate software program.

ITEX PMD data collection device has a performance led lights on the top and a quality led lights on the bottom. The colour and behaviour settings of the LED lights of the ITEX PMD device are made on the screen. The minimum and maximum range values represent the percentage values of "Performance". Red, blue and green LED light settings are adjusted to operate between desired percentage values. The minimum and maximum range values represent the amount of “Repair” (correctable poor quality). This value is the number range of repair amount in operation. Red, blue and green LED light settings are adjusted to operate between the desired range values. The LED light settings also can be adjusted in three different ways: fixed, flashing and off. Table 2 presents periodic line report for the men’s’ hoody sweatshirt

We can accept a sewing line as a simple assembly line , so we can measure availability, performance and quality rate with PMD shop floor device directly (Table.2) .To measure OEE , we use formulas (Eq.1).

$$Overall\ Equipment\ Efiiciency\ (OEE) = Performace \times Availibility \times Quality\ Rate \qquad \text{Eq. 1}$$

OEE FOR Line-7 = 0,65x0,849*0,94

= 51.87%

Table 2. Periodic line report for the men’s’ hoody sweatshirt.

ABC APPAREL

Periodic Line Report

Üretim Hattı	Hat Üretim Verimliliği	Hat Verimliliği	Line Performance	Availibility	Üretim Adet	Maliyet (TL)	Ciro (TL)	Kar / Zarar	Fabrika K.K.Z	Fabrika Kaynaklı K.Z. %	Kişi K.K.Z	Kişi Kaynaklı K.Z. (%)
BANT 07	**82%**	**56%**	**65%**	**84,90%**	5.300	0	0	0	16.619	10,81%	5.613	3,65%

Sipariş No	Model Adı	STD	Kesim Adet	Toplam Üretim Miktarı	Sipariş Tamamlanma Oranı (%)	Üretim Adet	Kalite Adet	1. Kalite	First Quality	2.Kalite	2. Kalite (%)	Tamir	Tamir Oranı(%)	Günlük Ciro
319396 KOLL-3 / 3119557	319396 KOLL-3	23,725	13.642	6.201	45%	5.280	5.280	5.278	94%	2	0%	347	6%	0
319396-222703 / 3119557	319396-222703	23,939	559	400	72%	20	20	20	94%	0	0%	0	0%	0
						5.300	**5.300**	**5.298**	**94%**	**2**	**0%**	**347**	**6%**	**0**

Defect Report

							Baskı Defo		Dikim Defo		Kumaş Defo		Nakış Hata		Toplam
Sipariş No	Model	Üretim Adet	2. Kalite	2.Kalite (%	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	
319396 KOLL-3 / 3119557	319396 KOLL-3	5280	2	0 %			0	0 %	0	0 %	2	100 %	0	0 %	2
319396-222703 / 3119557	319396-222703	20	0	0 %	0										0
Toplam					0		0	0 %	0	0 %	2	100 %	0	0 %	2

Repair Report

					El Tamiri		Jut		Leke		Overlok Tamiri		Reçme Tamiri		Renk Farkı		Singer Tamiri		Ütü Hatası		Toplam
Sipariş No	Model	Üretim Adet	Tamir Adet	Tamir (%)	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	Adet	Oran %	
319396 KOLL-3 / 3119557	319396 KOLL-3	5280	347	6 %	10	3 %	19	5 %	23	7 %	23	7 %	49	14 %	2	1 %	212	61 %	9	3 %	347
Toplam					10	3 %	19	5 %	23	7 %	23	7 %	49	14 %	2	1 %	212	61 %	9	3 %	347

Loss Time Report

Kayıp Zaman Adı	Fabrika K.K.Z	Fabrika Kaynaklı K.Z. %	Kişi K.K.Z	Kişi Kaynaklı K.Z. (%)
Doktor	0	0,00%	47	0%
Hat Kurulumu	44	0,20%	0	0%
Belirsiz İzin	0	0,00%	2690	12%
Operasyon Değişikliği	4643	20,88%	0	0%
Ek İş	10771	48,45%	0	0%
Kırık İğne Arıza	0	0,00%	8	0%
Makine Arıza	36	0,16%	0	0%
İş Bekleme	7	0,03%	0	0%
Tamir(Fabrika Kaynaklı)	1118	5,03%	0	0%
Erken Çıkış	0	0,00%	1731	8%
Kişisel İzin	0	0,00%	1137	5%
	16.619	**75%**	**5.613**	**25%**

Finally, with the identification of losses through OEE metrics, leads to the implementation of better performance overall, maintenance of production tools to limit downtime, eliminating bottlenecks, compliance with the planned rate and maintaining quality, increasing efficiency over continuous improvement process.

2.2. Digital Line Balancing Algorithms:

In the sewing line optimization, the concept of station refers to the employee and accepted that there are no machine restrictions. The solution of the problem that will minimize the cycle time is also provided by the software. It can be done as explained below:

1. Optimization to be made according to the minimization of cycle time, "Minimum Cycle Time Optimization" is selected as the line balancing type on the screen.

2."Daily production target or total number of operators" is written as the optimization interval. The program will calculate the most effective cycle time for optimization.

3. Operations are following the work sequence, the constraint that one operation cannot start another operation is defined here. For the optimization calculation to be correct, the dependent operations must be defined correctly.

4. After the parameters are determined, the calculation button is clicked. The program will calculate the tasks in the stations and the total working time in the tasks, the hourly production of the line and the efficiency of the line by optimizing.

When this digital (type-2) algorithm is used, the program will optimize the assembly line in the minimum cycle time with 65 operators. The cycle takt time is defined as 0.422 min/pcs. and line efficiency will be calculated as 90% (Operators' performance rate is accepted 75% for the sewing line). After the line balancing, the established work stations and optimization rates can be seen at the Table.3. In order to compare the effectiveness of the digital line optimization results, we have studied on this stitching line and optimized the line by using capacity algorithm technique. The results of this algorithm can be seen in the Table 4.

Table 3. Type-2 Assembly line balancing report.

Number of Operators	Machine	Operation	Optimization time	Optimization Percentage
1-2	LOCK STITCH	HOOD EDGE STITCH	9,500	%100
3	LOCK STITCH	HOOD FIXING STITCH	9,500	%100
4	IRON	FRONT IRONING	9,500	%100
5-6	LOCK STITCH	POCKET FUSING	9,500	%100
7	OVERLOCK	POCKET PARTS ATTAHED	9,500	%100
8-9	IRON	POCKET PREP. IRONING	9,500	%100
10	LOCK STITCH	POCKET UPPER STITCH	9,500	%100
11-12	LOCK STITCH	POCKET JOINING	9,500	%100
13	OVERLOCK	SLEEVE JOINING	9,500	%100
14-15	OVERLOCK	SIDE JOINING	9,500	%100
16	COVER STITCH	SLEEVE COVER STITCH	9,500	%100
17	OVERLOCK	HOOD JOINING	9,500	%100
18	OVERLOCK	FRONT ZIPPER BABY OVERLOCK	9,500	%100
19	LOCK STITCH	FIRST ZIPPER JOINING(70cm)	9,500	%100
20-21	LOCK STITCH	SECOND ZIPPER JOINING(70cm)	9,500	%100
22-23	LOCK STITCH	ZIPPER COVERING STITCH	9,500	%100
24	COVER STITCH	NECK PIPING JOIN	9,500	%100
25	LOCK STITCH	NECK PIPING STITCH	9,500	%100
26	LOCK STITCH	LABEL JOIN	9,500	%100
27	LOCK STITCH	RIGHT ZIPPER STITCH	9,500	%100
28	LOCK STITCH	LEFT ZIPPER STITCH	9,500	%100
29	LOCK STITCH	ZIPPER LOCK STITCH	9,500	%100
30	IRON	IN-LINE IRON	9,500	%100
31-33	IRON	IRONING	9,500	%100
34	MANUEL	FINAL CONTROL	9,500	%100
35	OVERLOCK	HOOD ATTACHED	7,872	%82
	IRON	FRONT IRONING	1,320	%13
35 Total			9,192	%95
36	LOCK STITCH	POCKET STITCH	0,990	%10
		HOOD LOCK STITCH	8,108	%85
	LOCK STITCH Total		9,098	%95
	OVERLOCK	POCKET PART ATTACHED	0,229	%2
36 Total			9,327	%97
37	LOCK STITCH	POCKET PART STITCH	8,550	%90
38	OVERLOCK	HOOD LINING STITCH	8,344	%87
39	OVERLOCK	HOOD LINING ATTACHED	8,727	%91
40	IRON	POCKET PREP. IRONING	8,161	%85
41	EYELET	EYELET	7,548	%79
42	LOCK STITCH	HOOD STITCH	5,560	%58
43	LOCK STITCH	HOOD FIXING STITCH	6,716	%70
44	OVERLOCK	HOOD STITCH	8,933	%94
45	LOCK STITCH	POCKET UPPER STITCH	4,062	%42
	IRON	POCKET IRONING	3,237	%34
45 Total			7,299	%76
46	OVERLOCK	POCKET PART PREPERATION	6,103	%64
47	LOCK STITCH	POCKET JOINING	9,010	%94
48	OVERLOCK	SHOULDER JOIN	8,226	%86
49	OVERLOCK	SLEEVE JOIN	3,768	%39
50	OVERLOCK	SIDE JOINING	7,536	%79
51	COVER STITCH	SLEEVE COVER STITCH	9,163	%96
52	LOCK STITCH	HEM EDGE STITCHING	7,430	%78
53	COVER STITCH	HEM STITCH	9,346	%98
54	OVERLOCK	HOOD JOINING	1,291	%13
	COVER STITCH	ZIPPER PIPING	8,108	%85
54 Total			9,399	%98
55	LOCK STITCH	ZIPPER EDGE STITCH	8,491	%89
56	OVERLOCK	FRONT ZIPPER OVERLOCK	6,716	%70
57	LOCK STITCH	FIRST ZIPPER JOINING (70cm)	5,124	%53
58	LOCK STITCH	SECOND ZIPPER JOINING (70cm)	5,324	%56
59	OVERLOCK	FRONT SOUFFLE STITCH	9,258	%97
60	LOCK STITCH	NECK PIPING STITCH	0,259	%2
		FRONT ZIPPER STITCH	0,666	%7
	LOCK STITCH Total		0,925	%9
	COVER STITCH	NECK PIPING	4,151	%43
60 Total			5,076	%52
61	LOCK STITCH	LABEL JOIN	6,804	%71
		RIGHT ZIPPER STITCH	1,379	%14
	LOCK STITCH Total		8,183	%85
62	LOCK STITCH	FRONT ZIPPER STITCH	7,571	%79
		LEFT ZIPPER STITCH	1,320	%13
	LOCK STITCH Total		8,891	%92
63	RIVET	RIVET	9,169	%96
64	LOCK STITCH	LABEL JOIN	9,346	%98
65	MANUEL	FINAL CONTROL	1,291	%13
	IRON	IN-LINE IRON	1,291	%13
		IRONING	0,984	%10
	IRONING Total		2,275	%23
65 Total			3,566	%36

Table 4. Line balancing with capacity algorithm technique.

Task Number	Operation	Machine Type	SMV	Precedence	Daily Target	Accepted Performance	Production minutes	Daily Working Minutes	Balance Minutes	Number of Extra Operators	Final Balance Minutes
1	HOOD PARTS ATTACHMENT	OVERLOCK	0,267	0	1350	0,75	480,600	570	89,400		89,400
2	HOOD LOCK STITCH	LOCK STITCH	0,275	1	1350	0,75	495,000	570	75,000		75,000
3	HOOD LINING ATTACHMENT	OVERLOCK	0,283	2	1350	0,75	509,400	570	60,600		60,600
4	HOOD LINING STITCH	OVERLOCK	0,296	3	1350	0,75	532,800	570	37,200		37,200
5	EYELET MACHINE	EYELET	0,256	4	1350	0,75	460,800	570	109,200		109,200
6	HOOD LOCK STITCH	LOCK STITCH	0,833	5	1350	0,75	1499,400	570	-929,400	2	210,600
7	HOOD FIXING	LOCK STITCH	0,550	6	1350	0,75	990,000	570	-420,000	1	150,000
8	HOOD OVERLOCK	OVERLOCK	0,303	7	1350	0,75	545,400	570	24,600		24,600
9	FRONT IRONING	IRON	0,367	0	1350	0,75	660,600	570	-90,600		-90,600
10	POCKET FUSING	IRON	0,678	0	1350	0,75	1220,400	570	-650,400	2	489,600
11	POCKET OVERLOCK	OVERLOCK	0,330	10	1350	0,75	594,000	570	-24,000		-24,000
12	POCKET LOCK STITCH	LOCK STITCH	0,290	11	1350	0,75	522,000	570	48,000		48,000
13	POCKET PEREPERATION	IRON	0,599	12	1350	0,75	1078,200	570	-508,200	1	61,800
14	POCKET UPPER LOCK STITC	LOCK STITCH	0,460	13	1350	0,75	828,000	570	-258,000	1	312,000
15	POCKER PEREPERATION IRO	IRON	0,432	14	1350	0,75	777,600	570	-207,600		-207,600
16	POCKET PART CONTROL	MANUEL	0,207	15	1350	0,75	372,600	570	197,400		197,400
17	POCKET JOIN TO FRONT	LOCK STITCH	0,950	9,16	1350	0,75	1710,000	570	-1140,000	2	0
18	SHOULDER STITCH	OVERLOCK	0,279	17	1350	0,75	502,200	570	67,800		67,800
19	SLEEVE JOINING	OVERLOCK	0,450	18	1350	0,75	810,000	570	-240,000	1	230
20	SIDE JOINING	OVERLOCK	0,900	19	1350	0,75	1620,000	570	-1050,000	2	90
21	SLEEVE COVERSTITCH	COVER STITCH	0,633	20	1350	0,75	1139,400	570	-569,400	1	0
22	HEM LOCK STITCH	LOCK STITCH	0,252	21	1350	0,75	453,600	570	116,400		116,400
23	HEM COVERSTITCH	COVER STITCH	0,317	22	1350	0,75	570,600	570	-0,600		0
24	HOOD JOIN TO BODY	OVERLOCK	0,366	8,23	1350	0,75	658,800	570	-88,800		-88,800
25	ZIPPER PIPING	COVER STITCH	0,275	24	1350	0,75	495,000	570	75,000		75,000
26	ZIPPER EDGE FIXING	LOCK STITCH	0,288	25	1350	0,75	518,400	570	51,600		51,600
27	FRONT ZIPPER BABY OVERL	OVERLOCK	0,550	26	1350	0,75	990,000	570	-420,000	1	150,000
28	FİRST ZIPPER JOIN	LOCK STITCH	0,496	27	1350	0,75	892,800	570	-322,800	1	247,200
29	SECOND ZIPPER JOIN	LOCK STITCH	0,825	28	1350	0,75	1485,000	570	-915,000	2	225,000
30	FRONT SOUFFLE STITCH	OVERLOCK	0,314	29	1350	0,75	565,200	570	4,800		4,800
31	ZIPPER COVERING LOCKSTI	LOCK STITCH	0,667	30	1350	0,75	1200,600	570	-630,600	1	-60,600
32	NECK PIPING	COVER STITCH	0,463	31	1350	0,75	833,400	570	-263,400	1	306,6
33	NECK PIPING STITCH	LOCK STITCH	0,331	32	1350	0,75	595,800	570	-25,800		-25,800
34	LABEL JOIN	LOCK STITCH	0,553	33	1350	0,75	995,400	570	-425,400	1	144,600
35	SECOND ZIPPER STITCH	LOCK STITCH	0,369	34	1350	0,75	664,200	570	-94,200		-94,200
36	FIRST ZIPPER STITCH	LOCK STITCH	0,367	35	1350	0,75	660,600	570	-90,600		-90,600
37	ZIPPER LOCK STITCH	LOCK STITCH	0,579	36	1350	0,75	1042,200	570	-472,200	1	97,800
38	RIVET MACHINE	RIVET	0,311	37	1350	0,75	559,800	570	10,200		10,200
39	CARE LABEL JOIN	LOCK STITCH	0,317	38	1350	0,75	570,600	570	-0,600		-0,600
40	IN LINE IRONING	IRON	0,366	39	1350	0,75	658,800	570	-88,800		-88,800
41	IRONING	IRON	1,000	40	1350	0,75	1800,000	570	-1230,000	2	-90,000
42	FINAL CONTROL	MANUEL	0,366	41	1350	0,75	658,800	570	-88,800	1	302,400
			19,010								3123,200
										66	Operators

3. RESULTS

The results of ITEX SOFT Type-2 Digital Algorithm and Capacity Algorithm are given below:

When the number of operators (stations) is accepted as 65, the minimum optimized cycle time will be 0.422 minute, the productivity of assembly line will be 90.77% and smoothness index is 2.26%.

When we accept the same cycle takt time which is 0.422 min/pcs, the daily production target will be calculated 1350 pcs. When we use Capacity Algorithm technique, we reach at 91.70% efficiency with the number of 66 operators and smoothness index will be 2.67%.

Since the results of both techniques are close to each other, we can assume that the digital line balancing program is running effectively and helps shop floor managers to optimize their stitching lines properly and easily. The main idea is that the algorithms should be supported by software that can be easily used by the industry, and this software program should be integrated into companies' ERP programs.

4. CONCLUSION

While it's easy to implement ITEX PMD as a shop floor control technology, focusing solely on the technology without looking at the whole manufacturing processes will likely get worse unsatisfactory results. Lean manufacturing and digitalization support each other in a positive way. Considering the above improvements, implementing a digital lean management can lead to productivity improvement and reduced costs in the range of 10-30% depending on the current situation [11]. Real-time shop floor control gives management the data to assess risk in real-time. Fully interacting with the software program, management can monitor the factory floor and make quicker and better decisions at the right time.

ITEX SOFT helps the supervisors to optimize their assembly lines at the high rate of productivity in a very short time. It is strongly advised that the skill levels of operators, performance rate and machine types should be added as a criteria on this program. By developing the present algorithms, it will be possible to assign the right operators to the right task automatically and get the best optimization proposal for the sewing lines [12].

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REFERENCES

[1] Womack, J., & Jones D., & Roos, D. (1990). The Machine that Changed the World. *Rawson Associates*. New York.
[2] Zhou, K., & Liu T., & L. Zhou, L. (2016, August). "Industry 4.0: towards future industrial opportunities and challenges". *12th International Conference on Fuzzy Systems and Knowledge Discovery*. (pp. 2147-2152). Changsha, China.
[3] Porteboeuf, F. Lean management and digital: A winning pair!. Retrieved from https://www.pingflow.com.
[4] Beata Mrugalska. B., & Wyrwicka, Magdalena K. "Towards Lean Production in Industry 4.0". Poznan University of Technology. Faculty of Engineering Management. *Strzelecka 11*, 60-695. Poznan, Poland
[5] Nakajima, M., & Uchiyama, S., & Miura, Y., &Sakamoto K., & Ando Y. (1980). Line Balancing of Sewing Systems (A Simple Calculating Method to Determine the Number of workstations and Cycle Time). Japan.
[6] Gökalp E. & Gökalp Mert O., & Eren, Erhan P. (2018). Industry 4.0 Revolution in Clothing and Apparel Factories: Apparel 4.0.
[7] Bruno, F. d., S. & Pimentel, F. (2016). Apparel Manufacturing 4.0: A Perspective For The Future of The Brazilian textile and apparel industry. São Paulo.

[8] Küçükkoç, İ. Montaj Hattı Tasarımı ve Analizi-7. Balikesir Universitesi Endustri Muhendisliği Bolumu.
[9] Kamarudin, N.H., & Rashi, M.F.F. Modelling of Simple Assembly Line Balancing Problem Type 1 (SALBP-1) with Machine and Worker Constraints.
[10] Rachamadugu, R., & Talbot, B. (1991). Improving the equality of workload assignments in assembly lines. *The International Journal of Production Research*, *29*(3), 619-633.
[11] Ready to Maintain Shop Floor Control. Retrieved from https://www.aptena.com.
[12] Koç, B. (2023). "Dikim İşletmesinde Yalın Üretim ve Sürdürülebilir Yalın Dijital Model Tasarımı". Istanbul Technical University, Faculty of Textile Engineering, Unpublished Phd Thesis.

FUTURE FASHION FACTORY: DEVELOPING AN ECO-SYSTEM TO SUPPORT SUSTAINABLE CHANGE

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ABSTRACT

This paper will explore and unpack the impact of the initiatives established by the Future Fashion Factory (FFF) programme, led by the University of Leeds. In 2018, the UK's Arts and Humanities Research Council awarded funding for nine Creative Industries Cluster Programmes (CICPs) of which the Future Fashion Factory was one. This is a £5.5 million R&D industrial-academic partnership exploring and developing new digital and advanced textile technologies to boost the design of high-value creative products. The purpose of the study was to explore the Core Research Themes that represented challenge areas, identified by the sector as critical to their business operations. Themes were identified with academic partners (University of Leeds, University of Huddersfield, Royal College of Art) and industrial members of the FFF eco-system. This included sectorial bodies (UK Fashion & Textile Association (UKFT) & British Fashion Council (BFC)) alongside industrialists (Burberry & Yorkshire-based mills) and regional authorities (Leeds City Council, Leeds City Region LEP, Yorkshire Textiles). The research employed a qualitative and quantitative approach. Methods of data collection encompassed practice based and auto-ethnographic research. This encompassed participation in the practice-based, practice-led and practice through research activities involved in the broad and varied initiatives established by FFF (Nelson, 2013). Auto ethnography was employed to self-reflect on the personal experiences related to involvement in the FFF initiatives to connect them to a wider level of understanding of their cultural and industrial context (Chang, 2008; Adams, Holman Jones and Ellis, 2015). An integrated programme of 'Responsive Research &Development' funding enabled Future Fashion Factory to allocate 55 grants to industrial ecosystem members. Projects were aligned with the core research themes. This mechanism represents an investment of £1.6m that has leveraged co-financing of £2.7m. The Future Fashion Factory network provides high profile events to serve member's need. At the University of Leeds, a new multi-disciplinary institute, the Leeds Institute of Textiles and Colour (LITAC), was formed in September 2021 with finance from University of Leeds and the Clothworkers' Company. It has attracted investment of £21.1m and 'Future Fashion Factory' continues as an integral brand within the new Institute.

Keywords: *Fashion, Creative Industries, Impact, Commercialisation, Eco-System*

1. INTRODUCTION

Aim: To develop an eco-system to support sustainable change exploring and developing new digital and advanced textile technologies to boost the design of high-value creative products in the UK fashion and textile industry.

Objectives: To explore the ***Core Research Themes*** that represented challenge areas, identified by the UK fashion and textile sector, as critical to their business operations. To unpack the integrated programme of 'Responsive R&D' funding that enabled Future Fashion Factory to allocate 55 grants to industrial ecosystem members with projects aligned with the Core Research Themes.

The Opportunity

In autumn 2017 a report was presented by Sir Peter Bazelgette (co-chair of the Creative Industries Council) following a period of independent review of the creative industries for DCMS into the potential of the creative sector to support the UK economy and become a *"growth sector for the future"* (2017, 1). The report concluded that the Industrial Strategy and accompanying Sector Deals were perfectly positioned to support growth within the creative industries (Gov.UK). The network of nine Creative Industries Cluster Programmes (CICPs) that were established as a result epitomise the aspiration of these Sector Deals, being based on existing geographic clusters of academic – industrial excellence deemed to have high growth potential. The CICPs followed Sir Bazelgette's recommendation for a 'bottom up' approach, allowing in the majority of cases regional focus to drive innovation opportunities. The resultant network was established as result of the "*unprecedented £80m investment"* by the Industrial Strategy Challenge Fund (ISCF) which was awarded via UKRI / Arts and Humanities Research Council (AHRC). The aim was to "*create jobs and drive the creation of companies, products and experiences that can be marketed around the world, significantly contributing to UK economic growth both regionally and nationally"* (UKRI, 2023). Now in its final year of the original delivery period the CICPs have outperformed original targets with the initial investment now worth £252m, having funded over 700 R&D projects, created or safeguarded over 4,000 jobs, trained over 3,500 industry professionals and academics, supported 227 new spin outs and start-ups, and created 566 new products and services (CICP Directors, 2023).

The Building Blocks

The subject of this paper is the methodology underlying one of the nine CICPs established through the AHRC investment, the Future Fashion Factory (FFF) whose base is at University of Leeds. In line with established thinking around Sector Deals this Fashion & Textile focused technology cluster was built on a range of existing relationships between regional centres of academic expertise in Yorkshire (Universities of Leeds and Huddersfield), the Leeds – London corridor (Royal College of Art) and the world-renowned Yorkshire textile mills (Conti, 2022). The combination of world-leading academic expertise, led by the University of Leeds who will celebrate 150 years of ***Textiles at Leeds*** in 2024, and the industrial partners representing the historic heartland of textile production in the UK, created a compelling narrative for cluster establishment (University of Leeds, 2023). At the heart of the cluster was the strong drive to develop industry-facing co-development. This included the following:

- Yorkshire-based regional cluster of significant academic & industrial members.
- Lead partner, University of Leeds with >140 years textile experience delivering academic programmes and projects with the industry.
- Good academic connectivity through staff networks in industry and education.
- Great links to Local Government and Local Enterprise Partnerships.
- Strategic Alignment with local, regional and national priorities.

The development of an eco-system to support sustainable change within the fashion and textile industry made sense both strategically and creatively within the UK economy. The support for the design and realisation of high-value creative products in the UK fashion and textile industry was also considered in relation to the below:

- There are > 4,000 fashion & textile businesses in the UK with 1,800 new companies registered 2017-19.
- Over 100,000 people work in fashion and textile businesses including 40,000 in textile manufacturing, generating £8 Billion in UK revenues.
- Yorkshire's mills supply global luxury brands, some exporting up to 90% of total production.
- Burberry's UK vertical manufacturing operations are located in the Leeds City Region.

The Process and Outcome

The process for developing the concept behind the Future Fashion Factory was centred on a listening approach (Future Fashion Factory1) The views and ambitions of the UK fashion and textile industry were paramount to shaping the development of the ecosystem in order to initiate change that was sustainable, creative and pioneering. This involved adapting to and building in industrial ideas for increased connectivity that was both flexible and responsive, supporting end-to-end innovation across design, manufacture and retail. The outcome of the initiative was £5.5 million awarded by AHRC with an additional £3 million commitment pledged by industry, University of Leeds, University of Huddersfield and the Royal College of Art. The programme began in October 2018 with a profiled 4.5-year duration until March 2023.

2. EXPERIMENTAL STUDY

2.1. Structure

Funded by the Industry Strategy Challenge Fund, via the Arts & Humanities Research Council, Future Fashion Factory represents a £5.5m investment by the UK Government in the UK Fashion & Textile sector. The original application was supported by £3m of 'Pledged' co-investment derived from academic & key industrial partners. The FFF organisational structure, delivery mechanisms and outcomes were co-developed with an initial core of ten key industrial contacts & sectoral membership bodies. Crafted in such a way as to be able to demonstrate impact for the sector the management structure comprises a strategic 'Steering Group', a 'Programme Management Group' providing a mechanism to update industry members and cross-organisational academic partners on progress with Core Research Theme activity, and a core management team. Each academic partner had a nominated lead investigator who had a place on the Steering Group. Management groups meet quarterly aligned with funder reporting requirements.

Initial planning for programme delivery identified 7 different ways of working which would achieve the aims and objectives of the programme (Figure 1). These covered the identified five Core Research Themes (Core Collaborative R&D projects), three Responsive R&D mechanisms (Proof of Market, Proof of Concept and Innovation Challenge Projects) which themselves act as sample prototyping and test bedding of new technologies, alongside skills-focused activities (Internships & Placements, Training and Incubation).

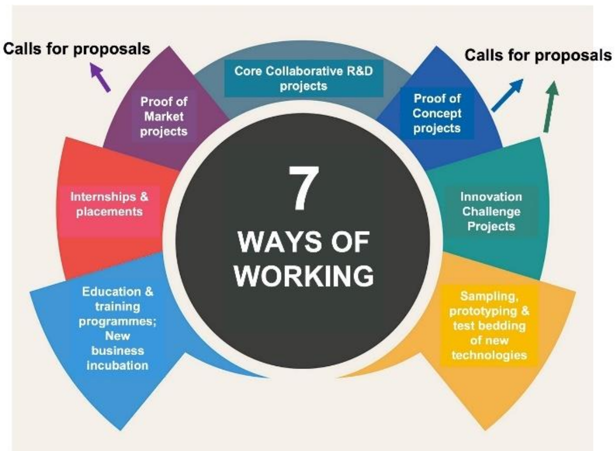

Figure 1. Aims & Objectives.

As programme thinking developed this became embedded in FFF in a three-layered structure of Core Research Theme activity which underpinned the Responsive R&D Investment process and informed Strategic Brokerage, ecosystem events and dissemination activity. The Responsive R&D programme itself was designed as a series of ‘open’ industry-led calls with levels of funding allocated to projects depending on how close to market the proposed innovation was at project start. FFF activity is predicated on achieving commercial impact, so market readiness was a key consideration in the independent *Investment Committee* process which awarded funding (Figure 2). Responsive R&D funding awards started at up to £10k for a Proof of Market project, working up to a maximum of £100k for an Innovation Challenge award. All projects were structured with an element of skills development in mind with both senior academics and Early Career Researchers being directly connected with industrial funding applicants throughout project delivery. This approach has broken down barriers to industrial-academic engagement and fostered an open and exploratory way of working across the FFF network.

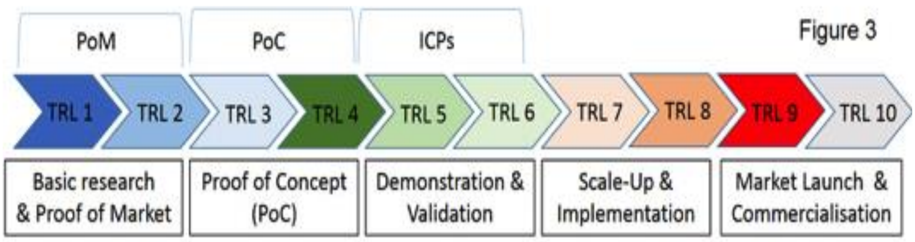

Figure 2. Responsive R&D TLRs.

Additional to fundamental innovative exploration of sectoral challenges and R&D directed at industrial problem-solving, FFF used other methodologies to ensure ecosystem cohesion and effective dissemination of programme outcomes. A series of physical and online speaker events, seminars, creative labs and Showcase events (examples in Figure 3) has been delivered during the programme to date with more planned for the future. A formal ‘membership’ system for industrial partners provides a mechanism to ensure that comments and requests are captured and as a focus for the development of new activity.

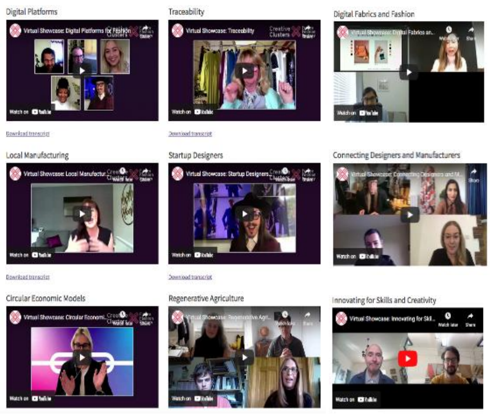

Figure 3. Engagement activity.

3. RESULTS

The integrated series of open calls and Investment Committee appraisal that comprised the ‘Responsive R&D’ funding enabled Future Fashion Factory to allocate 55 innovation challenge grants. This part of the FFF programme focused on short-term industrial challenges and awards were made under one of three funding mechanisms; Proof of Market, Proof of Concept, Innovation Challenge. The funding was only available via industry-led applications to ensure sectoral fit and impact. In line with initial learning at the inception of the FFF programme all of these projects were aligned with one or more of the Core Research Themes and each project was devised to align an industry investigator with an academic from one of the three educational institutes (Leeds, Huddersfield and RCA), whose research interests and expertise matched the aims of the undertaking. This process represented an investment of ca. £1.6m that has since leveraged co-financing of >£2.7m from both industrial and academic participants in the projects awarded funding.

Successful projects covered a wide range of industrial areas such as: development of sustainable materials and processes; design of mechanisms to support industry engagement; development of digital tools to aid both designers and manufacturers; data-driven design learning to inform product decisions and optimise production processes. An overview of all the completed Responsive R&D projects is available on the Future Fashion Factory funded projects and news pages (Future Fashion Factory2 and Future Fashion Factory3). This section of the paper describes two of the projects in detail to give a flavour of the diversity of experimentation and innovation developed within them.

Responsive R&D: Example Case Studies
Call 1: A.W. Hainsworth & Yorkshire Textiles

Call 1 of the scheme funded a project between the award winning, heritage woollen mill, A.W. Hainsworth based in Leeds and Yorkshire Textiles Ltd, a not-for-profit organisation co-founded by co-director of Future Fashion Factory, Suzy Shepherd. This was supported by an academic, Dr Kevin Almond, with significant experience in the use of fashion and textile archives as inspiration to inform contemporary design. The scheme involved digitising early jacquard designs from punch-cards in the collection at Leeds Industrial Museum to produce a 'new heritage' fabric for manufacture on a modern jacquard loom (Leeds Museums and Galleries, 2023). A.W. Hainsworth used the project to trial a new designer-led short production run service, for bespoke fabrics which has since gone on to be featured in their Sustainability Strategy being offered as a bespoke short-run service.

In support of the 'Skills and Education' Core Research Theme the project was incorporated into the delivery of an undergraduate project for second year of the BA (Hons) Fashion Design course at University of Leeds to stimulate student innovation and inspire learning activities. The project required the students to redesign and reinvent heritage garments held in the Yorkshire Fashion Archive housed at University of Leeds. The students were able to visit the Hainsworth factory and observe the fabric being woven on the loom as well as gain a more in depth understanding of how heritage products such as fabric and garments could be reworked and recreated in a new approach for a contemporary customer. The results of the project were exhibited at the first Future Fashion Factory Showcase at Salts Mill in West Yorkshire in October 2019.

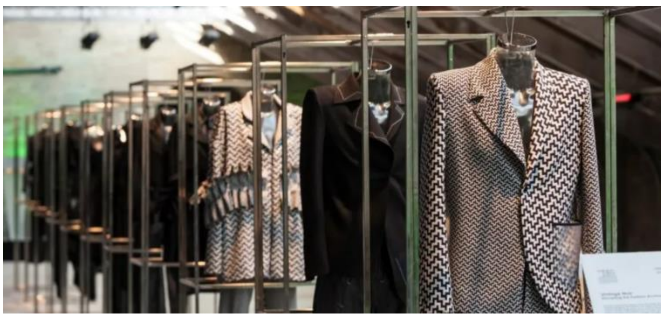

Figure 4. Student garments, jacquard short run.

Call 3: Numerion Software Ltd

Call 3 of the scheme funded a project with Numerion Software and an academic with research expertise in virtual reality and augmented fashion. Numerion is a boutique dynamics consultancy based in

Milford, UK (Leprovost and King 2021: n.pag.). The aim of the project with Future Fashion Factory was to develop and explore how best to bring to market a virtual 3D garment draping service that worked for both the fashion industry and education as well as commercially for Numerion themselves. The prototype needed to be accessible and easy to use without the need for deep technical knowledge. Based on a market-leading garment simulation tool, used by major movie studios, the new cloud-hosted 3D garment visualisation service would allow consumers and designers to engage with different styles on a webpage as part of an AR/VR/MR experience. This new platform aimed to reduce product lead times, waste from excessive sampling and customer return rates.

A focus group consisting of leading fashion industrialists and educators was formed and sent a questionnaire. This sought opinion from participants on how the software could be developed in future and how individual designers, brands and educationalists would like to use the service and interact with it to deliver best outcomes. The resultant responses were used to improve and develop the user-interface prototype and subsequently trialed with the focus group. The outcomes identified the challenges facing the fashion industry as they seek to embrace live 3D simulation and informed future development work, this enabled Numerion to identify a clear pathway to commercialization for the 3D garment draping service.

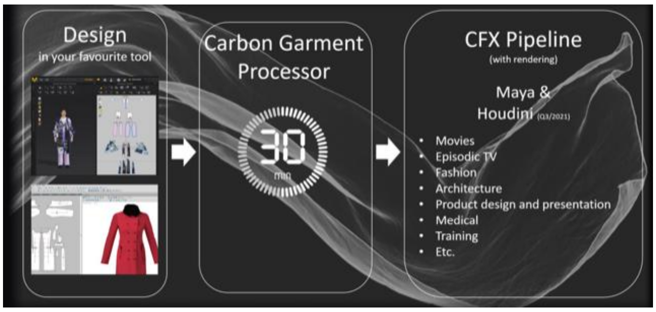

Figure 5. Numerion, carbon garment workflows.

Outcomes

Following a period of consultation in the early years of programme delivery, involving both industrial and academic participants across the whole CICP network, five key overarching CICP Benefits were identified. These high-level benefits capture the essence of the CICP programme; to stimulate, raise awareness of and add value to the UK's creative sector; thus ensuring they have the resourcing & skills-base required for sustainable growth.

B1: Creation of an environment for new & experimental creative content, products, services and experiences

B2: Generation of long-term strategic applied research partnerships creative enterprises, HEI & other relevant sectoral and local stakeholders

B3: Improvement of creative and digital enterprises' ability to access the skills, knowledge and expertise they require to develop new products and services

B4: Key place-based/sector issues are addressed through applied research programmes

B5: Economic and social benefits are generated (including co-investment)

For FFF 'Benefit 4' was a strand running throughout the programme, even though the extent of the FFF ecosystem is UK-wide (with some additional international partnerships), linkages back to the Yorkshire & Humber region are in-built to every deliverable. Other Benefits though could be shown to be directly supported by FFF specific KPIs, each of which had been carefully designed at the outset of the CICP development as a way of recording and demonstrating the significant impact for the sector the programme was designed to stimulate. To provide examples of this approach: KPIs that reflect FFF's

'Skills and Education' Core Research Theme, such as embedding of learning within new and existing training opportunities, are aligned against the CICP Benefit 3; whilst KPIs that reflect activities designed to stimulate creative co-development leading to adoption of innovative solutions align with CICP Benefit 1 and draw upon a wider range of activity occurring across multiple Core Research Themes.

At the time of writing, as we near the original delivery end point of March 2023, the results of planned FFF activity against these initial targets are outstanding. To give a flavour of outcomes delivered: Co-investment leverage stands at ~7 times the original investment, 55 projects have been awarded Responsive R&D funding, and FFF has evaluated 418 innovation ideas from across the established, and still growing ecosystem. Of the 18 contracted KPIs 12 have already been met or exceeded and the remaining 6 are on target.

4. CONCLUSION

Through its integrated programme of activity; Core Research Theme investigation, Responsive R&D innovation industry-academia co-delivery, ecosystem led support activity and dissemination; the Future Fashion Factory has very effectively fulfilled its mission to stimulate innovation within the target creative industries cluster, UK Fashion & Textiles. As part of the Creative Industries Cluster Programme (CICP) FFF has provided data to inform the UK-wide 'Benefits Mapping' approach as well as speaking to more specific Key Performance Indicators (KPIs) contracted to its funding award. The overriding contribution of the initiative has created a catalyst for new thinking, practices and paradigms within the UK fashion and textile sector. This has subsequently had a significant impact on the range and depth of the research and its application in a global context. Future Fashion Factory will continue as an important brand in Leeds Institute of Textiles and Colour (LITAC) and embrace further opportunities for creative innovation in the global fashion and textile sector.

ACKNOWLEDGMENT

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REFERENCES

Adams, T. E., Holman Jones, S., & Ellis, C. (2015). *Auto ethnography: Understanding Qualitative Research*. Oxford, England: Oxford University Press.

A.W. Hainsworth (2023, February 10). Sustainability Report 2020. Retrieved from https://www.awhainsworth.co.uk/wp-content/uploads/2020/01/AW_Hainsworth_Sustainability_2020.pdf.

Almond K. (2022). Virtual 3D Garment Draping as a Service. Fashion, Style and Popular Culture. **9**(4), 437-456.

Arts & Humanities Research Council. (2022, December 06). *Arts and Humanities Research Council.* Retrieved from https://www.ukri.org/councils/ahrc/

Bazelgette, P. (2023, 10 February). *Independent Review of the Creative Industries.* Retrieved from https://apo.org.au/sites/default/files/resource-files/2017-09/apo-nid198251.pdf.

British Fashion Council. (2022, December 06). *British Fashion Council.* Retrieved from https://www.britishfashioncouncil.co.uk.

Conti, S (2023, February 10). Boris Johnson Pledges Millions in Funding for Green Fashion Programme. Retrieved from https://wwd.com/fashion-news/fashion-features/boris-johnson-green-fashion-british-1235198913/?utm_campaign=Twitter-WWD&utm_source=Twitter&utm_medium=social.

Creative Industries Cluster Programme (2023, February 10) Creative Industries Cluster Programme. Retrieved from https://creativeindustriesclusters.com/.

Chang, H. (2008). *Autoethnography as Method*. Walnut Creek, CA: Left Coast Press.

CICP Directors (2023). Internal commuications and reporting.
Future Fashion Factory1. (2022, December 06). *Future Fashion Factory: Supporting Innovation in the UK Fashion and Textiles Industry*. Retrieved from https://futurefashionfactory.org.
Future Fashion Factory2. (2023, February 10). *Funded Projects*. Retrieved from https://futurefashionfactory.org/funded-projects/
Future Fashion Factory3. (2023, February 10). *News*. Retrieved from https://futurefashionfactory.org/news/
Gov.UK. (2023, February 10). *The UK's Industrial Strategy.* https://www.gov.uk/government/topical-events/the-uks-industrial-strategy
Leeds Institute of Textiles and Colour. (2022, December 06). *Leeds Institute of Textiles and Colour*. Retrieved from https://www.leeds.ac.uk/leeds-institute-textiles-colour.
Leeds Museums and Galleries (2023, February 10) Leeds Industrial Museum. Retrieved from https://museumsandgalleries.leeds.gov.uk/leeds-industrial-museum/.
Leprovost, J. C and King, M. (2021, February 16). About Us: Numerion Software. Retrieved from https://www.numerion-software.com/index.php/aboutus.
Nelson, R. (2013). *Practice as Research in the Arts: Principles, Protocols, Pedagogies, Resistances*. London, England: Palgrave Macmillan.
University of Leeds. (2023, February 10). Leeds Institute of Textiles and Colour. Retrieved from https://www.leeds.ac.uk/leeds-institute-textiles-colour/doc/litac-heritage.
UKFT Fashion & Textile Association. (2022, December 06). *UKFT.* Retrieved from https://www.ukft.org/about/.
Frontier Economics. (2023, February 10). *Understanding the Growth Potential of Creative Clusters.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1115486/Understanding_the_growth_potential_of_creative_clusters_-_accessible.pdf.
UKRI (2023) Areas of Investment and Support, Creative Industries Cluster Programme. Last updated 13/02/23
Retrieved from https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/creative-industries-clusters-programme/

INVESTIGATION OF THE DYEABILITY OF COTTON FABRICS WITH BACTERIAL COLORANTS

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ABSTRACT

Dyestuffs are used in almost every industry. However, due to the negative effects of synthetic dyestuffs on the environment and human health, environmentally friendly natural dyestuffs become more important in recent years, especially in the textile sector. Mostly plant and plant waste-based dyes are used in colouring fabrics with natural dyes. However, with the developments in the field of biotechnology, there are also studies in which bio-color is produced by microorganisms. Within the scope of this study, 100% cotton woven fabric was dyed using 6 different processes with 3 bio-colors, blue, pink and brown, produced by bacterial fermentation. The dyeings were carried out in presence of salt, salt-soda, salt-alum, salt-soda-alum, alum and in the absence of chemicals respectively. In order to evaluate the dyeing performance, the K/S values of the fabrics were measured and their washing, water, perspiration and rubbing fastnesses were checked. As a result of the studies, it was concluded that each dyestuff reacts in a different way with a different process. While the most suitable process for blue and pink bio-color is that salt used process, the highest K/S value with brown bio-color was obtained as a result of dyeing with salt-soda. Also fastness values of the dyed fabrics were quite good.

Keyword: *Bacterial dyeing, bio-based colors, sustainable dyeing, microbial dyeing*

1. INTRODUCTION

Nowadays, plant-based dyes have been used instead of synthetic dyes, especially in textile products [1]. Natural colorants have many disadvantages such as higher usage costs and low stability when compared with synthetic colorants [2]. But micro-organisms produce a wide variety of stable pigments such as carotenoids, flavonoids, quinones and rubramines, and fermentation has higher yields compared to pigments derived from plants and animals [3-4]. Studies on the use of pigments obtained from bacteria and algae in textile dyeing have gained momentum in recent years.

According to the literature, some microorganisms which were used in bacterial dyeing were Streptomyces, Vibrio spp., Serratia marcescens, Chromobacterium violaceum, Chryseobacterium sp., Vibrio psychroerythrus and Hahella chejuensis [5-12]. Used bio-colors were produced by bacterial fermentation process and dyeings were carried out at 80-85°C at different pH values [5, 10, 11]. Promising results were obtained from the studies.

In this paper, the dyeings of cotton poplin fabric was carried out with different processes by using three different bacterial-based bio-color. K/S values of dyeings were compared to find the most suitable dyeing technique and fastness values were checked.

2. EXPERIMENTAL STUDY

2.1 Materials

100% cotton poplin fabric with a weight of 108 g/m2 was used in the study. Three bio-colors (pink, blue and brown) were used for dyeing fabrics and these bio-colors were obtained by using bacterial fermentation. They were powder form and water-soluble. Trade names were not disclosed for commercial concerns. But blue bio-color belongs to the Indole Family Group, brown bio-color belongs to the alcoholic carotenoid pigment family and pink bio-color belongs to the pyrrole family. The bio-colors were free from the bacterias. All microorganisms worked with have Biosafety Level 1. Potassium aluminum sulfate dodecahydrate, also known as alum [$KAl(SO_4)_2 \cdot 12H_2O$] mordant material, was used. Sodium chloride (NaCl) was used as salt and sodium carbonate (Na_2CO_3) was used as soda. Washing soap used in washing after dyeing is non-ionic.

2.2 Method

The dyeing process of the fabrics with bacterial dyestuffs was carried out using a TERMAL branded 30 liter water bath. The bath ratio is 1:20. Dyeing was carried out at 85°C for 45 minutes. Then, the dyed fabrics were rinsed with cold water and then washing were carried out at 60°C for 30 minutes by using 0,5 g/l washing soap. Dyeing receipts are given in Table 1.

Table 1. Dyeing Receipts of bio-colors

Receipt No	**Bio-Color Rate (%)**	**Na Cl (g/l)**	**SODA ASH (g/l)**	**ALUM (g/l)**
Receipt 1	5	-	-	-
Receipt 2	5	25	-	-
Receipt 3	5	25	15	-
Receipt 4	5	25	-	2,5
Receipt 5	5	25	15	2,5
Receipt 6	5	-	-	2,5

K/S values of dyed fabrics were measured by using Datacolor 1050 model spectrophotometer. Washing fastness, water fastness, perspiration fastness and rubbing fastness values were checked according to ISO 105-C06:2012 A2@40°C, ISO 105-E01:2013, ISO 104-E04:2013, ISO 105X12:2006 respectively.

3. RESULTS

When the results of the studies were examined, it was seen Table 2 that the highest K/S values were obtained by using Receipt 2 for Pink and Blue bio-color, and Receipt 3 for brown bio-color respectively.

The highest K/S value of pink color was 0,30. In this recipe, salt supported to improve the exhaustion.

In blue color, the best result was obtained from Recipe 2 and the worst results were obtained from Recipe 3 and Recipe 5. Blue bio-color due to its structure has the best pick-up and affinity. The exhaustion rate was already good for blue color, but adding salt was increased the exhaustion. It was observed that alkaline dyeing baths damaged the blue color chromophore groups. pH values for Recipe 3 and Recipe 5 were 9,93 and 9,58 respectively.

Table 2. K/S and CIE Lab values of dyed fabrics

Recipe no -Color	L	a	b	C	h	K/S
Recipe 1 - Pink	93,13	1,97	4,25	4,69	65,15	0,05
Recipe 2 - Pink	80,93	22,29	-5,79	23,03	345,44	0,30
Recipe 3 - Pink	83,2	20,75	-5,05	21,35	346,32	0,24
Recipe 4 - Pink	84,05	19,08	-4,06	19,51	348	0,22
Recipe 5 - Pink	81,02	22,61	-5,74	23,33	345,76	0,29
Recipe 6 - Pink	85,75	15,25	-2,02	15,38	352,46	0,17
Recipe 1 - Blue	80,5	0,04	-10,05	10,05	270,21	0,21
Recipe 2 - Blue	78,97	0,38	-12,44	12,44	271,75	0,26
Recipe 3 - Blue	91,18	-0,04	1,02	1,02	92,49	0,05
Recipe 4 - Blue	84,71	-0,34	-6,17	6,18	266,81	0,12
Recipe 5 - Blue	89,49	0,38	-0,55	0,67	304,84	0,05
Recipe 6 - Blue	79,96	-0,08	-10,67	10,67	269,57	0,23
Recipe 1 - Brown	89,25	1,68	10,75	10,88	81,1	0,16
Recipe 2 - Brown	81,43	4,03	14,3	14,86	74,27	0,43
Recipe 3 - Brown	67,69	5,89	15,43	16,52	69,1	1,25
Recipe 4 - Brown	92,8	-0,03	6,94	6,94	90,23	0,07
Recipe 5 - Brown	70,79	5,44	14,06	15,08	68,86	0,94
Recipe 6 - Brown	92,95	0,09	6,83	6,83	89,24	0,07

In brown color, the highest K/S value was obtained with Recipe 3. Because these pigments were not naturally soluble in water and alkali was added in the process to improve the solubility of brown bio-color. Salt was added to improve exhaustion. Recipe 4 and Recipe 6 has the lowest K/S value since the alum was in the recipe and it decreased pH. While pH value of Recipe 3 was 10,56, pH values of Recipe 4 and Recipe 6 were 4,2 and 4,1 in these dyeing baths respectively.

Table 3. Fastness results of all dyeings

	Color Fastness to Washing		**Color Fastness to Water**		**Color Fastness to Perspiration (Acid)**		**Color Fastness to Perspiration (Alkali)**		**Rubbing Fastness**	
	ISO 105-B02: 2014		**ISO 105-E01:2013**		**ISO 105-E04:2013**		**ISO 105-E04:2013**		**ISO 105X12:2006**	
	Color Change	Color Staining	Color Change	Color Staining	Color Change	Color Staining	Color Change	Color Staining	Dry	Wet
Recipe 1 Pink	3	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 2 Pink	4	4/5	4	4	4	4	4	4	4/5	4/5
Recipe 3 Pink	3/4	4/5	3	4	3	4	3	4	4/5	4/5
Recipe 4 Pink	3/4	4/5	4	4	4	3/4	4	4	4/5	4/5
Recipe 5 Pink	3/4	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 6 Pink	2/3	4/5	3	4/5	3	3/4	3	4	4/5	4/5
Recipe 1 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5

Recipe 2 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 3 Blue	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 4 Blue	4	4/5	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 5 Blue	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 6 Blue	4	4	4	4/5	4	4/5	4	4/5	4/5	4/5
Recipe 1 Brown	3	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 2 Brown	3/4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 3 Brown	3/4	3/4	4	4/5	4	4	4	3	4/5	4/5
Recipe 4 Brown	3/4	4/5	3/4	4/5	3/4	4/5	3/4	4/5	4/5	4/5
Recipe 5 Brown	4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5
Recipe 6 Brown	4	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5	4/5

As it is important to bind a bio-color to the fabric, it is also important that the fastness values of the dyed fabric are good. For this reason, washing fastness, water fastness, acidic and alkaline perspiration fastness and dry and wet rubbing fastness of 18 dyed fabrics were checked. The results were given in Table 3. All fastness values had good results and it shows that bio-colors were fixed to the fabric.

4. CONCLUSION

In the trials carried out within the scope of this project, it has been observed that each dyestuff has its own characteristic properties since the pigment classes are different. Laboratory scale trials shows that bacterial-based dyes are suitable for cellulosic fabric dyeing. With the widespread use of this practice in the textile industry, the natural resource consumption, high energy requirement and emission of harmful gases required in the production of synthetic dyestuffs will be eliminated, and the waste load of textile waste water will be reduced.

REFERENCES

[1] Tilak, J. C., Baneriee, M., Mohan, H., Devasagayam, T. P. A., (2004), Antioxidant Availability of Turmeric in Relation to its Medicinal and Culinary Uses, Phytother. Res. 18, 798–804.
[2] Martins, N., Roriz, C., L., Morales, P., Barros, L., Ferreira, I. C. F. R., (2017), Coloring attributes of betalains: A key emphasis on stability and future applications, Food and Function, 8(4), 1357-1372.
[3] Gürcüm, B.H., Öneş, A., (2018), Bakteri ve mikroalglerin tekstil boyamacılığında kullanım olanakları, İdil Dergisi, 7(46), 701-709.
[4] Hobson, D. K., Wales, D. S., (1998), Green dyes, Journal of the Society of Dyers and Colourists, 114, 42-44.
[5] Kramar, A., Ilic-Tomic, T., Petkovic, M., Radulovic´, N., Kostic, M., Jocic, D., Nikodinovic-Runic, J., (2014). Crude bacterial extracts of two new Streptomyces sp. isolates as bio-colorants for textile dyeing, World Journal of Microbiology and Biotechnology, 30, 2231-2240.
[6] Venegas, F.A., Köllisch, G., Mark, K., Diederich, W. E., Kaufmann, A., Bauer, S., Chavarría, M., Araya, J. J., García-Piñeres, A. J., (2019). The Bacterial Product Violacein Exerts an Immunostimulatory Efect Via TLR8, Nature Research, 9:13661, 1-17.

[7] Ahmad, W. A., Ahmad, W. Y. W., Zakaria, Z. A., Yusof, N. Z., (2012). Application of Bacterial Pigments as Colorant: Malaysian Perspective, Springer Berlin, Heidelberg, 57-74.
[8] Bennett JW, Bentley R (2000). Seeing red: The story of prodigiosin, Advances in Applied Microbiology, (47), 1–32.
[9] Yu, Victor L. (1979). Serratia marcescens - Historical Perspective and Clinical Review, New England Journal of Medicine, 300 (16), 887–893.
[10] Venil, C. K., (2013). Bacterial pigments and their applications, Process Biochemistry, 48, 1065-1079.
[11] Alihosseini, F., Ju, K. S., Lango, J., Hammock, B. D., Sun, G., (2008). Antibacterial colorants: characterization of prodiginines and their applications on textile materials, Biotechnology Programme, 24 (3),742-747.
[12] Yusof, N. Z., (2008). Isolation and applications of red pigment from Serratia marcescens, Universiti Teknologi Malaysia, BSc thesis.

DIGITALISED R&D AND PRODUCTION IN THE TEXTILE INDUSTRY FOR REDUCED ENERGY CONSUMPTION AND EFFICIENT PRODUCTION RATES

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ABSTRACT

The requirements placed on the textile industry are changing drastically. Zero-emission targets for 2030 and beyond require cross-sectoral changes. This also challenges the textile industry to find viable all-in solutions that satisfy social, economic, and sustainable requirements. Currently, the use of textiles in transdisciplinary sectors demands a high level of tailor-made solutions. This requires a broad understanding of the processed materials, complex multiphysics as well as machine settings. Hence, to consolidate high production rates with optimal energy consumption and the use of sustainable resources, systematic research and product development need to be pursued. The digitalisation of research and production in the textile industry aids to close the gap between the complex production processes and the quality measure of the end products. For this purpose, a systematic approach comprising experimental measurements and emerging digital technologies is used. Textile fabric manufacturing machine park results have been used for the benchmark study.

Keyword: *AI, Nonwoven, Multiphysics, Digitalisation, Digital twin, Machine-Learning*

1. INTRODUCTION

The recognition of climate-neutral manufacturing and sustainable R&D has raised great attention in transdisciplinary deep-tech sectors such as advanced textile materials, energy or electrified vehicles for many years. Worldwide a strong commitment continues for reduced energy consumption [1–4] and to improve production efficiency. Consumers from various sectors are increasingly demanding tailor-made textile products, influencing the production rates by affecting the processes and product quality. The textile sector is also challenged to find satisfactory all-in solutions to forge sustainability and contribute to change.

This requires digitalisation-assisted production as well as systematic research and product development procedures. High production rates with optimal energy consumption and the use of sustainable resources demand extensive knowledge of the processes and product behaviour. The result depends decisively on the quality and quantity of the acquisition, processing and analysing of available data. In the textile industry, enough measurements are usually collected for quality control. However, key data available is usually lacking that links the main and interaction effects of the process parameters with the product quality. Moreover, an improved understanding of the processed materials, complex multiphysics, as well as machine settings, is required.

This means that information can not purely rely on experimental data-driven information transfer - especially in production plants where the optimisation of textile machinery, processes and fabrics for customer-specific cases is critical. The emerging hybrid artificial intelligence-multiphysics process will be demonstrated in this context. The study uses the optimisation of complex nonwoven production machines as an example to improve production rates and reduced energy consumption. The study aids to close the gap between systematic research and industrial challenges in production.

2. RESEARCH METHOD

To assess and optimise textile machinery, production processes as well as materials or product quality, traditional numerical methods such as the FEM or CFD are frequently used. Experimental data are used to validate and provide the input data for this kind of multiphysics analysis. Typically, sampling-based approaches, trial and error or techno-economic assessments are used in sensitivity studies to aid in improved understanding and to estimate operating efforts based on technical or financial input. However, in cross-sectoral industries such as the textile industry, the desired outcome is strongly tied to the integrated approach of R&D and production, as rapid response to changes is demanded. Thus, detailed modelling and simulation have been intensively used in this current study to improve the understanding and interpret the relationship between process parameters, machine components as well as product quality interactions. The current study uses an experimentally validated digital twin model of the machine and AI-based machine learning for accelerated process optimisation as a design tool. Experimentally determined data from industry has been used as boundary conditions to mimic and calculate the thermo fluid flow of the complex textile machine architecture. Figure 1 displays the industrial textile manufacturing machine from which experimental data was gathered for boundary conditions and validation purposes.

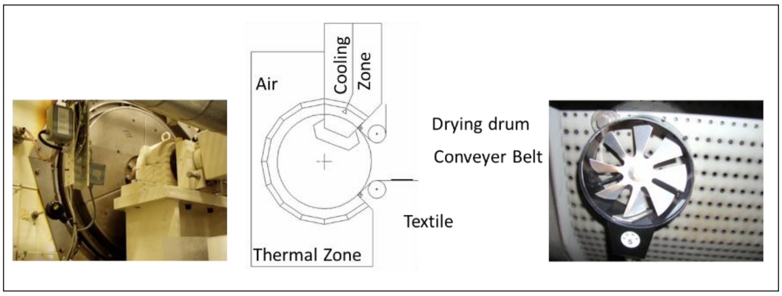

Figure 1. Industrial textile machine details during measurements inside the machine.

2.1. Digital Twin and Multiphysics Modelling of the Machine

The digital twin of the textile machine has been constructed using computer-aided engineering tools. The machine system attributes including the textile transport belt, drying drum components as well as the nonwoven web are considered. To ensure a realistic portrayal of the industrial machine, each component has been characterised and considered in complicated CFD analyses. The experimental validation and detailed procedures including thermal and flow measurements have been elucidated in previous studies conducted on pilot scale machines such as those given in Ref. [5], and will not be detailed further.

2.2. Proof of Concept and Data Generation

The thermal fluid flow of the system has been numerically simulated using the textile machine's digital twin. To simulate the complicated behaviour, the permeabilities of the system attributes and thermophysical material properties have been incorporated. The rotation of the machine has been represented as a moving reference frame to also represent the machine's actual drum rotation. The model will be used to demonstrate and examine various thermofluid process conditions. Based on a D-optimal design of experiments (DoE) approach, a systematic investigation for data collecting is performed. For this purpose, the effects of three operating parameters on the textile machine have been assessed methodically. The parametric research will serve as an illustrative reference for decreasing the prediction time of conventional numerical approaches and enhancing the understanding required to develop optimum machine settings for desired process and product qualities. Moreover, it generates the data for the development and training of an AI-based machine learning model. Table 1 illustrates the used parameters.

Table 1. Investigated variables used for the systematic assessment.

Factor level	-1	0	1
Air Temperature [°C]	225	230	235
Air velocity [m/s]	0.7	2	4
Dryer rotation speed [rad/s]	0.7	0.8	0.9

CFD simulations were calculated to represent the various factor-level combinations that are utilised. As the fluid velocities and the associated temperatures determine the amount of energy introduced into the system, they are selected as variables. The nonwoven product quality is associated with the quality of fiber bonding during the manufacturing process. Therefore, it is also important to predict the temperature distribution of the nonwoven web to evaluate the quality of the product. The measure for this is set as the melting temperature of the used thermoplastic fibers. In this example, this has been set as technical nylon 66 with a melting point temperature of 221°C. This must be achieved in the most efficient way to obtain high production rates.

2.3. Machine Learning Model Development and Training

An analysis based on the machine's thermofluid flow behavior and optimization capacity has been explored as a consequence of the successful application of AI capabilities. The processed and stored data also helps the problem's scalability. By working with machine learning (ML) techniques based on artificial intelligence (AI), the execution of increasingly complicated transient CFD analyses is compensated. In this work, a link between factors and the nonwoven web temperature was found using supervised learning. As the researched variables and output are numerically predicted, a mathematical algorithm is used to understand the patterns contained in the data to produce new predictions. The learning-training procedure in machine learning involves the separation of input data into training data and test data. A supervised learning-training procedure requires data. The initial set of simulation data calculated numerically is used to shape the training data, which is used to train the model, while the test data are used to evaluate the model's accuracy. A cross-validation procedure is utilized to divide the data for training purposes. To enhance the reduction of energy consumption and control of the process, machine learning predictions will provide invaluable information. Thus, specified nonwoven temperatures of the manufacturing process can be generated, allowing it to be processed with the most efficient machine settings for reduced energy consumption. The flow chart of the overall optimization procedure is depicted in Figure 2.

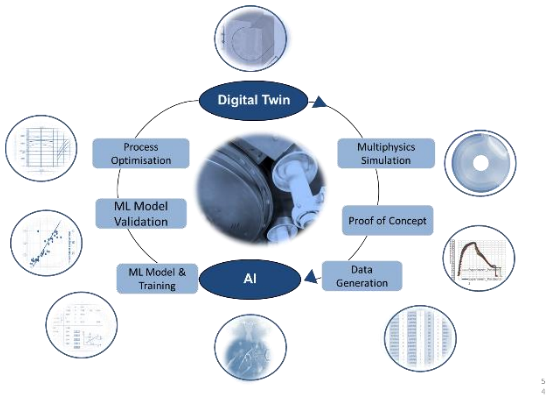

Figure 2. Flow chart of the textile machinery process optimisation using AI-based machine learning.

3. RESULTS

The experimental measurements performed on the used textile machine revealed a non-uniform dispersion of fluid flow along the rotating machine width. The rotating speed of the machine is dependent on the conveyer belt speed; therefore, it has been essential to comprehend the rotational thermos fluid through the system components and the textile fabric over time. The results provided a data pool for the successful development of a machine learning model for optimisation purposes. Figure 3 displays an example of the transient temperature distribution results produced by the digital twin of the machine that was created to effectively replicate the thermo fluid flow within the machine. The results are taking into account the machine's rotation and the complex material behaviour of all system components.

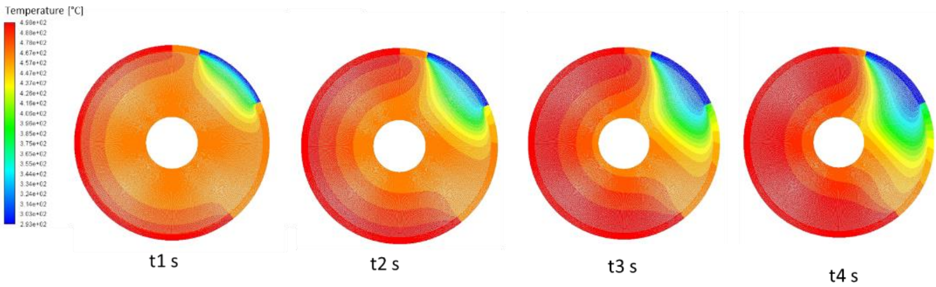

Figure 3. Temperature distribution inside the rotating machine and transported textile.

The nonwoven temperature has been selected for the optimisation criteria to achieve a controlled process with desired product quality. Nonlinear analysis of the data has been undertaken in order to grasp the mathematical relationship between the parameters throughout the machine learning model development phase. Figure 4 depicts the results for the main machine parameter effects on the nonwoven temperature.

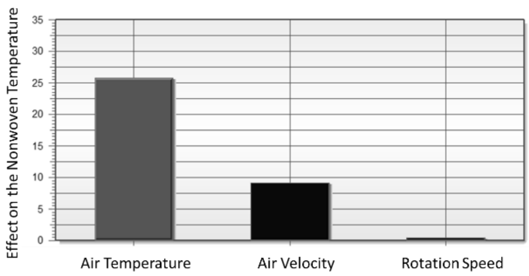

Figure 4. Main parameter effects on the nonwoven fabric temperature value.

The predicted outcomes provide the necessary data for statistically reliable AI analyses. Within a 99% confidence interval, a multi-regression analysis determined the relationship between the investigated variables and the mass-weighted nonwoven product temperature. The results of the analysis indicate that a significant portion of the data variance can be explained by the model. This is evident from the coefficient of determination value (R2) of 0.999 and root-mean-square (RMS) of 0.29. This directly enables us to identify the variable with the greatest potential for improvement. The air temperature indicates having the greatest impact among the demonstrated three variables. But the interesting information has been how these variables interact and affect the nonwoven temperature. Figure 5 demonstrates the relationship between these parameters and the nonwoven temperature.

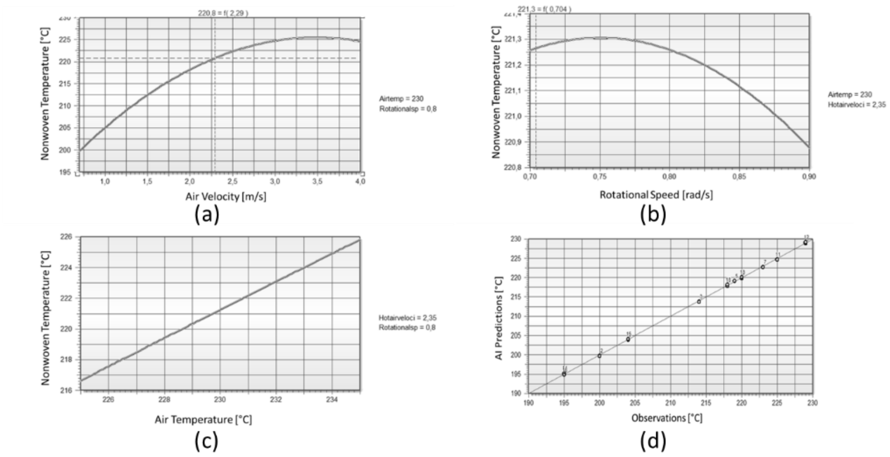

Figure 5. Interacting effects on the nonwoven fabric temperature value.

The interactions of the investigated machine parameters have a considerable influence on the nonwoven web temperature. Nonlinear effects are observable considering the air velocity Fig. 5 (a) and the machine rotational speed Fig. 5 (b), whereas the effect of air temperature Fig. 5 (c) shows a linear effect on the nonwoven temperature response. The projections reveal a mid-range air velocity operation as favourable, whereas the lower end of the rotating speed demonstrates a better nonwoven temperature response. The predictions of the model are in excellent agreement with the observations of the machine-learning model, suggesting its use for optimising machine operation.

The trained machine learning model was used to estimate the ideal machine operation point for minimising energy consumption while maintaining the target level of product quality. This might be accomplished by locating the optimal temperature at which the nonwoven material hits 221°C. It should be noted that characteristics such as time of operation and additional aspects may be considered; however, for the purpose of the study and the generated training data, a machine process time of 20 seconds has been considered and its response has been investigated. Figure 6 summarises the results.

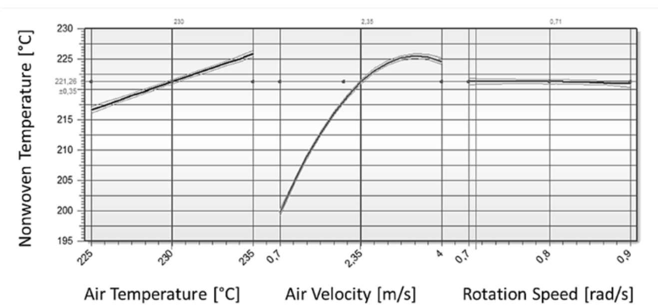

Figure 6. Interacting effects on the nonwoven fabric temperature value.

The optimisation procedure has been carried out for various distinct cases to predict the optimal machine operational points. The set parameter values are labelled in the upper portion of each graph, and the response output value is depicted horizontally along the axis displaying the nonwoven fabric temperature. Using the considered parameters and established levels, an optimal operation with the lowest energy usage while maintaining the specified fabric temperature of 221°C could be achieved. The air feed temperature set to 230°C and an air velocity of 2.35 m/s have shown to be energy efficient. Retaining a rotation speed of 0.7 rad/s has been sufficient for maintaining the target nonwoven temperature. Using the model, it was possible to forecast the operating behaviour of the manufacturing process by optimal adjustment of the chosen machine parameters, as demonstrated by the results.

4. CONCLUSION

The introduced study aims to demonstrate the use of emerging digital technologies in textile industry research and product development. An AI-based machine learning model was developed using a digital twin model of an industrial nonwoven manufacturing machine that has been experimentally validated. The model successfully determined the main and interaction effects of machine parameters such as air temperature, air velocity and rotational speed of the machine. The operational machine settings have been optimized with the aid of improving process and product quality. An air temperature of 230°C and an air velocity of 2.35m/s are shown to be maintaining the required nonwoven temperature of 221°C Thus, an optimal bonding temperature could be predicted with the most efficient machine settings for the selected parameters. The power of digital methods-based optimization proved to be a very cost-effective way to assist sustainable industrial research and development. Moreover, the time and resource-efficient approach also mitigated hazards due to experimentation on thermal machinery.

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REFERENCES

[1] Peksen, M. (2022). Artificial Intelligence-Based Machine Learning toward the Solution of Climate-Friendly Hydrogen Fuel Cell Electric Vehicles. *Vehicles 4*, 663–680.
[2] Peksen, M. (2021). Hydrogen Technology towards the Solution of Environment-Friendly New Energy Vehicles. *Energies*, *14*(16), 4892 doi: 10.3390/en14164892.
[3] Peksen, M. Acar, M., Malalasekera, W. (2018). Optimisation of machine components in thermal bonding process of nonwovens: Effect of the conveyer belt on the porous web performance. *Journal of Industrial Textiles*, *47*(5), 978 – 990.
[4] Peksen, M. (2018). *Multiphysics Modelling-Materials, Components, and Systems*. London, England: Ed. Academic Press.
[5] Peksen M, Acar M., Malalasekera W. (2014). Optimisation of machine components in thermal fusion bonding process of porous fibrous media: Material optimisation for improved production capacity and energy efficiency. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 226*(4), 316-323.

TEXTILE PATTERN GENERATION USING DIFFUSION MODELS

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ABSTRACT

The problem of text-guided image generation is a complex task in Computer Vision, with various applications, including creating visually appealing artwork and realistic product images. One popular solution widely used for this task is the diffusion model, a generative model that generates images through an iterative process. Although diffusion models have demonstrated promising results for various image generation tasks, they may only sometimes produce satisfactory results when applied to more specific domains, such as the generation of textile patterns based on text guidance. This study presents a fine-tuned diffusion model specifically trained for textile pattern generation by text guidance to address this issue. The study involves the collection of various textile pattern images and their captioning with the help of another AI model. The fine-tuned diffusion model is trained with this newly created dataset, and its results are compared with the baseline models visually and numerically. The results demonstrate that the proposed fine-tuned diffusion model outperforms the baseline models in terms of pattern quality and efficiency in textile pattern generation by text guidance. This study presents a promising solution to the problem of text-guided textile pattern generation and has the potential to simplify the design process within the textile industry.

Keyword: *AI, Deep Learning, Diffusion models, Textile Pattern, Text-guided Image generation*

1. INTRODUCTION

Textile pattern generation, which involves creating high-quality patterns based on text guidance for industries such as fashion, home decor, and industrial design, is challenging due to the diverse range of patterns and styles and the complex relationship between patterns and text descriptions. However, synthetic image generation, which is the artificial creation of images that resemble natural images, has emerged as a popular area of research in AI and has the potential to significantly simplify the textile pattern design process. Recently, there has been a shift in the field of generative AI, with Denoising Diffusion models [1] emerging as the new state-of-the-art technology. This change is particularly evident in image generation, where these models have outperformed Generative Adversarial Networks (GANs) [2], which have been the dominant technology for a significant time.

On the other hand, the CLIP [3] model is a highly utilized AI model enabling text-guided image generation by connecting visual representations with natural language supervision. This hybrid model has been widely adopted for text-guided image generation, allowing for creating images based on text descriptions.

We choose the Stable Diffusion model [4] for this work due to its open-source availability and proven ability to produce high-quality images for various tasks. The use of diffusion models [1] in image generation has significantly advanced the field, allowing for creating realistic images for various purposes.

Our goal is to produce pattern images for textiles using the Stable Diffusion model and a given prompt text. Although Stable Diffusion effectively generates scenes, it falls short in generating patterns for textiles. To overcome this limitation, we fine-tune the model using custom datasets tailored for textile pattern generation. The pattern images are collected in various styles, and the images are then captioned using the BLIP [5] model. The fine-tuned model with the new dataset generates improved results, yielding highly realistic and visually appealing pattern images.

2. EXPERIMENTAL STUDY

2.1 Diffusion Models

In this study, we use diffusion model architecture as a method for textile pattern generation. To improve the model's performance for this specific task, we fine-tune the pre-trained Stable Diffusion model with a custom dataset of textile patterns.

Denoising Diffusion models, such as the Stable Diffusion model, are inspired by considerations from nonequilibrium thermodynamics. Stable Diffusion differs from other proposed diffusion models in that it operates on the latent space rather than the pixel space, which reduces computational complexity and makes it more practical to implement with systems with limited computational power.

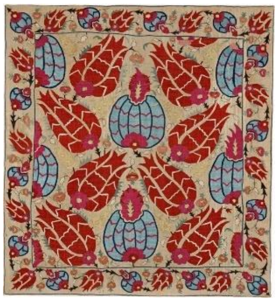
Overall, the Stable Diffusion model has demonstrated that diffusion models can be effectively utilized for generating high-quality images in the latent space domain and offers a promising approach for tasks such as text-guided textile pattern generation.

2.2 Dataset

In order to train our model for text-guided textile pattern generation, we have compiled a diverse dataset of approximately 4.000 pattern images from various sources on the internet. Some examples are given in Figure 1. Our dataset consists of a wide range of styles and designs to ensure that the model can generalize to a wide range of textile patterns. As a result of the promising initial results obtained from our model, we have also taken steps to improve further and expand our dataset to achieve even better performance.

To provide natural language supervision for our dataset, we have utilized a pre-trained image caption model called BLIP. This model has been trained on a large dataset of images and their corresponding captions and can generate textual descriptions of images based on their visual content. By using BLIP to generate captions for our dataset, we have provided our model with a rich source of textual information to guide the generation process. In addition to the captions generated by BLIP, we have also included a selection of keywords related to the style and content of the patterns in our dataset as an additional source of guidance for the model.

(a) Animal Patterns



(b) Ottoman Embroidery

(d) Indian Patterns

(c) Traditional Japanese

(e) Aboriginal Patterns

(f) Persian patterns

Figure 1. Samples from datasets and their keywords.

Table 1. All keywords used to create the dataset.

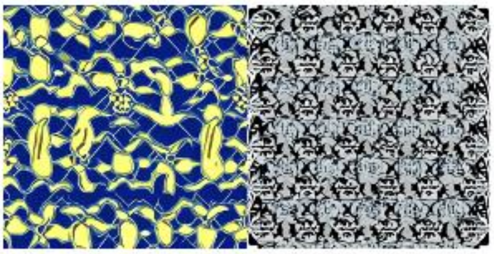
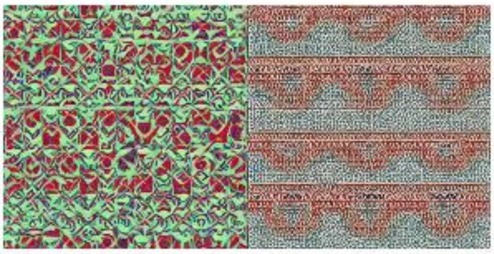
All Keywords In Our Dataset		
Allover patterns	Abstract Patterns	Calico Patterns
Animal Patterns Printed	Ottoman Embroidery Patterns	Indian Fabric Patterns
Traditional Japanese Patterns	African Pattern Fabric	Iranian Rug pattern
Floral Pattern Fabric	Turkish Patterns	Oriental patterns
Aborigin patterns	Vintage Fabric Patterns	Art Nouveau pattern

3. RESULTS

Our newly developed textile-generating diffusion model outperforms the original Stable Diffusion model. We reach this conclusion through both qualitative and quantitative evaluations.

We perform a qualitative evaluation of the results of the newly developed textile-generating diffusion model to compare its performance with the original Stable Diffusion model. The comparison can be seen in Table 2, where it is evident that the fine-tuned Textile Diffusion model outperforms the original Diffusion model across various textile patterns in given captions.

Table 2. Qualitative comparison between the base model and proposed model.

Prompt	Our Model	Base Model
Aboriginal Flower Pattern		
Vintage Floral Patterns		
Oriental Japanese Pattern		
Turkish Patterns		
Ottoman Embroidery Patterns		

In addition to the qualitative evaluation, we use perceptual loss [6] and clip similarity for the quantitative evaluation. We calculate the clip similarity by analyzing keywords in the dataset given in Table 1 and using the CLIP model to compute the similarity between the generated images and the keywords. We calculate the perceptual loss by selecting base images randomly from the dataset related to the selected keywords and determining the differences in style and features between the generated images and the base images. It is seen in Table 3 that these results provide further support for the conclusion that the fine-tuned Textile Diffusion model outperforms the original Diffusion model.

Table 3. Quantitative comparison between the base model and proposed model.

	Perceptual Loss (Lower is Better)		Clip Similarity (Higher is Better)	
Keywords	**Our Model**	**Base Model**	**Our Model**	**Base Model**
Calico Pattern	30.13	71.08	65.31	57.0
Traditional Japanese Patterns	67.042	175.88	82.75	72.0
African Pattern fabric	132.26	164.88	79.87	73.31
Turkish Patterns	40.71	44.79	74.12	68.5
Oriental Patterns	49.70	115.76	78	73.87
Aboriginal Patterns	165.04	189.88	86.25	75.37
Modern Flower Print Fabric	80.13	101.78	74.75	73.18
Native American Pattern	66.19	84.57	81.0	70.56
Iranian Pattern	41.91	47.56	79.0	77.31

4. CONCLUSION

In conclusion, the fine-tuned Diffusion model represents a significant advancement in the field of text-guided textile pattern generation, providing improved results compared to the original model. This work has the potential to transform the way textile patterns are designed and created, streamlining the process and enabling the generation of intricate and sophisticated patterns with ease. The use of the Diffusion model for this specific task demonstrates its versatility and adaptability, making it a valuable tool for image generation in a wide range of domains.

Overall, this research contributes to the ongoing efforts in image generation, adding to the growing body of knowledge and expanding the capabilities of AI in this area. The ability to generate high-quality textile patterns based on text descriptions can revolutionize the textile industry, enabling designers to quickly and easily create complex patterns and bring new ideas to life. This work opens up exciting possibilities for the future of text-guided image generation, and we look forward to seeing the impact it will have in the field.

REFERENCES

[1] Ho, J., Jain, A., & Abbeel, P. (2020). Denoising Diffusion Probabilistic Models. *ArXiv*. https://doi.org/10.48550/arXiv.2006.11239

[2] Goodfellow, I. J., Mirza, M., Xu, B., Ozair, S., Courville, A., & Bengio, Y. (2014). Generative Adversarial Networks. *ArXiv*. https://doi.org/10.48550/arXiv.1406.2661
[3] Radford, A., Kim, J. W., Hallacy, C., Ramesh, A., Goh, G., Agarwal, S., Sastry, G., Askell, A., Mishkin, P., Clark, J., Krueger, G., & Sutskever, I. (2021). Learning Transferable Visual Models From Natural Language Supervision. *ArXiv*. https://doi.org/10.48550/arXiv.2103.00020
[4] Rombach, R., Blattmann, A., Lorenz, D., Esser, P., & Ommer, B. (2021). High-Resolution Image Synthesis with Latent Diffusion Models. *ArXiv*. https://doi.org/10.48550/arXiv.2112.10752
[5] Li, J., Li, D., Xiong, C., & Hoi, S. (2022). BLIP: Bootstrapping Language-Image Pre-training for Unified Vision-Language Understanding and Generation. *ArXiv*. https://doi.org/10.48550/arXiv.2201.12086
[6] Zhang, R., Isola, P., Efros, A. A., Shechtman, E., & Wang, O. (2018). The Unreasonable Effectiveness of Deep Features as a Perceptual Metric. *arXiv*. https://doi.org/10.48550/arXiv.1801.03924

THE EFFECT OF POLYMER CONCENTRATION ON COAXIAL ELECTROSPINNING OF PVP/PCL CORE-SHEATH NANOFIBERS

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ABSTRACT

Core-sheath nanofibers are being developed with coaxial electrospinning for use in drug release studies. In this study, nanofiber structures were developed as hydrophobic PCL in the sheath and hydrophilic PVP in the core. The effect of polymer concentrations on fiber structure and water contact angle was observed by forming two different test groups. In the first group, fiber diameters were observed to decrease depending on viscosity as the polymer concentration decreased from 10 % PCL / 10 % PVP to 6 % PCL / 6 % PVP. It was also observed that the contact angle decreased from 104.3° to 57.61° as the concentration decreased. In the second group, the shell polymer ratio was kept constant as 10 % wt PCL, while the core polymer ratio was decreased to 10 %, 8 % and 6 %. It was observed that the core polymer in the structure became hydrophilic as its viscosity decreased. Compared to the first group, the decrease in the contact angles of the surfaces was less since the shell polymer ratio was kept constant. Contact angles decreased from 104.3° to 96.29°.

Keyword: *Nanofiber, Coaxial Electrospinning, Polycaprolactone, Polyvinylpyrrolidone*

1. INTRODUCTION

Electrospun nanofibers made from a variety of biocompatible and biodegradable polymers have shown a great potential for usage as efficient biomedical applications such as wound dressings and tissue engineering. For instance, due to their outstanding electrospinning capabilities and biocompatibility, poly(e-caprolactone) (PCL) and polyvinylpyrrolidone (PVP) are frequently utilized as scaffolds and controlled drug delivery systems [1, 2]. PCL is a semi-crystalline polyester that is simple to work with, has strong mechanical qualities, and is very compatible with many different kinds of polymers. However, its hydrophobic feature restricts its use as a scaffold in tissue engineering since it may influence cell adhesion. By combining PCL with the proper hydrophilic polymer, it is possible to modify its hydrophobicity [3]. In the literature, there are different studies in which PCL and PVP polymer are used in core-shell nanofiber production. Kaviannasah et al. tested the fiber structures, strength and degradation differences by using PCL and PVP polymers in different combinations in both the core and the shell in coaxial nanofiber production [4]. Suganya et al. defined the role of polymers in the structure in their study that produced herbal medicine-added PCL/PVP dressings. In the study, while PVP polymer acts as a drug carrier medium, the contribution of PCL polymer to the strength of the structure is mentioned [5]. The combination of strength and degradation properties of polymers was also utilized in the study in which drug-loaded PCL and PVP coaxial nanofibers were produced for bone regeneration [6].

Coaxial electrospinning method has been developed in order to minimize the burst release in blend electrospinning and to load some sensitive additives such as proteins, growth hormones, drugs etc. negatively affected by organic solvents into the fiber without being damaged [7]. In this method, two polymer solutions are fed through with special nozzle with two needles, one of which is in the center of the other, to form the shell and core. Existing studies show that the spinnability of the core fluid is not as important as the shell fluid. But fiber formation problems arise when the viscosity of the core fluid is too low. Therefore, the core fluid must have a certain minimum viscosity if it is to be entrained continuously without breaking [8].

In this study, it was aimed to produce nanofiber structures in the form of PCL in shell and PVP in core by using coaxial electrospinning method. By changing the polymer concentration, the effect of polymer/solvent ratios in coaxial electrospinning was observed.

2. EXPERIMENTAL STUDY

In this study which PCL solutions were used as shell and PVP solutions were used as core solutions, Polyvinylpyrrolidone (PVP) (Mw: 360.000 g/mol) and Polycaprolactone (PCL) (Mw: 80.000 g/mol) was obtained from Sigma-Aldrich. Formic acid (100%), glacial acetic acid (100%) and ethanol were purchased from Merck. Distilled water was used as one of the solvents. PCL polymer solutions were prepared by dissolving PCL at different polymer ratios (10, 8, 6 % wt.) in acetic acid/formic acid (1:2 w/w) under magnetic stirring for 3 hours at room temperature. To prepare the PVP solutions, PVP (10, 8, 6 % wt.) was dissolved in distilled water/ethanol (1:1 w/w) solvent mixture for 12 hours at room temperature.

To produce nanofibers NanoSpinner NE300 model electrospinning device was used. Inovenso IPS-14 double syringe pump was used to feed the polymer solutions that will form the shell and core structures at different feed rates. The coaxial nozzle has an outer syringe diameter of 2 mm and an inner syringe diameter of 1.15 mm. Optimum electrospinning parameters were adjusted as in Table 1 by making changes in the parameters during production and the same production parameters were used for all samples.

Table 1. Electrospinning production parameters of PVP/PCL coaxial nanofibers.

Feed Rate (mL/h)	Voltage (kV)	Distance (cm)	Collector Speed (rpm)
0.8 for PCL 0.2 for PVP	24.4	20	200

ZEISS EVO 40 Scanning Electron Microscope (SEM) was used for image analysis of nanofiber surfaces. Fibre diameters were measured with the ImageJ software by selecting 100 different fibres from SEM images. To determine the water contact angle (WCA) of the samples, the contact angle measuring system - KSV - CAM 101 was used. Viscosities of all polymer solutions were measured with Brookfield DV-E Viscometer in order to examine the effect of polymer ratio and viscosities on fiber morphology and surface properties.

3. RESULTS

When the first three SEM images (Figure 1. A, B, C) are examined, it is clearly seen that there was a decrease in fiber diameters as the concentration decreased in both the shell and core polymer. The average fiber diameters are 280 ± 276.26 , 145 ± 66.08 and 98 ± 38.31 nm, respectively. Since there were problems in jet formation during the production of sample A, the diameter distribution was not homogeneous and the standard deviation was high, as can be seen from the SEM images. The reason for the changes in fiber diameters can be explained by the decrease in the viscosity of the polymer solutions with the decrease in concentration. Viscosities of polymer solutions are given in Table 2. According to the literature, viscosity of the solution is a parameter that has an effect on the morphological structure and average diameter of the nanofibers [9]. When the other SEM images (Figure 1. D, E, F) were examined, it was observed that the bead formation in the fibers increased as the PVP concentration in the core decreased. This may be due to the fact that the viscosity values of the shell and core structures are different from each other.

Table 2. Viscosities of PCL and PVP polymer solutions.

Polymer Type	Polymer Ratio	Viscosity (cP)
PCL	6%	110
PCL	8%	301.5
PCL	10%	666
PVP	6%	144.5
PVP	8%	300
PVP	10%	593.3

To assess the surfaces' hydrophilicity and hydrophobicity, WCA test was conducted. It has been demonstrated that the contact angle of the 10 % PCL nanofiber, which is known to be hydrophobic, is 109°, and the contact angle of the 10 % PVP polymer, which is known to be hydrophilic, is 54.21°. The outcomes demonstrated that adding PVP to PCL nanofibers decreased the final core-shell structure's hydrophobicity (Figure 2). As the viscosity decreases with the decrease of the polymer ratio, it could be easier for the hydrophilic polymer in the core to migrate towards the shell and the enclosing the core polymer may not have been sufficient. In a study by Koushki et al., it was found that PCL has a water contact angle of 110° and PVA/PCL coaxial electrospun nanofibers have a water contact angle of 83°. According to the results of the study, it was observed that the addition of PVA to the PCL nanofibers reduced the hydrophobicity of the final core-shell structure. PVA is generally known to be very hydrophilic due to the presence of hydroxyl groups (O-H) and hydrogen bands; therefore, adding PVA to a hydrophobic polymer such as PCL can increase the hydrophilicity of the final structure [10]. In addition, in the study conducted by Huang, Zhang and Ramakhrishna, the WCA values of pure PCL polymer and shell core PCL-GEL nanofibers were compared and it was found that the contact angle of coaxial fibers was lower [11].

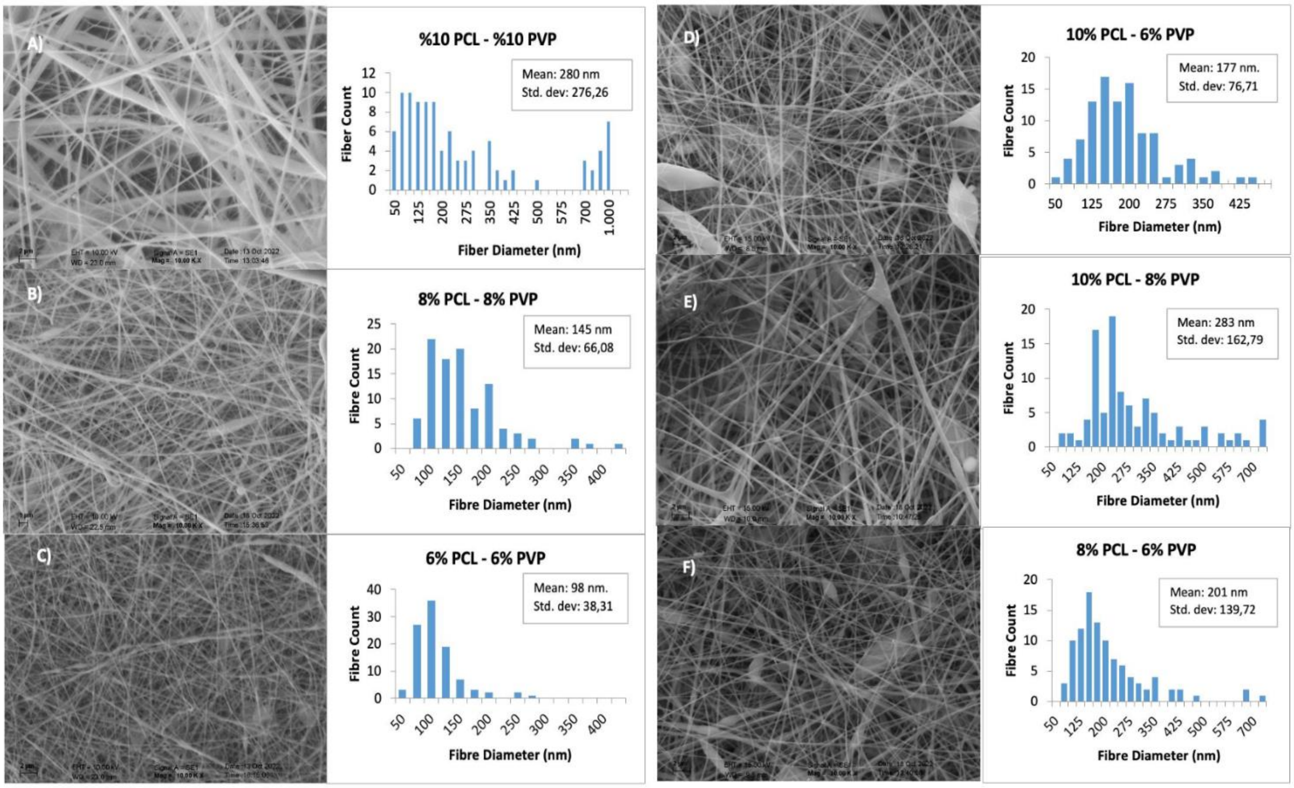

Figure 1. SEM images (at x10.000 magnifications) and fibre diameter distribution graphs of coaxial nanofibers 10% PCL – 10% PVP A), 8% PCL – 8% PVP B), 6% PCL – 6% PVP C), 10% PCL – 6% PVP D), 10% PCL – 8% PVP E), 8% PCL – 6% PVP F) samples, respectively.

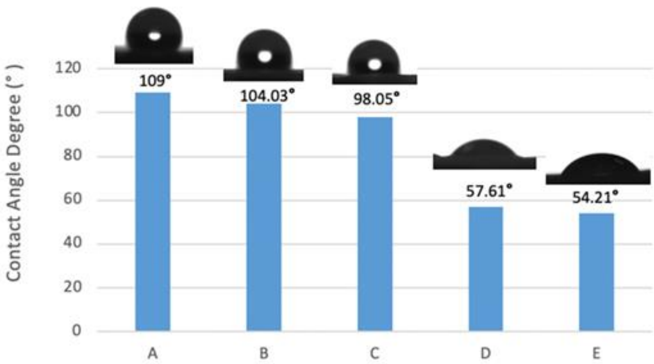

Figure 2. WCA values of monolitic PCL - PVP nanofibers and coaxial nanofibers with different polymer ratios; %10 PCL A), %10 PCL - %10 PVP B), %8 PCL - %8 PVP C), %6 PCL - %6 PVP D), %10 PVP E), respectively.

When the results in Figure 3 are examined, as in the first group, as the viscosity of the core polymer decreases, there may be polymer migration from the core to the shell. Contact angles decreased less in the second group compared to the first group. The reason for this might be due to the fact that core enclosing performance of the shell polymer did not change since the PCL ratio (and the viscosity) was kept constant. To the best of our knowledge, no study has been found in the literature that tests the changes in the contact angle depending on the viscosity change in the core polymer. In our study, surrounding PVP fibers with PCL fibers helped to combine the different properties of the two polymers and eliminated the disadvantages of individual polymers in the production of wound dressings.

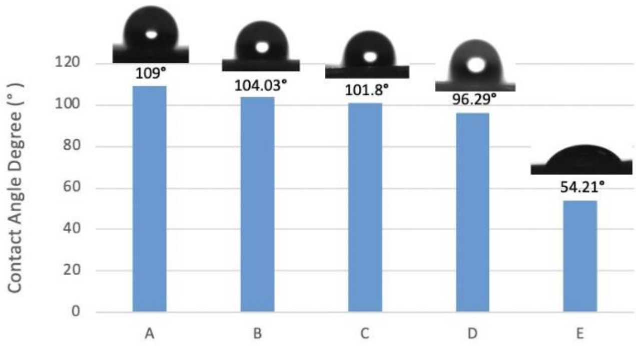

Figure 3. WCA values of monolitic PCL - PVP nanofibers and coaxial nanofibers with different polymer ratios; %10 PCL A), %10 PCL - %10 PVP B), %10 PCL - %8 PVP C), %10 PCL - %6 PVP D), %10 PVP E), respectively.

4. CONCLUSION

In this study, changes in core-sheath nanofiber morphology were observed depending on polymer concentration and viscosity. By creating two separate test groups, changes in fiber morphologies and hydrophilic properties of surfaces were examined separately when the shell and core polymer concentrations decreased at the same rate and the shell polymer ratio was kept constant while the core polymer ratio was decreased. According to SEM images, nanofiber diameters decreased as polymer concentration decreased. The nanofiber diameters of 10% PVP-10% PCL, 8% PVP-8% PCL and 6% PVP- 6% PCL were 280 ± 276.26, 145 ± 66.08 and 98 ± 38.3, respectively. In addition, in the second group, beaded fiber formation was observed as the difference between the shell and core polymer concentrations increased. Besides, as the polymer concentration decreases, the contact angle of the PVP/PCL core-sheath nanofibers decreases, so the structure becomes more hydrophilic. The contact angle decreased from 104.3° to 57.61° when 10% PVP-10% PCL was reduced to 6% PVP-%PCL. When the shell polymer ratio was kept constant at 10% wt PCL and the PVP ratio in the core was reduced to 6%, the contact angle decreased from 104.3° to 96.29°. The reason for this was thought to be the increase in the tendency of PVP in the core to migrate towards the shell with the decrease in viscosity. In future studies, the release behavior of drugs and similar therapeutics to be added to the core of nanofibers will be evaluated.

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REFERENCES

[1] Karami, Z., Rezaeian, I., Zahedi, P., & Abdollahi, M. (2013). Preparation and performance evaluations of electrospun poly (ε-caprolactone), poly (lactic acid), and their hybrid (50/50) nanofibrous mats containing thymol as an herbal drug for effective wound healing. Journal of applied polymer science, 129(2), 756-766.
[2] Gobi, R., Ravichandiran, P., Babu, R. S., & Yoo, D. J. (2021). Biopolymer and synthetic polymer-based nanocomposites in wound dressing applications: A review. Polymers, 13(12), 1962.
[3] Varsei, M., Tanha, N. R., Gorji, M., & Mazinani, S. (2021). Fabrication and optimization of PCL/PVP nanofibers with Lawsonia inermis for antibacterial wound dressings. Polymers and Polymer Composites, 29(9_suppl), S1403-S1413.

[4] Kaviannasab, E., Semnani, D., Khorasani, S. N., Varshosaz, J., Khalili, S., & Ghahreman, F. (2019). Core-shell nanofibers of poly (ε–caprolactone) and Polyvinylpyrrolidone for drug delivery system. Materials Research Express, 6(11), 115015.
[5] Suganya, S., Senthil Ram, T., Lakshmi, B. S., & Giridev, V. R. (2011). Herbal drug incorporated antibacterial nanofibrous mat fabricated by electrospinning: an excellent matrix for wound dressings. Journal of Applied Polymer Science, 121(5), 2893-2899.
[6] Sruthi, R., Balagangadharan, K., & Selvamurugan, N. (2020). Polycaprolactone/polyvinylpyrrolidone coaxial electrospun fibers containing veratric acid-loaded chitosan nanoparticles for bone regeneration. Colloids and Surfaces B: Biointerfaces, 193, 111110.
[7] Wang, J., & Windbergs, M. (2017). Functional electrospun fibers for the treatment of human skin wounds. European Journal of Pharmaceutics and Biopharmaceutics, 119, 283-299.
[8] Moghe, A. K., & Gupta, B. S. (2008). Co-axial electrospinning for nanofiber structures: preparation and applications. Polymer Reviews, 48(2), 353-377.
[9] Liao N, Unnithan AR, Joshi MK, Tiwari AP, Hong ST, Park CH, Kim CS. Electrospun bioactive poly (ε-caprolactone)–cellulose acetate–dextran antibacterial composite mats for wound dressing applications. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2015; 469:194-201.
[10] Koushki, P., Bahrami, S. H., & Ranjbar-Mohammadi, M. (2018). Coaxial nanofibers from poly (caprolactone)/poly (vinyl alcohol)/Thyme and their antibacterial properties. Journal of industrial textiles, 47(5), 834-852.
[11] Huang, Z. M., Zhang, Y., & Ramakrishna, S. (2005). Double-layered composite nanofibers and their mechanical performance. Journal of Polymer Science Part B: Polymer Physics, 43(20), 2852-2861.

EXTERNAL BENCHMARKING AMONG PRIVATE SALE WEBSITES HAVING DIFFERENT RETAIL BUSINESS MODELS

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ABSTRACT

Having gained popularity among a large customer base, the private sale websites should be ready for a more competitive market and build their own business models at firmer grounds. Moreover, some precautions should be established to increase the customer satisfaction in accord with the type of business model. In this study, a methodology integrating an external benchmarking process derived from the quality function deployment technique was proposed to find out best performing private sale websites running within the framework of distinctive type of business models. The proposed methodology was implemented in a real case for the private sale websites in Turkey by getting data from a conducted survey among 584 participants. Based on the findings, final remarks and suggestions were made for the companies having different business models.

Keyword: *External Benchmarking, Quality Function Deployment, Private Sale Websites, Retail, Business Models*

1. INTRODUCTION

Private sale websites (PSW) have been favored by the customers and they presented a unique niche as distinctive e-retail channel all over the world beginning with their first appearance with French market leader Ventee-privee.com in 2001 [1]. The private sale websites benefited the continuing demand from the customers until so far, but they should maintain their competitiveness against rising number of competitors by providing more satisfaction to their customers. Therefore, they should select the most suitable customer-oriented business model, a well-specified system of interdependent structures, activities and processes that serve a firm's organizing logic for value creation and proposition [2].

Benchmarking is an useful comparison method for the assessment of products and/or services and; the analysis of the current and potential techniques or processes in the business models [3]. Quality Function Deployment (QFD) can be used for benchmarking the objects in concern in terms of customer satisfaction by integrating the competitive analysis and the customers' opinions.

Within this respect, the purpose of this paper is to analyze different types of business model established by the private sale websites. To reach this aim, a methodology for external benchmarking was proposed for determination of the best performing private sale websites associated with distinctive type of business models with the major purpose of creating high level of customer satisfaction. Specifically, the value creation and value proposition components of the retail business models implemented by the private sale websites were determined and a methodology derived from QFD technique was proposed. The proposed methodology was validated with an implementation in a real world case.

2. EXPERIMENTAL STUDY

The data for study was gathered in the survey conducted among 584 participants. The participants evaluated four PSWs having different business models in terms of satisfying their requirements. The questionnaire was prepared with 5 points Likert scale and it involved 23 questions corresponding to 13 customer requirements (CR) identified.

In the study, four PSWs executing different business models were selected based on their activities and processes in value creation and value proposition. Value creation was evaluated in regards to ‘sourcing of products (SOP)’ and ‘stockholding, inventory and merchandising (SIM)’and; value proposition was evaluated in regards to ‘marketing efforts including branding (MEIB)’, ‘customer selection, picking and payment(CSPP)’and ‘distribution of goods (DOG)’ [4]. Moreover, these aspects were associated with retailing and private sale characteristics, technology and logistics.

The external benchmarking methodology was derived from QFD technique involving specifically three components of house of quality matrix of QFD ‘Whats’, ‘Importance Ratings’ and ‘Customer Competitive Assessment’. The customer requirements in ‘Whats’ bloc and the importance rating (IR) in ‘Importance ratings’ bloc were established based on the findings of a previous study [5]. The customer requirements were related with the aspects of business models and so their associations. The data obtained from ‘Customer competitive assessment’ bloc corresponded to Current Performance Level (CPL). The most successful PSW was determined according CPL and ‘Overall success’(OS) score, which was calculated by using CPL and IR according to Equation 1. Moreover, Target Performance Level (TPL), Improvement Ratios (IMPR) and Overall Weight (OW) were also calculated for each PSW in regards to each CR. Target Performance Level (TPL) was taken as being equal to the CPL of most successful PSW regarding CR in concern. Using the CPL, TPL and importance ratings (IR), Improvement Ratios (IMPR) and Overall Weight (OW) were calculated according to Equation 2 and 3 in order to show the key points that should be improved for each PSW or business model.

$$OS = CPL * IR / 100 \quad \text{Eq. 1}$$

$$IMPR = (TPL - CPL) / CPL \quad \text{Eq. 2}$$

$$OW = IMPR * IR \text{ for all CRs} \quad \text{Eq. 3}$$

Based on the findings, final remarks and suggestions were made for the companies having different business models by relating CRs with the aspects of business models and their associations.

3. RESULTS

Four private sale websites were selected for the study. PSW1 is the first private sale website in Turkey working in collaboration with a foreign partner. It has business activities abroad but logistic center for quality control and allocation of the products are in Turkey [6]. It is a sample case for vertical websites, which has online activities for different products categories. It holds the green browser certificate, which provides shopping opportunities with maximum security for its members. PSW2 is the most popular website in Turkish market. It has launched its own online brands and private labels. It has the mission of supporting Turkish designers. It is the first private sale website in Turkey that held the green browser certificate. PSW3 is owned by a large department store in Turkey. Therefore, it offers new seasonal products as well as the discount sales for the brands. It provides the opportunity for customers to receive or to send the products from stores. The data processing operations are outsourced to an internet service provider and the logistics activities are managed by a professional logistics company. PSW4 was founded as a joint venture of 12 apparel retailers acting in Turkey. It uses a common platform to sell both new and off-season products and acts as an advertising platform by increasing the visibility of the products of these retailers.

The identification of retail business models was based on value creation and value proposition aspects which are SOP, SIM, MEIB, CSPP and DOG. The activities and processes for each PSW were summarized in Table 1.

Table 1. The components of business model for each private sale website.

	SOP	SIM	MEIB	CSPP	DOG
PSW1	Outsource	-own logistics and operation center - in-house IT activities	-sells retailer brands and few designer brands	-1 cart 1 shipment charge, credit card and debit card, 1-click type buying -has green browser certificate	-courier delivery
PSW2	Outsource	-operation center partnership with a professional company - in-house IT activities	-has private label -sell retailer brands	-1 cart 1 shipment charge, credit card and debit card, 1-click type buying -has green browser certificate	-courier delivery
PSW3	Insource	-operations and logistics held by department store - in-house IT activities	-brands sold in department store	-1 cart and 1 shipment charge, credit card and debit card, paying on the door, 1-click type buying	-courier delivery -delivery from stores
PSW4	Insource	-all logistics outsourced - in-house IT activities	-sells retailers' brands in joint venture	-1 cart 1 shipment charge, credit card and Paypal	-courier delivery

The analysis of activities in value creation and proposition revealed that SOP and MEIB present retailing characteristics; MEIB and CSPP have common aspects in regards to private sale characteristics; CSPP and SIM have the aspects of technology and; finally, SIM and DOG were highly associated with logistics.

Four private sale websites were evaluated in regards to 13 CRs, which were associated with at least one aspects regarding the value creation and proposition as given in Table 2. Specifically, MEIB was related with the highest number of CR followed by SIM and CSPP. The CPL for CRs measured with the more than question was calculated getting the average values for each CR. The IR was given in the first column and OS for each PSW was given in the last row of Table 2. Here it should be noted that the first three critical CRs having the highest IR were related with SIM, CSPP and DOG which are associated with technology and logistics, although IR values are not the findings of this study, instead they are based on previous study [5].

Table 2. Customer Competitive Assessment Matrix values for Private Sale Websites.

Question and/or CR:IR	Questions	PSW1 CPL	PSW2 CPL	PSW3 CPL	PSW4 CPL
Q1	The personal information is secured	4.00	3.95	3.65	3.43
Q2	Card and payment information is safely protected	4.11	4.04	3.76	3.36
CR1:20.7	**Privacy/Security (SIM,CSPP)**	**4.05**	**4.00**	**3.70**	**3.39**
Q3	Return of the product without any reason is long	3.48	3.27	3.48	3.09
Q4	No problem with the change of faulty item	3.44	3.55	3.48	3.17
Q5	Return of the payment in return is fast	3.44	3.41	3.35	3.12
CR2:12.7	**Return policy (SIM,CSPP,DOG)**	**3.45**	**3.41**	**3.44**	**3.13**
Q6	Shipment is fast and easy	3.76	3.82	3.52	3.26
Q7	Payment for shipment is low	2.92	3.43	3.23	3.02
CR3:9.03	**Delivery time (SOP,MEIB,CSPP,DOG)**	**3.34**	**3.62**	**3.37**	**3.14**
Q6-CR4:5.25	**The website is easy to use (SIM,MEIB)**	**4.24**	**4.22**	**3.67**	**3.22**
Q7-CR5:7.03	**Payment options are convenient (SIM, MEIB, CSPP)**	**3.82**	**4.05**	**3.67**	**3.22**
Q8-CR6:4.24	**Campaigns are sufficiently frequently held (SIM,MEIB, CSPP)**	**3.74**	**3.83**	**3.46**	**3.26**
Q9	Duration of campaigns are short to ship the product fast	3.26	3.48	3.42	3.14
Q10	Duration of Campaigns are long to become aware of it	3.35	3.43	3.40	3.11
CR7:7.03	**Duration of campaigns (SOP, MEIB)**	**3.31**	**3.45**	**3.41**	**3.12**
Q11-CR8:4.24	**Product in every color and size are available (SOP, SIM,MEIB)**	**3.18**	**3.31**	**3.42**	**3.06**
Q12-CR9:6.64	**Many promotions are available such as gift card, free shipping and so on (MEIB,CSPP)**	**3.46**	**3.48**	**3.39**	**3.09**
Q13	The products are sold cheaper compared with the other websites	3.07	3.37	3.29	2.98
Q14	The products are sold with attractive discount ratios	3.42	3.60	3.32	3.00
CR10:7.18	**Discount ratio (SOP, MEIB,CSPP)**	**3.25**	**3.49**	**3.31**	**2.99**
Q15	Information regarding the fabric and its content is available	3.53	3.67	3.57	3.07
Q16	The information regarding size and measures are available	4.07	3.97	3.61	3.18
CR11:8.34	**Product information (SOP, MEIB)**	**3.80**	**3.82**	**3.59**	**3.13**
Q17	The website is known by many people and it has positive image	4.12	4.25	3.72	3.26
Q18	The real price information given in the website are correct	3.16	3.38	3.32	3.05
Q19	My experience with these websites are positive and all the problems I came across was solved	3.74	3.65	3.55	3.13
CR12:4.31	**Retailer's image (SOP, SIM, MEIB,CSPP)**	**3.67**	**3.76**	**3.53**	**3.15**
Q20	The variety of brands and campaign are high in number	4.07	3.98	3.62	3.35
Q21	The product variety is high in number	4.13	3.98	3.57	3.29
CR13:4.82	**Variety of product, brands and campaigns (SOP, SIM, MEIB)**	**4.10**	**3.98**	**3.60**	**3.32**
OVERALL SUCCESS		**3.72**	**3.78**	**3.57**	**3.24**

The overall performance in each customer requirement was evaluated by getting the average scores in the questions associated with this customer requirement. The general assessments of the private sale websites showed that PSW1 and PSW2 showed better performance. Considering on CPL values, PSW2 showed the highest performance in regards to 9 of 13 CRs, PSW1 showed the highest performance in 4 of 13 CRs and finally, PSW3 showed the highest performance in 2 of 13 CRs. As the importance rating of customer requirements differ, the performance was also evaluated with OS. PSW2 showed the highest OS score, which was closely followed by PSW1. PSW1 reached the OS score of 3.72 by getting the highest performance in CR1 and CR2 having the highest importance ratings. Among the four PSW, PSW4 showed the poorest performance.

Table 3. Customer Competitive Assessment Matrix values for Private Sale Websites.

Question number or Customer Requirement	Importance ranking (%)	Target performance level (TPL)	Improvement Ratio (IMPR)				Overall Weight (OW) (scores including the influence of importance ratings)			
			PSW1	PSW2	PSW3	PSW4	PSW1	PSW2	PSW3	PSW4
CR1	**20.5**	4.05	**0.00**	0.01	0.09	0.19	0.00	**0.26**	**1.94**	**3.99**
CR2	**12.7**	3.45	**0.00**	0.01	**0.00**	0.10	0.00	**0.15**	0.04	**1.29**
CR3	**9.03**	3.62	0.08	**0.00**	0.07	0.15	**0.76**	0.00	**0.67**	**1.38**
CR4	5.25	4.24	**0.00**	**0.00**	0.16	0.32	0.00	0.02	0.82*	1.66*
CR5	**7.03**	4.05	0.06	**0.00**	0.10	0.26	**0.42**	0.00	**0.73**	**1.81**
CR6	4.24	3.83	0.02	**0.00**	0.11	0.17	0.10	0.00	0.45	0.74
CR7	**7.03**	3.45	0.04	**0.00**	0.01	0.11	0.30	0.00	0.08	**0.74**
CR8	4.24	3.42	0.08	0.03	**0.00**	0.12	0.32	0.14	0.00	0.50
CR9	**6.64**	3.48	0.01	**0.00**	0.03	0.13	0.04	0.00	0.18	**0.84**
CR10	**7.18**	3.49	0.07	**0.00**	0.05	0.17	**0.53**	0.00	0.39	**1.20**
CR11	**8.34**	3.82	0.01	**0.00**	0.06	0.22	0.04	0.00	**0.53**	**1.84**
CR12	4.31	3.76	0.02	**0.00**	0.07	0.19	0.11	0.00	0.28	0.83
CR13	4.82	4.1	**0.00**	0.03	0.14	0.23	0.00	0.15	0.67*	1.13*

Apart from CPL and OS, IMPR and OW scores were also calculated for the PSWs as seen in Table 4. In Table 4, IR having higher contribution, PSWs showing better performance in each CR and PSWs that has to make critical improvements in key CR (CR having higher IR) were written in bold. Moreover, the critical improvements that has to be made in the CRs (the ones except key CRs but CR important for PSW in concern in terms of OW) were shown with asterisk. Based on these, the key areas for each PSW were found out. Accordingly, PSW1 has to make adjustments in CR3, CR5 and CR10. The most successful PSW, PSW2 has to make adjustment in CR1 and CR2, which are the key CRs because of having the highest IRs. PSW3 has to make improvements in key areas of CR1, CR3, CR5, CR11 as well as CR4 and CR13. Finally, PSW4 has to make improvements in key areas of CR1, CR2, CR3, CR5, CR7, CR9, CR10, CR11 as well as CR4 and CR13.

Interpreting these findings with aspects of business models and their associations, it might be stated that the data showed that PSW1 and PSW2, whose only activities are making retailing online are much more successful in meeting CRs. These two PSWs showed better performance chiefly in terms of SIM, CSPP and DOG aspects, which are associated with technology and then the logistics components of the retailing business model. On the other hand, PSW3, which is a member of a group company owned by a department store, also showed a good performance in relation to the logistics component of the retailing business model. Thus, the two driving components, which created a competitive advantage for private sale companies, are the better use of technology and logistics. These points are quite understandable. The association of business model to technology primarily provides privacy and security on internet platform for customers, who are concerned about the storage of private data [7]. On the other hand, the role of logistics has actually a larger scope of online business models as delivery is made directly to consumers instead of stores. Actually online businesses are described by a large number of small orders, which meet with the customers using different distribution system [8, 9]. Because of this reason, it was pointed out that, logistic activities have a direct impact on customer loyalty and further success in online retailing [10]. Regarding the aspects of SOP, MEIB, CSPP associated with private sale characteristics and retailing components of the retailing business model, PSW2 showed the best performance. PSW1 followed PSW2 in terms of private sale characteristics. The leading performances of these two websites may be the result of the fact that they were initially founded as PSWs instead of transformation of the initial business model into new business model. This type of foundation also allowed to offer more variety as they could present many brands to consumers via outsourcing. Offering many brands enabled the market to be expanded on one hand [11]; convinced all consumers to be able to find exactly the option they were seeking on the other hand. Even though some researched implied that high variety in terms of brands and categories can be overwhelming [12], it actually helps to quickens to make consumer decision and decreases the switching behavior. It should also be added that PSW2, which has built its own brands, showed a better performance than PSW1. This means that PSW2's private label has gained a popularity, trust and even loyalty. On the other hand, enabling to offer products in every color and size, PSW3 followed PSW2 in terms of retailing characteristics of the business model. The reason for this probably lies beyond the fact that these companies have better control of manufacturing activities of their own.

When the required improvements that each PSWs should conduct are discussed with aspects of business models and their associations, the results showed that the most successful PSW, PSW2, having its own brand and outsourcing the production of the goods for this brand, should be careful with the aspects of business model associated with technology. PSW1, which is the first PSW entered the market and deals with only private sale operations, should improve itself in the association of business models namely, logistics and private sale characteristics. Similarly, PSW3, having its own brick and mortar retailing mall, should first focus on the aspects of business models associated with technology. This pointed out that the retailing activities differ in an online environment considering the lower success achieved by PSW3, which has initiated its activities in traditional retail business. Finally, PSW4 has to make changes in a diverse set of business aspects, especially the ones associated with technology. The comparatively lower score of PSW4 to PSW3, which have similar activities and process in regard to business model might be attributed to managerial organization. It is quite probable that there are some problems with the independence of the management unit of this PSW4, which has been founded as a joint venture of 12 apparel retailing companies.

4. CONCLUSION

This study attempted to analyze different types of business models established by the private sale websites by proposing an external benchmarking methodology based on QFD. Whereas the determination of most successful PSW was made based on QFD and the findings were interpreted by considering the aspects of business models and their associations. The methodology was validated on a real case for four PSWs running different type of business models in regards to value creation and proposition aspects, SOP, SIM, MEIB, CSPP and DOG, which are associated with retailing and private characteristics as well as technology and logistics.

The findings and the following discussions revealed that, the PSWs, which are founded as independent marketing units are much more successful than the ones, which have online retailing activities as a complementary to their brick and mortar businesses. The PSW, which wants to be successful within this business, should put greater emphasis on technology and logistics aspects of the business, which come even before the retailing activities. Therefore, SIM in terms of value creation and CSPP and DOG in terms of value proposition are the most important aspects of business models of private sale websites whose primary business comprises online activities. These might be followed by MEIB for value proposition and SOP for value creation.

The study contributed on literature by providing and external benchmarking methodology to determine the performance level of the company aiming to satisfy consumer requirements. Besides, interpretation of the findings was made on the basis of business models providing information for the companies acting in private sale retail business. The findings might encourage the researchers working in this field and the suggestion might be employed by the companies acting specially in this arena.

Nonetheless, the proposed methodology might be reestablished with customer requirements, which might further be revised both in definition and number in case that, the aspects of business model are associated with distinctive set of customer requirements.

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REFERENCES

[1] Ayadi, N., Giraud, M., & Gonzalez, C. (2013). An investigation of consumers' self-control mechanisms when confronted with repeated purchase temptations: Evidence from online private sales. Journal of Retailing and Consumer Services, 20(3), 272-281.
[2] Sorescu, A., Frambach, R. T., Singh, J., Rangaswamy, A., & Bridges, C. (2011). Innovations in retail business models. Journal of Retailing, 87, 3-16.
[3] Kumar, A., Antony, J., & Dhakar, T. S. (2006). Integrating quality function deployment and benchmarking to achieve greater profitability. Benchmarking: An International Journal, 13(3), 290-310.
[4] Burt, S., & Sparks, L. (2003). E-commerce and the retail process: a review. Journal of Retailing and Consumer Services, 10(5), 275-286.
[5] Saricam, C., & Erdumlu, N. (2017). Determination of priorities in Apparel Purchasing from Private Sale Websites, Autex Research Journal, 17(4), 386-394.
[6] *Lojistik Hattı (News)* -- Markafoni Dağıtımı Uzmanına Bıraktı (Markafoni Outsouced the Distribution from a Specialist). (2017, January 08). Retrieved from: http://www.lojistikhatti.com/haber/2016/01/markafoni-dagitimi-uzmanina-birakti
[7] Sheehan, K. B., & Hoy, M. G. (2000). Dimensions of privacy concern among online consumers. Journal of public policy & marketing, 19(1), 62-73.
[8] Rutner, S. M., Gibson, B. J., & Williams, S. R. (2003). The impacts of the integrated logistics systems on electronic commerce and enterprise resource planning systems. Transportation Research Part E: Logistics and Transportation Review, 39(2), 83-93.
[9] Joong-Kun Cho, J., Ozment, J., & Sink, H. (2008). Logistics capability, logistics outsourcing and firm performance in an e-commerce market. International journal of physical distribution & logistics management, 38(5), 336-359.
[10] Ramanathan, R. (2010). The moderating roles of risk and efficiency on the relationship between logistics performance and customer loyalty in e-commerce. Transportation Research Part E: Logistics and Transportation Review, 46(6), 950-962.
[11] Gruca, T. S., & Rego, L. L. (2005). Customer satisfaction, cash flow, and shareholder value. Journal of marketing, 69(3), 115-130.
[12] Desmeules, R. (2002). The impact of variety on consumer happiness: Marketing and the tyranny of freedom. Academy of Marketing Science Review, 2002, 1.

AUTHENTIC FASHION BRAND CSR THROUGH EFFECTIVE SOCIAL MEDIA MARKETING AND BRANDING COMMUNICATIONS: A CASE STUDY APPROACH

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ABSTRACT

Due to increasing consumer demands from fashion companies to support social causes, practice sustainability and actively contribute to making a better world, many fashion businesses are designing marketing collateral and campaigns around corporate social responsibility (CSR) and ethical initiatives. For fashion brands to maintain their brand DNA, it is imperative that CSR reflects brands' core values and maintains authenticity and alignment with shifting consumer views. The purpose of this study is to investigate a selection of fashion marketing communications on social media of a small group of fashion brands, across different market levels. The aim of this investigation is to assess alignment of the fashion brand values with the brand's CSR strategies to determine how authentic this alignment is. To achieve these aims the study examines the match between the branding and various stakeholder communications with regards to corporate social responsibility. The study is undertaken in the form of critical literature review and drawing upon a range of case studies from a small group of fashion brands. Theories included in the Literature Review are: sustainability, circular economy, transactional cost theory and stakeholder theory, authenticity, CSR, brand values, mission and vision and Expectancy Disconfirmation Theory (EDT). The results aim to highlight that social media effectiveness in communicating CSR is conditional on the alignment of brand DNA and type of stakeholder. The results further show that despite the brands using different approaches for different stakeholders, the core values embedded within marketing and branding should be authentic in order to validate EDT.

Keywords: *Social media marketing, Corporate social responsibility, Branding, Fashion*

1. INTRODUCTION

Over the last decade, the fashion industry has come under intense scrutiny for unsustainable practices resulting in vast environmental and social consequences, stemming from both production and consumption of clothing [1,2]. To address the challenges and accusations, fashion brands are increasingly implementing corporate social responsibility [CSR] initiatives signalling their commitment towards sustainability to stakeholders. CSR has not only become a moral and ethical responsibility but also a strategic part of corporate philosophy resulting in improving brand image, reputation and competitive advantage [3]. CSR has spanned a multitude of definitions as well as complementary concepts (e.g. business ethics, stakeholder management, corporate citizenship) which warp its meaning and are context-dependent [4]. In a broad sense, CSR covers the responsibilities organisations have towards the wider society and their stakeholders which includes consumers, producers, employees and shareholders [5].

Fashion companies are now actively using social media as a medium to communicate their CSR information in order to develop a socially responsible or conscientious brand image [6]. Contemporary research confirms that social media represents an opportunity for these brands to promote their CSR initiatives through engaging in two-way dialogue with the consumers, pushing the companies to a new level of openness and transparency thus helping in reducing consumers' scepticism towards CSR and supporting authenticity of brands [3,7]. Consumers may perceive how CSR is conveyed via social media marketing differently. One chief factor affecting the perception is the saliency of the brand, which includes its authenticity [8]. This dictates the expectations of the brand's performance, that is, the consistency degree between CSR messages and practice [9].

As adoption of CSR becomes mainstream in the industry, the authenticity of brands is contested. Brand authenticity can be defined as 'the extent to which consumers perceive a brand to be faithful and true toward itself and its consumers, and to support consumers being true to themselves' [10]. Hancock emphasised that fashion brands should take a holistic approach to the design of branding and CSR [11]. In fashioning their linkage, the brands must take account of their vision and culture and how these can be effectively communicated through the CSR initiatives [12] Brands should therefore strive for a seamless alignment between brand values, actions and behaviour and their subsequent CSR communications and thereby reinforcing their own authenticity. This paper employs qualitative case study approach, using Saltyco and Rakha, to investigate and assess the alignment of the brands' values with CSR strategies as communicated via social media and company's website linking to brand's authenticity. The following research question guide the analysis of the case studies: How can companies' CSR be communicated authentically and reinforced through branding communications/mix?

2. RESEARCH METHODOLOGY

Case study was the method used for this study. A qualitative approach was selected for an in–depth analysis into the framed phenomenon. For the selection of case studies, a non-probability purposive sampling strategy was followed [13] and two cases were selected from the fashion and textile sector: Rakha and Saltyco. The case studies were chosen based on the criteria that both the companies were using a Sustainable Business Model, thereby allowing exploration of CSR communications and its alignment with the Brand's DNA.

Rakha is a contemporary and sustainable womenswear brand based in London. With a strong focus on circular design and approach to product development, sustainability lies at the heart of Rakha's brand philosophy. The brand produces organic, eco-friendly, and guilt-free fashion through the optimisation of design, materials and processes involved in the fashion supply chain. Saltyco uses their "planet-positive" ethos to guide every decision and action from process to product. Saltyco implements this strategy through the selection of resilient crops, re-thinking of regenerative agriculture and in setting of sustainability into their novel technology. Saltyco technology continues to develop with a series of partner institutions that are leading the way in biological fiber coatings and architectures.

Online observations were undertaken as a data collection method, and the source of information included the brands' websites and social media pages, which comes under visual and digital materials according to the classification proposed by [14]. The brands' copywriting materials (i.e., texts) on both selected mediums were also analysed. The following questions were used to guide the analysis: What is the brand's copy suggesting about the tone of voice and personality of the brand?; Is the brand effectively communicating its mission, vision, and values?; Are the branding fundamentals understudy, explicitly stated or implicitly embedded in the brand's copy?; Are there statements of the beliefs (values) and sustainability journey of the company? Does the brand state a particular approach?; Is there concrete evidence of initiatives taken by the company to solve social and environmental issues?; Are the CSR initiatives and branding mix in alignment?

Expectancy disconfirmation theory (EDT) was used as a theoretical lens to analyse the qualitative data. The theory has been widely used in management and consumer research [15-17]. EDT is typically employed to explain the difference between perceived performance of a brand and the objectively measured performance [18]. The theory carries an assumption that people, in this case consumers, use various marketing materials to form their subjective evaluation towards a brand and its performance and compare it with the existing brand perception. This suggests that people judge the performance of a brand based on an implicit comparison of implementation quality with their prior expectations. Within the context of this research, EDT can help elucidate the consumer perception process towards brands' CSR marketing outputs. For the observational analysis on the brand's websites and Instagram page, four key branding fundamentals including brand values, brand promise, mission, and vision statement were considered [11,19].

3. RESULTS & DISCUSSION

Rakha and Saltyco are analysed and critically evaluated, discussing how each case communicates its CSR stance through key branding fundamentals. Table 1 provides a summary of branding fundamentals of each case.

Table 1. Summary of branding fundamentals of case studies: Rakha and Saltyco

Branding Fundamentals	Rakha [20,21]	Saltyco [22, 23]
Mission statement	*"We are on a mission of wasteless production and consumption. We work with new technologies and materials to ensure we ultimately create circular garments"*	*"We use our "planet-positive" ethos to guide every decision and action from process to product. This is implemented through our selection of resilient crops, re-thinking of regenerative agriculture and in setting of sustainability into our novel technology"*
Vision statement	*"We aim to achieve a closed loop system where everything is either a technical or biological nutrition for their next-life cycle phase"*	*"Our vision is to build a planet-healing supply chain and that begins with our approach to regenerative agriculture. To bring this vision to life, we partner with a community of farmers and conservation groups"*
Brand Values	*Circularity and Sustainability, Vegan Friendly, Sustainable Materials, Plastic Free, Ethically Source*	*Planet-positive, Eco-friendly, Innovative, Sustainable, Restorative, Community partnerships,*
Brand Promise	*"Circular garments that makes you feel good for change"*	*"Only through true planet-positive design can we begin to build inherent sustainability and environmental healing into the materials of the future"*

3.1 Case Study 1: Rakha

Based on the observations, it was found the brand's copy was written in simple language to make it easier for consumers to understand the complex in and out of circular fashion. It was transparent and intentional, educating the customers and other stakeholders about this brand's unique approach to sustainability. The brand's tone of voice was positive, sincere, considerate, and inspiring reinforcing the brand's core values, promise and mission. The mission was explicitly communicated through the brand's Instagram page. However, this was not the case for the vision of the brand which was implicitly embedded in the brand's copy on the website. In addition to this, the core values of the brand were also communicated clearly on both company's website and Instagram page. Moreover, the brand promise was implicitly stated on the website but was missing from the Instagram page.

Concerning CSR, the statement of the beliefs and sustainable journey of the company was communicated effectively through the brand's website. There was a separate page on "Sustainability" to reinforce the company's stance on social and environmental responsibility and CSR was ingrained in the Brand's DNA. With regards to how the brand is tackling some of the prevalent environmental and social issues, there was concrete evidence presented on the website and Instagram page. For example:

to reduce the harmful environmental impact during the garment production and manufacturing stage, the brand commits to using only ethically sourced materials. Giving weight to this statement, the brand highlighted its approach to circularity and provided information on the fabric, trims and materials used in their garments. Additionally, the brand's commitment to transparency and accountability was evident from the product page on the website. Rakha does not only claim to use eco-friendly and sustainable materials but also provides concrete examples of how each one of its products is ethically made. Rakha also solidified its positioning as a sustainable brand through its membership with 1% for the Planet Initiative which supports environmental solutions.

Further analysing the posts on the Instagram page, it was clear that Rakha is actively creating awareness and engaging with the stakeholders about their sustainability initiatives. The visual dimension was strongly connected to both fashion and nature-centric images. There was a consistency in the use of images with muted colours and tones, and the brand presented itself with a strong characterisation of sustainability that shined through in brand images and messaging. Several posts referred to their sustainable brand ethos, sustainability of their products and materials, and packaging. However, no specific images related to production methods or processes were posted [24]. While this could hinder the perceived consistency between consumer expectation and the CSR message, the absence of the mentioned content may be explained by the specific nature of Instagram, which emphasises the creation of visual content that can generate greater users' attention and engagement.

Overall, Rakha has made effective use of the branding fundamentals to communicate its brand philosophy which is centered on circular and sustainable fashion page. The information was supplemented by concrete evidence to highlight how the brand is playing its part in reducing environmental and social issues. There was coherence in their branding mix and approach to sustainability that was reinforced effectively in the branding communications.

3.2 Case Study 2: Saltyco

Based on the observations, it was found the brand’s copy was similarly written in simple language to make it easy for consumers to understand the complexity of the brands commitments to making planet-positive textiles. This use of simple language was also transparent and intentional, educating the customers and other stakeholders about the brand’s unique approach to sustainability. Similar, to Rakha, Saltyco brand’s tone of expression is positive, sincere, considerate, and inspiring, reinforcing the brand’s core values, promise and mission.

Concerning CSR, the statement of the beliefs and sustainable journey of the company was communicated effectively through the brand’s website: This is exemplified in this statement from the brand website: “We do this by actively healing damaged ecosystems through the innovative processes and plants we use to make our materials” [22] In addition, the brand website also has a separate page that sets out Regenerative Agriculture: “Our vision is to build a planet-healing supply chain and that begins with our approach to regenerative agriculture. There’s no single solution to “sustainability”, and our farming reflects this. At Saltyco our agricultural practices focus on three elements: restoring, context-lead farming, and steady growth [23]. Extending these shared details of the brands agricultural practices the website adds a page on “BioPuff® a plant-based fiber fill material designed to keep you warm without harming the environment. This alternative to animal and petroleum-based products, is created by growing plants using regenerative wetland agriculture. BioPuff® is lightweight, warm, and naturally water resistant whilst being biodegradable and cruelty free”.

Saltyco uses their Instagram to share with their followers their achievements and successes. These posts share how Saltyco gains recognition from funding bodies such as International and National Government and not for profit organizations that offer support for Saltyco efforts that align with their Brand Values of Circularity and Sustainability. These illustrated stories involve the people and places where their work is carried out and act as an account of what Saltyco does to realise their brand promise, brand values and mission. These stories assist in making emotional connections with the audience sectors (consumers, local councils, farmers, manufacturers etc.), improving the authenticity of the brands actions through place and people. The stories address a variety of activities that while aligned with discrete audiences maintain authenticity to the brand core values and missions [25]. This approach aligns with the demands of today's consumers for more transparency and action from fashion brands, they want to know where the products come from, what the products are made from and whether the brand is fulfilling their brand promise. Instagram is used along with the company website to build the brand image through authentic narratives that make emotional connections with their followers across all identified audience sectors.

4. CONCLUSION

Overall, Rakha and Saltyco have effectively highlighted their commitment to social and environmental responsibility through the branding mix; giving consumers the required information and insight to determine whether the brand is authentic and living up to its promises. Such brand marketing outputs aids the increase of the perception that the brand performance exceeds the consumer expectations, which can lead to more salient perceived authenticity. One key recommendation is to ensure stronger brand CSR message consistency across all the marketing outputs and touchpoints as this enables the creation of a unified experience for consumers. Aligning with core assumptions of EDT, a crucial aspect of mitigating the discrepancy between CSR marketing outputs and consumer perception is to build strong brand image. Akin to connecting with others within a society, brand image allows consumers to relate their self-image with a brand and vice versa. Such a process aids in forming emotional connections important for positive consumer expectations towards a brand. Revisiting brand image therefore is another fundamental action that fashion brands must arguably undertake. Including CSR as a determinant in solid brand image helps increase consumer relevance, which in turn, could improve a brand's perceived authenticity. Another recommendation for the brands is to focus on humanistic approaches to marketing through humanisation of branding; making the brand narratives more human, personal, emotionally engaging and authentic.

This study has implication for fashion brands, stakeholders, and practitioners regarding effective communication of CSR on social media underpinned by the expectancy disconfirmation theory. It provides a guideline to fashion brands on how they can ensure consistency between the brand DNA, and CSR messages in brand marketing outputs. It is hoped that the insights gained can help brands implement consistent CSR outputs at a practical level, leading to better perceived brand authenticity.

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REFERENCES

[1] Coscieme, L., Akenji, L., Latva-Hakuni, E., Vladimirova, K., Niinimäki, K., Henninger, C., Joyner-Martinez, C., Nielsen, K., Iran, S. and D´Itria, E. (2022). Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space. Berlin: Hot or Cool Institute.

[2] Niinimaki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T. and Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1, 189-200.

[3] Castillo-Abdul, B., Ortega Fernandez, E., and Romero-Rodriguez, L.M. (2022). Corporate social responsibility communication of male luxury fashion brands: analysis on Instagram, Facebook and TikTok. *Management Decisions*, ahead of print.

[4] Carroll, A.B. and Brown, J.A. (2018). Corporate Social Responsibility: A Review of Current Concepts, Research, and Issues. *Business and Society*, *360*(2), 39-69.

[5] Okpara, J.O. and Idowu, S.O. (2013). Corporate Social Responsibility: A Review of the Concept and Analysis of the Business Case for Corporate Social Responsibility in the Twenty-First Century. In Okpara, J. and Idowu, S. (Eds), *Corporate Social Responsibility. CSR, Sustainability, Ethics & Governance.* Berlin: Springer.

[6] Kwon, K. and Lee, J. (2021). Corporate social responsibility advertising in social media: a content analysis of the fashion industry's CSR advertising on Instagram. *Corporate Communications: An International Journal*, *26*(4), 700-715.

[7] Chu, S.C., Chen, H.T. and Gan, C. (2020). Consumers' engagement with corporate social responsibility (CSR) communication in social media: Evidence from China and the United States. *Journal of Business Research*, 110, 260-271.

[8] Södergren, J. (2021). Brand authenticity: 25 Years of research. *International Journal of Consumer Studies*, *45*(4), 645-663.

[9] Rathjens, B., Van Der Heide, B., Pham, D., Earle, K., Ulusoy, E., Mason, A. J., and Bredland, A. (2022). Negative Online Reviews and Manager Response: Applying Expectancy Disconfirmation Theory in a CMC Context. *Communication Reports,* 1-13.

[10] Morhart, F., Malar, L., Guevremont, A., Girardin, F. and Grohmann, B. (2015). Brand authenticity: An integrative framework and measurement scale. *Journal of Consumer Psychology*, *25*(2), 200-218.

[11] Hancock, J. H. (2016). *Brand Story: Cases and Exploration in Fashion Branding*. 2nd ed. New York, Fairchild Books: Bloomsbury Publishing.

[12] Hatch, M.J. and Mirvis, P.H. (2010). Designing a positive image: Corporate branding and social responsibility. In Thatchenkery, T., Cooperrider, D.L. and Avital, M. (Eds), *Positive design and appreciative construction: From sustainable development to sustainable value*. Bingley: Emerald Group Publishing Limited.

[13] Bryman, A. (2016). *Social Research Methods*: 5th ed. Oxford: Oxford University Press.

[14] Creswell, J. W. and Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative & Mixed Methods Approaches*. 5th ed. London: Sage.

[15] Cromhout, D. and Duffett, R. (2022). Exploring the impact of student developed marketing communication tools and resources on SMEs performance and satisfaction. *Small Business International Review*, *6*(1), e422.

[16] Chen, W., Dong, B., Hsieh, C. W., Lee, M. J., Liu, N., Walker, R. M., and Zhang, J. (2022). A replication of "an experimental test of the expectancy-disconfirmation theory of citizen satisfaction". *Public Administration*, *100*(3), 778-791.

[17] Li, H., Meng, F. and Pan, B. (2020). How does review disconfirmation influence customer online review behavior? A mixed-method investigation. *International Journal of Contemporary Hospitality Management*, *32*(11), 3685-3703.

[18] Morgeson, F. V. (2012). Expectations, disconfirmation, and citizen satisfaction with the US federal government: Testing and expanding the model. *Journal of Public Administration Research and Theory*, *23*(2), 289-305.

[19] Hameide, K. K, (2011). *Fashion Branding Unraveled,* New York: Fairchild Books, Bloomsbury Publishing.

[20] Rakha (2023a). About Rakha [Online]. [Accessed: 6th January 2023]. Retrieved from https://rakha.co.uk

[21] Rakha (2023b). Sustainability [Online]. [Accessed: 6th January 2023]. Retrieved from https://rakha.co.uk/pages/sustainability

[22] Saltyco (2023a). Saltyco [Accessed: 6th January 2023]. Retrieved from: https://www.Saltyco.uk/

[23] Saltyco (2023b). Regenerative agriculture [Accessed: 6th January 2023]. Retrieved from https://www.Saltyco.uk/regenerative-agriculture-page

[24] Rakha (Instagram profile). Instagram. [Accessed: 5th February 2023]. Retrieved from https://www.instagram.com/rakhaofficial/

[25] Saltyco (Instagram profile). Instagram. [Accessed: 5th February 2023]. Retrieved from https://www.instagram.com/Saltyco.uk/channel/

DEVELOPMENT OF ECO-FRIENDLY CURTAIN FABRIC USING NATURAL DYES

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ABSTRACT

Today, natural dye applications are developed as a result of scientific and technological developments and different interdisciplinary studies as well as known traditional applications. This project, it is aimed to color home textile products with pigments obtained from natural resources on the sustainability phenomenon that comes to the fore in today's conditions. For this purpose, it is aimed to color textile surfaces with natural pigments and to achieve good fastness properties as an alternative to synthetic dyestuff groups with a high waste load, from synthesis to application to textile surfaces. Within the scope of the project, naturally obtained dyestuffs and clay as binders were used for dyeing works. Appropriate coloring recipes were determined and dyeing studies were carried out on the fabrics.

Keyword: *Natural dye, Nature friendly, Sustainability, Home textile product*

1. INTRODUCTION

In today's conditions, when the environmental effects of industrial areas are examined, it is observed that the textile sector has a great impact. Until synthetic dyestuffs were found, all coloring processes were done with natural dyestuffs. Today, the application is mostly met with synthetic dyestuffs [1]. The beginning of these effects is high water consumption and the high waste load of industrial dyestuffs causing environmental pollution. It is thought that the use of natural pigment products, which are the source of nature and can be applied to textile surfaces, will be an important breakthrough for the environment in reducing these effects.

Natural dyes have more matte colors compared to synthetic dyes. Natural dyes; Have UV-absorbing properties [2]. On the other hand, the price range and color palette of synthetic dyes are wider. However, these dyes can cause allergies, toxic wastes, and harm to the human body [3]. The main difficulties of natural dyes are; They do not have repeatability in dyeing, uniform dyeing cannot be obtained with them, and their color fastness is limited [4]. Natural dyes have been obtained from various plants, animals, and minerals over the years. One of the oldest known dyestuffs is known as indigo and is thought to have been used for the first time in India [5].

Kayabaşı et al. (1996) used root dye, walnut, buckthorn, onion, exhibition, and pomegranate plants, which are important in herbal dyeing. Each plant was taken at an equal rate (50% + 50%) and used 100% according to the weight of the wool yarn and 15 mordant dyeings were done. In order to obtain different colors and color tones and to increase the fastness values, copper sulfate, potassium bicarbonate, and tin chloride mordants were taken at the rate of 3%, and 45 more mordant dyeings were performed. A total of 60 types of stainings were evaluated subjectively. Colors in dyeing without mordant; light and dark dried rose, tile, dark tile, earth color, baked apple, light cumin, amber, etc. Colors such as brown, light and dark red-brown, dark straw yellow, light and dark orange, milky brown, tile, dark cumin, light and dark green-brown, olive green, orange, and dirty yellow were obtained in dyeing with mordant [6].

Tutak and Benli (2008) stated that natural dyestuffs obtained from some fruits and plants can dye wool fibers of different shades well. In this study, the textile product in the form of yarn produced from 100% wool fiber with 5 different natural dyestuffs was dyed with 3 different mordant substances. In addition, color measurements and fastness studies were carried out after dyeing. It has been concluded that these natural dyes from the obtained colors can be easily used in woolen fabrics in terms of washing, rubbing, sweat, and light fastness [7].

The purpose of this project studies coloring home textile products carried out by dyeing methods using natural pigments. In addition, it is aimed to achieve the fastness values of industrial dyestuffs in coloring with natural pigments.

2. EXPERIMENTAL STUDY

In this study, five different natural dyes were used: Rubia Tinctorium (madder), Indigofera Tinctorial T., Olea Europaea Leaf Extract, Juglans Jegias Extract, Lavender and Pomegranate cover (as seen in Table 1). Clay minerals were used as binders. No mordant material was used in the study.

Table 1. Plant extracts used in the experiments.

Material Number	Material Name
1	Rubia Tictorium (madder)
2	Indigofera Tinctorial T.
3	Olea Europaea Leaf Extract
4	Juglans Regia Extract
5	Lavender and Pomegranate Peels

2.1. Characteristics of the Materials Used

2.1.1. Rubia Tictorium

Rubia Tinctorum, a perennial plant (which can survive for more than two years) belonging to the Rubiaceae family, known by different names in Anatolia such as dye root, red dye, red root, sticky egg dye, scarlet dye, and scarlet root. It is a plant that grows by itself in our country and can grow 50-150 cm according to the conditions (as seen in Figure 1(A)). It gives red and pink tones to the fabric.

2.1.2. Indigofera Tinctorial L.

The homeland of the Indigofera tinctorial L. in India and it can be produced in tropical climates. There are about 700 species of the genus Indigofera tinctorial L., including in tropical countries. Indigofera tinctorial L., which has an important place among these species with its dye source, is a branched shrub plant with 7-13 small leaves (as seen in Figure 1(B)). It gives blue and lots of tones to the fabric.

2.1.3. Olea Europaea Leaf Extract

Olive (Olea europaea L.) is a tree species belonging to the Oleaceae family and grows naturally in the Mediterranean climate. It usually has a lifespan of 300 to 400 years and it is about 10 m high. Olive fruits first turn green and then turn purple (as seen in Figure 1(C)). It gives yellow and lots of tones to the fabric.

2.1.4. Juglans Regia Extract

Dark brown, brown, and light brown colors are obtained from the shell and leaves of walnut (Juglans regia). The factor that gives this color is the ‘‘Juglon’’ substance found in the shell and leaf of the walnut (as seen in Figure 1(C)).

2.1.5. Lavender and Pomegranate Peels

Lavender is a perennial herb that can be 20-60 cm tall, with semi-bush, lilac, or grayish-blue flowers. Dried lavender is used as a natural dye source. Pomegranate is a deciduous plant in the form of a tree or shrub. It is a small tree or shrub, 5 to 6 meters tall, with sparsely branched, broad crowns. For dyeing, the peels of the fruit are used fresh or dried (as seen in Figure 1(D, E)).

Figure 1. Illustration images of the materials used (A= Rubia Tictorium Botanical Illustration, B= Indigofera Tinctorial L., C= Olea Europaea Leaf Extract, D= Juglans Regia Extract, E= Lavender and Pomegranate Peels).

2.2. Fabric Properties

For dyeing, 70,6 g/m^2 of fabric consisting of 100% cotton yarn was used. The properties of the fabric used are indicated in the table below (as seen in Tablo 2).

Table 2. Fabric properties.

Warp Thread	Weft Thread	Warp/Weft Density	Weight(g/m^2)
40/1 Ne %100 Cotton PNY	40/1 Ne %100 Cotton PNY	21,8*22	70,6

2.3. Experimental Plan

After the dyes taken in liquid form were mixed with a mixer, they were applied to the fabrics by the padding method in the Stenter machine. Process parameters used in the dyeing process are shared in Table 3. Color fastness and garment wash tests were carried out on the fabrics produced.

Table 3. Process parameters used in the dyeing process.

Lower Fan (%)	Bottom Fan (%)	Velocity (m/dk)	Transition Temperature (^0C)	Pick Up (%)
51	50	25	170	80

3. RESULTS

3.1. Fastness Test Results

Fastness tests were applied to the fabrics produced. In order to determine the color performance of dyed fabrics, perspiration, water, color, washing, and rubbing fastnesses, which are important fastnesses of textile products, are shared as tables, graphics, and figures.

3.1.1. Perspiration Fastness Test Results

Color fastness values of the dyed samples against perspiration were made according to the ISO 105-E04 standard and the results were evaluated in a standard light cabinet. Test results are shown in Table 4.

Table 4. Perspiration fastness test results.

Perspiration Fastness	Green		Yellow		Blue		Grey		Pink	
	Acid	**Base**	**Acid**	**Base**	**Acid**	**Base**	**Acid**	**Base**	**Acid**	**Base**
Color fastness to Perspiration (ISO 105-E04)	4+	4+	4+	4+	4+	4+	4+	4+	4+	4+

3.1.2. Water Fatness Test Results

Color fastness values of the dyed samples against the water were made according to the ISO 105-E01 standard. Test results are shown in Table 5.

Table 5. Water fastness test results.

Water Fastness	Green	Yellow	Blue	Grey	Pink
Color Fastness to Water (ISO 105-B01)	4+	4+	4+	4+	4+

3.1.3. Color Fastness Test Results

The light fastness of the fabrics produced was made according to the ISO 105-B02 standard. Fastness tests of the fabrics were made. Test results are shown in Table 6.

Table 6. Color fastness test results to artificial light.

Color Fastness	CV %100 Cotton 70 g/m^2 Voile (Curtain Quality)
Color Fastness to Artificial Light (ISO 105-B02)	5/5-6

3.1.4. Garment Wash Test Results

The washing appearance test results of fabrics are given in Table 7.

Table 7. After washing appearances test results.

Garment Wash	Green	Yellow	Blue	Grey	Pink
After 1 Wash	3	3-4	3-4	3-4	3
After 5 Wash	2	2-3	3	2-3	2
After 10 Wash	1-2	2	2-3	2	1-2

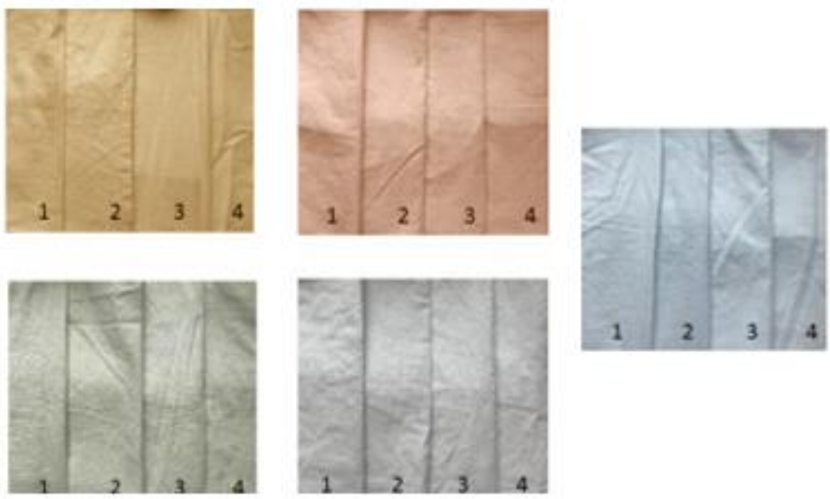

Figure 3. Fabric images after washing (number 1: before washing, number 2: after 1 wash, number 3: after 5 wash, number 4: after 10 wash).

Color changes after washing are shown in Figure 3. Sample number 1 is unwashed, sample number 2 shows images after one wash, sample number 3 shows images after five items of washing, and sample number 4 shows images after ten items of washing.

3.1.5. Rubbing Fastnesses Test Results

Determination of color fastness of dyed samples to dry and wet friction ISO 105x12 made in accordance with the standard and the results were evaluated in a standard light cabinet. Test results are shown in Table 8.

Table 8. Rubbing fastnesses test results.

Rubbing Fastness	Green		Yellow		Blue		Grey		Pink	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Color Fastness to Rubbing (ISO 105x12)	4+	4+	4+	4+	4+	4+	4+	4+	4+	4+

3.2. Electricity, Water, and Steam Consumption Results

In the study, natural dyeing methods, pigment and reactive dyeing, and traditional dyeing processes were compared. Fabrics with the same parameters were dyed with different dyeing techniques. Electricity, water, and steam consumption were calculated for each dyeing technique during dyeing (as seen in Table 9 and Figure 4).

Table 9. Electricity, water, and steam consumption.

Dyeing Type	Electricity Consumption (kW/kg)	Water Consumption (L/kg)	Steam Consumption (kg/kg)
Pigment Dyeing	0,43	29,33	2,45
Reactive Dyeing	0,40	54,96	9,38
Natural Dyeing	0,26	27,18	2,49

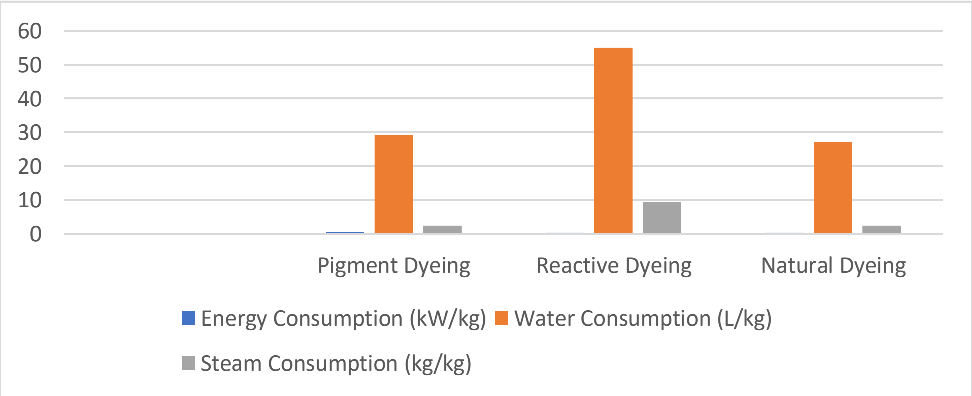

Figure 4. Electricity, water, and steam consumption.

It has been observed that natural dyeing provides 40% energy and 7% water saving compared to pigment dyeing. Compared to reactive dyeing, 73% steam, 35% energy, and 50% water saving were achieved.

4. CONCLUSION

The dyeing behavior and usage fastness of natural dyestuffs obtained from various sources on the cotton fabric were investigated. When the results of washing the products 1, 5, and 10 times were evaluated, it was observed that there was some discoloration. However, since there is no need for too much washing on the curtains, the washing results meet the expected criteria. In our study, compared to other studies, heavy metals are not used and they are biodegradable.

In addition, with the developed products, saving was achieved in both energy, water, and steam consumption. It is foreseen that with an environmentally friendly product design, the responsibility to the environment can be increased as well as reducing the resources consumed.

REFERENCES

[1] Hunger, K., (2003). Industrial Dyes, Wiley-VCH, Weinheim.
[2] Iqbal, J., Bhattı, J.A., Adeel, S. 2007. Effect of Uv Radiation on Dyeing of Cotton Fabric with Extracts of Henna Leaves, Indian Journal of Fibre& Textile Research, 33, 157-162
[3] Samanta, A.K., Agarwal, P. 2006. Dyeing of Jute and Cotton Fabrics Using Jackfruit Wood Extract: Part I –Effects of Mordanting and Dyeing Process Variables on Colour Yield and Colour Fastness Properties, Indian Journal of Fibre& Textile Research, 32, 466-476.
[4] Samanta, A.K., Agarwal, P. 2009. Application of Natural Dyes on Textiles, Indian Journal of Fibre& Textile Research, 34, 384-399.
[5] Sunerli, E., Aydın, MÇ., Effect of Natural Dyeing on Surfaces Formed with Different Textile Fibers, The Journal of International Lingual, Social and Educational Sciences Year, 2019, 5, 1 DOI: 10.34137/jilses.477947
[6] Kayabaşı, N., Colors obtained by dyeing Carpet and Rug Yarns with Walnut (Juglans Rega) fruit peel and leaves and some fastness values of these colors, International Textile Conference and Exhibition, Bursa, s. 475-480, 1996.
[7] Tutak, H., ve Benli, H., Investigation of dyeing properties of natural dyes obtained from some plants on wool, Journal of Balıkesir University Institute of Science and Technology, Vol. 10, No. 2, pp. 53-59, Aralık 2008.
[8] Rubia Tictorium Botanical Illustration. Accessed: 08.02.2023 Retrieved from https://kocaelibitkileri.com/rubia-kokboyasi/
[9] Plant Indigofera tincture L.: Accessed: 08.02.2023, Retrieved from https://en.wikipedia.org/wiki/Indigofera

INVESTIGATION OF RECYCLED COTTON DYEING WITH *RUBIA CORDIFOLIA* AND BIO-MORDANT CHITOSAN

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ABSTRACT

Today, the main cause of global warming, as one of the biggest and most important problems of mankind, is again human beings. One of the reasons for the problem is the excessive consumption of cotton, which is the most preferred natural fiber in textile as the second most polluting sector in the world, and the high amount of water, pesticides, chemicals and energy consumed during its cultivation and processing. Many of the synthetic dyes used to color textiles pose a great threat to the environment. For this reason, dyeing of recycled cotton with natural dye and bio-mordant chitosan was investigated in this study. The results showed that natural dye could be used successfully in dyeing of recycled fibers although it provided low color efficiency. In addition, it was thought that the high fastness values obtained were due to the strong bonds of the dye with the fiber or the low color strengths. Finally, the dyeing conditions in this study were not very suitable for the use of chitosan as a mordant. As a result, it was revealed that although natural dye could be used alone for dyeing of recycled cotton, additional studies must be done to improve the color strengths.

Keyword: *Madder, Natural dye, Dyeing, Chitosan, Fastness*

1. INTRODUCTION

It is a fact that the textile industry has grown many times during the last decades to meet global and domestic demands. This tremendous growth has also led to a parallel growth in environmental problems, which usually remained unnoticed. While any industrial activity produces pollution in one form or the other, the textile industry certainly released a wide spectrum of pollution into the environment. Textile manufacturing processes are usually characterized by the high consumption of resources such as water, fuel and a variety of chemicals in a long process sequence generating a significant amount of waste. The common practices of low process efficiency result in substantial wastage of resources and severe damages to the environment [1,2]. Therefore, the worldwide demand for the use of environmentally friendly products in the textile industry is nowadays of great interest, possibly because of increasing concern about the environment, ecology, and pollution control [3,4].

Recycling technologies have been a well-established part of the textile industry since the first industrial revolution [5]. The use of recycled cotton in textiles has been increasing.

Chitin is the second most abundant biopolymer in nature after cellulose and presented in the outer skeleton of shellfish like shrimps, lobsters, crabs, and insects [6,7]. Chitosan is attracting great interest in textile applications; from fabric pre-mordantings to finishing processes [8–12].

Within the scope of sustainable production in textile, environmentally-friendly products and processes have become important. The green movement in textiles has increased the interest in natural dyes as an alternative to synthetic dyes. Natural dyes from plants, minerals, insects and animals are better biodegradable and less harmful to the environment than synthetics, but have a limited color gamut and low fastness. These disadvantages are tried to be eliminated by the use of environmentally-harmful metallic mordants. Due to the environmental hazard caused by metallic mordant while dyeing of textile fabric, dyers are always looking for safe natural mordant for natural dyes [13–15].

The scope of this research was to create sustainable process designs. For this reason, it was investigated the effects of using different molecular weight chitosans as mordants in the dyeing of recycled cotton fibers with natural dye. In this method chitosan was used by different concentrations together with natural dye (*Rubia cordifolia*). The effects of these various independent variables on dyeing behavior of the recycled yarns were studied with color measurements (color coordinates and color strength values), and washing fastness. Control samples were obtained by natural dyeing without the use of mordant chitosan.

2. EXPERIMENTAL STUDY

In this study recycled 100% cotton yarns were used. These undyed and recycled cotton fibers were obtained from fiber and clothing waste. Cotton yarns count, which could contain small part of other cellulosic fibers, was Ne 20/1. For chitosan mordanting Sigma-Aldrich brand low molecular weight (LMW) and medium molecular weight (MMW) chitosan bio-polymers were used. The chitosan solution was prepared using soft water and 80% acetic acid of technical grade. Rubia cordifolia (C.I. Natural Red 16) natural dye used for dyeing [16]. The structure of the dye is given in Figure 1. The Genclear RWM1 obtained from GenKim was used for washing.

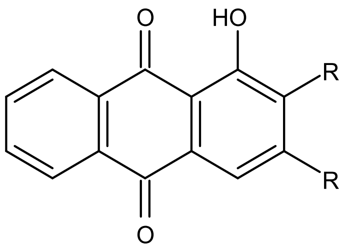

Figure 1. Chemical structure of *Rubia cordifolia* [17].

Prepared three different solutions with concentrations of 1%, 3% and 5% (o.w.f.) from two types of chitosan (LMW and MMW). Chitosan was dissolved by the aid of acetic acid at pH 3-4. Chitosan LMW solution prepared during 30 minutes by magnetic stirrer at 1.000 rpm in 24°C. With the same parameters chitosan MMW prepared for 24 hours. Natural dye Rubia cordifolia was used by taking the same concentration (10% o.w.f.) for each test after detailed experiments. Naturel dye solutions were prepared by adding dyes to in water at neutral pH.

Chitosan and natural dye solutions were used together, a process which is called meta-mordanting. In the meta-mordanting, chitosan mordanting and dyeing were carried out simultaneously in the same bath. Chitosan solution and dyeing baths liquor ratio was 40:1 (o.w.f.) for wet treatments. The treatments were conducted in sample dyeing machine during 60 minutes at 60°C. These mordanting and dyeing processes started at 20°C and baths heated up to 60°C in 20 minutes by an increase of 2°C/minute. After dyeing, samples were washed with water at 60°C with 4g L-1 detergent. The time-temperature diagrams of the processes are given in Figure 2. The meta-mordanted and dyed samples were dried at 90°C-95°C for 15 minutes.

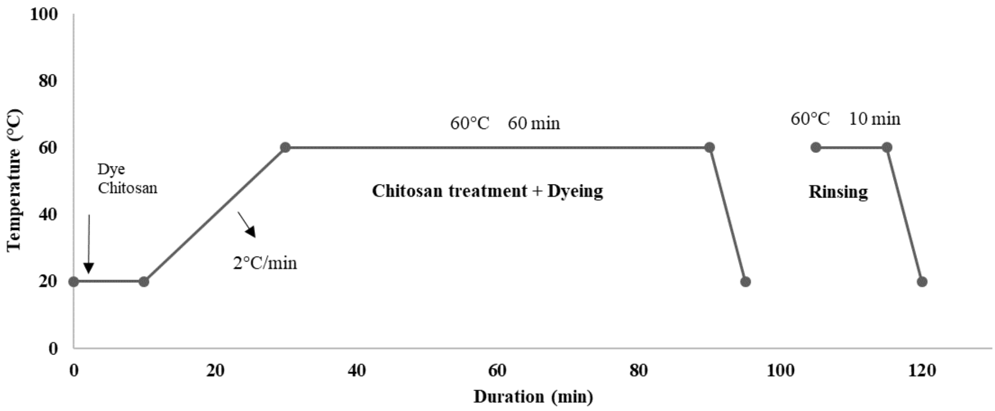

Figure 2. Meta-mordanting and dyeing details

The color coordinates (L*, a*, b*, C*, and h°) and color strengths were measured using Konica Minolta CM-3600D spectrophotometer (under D65 illuminant and 10° standard observer) in specular component included (SCI) mode. In order to reduce possible experimental errors, four color measurements were taken from each of the three samples, obtained by repeating each dyeing three times, by rotating 90°. The K/S values were calculated using the Kubelka-Munk equation. The color strength (K/S) equation [18] is presented in Equation 1.

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \qquad \text{Eq. 1}$$

In Equation 1, *R* is the decimal fraction of the reflectance of fabric, *K* is the absorption coefficient, and *S* is the scattering coefficient.

The washing fastness of the dyed fibers was carried out by a TEST color fastness tester, using the color fastness to domestic and commercial laundering standard test method (TS EN ISO 105-C06/A1M).

3. RESULTS

3.1. Colorimetry

Color coordinates of the yarns which mordanted with different molecular weight chitosan and dyed with natural dye are given in Table 1.

Table 1. Color coordinates of meta-mordanted and dyed yarns

Chitosan molecular weight	Chitosan conc.(%)	L*	a*	b*	C*	h°
-	-	64.73 ± 0.10	20.67 ± 0.11	12.11 ± 0.11	23.96 ± 0.17	30.38 ± 0.06
LMW	1	69.06 ± 0.10	16.40 ± 0.20	13.76 ± 0.12	21.41 ± 0.18	40.02 ± 0.06
	3	71.75 ± 0.14	14.19 ± 0.16	16.46 ± 0.10	21.73 ± 0.05	49.26 ± 0.05
	5	72.54 ± 0.08	11.56 ± 0.07	18.78 ± 0.08	22.05 ± 0.09	58.42 ± 0.18
MMW	1	68.43 ± 0.12	19.37 ± 0.12	12.82 ± 0.17	23.23 ± 0.11	33.52 ± 0.09
	3	70.09 ± 0.16	15.54 ± 0.18	13.17 ± 0.18	20.37 ± 0.05	40.30 ± 0.07
	5	72.35 ± 0.15	12.46 ± 0.09	15.34 ± 0.15	19.76 ± 0.18	50.94 ± 0.08

In Table 1, it was seen that while the increase in chitosan concentration decreased the redness (+a*) of the colors, it caused an increase in the yellowness (+b*). In dyeings without mordant, colors taken were in the most red and the least yellow. This showed that when chitosan was used together with natural dye, it caused a change in the color of the dye. This change was also clearly seen in the color angles (h°). These results showed that chitosan was more reactive towards fiber than dye. It was thought that this situation was caused by the structural differences of chitosan and dye molecules as well as the ionicity differences in the dyeing medium. Chitosan, which has a similar structure to cellulose, could have approached the fiber more easily than the benzene ring bulk dye. Moreover, the partially positively charged chitosan in neutral medium [19] could have bounded to the anionic fiber more than the dye, which was predicted to be anionic in neutral medium. The partially positively charged chitosan that binds to fiber may also have blocked the fiber's dyeing sites. Another possibility was that chitosan would reduce the dissolution of the dye. These revealed the reason for the higher L* values obtained from the control sample, in which only natural dye was used in the dyeing process, compared to the mordanted and dyed samples. It became clear that additional experiments must be carried out for the dyeing bath pH value.

In Figure 3, the color strengths obtained after the meta-mordanted chitosan and dyeings are given.

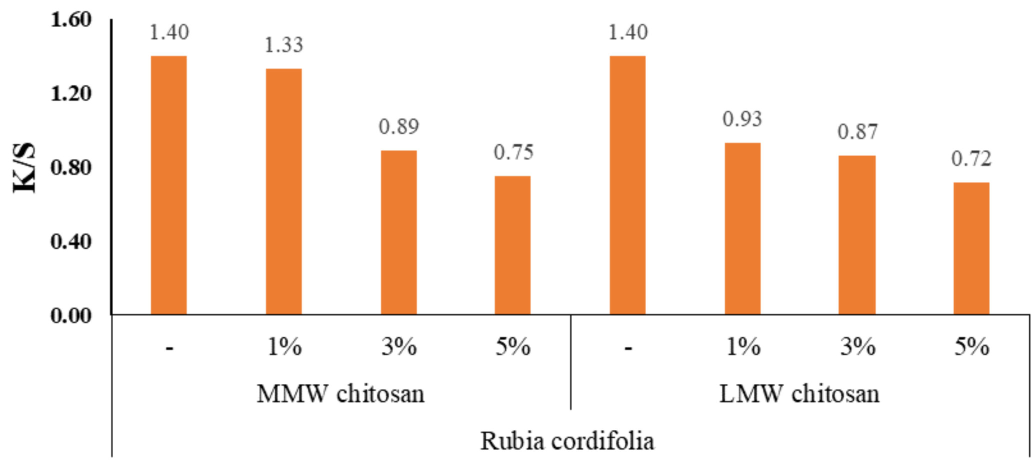

Figure 3. Color strengths of meta-mordanting process

It was observed that the color depths of the dyeings carried out in the presence of chitosan mordants of different molecular weights decreased compared to the control sample obtained by only natural dyeing without using mordant. With the increase in chitosan concentration, the decrease in color depths rose. Therefore, the highest color depths were obtained when chitosan was not used for dyeing. In other words, no mordant effect could be obtained from chitosan under these dyeing conditions. However, it was thought that chitosan cross-linked to the fiber because increased chitosan concentration caused a decrease in color strength, but it could not act as a bridge between fiber and dye. According to the color strength results, chitosan did not have a mordanting effect on the dyeing of cotton with natural dye could be explained by the following: (i) the partially positively charged chitosan could have occupied dyeing sites, (ii) the bulky nature of the natural dye could have reduced its ability to bind to the cotton, (iii) the ability of the natural dye to bind to fiber-bound chitosan may have been low, and (iv) chitosan could have reduced the solubility of the dye or *Rubia cordofila* not 100% soluble in water at neutral pH. Colorimetry results (Table 1 and Figure 3) revealed that chitosan was effective in dyeing, but the number of parameters that need to be changed must be increased in order for these effects to be positive.

3.2. Washing Fastness

Washing fastness values of dyed samples with/without mordant are given in Table 2.

Table 2. Washing fastness of unmordanted/mordanted and dyed samples

Chitosan molecular weight	Chitosan conc.(%)	Washing fastness
		CO
-	-	4/5
LMW	1	4/5
	3	5
	5	5
MMW	1	4/5
	3	5
	5	5

Washing fastness results were good to excellent levels. This could be explained by the low color strengths.

4. CONCLUSION

Chitosan, which has many superior properties, has a wide range of uses from cosmetics to textiles. From the viewpoint of the environmental and ecological concerns, natural dyeing by the help of chitosan as a biomordant have the potential to become a key green resource in the development of sustainable textile dyeing process. For this reason, in this study, we tried to evaluate whether chitosan was a suitable mordant in the dyeability of recycled cotton with *Rubia cordifolia*. Colorimetry results showed that the combination of chitosan and natural dye in the dyeing conditions of this study was not suitable for dyeing recycled cotton. It was thought that there were many structural and chemical reasons for this as explained in the corresponding sections of the study. However, this result could be changed after detailed studies to be carried out in the future.

REFERENCES

[1] Karthik, T., & Gopalakrishnan, D. (2014). Environmental Analysis of Textile Value Chain: An Overview. In S.S., Muthu (Ed.). Roadmap to Sustainable Textiles and Clothing:Environmental and Social Aspects of Textiles and Clothing Supply Chain (1st ed., pp. 153-188). Singapore, Springer.
[2] Toprak, T., & Anis P. Textile Industry's Environmental Effects and Approaching Cleaner Production and Sustainability: an Overview. J Text Eng Fash Technol 2017;2:429–42.
[3] Khan, M.I., Ahmad, A., Khan, S.A., Yusuf, M., Shahid, M., Manzoor, N., & Mohammad, F. (2011). Assessment of Antimicrobial Activity of Catechu and Its Dyed Substrate. Journal of Cleaner Production, 19 (12), 1385–1394.
[4] Vankar, P.S., Shanker, R., & Verma, A. (2007). Enzymatic Natural Dyeing of Cotton and Silk Fabrics without Metal Mordants. Journal of Cleaner Production, 15, 1441–1450.
[5] Horrocks, A.R. (1996). Recycling and Recovery Strategies. In A.R., Horrocks (Ed.). Recycling Textile and Plastic Waste (1st ed., pp.1-16). Cambridge, Woodhead Publishing Limited.
[6] Moattari, M., Moattari, F., Kouchesfehani, H.M., Kaka, G., Sadraie, H.S., & Naghdi, M. (2018). Chitosan and Textile Industry. Trends in Textile Engineering & Fashion Technology, 2, 236–238.
[7] Huang, L., Xiao, L., & Yang, G. (2018). Chitosan Application in Textile Processing. Current Trends in Fashion Technology & Textile Engineering, 4 (2), 32–34.
[8] Stegmaier, T., Wunderlich, W., Hager, T., Siddique, A.B., Sarsour, J., & Planck, H. (2008). Chitosan - A sizing Agent in Fabric Production - Development and Ecological Evaluation. Clean - Soil, Air, Water, 36 (3), 279–286.
[9] Ramadan, M. A. M., Samy, S., Abdulhady, M., Hebeish, A. (2011). Eco-Friendly Pretreatment of

Cellulosic Fabrics with Chitosan and Its Influence on Dyeing Efficiency. In E., Kumbasar (Ed.). Natural Dyes (1st ed., pp. 3-12). London: IntechOpen.

[10] Kaliyamoorthi, K., & Thangavelu, R. (2015). Union Dyeing of Cotton/Nylon Blended Fabric by Plasma-Nano Chitosan Treatment. Fashion and Textiles, 2 (1), 1–10.

[11] Huang, K.S., Wu, W.J., Chen, J.B., & Lian, H.S. (2008). Application of Low-Molecular-Weight Chitosan in Durable Press Finishing. Carbohydrate Polymers, 73 (2), 254–260.

[12] Leistner, M., Abu-Odeh, A.A., Rohmer, S.C., & Grunlan, J.C. (2015). Water-based Chitosan/Melamine Polyphosphate Multilayer Nanocoating that Extinguishes Fire on Polyester-Cotton Fabric. Carbohydrate Polymers, 130, 227–232.

[13] Teli, M.D., Sheikh, J., & Shastrakar, P. (2013). Exploratory Investigation of Chitosan as Mordant for Eco-Friendly Antibacterial Printing of Cotton with Natural Dyes. Journal of Textiles, 2013, 1–6.

[14] Chakraborty, J.N. (2014). Dyeing with Natural Dyes. In J.N., Chakraborty (Ed.). Fundamentals and Practices in Colouration of Textiles (2nd. ed., pp.233-261). New Delhi, Woodhead Publishing India Pvt. Ltd.

[15] Yusuf, M., Khan, S.A., Shabbir, M., & Mohammad, F. (2017). Developing a Shade Range on Wool by Madder (Rubia cordifolia) Root Extract with Gallnut (Quercus infectoria) as Biomordant. Journal of Natural Fibers, 14, 597–607.

[16] Blackburn, R.S. (2017). Natural Dyes in Madder (Rubia spp.) and Their Extraction and Analysis in Historical Textiles. Coloration Technology, 133, 449–462.

[17] Yusuf, M., Shahid, M., Khan, S.A., Khan, M.I., Islam, S.U., Mohammad, F. and Khan, M.A. (2013) Eco-Dyeing of Wool Using Aqueous Extract of the Roots of Indian Madder (Rubia cordifolia) as Natural Dye. Journal of Natural Fibers, 10, 14–28.

[18]Akgun, M., Becerir, B., & Alpay, H.R. (2014). Reflectance Prediction of Colored Polyester Fabrics by A Novel Formula. Fibers and Polymers,15, 126–137.

[19] Jocic, D., Vílchez, S., Topalovic, T., Navarro, A., Jovancic, P., Julia, M.R. & Erra, P. (2005). Chitosan/Acid Dye Interactions in Wool Dyeing System. Carbohydrate Polymers, 60, 51–59.

INNOVATIVE APPROACHES TO PATTERN-ORIENTED DESIGN

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ABSTRACT

Unconscious consumption and production, which have emerged as a result of the search of people for innovation in the rapidly changing world order and the desire of industries to keep up with it, have caused the impairment of the balance in nature and the destruction of resources. In the textile and fashion industry, perceived product value and understanding of design have changed due to rapid consumption as well as social and environmental concerns and caused the neglect of the purpose of design. The subject of this study was to create functional garment designs, which can be used as different garments to increase perceived product value and lifetime, with a pattern-oriented design approach. This study, which aimed to develop changeable and transformable functional garment design ideas that can be used as two different types of garments, consisted of 2 main parts: theoretical and applied. Design ideas were tested in the study, which was conducted using the applied research method. The applied part of the study involved the creation of 3 garment designs that could be used as skirts/blouses and 2 garment designs that could be used as shirts/vests/coats, all made of recycled fabrics targeting an audience of female fashion consumers sensitive about sustainability. According to the results of the study, it was observed that the technical details (tunnels, puckering, laces, zippers), which were used in the design to enable the use of the product as two different types of garments, could add different functionality to the product, and the wide parts of the product such as hips, chest, and shoulders could be adapted functionally. This study was considered important since the pattern-oriented design approach could improve the lifetime of the product and increase the product value in terms of sustainability and design processes, and it was believed that it would contribute to other researchers in the field by introducing a different perspective.

Keywords: *Design, Pattern-Oriented Design, Functional Design, Functional Garment*

1. INTRODUCTION

Design has been an important source of power for life practices and human environments, and a fundamental element of development throughout history. Looking at the history of design, it is observed that the items produced to address the needs ranging from daily objects, ornaments, and war tools to mobile vehicles have developed and transformed functionally and visually over the centuries. There are many factors affecting this transformation. Sociologists argue that a new revolution is underway with the information revolution after the agricultural and industrial revolutions. The impact of change created by this revolution has affected not only technology but also communication tools, information and learning methods, consumption patterns, and human relations [1]. Many sociological, economic, and technological factors have affected the lives and lifestyles of societies and individuals [2] and changed the understanding of design. In this context, the scope of design is observed to have expanded and evolved over the past centuries, shaping both objects and life [3].

With the capitalist production-consumption approach initiated by the industrial revolution, [4] industries have constantly been producing to maintain the momentum between society and the individual, follow the change, keep up with the dynamics, and meet the physiological and psychological needs of the individuals as well as their desire for innovation. In addition to many problems such as the development in living standards, population growth, and globalization [5], rapid and unconscious consumption within the fast production cycle has caused the design to become increasingly uniform, deviate from its purpose, lose value, deteriorate the balance in nature, and destroy resources. It is observed that some concerns have arisen about design because of the satisfaction-oriented understanding of consumption among individuals, their search for innovation, and the desire of industries to keep up with this order. Therefore, the design has moved away from "problem-solving", which is its main purpose in terms of the process.

This is also reflected in the current understanding of design within the textile and fashion industry. The concept of fast fashion, which emerged with the consumer culture, increased the number of seasons, which used to be mainly spring-summer and autumn-winter seasons. It is tried to keep up with this speed with the collections renewed at short intervals, special collections offered to the customers in certain periods of the year such as special days and weeks, and shop windows and contents that are redecorated every week. The industry launches products that lack creativity and quality, which are aimed at beautification, to offer products in a short time to consumers who are constantly in need and in search of innovation. This process is explained by the concept of fast fashion and generally satisfies the desire of consumers for innovation by diversifying the products, producing in small quantities, and not resupplying [6]. Nevertheless, developments, events, and reactions in political, economic, and social fields have changed the consumer profile over time and created a new consumer profile looking for unique, different, and distinctive features and personal definitions [7]. In addition to following the latest trends and fashion, consumers are now demanding high-quality products that have visual and functional performance, are produced around ethical and social values, have a fundamental purpose, and will minimize the damaging effects of the production-consumption cycle. In this context, designers are responsible for addressing the problems encountered by producing slow and sustainable products suitable for the rapid production and consumption cycle and developing creative, innovative, and original ideas that will appeal to all and have variable uses. Accordingly, it is thought that designers should find different solutions to adapt the dynamics brought by the world order to all areas of life and should carry out studies that can highlight the main purpose of designing.

Recently, studies have been conducted in the field of design to balance consumption and production, give importance to the use of resources and the method of use, serve a purpose, appeal to all, and offer different solutions. Accordingly, various methods and approaches have come to the fore, such as modularity, individualization, mass individualization, design-oriented thinking, user-oriented design, pattern-oriented design, and functional design. This study emphasized functionality as a concern of design and discussed a sustainable approach suitable for the expectations of consumers. In this context, the pattern-oriented design approach was adopted and functional garment designs were planned to be created. The pattern-oriented design approach combines the roles of a designer and a styler. This can be achieved by creating a series of sketches and incorporating patterns into the garment design process instead of creating patterns for the sketches. Based on this idea, the study was carried out within the pattern-oriented design approach, which maximized the efficiency of the pattern and design process, enabled the use of the fabric most efficiently, required minimum cutting time, reduced sewing processes, and referred to under functional and modular concepts. Looking at the studies in this field, it was found that Rissanen developed the Jigsaw Puzzle theory, attaching the parts of the pattern, Holly McQuillan referred to topology and developed the tesselation technique, Yohlee Teng created the Mobius strips, and Julian Roberts developed the subtraction cutting technique. Nevertheless, they could not be used widely due to the complexity of the techniques in terms of patterns and mass production and their time-consuming nature [8].

The designs developed within the scope of the study were functional garment designs that could be used as two different types of clothing. A Functional garment is defined as a general term that includes all types of garments or sewing specifically designed to offer the user a defined performance or functionality beyond their standard function [9]. Functional garments, which have different uses, have been defined as clothing or clothing systems that can be used in different forms and scenarios such as adaptation to different social situations, climatic conditions, and usage expectations (dynamic or non-dynamic) [10]. Designing a functional garment requires examining the mobile-immobile body dimensions in detail and knowing the joint movement areas well [11]. Considering that the garment projects should enable uses as a skirt-blouse and a dress-tunic/shirt-vest, hips in the lower body and shoulder, chest, and sleeve(arm) sizes, and joint movements in the upper body are important in this examination. The fact that the designs to be produced provide comfortable movement and are functional in both uses requires that the patterns are prepared using anthropometric measurements [12].

The main setup of the study involved the pattern-oriented design approach, which required the design and pattern processes to be carried out simultaneously. Functional garment designs, which were created using geometric forms within the scope of the pattern-oriented design approach, were planned according to ready-made manufacturing techniques. The design ideas were centered around current fashion problems and the recent consumer profile and based on problem-solving, which was the main purpose of design, as well as the idea that the existence and appearance of a product should have a purpose and function [4]. Accordingly, the problem situation of the study was determined as "how to create garment designs that can be used with different functions using the pattern-oriented design approach". During the design process, the focus was on the design and pattern components of the pattern-oriented design approach. Therefore, it was aimed to develop and produce changeable and transformable functional design ideas that can be used as two different types of garments. In line with the purpose of the study, answers were sought for the following sub-objectives:

- What are the necessary aesthetic and functional procedures to enable a type of garment to have dual use?
- What are the technical features to be considered when designing a garment with dual use?

The study is considered important in terms of demonstrating that creative and qualified solutions can be found in the designs to be created by including the pattern preparation process in the sketching stage of a design idea. It emphasizes the importance of technical knowledge in terms of being an example study for innovative ideas to be revealed in the execution of the design ideas based on patterns and knowledge of anthropometric measurement. Adoption of a technical approach while creating the design minimized the problems that may occur during the process. In this respect, it is thought that it will contribute positively to the workflows of businesses in terms of design and pattern preparation processes. It can be argued that the inclusion of such designs in the collections of ready-made brands will contribute to the increase in the interest of consumers and the possibilities of use. The designs developed can be combined in different ways as two different types of garments and personalized thanks to the functional movement details in the design. It is thought that this feature will increase the life cycle of a product and affect the means and speed of consumption. It is considered important in terms of contributing to the diversity of practice by introducing a different perspective to the designers, stylists, academicians, and students in this field. In addition, it is thought that it will contribute to the capsule cabinet approach since it occupies a small space in the wardrobe.

2. EXPERIMENTAL STUDY

This study examined garment designs, which could be personalized and transformed so that consumers could use the products they purchased for a longer period and in different functions. The applied research method was used in the study, where design ideas were tested and discovery processes were included.

This part of the study was constructed by experimenting with designs according to the applied research method, which referred to "the experimental application of the knowledge produced or being produced" [13].

The study consisted of two main parts, theoretical and applied. In the theoretical part, which was the first part of the study, relevant national and international printed and visual sources were investigated based on the purpose of design, the effects of consumer culture on design, pattern-oriented design, and functional design. The data obtained were systematically transferred according to the scope of the study. The applied part, which was the second part of the study, involved the creation of a capsule collection that consisted of transformable and changeable garment designs within the pattern-oriented approach.

The study, which was conducted as applied research, focused on a garment design with two different functions. The awareness and significance concerning the pattern-oriented design approach were highlighted during the preparation of the designs. Pattern-oriented designs were created, which could fit the width of the lower body (hips and waist) and the upper body (chest and shoulders). An experimental and iterative design process was planned during the design of the study. This design plan was created using the functional design process model.

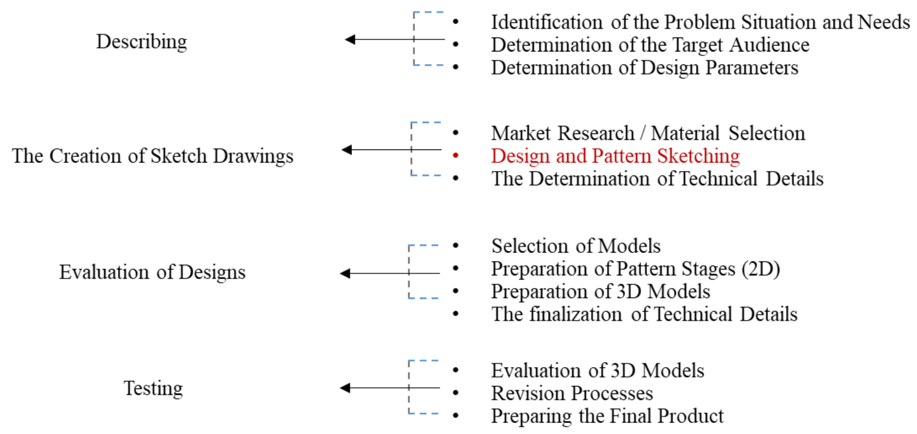

Figure 1: The Design Process Used

The study was initiated by determining the problem situation, "*how to create different functional garment designs based on pattern-oriented design approach*". According to the problem situation, a target audience was determined consisting of female fashion consumers, who were between 25 and 40 years of age and sensitive about sustainability, with the design and application team of ATT Clothing, the project partner, which would include the designs in their ready-made collections. According to the target audience and the problem situation determined, sketch drawings were made suitable for the functional garment design within a pattern-oriented design approach. Among the sketch drawings, the researchers and project partner agreed upon 5 pieces of garments, and patterns were created in the Lectra Modaris Expert V8 software. The technical details of each garment (eyelets, buttons, and hook and eye, etc.) were determined by considering functionality and aesthetic functions. The models selected from the garment designs were processed on a virtual try-on using CLO-3D Fashion Design Software. Within the garment design process, necessary corrections were made in the pattern and design stages during the virtual try-on, and designs with recycled fabrics were produced as the final product.

3. RESULTS

Figure 3: Boat Collar Blouse/ A-Line Skirt (Patterns, Technical Drawing, 3D Simulations, View of the Produced Design on the Mannequin)

The boat collar blouse/A-line skirt model displayed in Figure 3 has a functional feature that enables use in two different types of garments. The design has been created by working on how the armhole (sleeve hole) details in the blouse form to be worn on the upper body could be adjusted to obtain an aesthetic and functional appearance when the product is used as a skirt in the lower body. As a result of the developed design and pattern works, it is decided to use lace through the double-layer rectangular piece at the armholetoward the sleeve (arm). It has been observed that this piece, which could be defined as a tunnel, could become a pucker-up pocket (cargo pocket) by puckering in the skirt form, and the form of the sleeves covering thecouser head of the shoulder and biceps could be obtained in the blouse form by releasing the puckering of the tunnel. The lower part of the pocket position (C) has been sewn 3 cm and the rest is released to create the boat collar appearance and form the shoulder line. This ensures that the garment fit on the shoulder line and the opening part becomes the curving part of the collar over the shoulder. It functions as a slit in the skirt form. The buttonhole button has been preferred in the functional closure in the front center, enabling the adjustment of the dropping of the hem (A-line) to be used as a collar. Looking at the general outlines of the design, the skirt has an A-line cut with a buttonhole button closure in the front and belt detail in the waist part. In the blouse form, the components of the design are a boat collar, low shoulders, short sleeves, and puckered sleeve ends. In the skirt form, the model has a pucker-up pocket at the dysfunctional end and a short slit detail below the pocket. When the common components of the design are examined, the armhole in the blouse form (C) has been determined to mark the position of the pucker-up pocket (C) in the skirt form. The line (A), which forms the shoulder and collar detail in the blouse form, becomes the hem in the skirt form. The waistline (B) has been determined as the center in both garment forms. Considering the necessity of seaming in the inside of the garment as well as the sides and hem, the facing seam technique is used in the hem/collar parts, the English stitch technique is used in the stitches that are visible from the outside, and the sleeve part has been made of double layer fabric. Lace-up binding has been prepared for use at the sleeve end and pocket opening and puckered through the double layer of fabric.

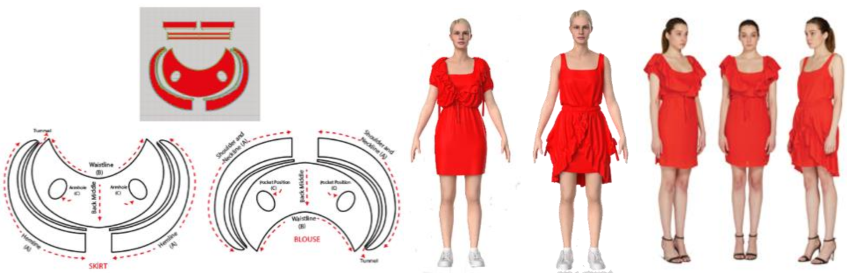

Figure 4: Puckered, Loose Blouse/Puckered Loose Skirt (Patterns, Technical Drawing, 3D Simulations, View of the Produced Design on the Mannequin)

The puckered loose blouse/puckered loose skirt model shown in Figure 4 has a functional feature that can be used as two types of garments. During the design, the problem of adjustment to the upper body was considered when the skirt was prepared in a circle form. The circle-design skirt has a wide range of use. The circle form has been separated from the main pattern by drawing a narrowing strip on the form from the middle of the back towards the middle of the front so that the product could be used as a blouse. A tunnel is prepared at the joint of the two pieces with a lacing placed inside. With this technique, the designed product has been puckered with the lace inside the tunnel and fit on the shoulder, making the product available for use as a blouse. In addition, the strip separated from the main pattern is formed so that it could turn into a flounce collar when used in the upper body, adding an aesthetic value to the product. The product was made easier to wear and remove functionally by designing an elastic waist part and a wrapped closure (double-breasted, envelop) in both garment forms. The general features of the design include a circle cut, a wrapped closing, and an elastic waist part. The components of the blouse form include a flounce collar, loose blouse, short sleeves, and puckered sleeve ends. The skirt form is loose with a bulge in the wrapped closing part and a pocket puckered in the dysfunctional part. When the common components of the design are examined, the armhole in the blouse form (C) has been determined to mark the position of the pucker-up pocket (C) in the skirt form. The line that forms the shoulder and collar details in the blouse form (A) becomes the hem (A) when used in the skirt form. The waistline (B) has been determined as the center in both garment forms. The bulge piece added to the main pattern using the tunnel technique (D) has been puckered from the tunnel part and the appearance of a flounce collar is obtained. The seaming on the inside, hem, and side parts has been performed with seamed stitches. The sleeve details have been applied using the same sleeve technique as the design given in Figure 3.

Figure 5: Cowl Sleeve Loose Blouse/ Asymmetrical Loose Skirt (Patterns, Technical Drawing, 3D Simulations, View of the Produced Design on the Mannequin)

The cowl (degage) sleeve loose blouse/asymmetric skirt model displayed in Figure 5 has a functional feature that can be used in two different garment forms. The design of the blouse for the upper body has been developed based on a common design form. The problem of how to make a design available for dual use by changing certain parts has been studied during the design. The shoulder lines have been joined in the front and back with eyelets and the sleeve part on the sides are left (C) loose without stitching, enabling the product to fit both parts of the body. The loose part formed in the blouse form creates the handkerchief skirt form when used as a skirt. The general outline of the design has a stylized hexagonal form with an asymmetrical cut and elastic waist detail. The blouse form has a boat collar, and loose sleeves as well as eyelets and laces in shoulder details. In skirt form, the product has a loose appearance with an asymmetric hem. The product could turn into a skirt by releasing the strip located in the shoulder part. When the common components of the design are examined, the sleeve opening (C) in the blouse form functions as a slit (C) in the skirt form. The line that forms the shoulder and collar details in the blouse form (A) becomes the hem (A) when used in the skirt form. Eyelets on the right and left corners of the hem are determined as a shoulder line in the blouse form. The waistline (B) has been determined as the center in both garment forms. Considering the necessity of seaming the inside of the garment as well as the sides and hem, the facing seam technique is used at and around the hem, and seamed binding was applied to the sleeves around the armpits. The lace binding used in the shoulder part has been prepared with a binding.

Figure 6: Shirt-Vest/Tunic (Patterns, Technical Drawing, 3D Simulations, View of the Produced Design on the Mannequin)

The other two garment designs, which can be used as shirt-vest and shirt/coat, have been developed based on the question of how to ensure that garments for the upper parts of the body can be used in two different forms. The design in Figure 6 consists of two parts. The design has been planned to have a shirt collar and low sleeves. The button details in the shoulders of the black piece with a vest appearance can be unbuttoned to turn the garment into a tunic. Considering the dual use of the garment on both sides, seam binding has been performed at the edges of the vest. In order to find an answer to this design question, design details such as slit, zipper, and button have been adapted to the upper body by using the standard pattern form. The closing has been designed with button hole buttons in the middle in the front part. The design included a shirt collar and low sleeves from the waist part. The shirt and vest have been attached from the waist parts with seaming, and the stitches in the waist part added an aesthetic appearance to the vest form in the upper body. When the vest piece turns to the upper body, button details are added to the shoulder parts so that it can fit the body. The black piece is in the vest form when dressed on the upper body and it transforms into the tunic/dress form when. unfolded to the lower body. The width of the hips has been taken into consideration while preparing the pattern of the vest, when it is unfolded from the waist to the lower body, pleats have been added to provide comfort and add a feature to the model. The main parts of the garment have been designed in cream, and the vest has been designed in black including the pocket detail to distinguish between the lower body and upper body. A contrast has been created between the main part and the vest part.

Figure 7: Coat-Vest/Tunic (Patterns, Technical Drawing, 3D Simulations, View of the Produced Design on the Mannequin)

The design in Figure 7 consists of two pieces. It has been designed with a collarband and long sleeves. The cream piece in the down vest form has a zipper detail on the shoulder part, which turns into a tunic when unzipped. Considering the dual use of the garment on both sides, seam binding has been performed at the edges of the vest. The design has a zipper in the middle in the front. The collar of the design is a collarband, and the sleeves are the set-in sleeves attached to the main body part. The shirt and the down vest have been attached by seaming and an aesthetic appearance has been added when the vest is used in the upper body. Zipper details have been added to the shoulder parts so that the product can fit the body when the vest is rotated to the upper body. The design has been transformed into an outerwear form using quilted fabric on the vest and collar pieces. The main parts of the garment have been designed in white and the vest rotating to the upper body has been designed in cream including the collar detail to distinguish between the lower body and upper body pieces. The design details can be differentiated by enabling the skirt to be fixed on the body with a snap to be placed in the middle of the side stitches of the skirt and changing its form.

4. CONCLUSION

The new product designs to be developed within the scope of the study were based on problem-solving, which was the main purpose of the design. For this reason, the pattern-oriented design approach was discussed as the answer to the question of how to develop functional clothing designs that could enable a single product to be used as two different types of garments. Accordingly, answers were sought through design proposals. The results of the applied study were presented below:

- Innovative and creative products can be obtained by including pattern techniques in the design process,
- It is important to consider the design details separately as the upper and lower body details in terms of the design, pattern, and manufacturing techniques,
- A single product can be improved for use in both the lower and upper body by drawing attention to the importance of pattern knowledge,
- It is important to know the anthropometric dimensions, body contours, joints, and movement areas and to design them in detail in order for the garment to adapt to the lower and upper body, and innovative and creative products can be created by using the pattern knowledge at the design stage,
- Innovative product designs can be made when the design, pattern, material, and manufacturing information are used correctly and appropriately,
- The forms used in the skirt design can adapt to the upper body with applications such as tunnels, puckers, regional stitches, and laces to be applied to the upper body within the determined body lines (shoulders, chest),
- The forms used in the skirt design can be created with puckering, tunnels, bulges (flounce), regional stitches, laces, and functional accessories (eyelet, snap fastener, zipper) to be used in the design details of different collar/neck types in the upper body,
- In the blouse design, the sleeve detail can be puckered in a rectangular form and the appearance of a bag appearance can be obtained to be used as a pocket on the skirt,
- A different appearance (pocket) can be added to the sleeve (arm) detail,
- The details to be used on the design (puckering, laces, etc.) enable the product to be partially personalized,
- A dual appearance can be obtained with a single garment,
- When the common elements of the design are designed to perform two functions, it can address the main purpose of design, which is performing a function,
- Regarding the manufacturing outcomes of the designs, no problems have been observed in manufacturing, the product did not restrict movement, and it could be used functionally.

According to the literature study conducted within the scope of the study, no functional design has been found on functional design samples that can be prepared according to ready-made manufacturing techniques within the pattern-oriented design approach and used in two forms. The results of the study are considered important in terms of being an innovative study in the field. It is thought that the inclusion of such design works in the collections of ready-made brands will bring a new perspective to the field of design. Widespread use of this design practice and similar practices will contribute to economic and environmental sustainability by changing consumption habits. Innovative design studies can be obtained when the designs developed within the scope of the study are applied together with different approaches such as modularity and mass individualization.

REFERENCES

[1] Ozcan, O. (Du.) (2016). Cogito: What does design expect? (Volume 83). Istanbul: Yapi Kredi Publications.

[2] Yilmaz, P. (2014). Design Culture in terms of Design, Designer, and Consumer in Contemporary Textile and Fashion Design, Master Thesis, Mimar Sinan Fine Arts University, Institute of Social Sciences, Istanbul.

[3] Yurdakul, I. (1988). General Outlines of Design. Art Papers III. Hacettepe University Faculty of Fine Arts Publications, 109-110-112.

[4] Erguven, A. (2021). What is a Good Design? Istanbul: Humanist.

[5] Yuzel, S., Tiber, B. (2018). Sustainable Fashion, Textile, and Engineer in the Garment Industry, 25(112), 370-380.

[6] Atilgan, C. (2015). Evaluation of the Fast Fashion Concept in terms of Producer and Consumer. Master's Thesis, Gazi University, Institute of Educational Sciences, Ankara.

[7] Koca, E., Koc, F., & Cotuk, S. (2009). Contributions of Traditional Clothing Items to Clothing Design as a Source of Inspiration. E-Journal of New World Sciences Academy (International Refereed E-Journal), 4(3), 88-103.

[8] Sharma, S. (2018). The Sustainable Model: Designing Within a Sustainable Framework. Textile Science and Clothing Technology Book Series pp 35–79. The Sustainable Model: Designing Within a Sustainable Framework | SpringerLink.

[9] Gupta D. (2011). Design and Engineering of Functional Clothing, Indian Journal of Fibre & Textile Research, Vol. 36, pp. 327-335.

[10] Cunha J., Broega A.C. (2009). Designing Multifunctional Textile Fashion Products, AUTEX 2009 World Textile Conference, pp.862-868.

[11] Mete, F. (1990). Human Body Mechanics, Textile, and Machinery in Terms of Clothing Design, 150-154.

[12] Koca, E. (2007). Determination of Clothing Problems in the Dressing Skills of Children with Cerebral Palsy and an Example Practice, Doctoral Thesis, Gazi University Institute of Educational Sciences, Ankara

[13] Karasar, N. (2014). Scientific Study Method: Concepts Principles Techniques, Nobel Academic Publishing.

THERMAL INSULATION AND SOUND ABSORPTION PROPERTIES OF FIBROUS LAYERED STRUCTURES

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ABSTRACT

In this study, the effects of the addition of activated carbon powder, polyacrylonitrile nanofiber web, application of Plasma treatment, and the number of treatment layers on thermal insulation and sound absorption properties of fibrous structures have been examined and compared to each other. The results revealed that plasma treatment, nanofiber web application, and activated carbon powder insertion resulted in an increase in thermal resistance of fibrous layered structures made of bamboo fiber and E-glass fiber. With regard to sound absorption, the PAN nanofiber web provided the highest improvement for both the bamboo fiber based layered structures and the E-glass based layered structures. E-glass based fibrous structures had slightly higher thermal resistance than that of bamboo fiber based fibrous structures. However, sound absorption of bamboo based fibrous layered structures was higher than that of E-glass fiber based fibrous layered structures.

Keyword: *E-glass fibrous layered structure, Bamboo fibrous layered structure, Thermal insulation, Sound absorption, Plasma treatment, Activated carbon powder, Nanofiber web.*

1. INTRODUCTION

Sound absorption and thermal insulation are vital for some industries such as construction, automotive, and insulation of high-speed rotating mechanical parts in order to increase the comfort level of the interior environment and the energy savings by eliminating disturbances. Other than the high-density materials that could insulate the sound efficiently, fibrous materials are preferred for acoustical applications; because the rigid materials do not allow the sound waves to get through and reflect the sound waves back into the environment [1]. Fibrous materials are efficient in sound absorption because of their characteristics such as porosity, tortuosity, density, airflow resistance, and thickness [2]. Besides, fibrous materials are also used for thermal insulation because of their inherent characteristics of high tortuosity and porosity [3]. Thus, the porosity of the material is an important property that influences both thermal insulation and sound absorption.

Some treatments such as plasma can improve both the sound absorption and thermal insulation of the porous materials. The plasma treatment increases the surface area of the fibers due to the etching effect and the sound waves of high frequency have a higher possibility to interact with fibers when there are smaller and more pores in the web with high porosity [4]. The studies also revealed that activated carbon materials and their integration into the material were found to improve the sound absorption ability of fibrous materials significantly [5]. Actually, activated carbon fiber (ACF) is stated to be an ideal porous material for sound absorption due to the developments in production processes and the decrease in the cost of production. Since it is light, fire resistant, and anticorrosive, they can be preferred in the insulation of buildings, automobile interiors, and road barriers [6]. Moreover, the application of innovative nanofibers is efficient in noise control at lower frequencies because of having porous structures [7]. In addition to good sound absorption properties [2], producing nanofibers with electrospinning also enables the production of highly porous structures with very small pore sizes [3,8]; which results in lower thermal conductivity and thus, higher thermal insulation. Nonetheless, the influence of the applications and treatments mentioned above were not investigated comparatively and in detail covering both thermal insulation and sound absorption.

Recently, natural fibers, as fibrous porous materials, were investigated for their sound absorption characteristics and proposed as an alternative for other conventional synthetic fibrous materials, like glass fiber and mineral wool [9] because of using the same mechanism of sound absorption and being lighter in weight. Besides, the natural fibers are also advantageous in eliminating some health concerns related to some common synthetic materials such as glass fiber, which adheres to the body during processing. Other than kenaf, jute and coir fibers [10-13], bamboo was also investigated as a sound absorbing material [14]. Koizumi et al. [14] have compared the sound absorption coefficient of the bamboo fiber to that of glass wool and found out that, the acoustic characteristics, sound absorption coefficient, the characteristics impedance and the propagation constant of the bamboo fiber are similar to that of glass wool. Thilagavathi et al investigated the sound absorption properties of nonwovens made of bamboo, banana and jute fibers blended with polypropylene in the ratio of 50:50. They observed that the bamboo/polypropylene nonwoven showed, higher tensile strength, higher stiffness, lower elongation, lower thermal conductivity, lower air permeability, and good absorption coefficient when compared to others and they stated that it is suitable for the automotive interior noise control [15].

Sound and thermal insulator materials can be used in many areas such as generators, engines etc. To the best of our knowledge, in the literature; the comparisons of these two fibers (bamboo and E-glass) for thermal insulation were not made and the effect of plasma treatment, activated carbon insertion and nanofiber web application on both sound absorption and thermal insulation properties of fibrous layered structures were not compared to each other. Given these limitations and the gaps in the literature, the purpose of this study is to contribute to the literature by providing novel comparative results regarding the effects of activated carbon powder (ACP), polyacrylonitrile nanofiber web (PAN), and plasma treatment (P) in different amounts on the sound absorption and thermal insulation properties of fibrous layered structures, made up of two fibers as bamboo and E-glass. Besides, the originality of the present study lies also in the comparison of the given properties of bamboo fiber with that of E-glass fiber, since the use of bamboo is relatively new and the knowledge about its potential in that area is quite limited, against the use of E-glass fiber.

2. EXPERIMENTAL STUDY

2.1 Materials

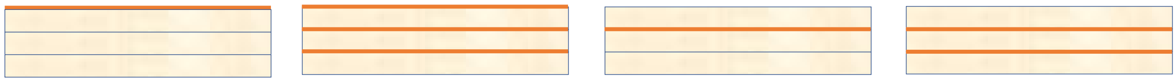
E-glass fiber and bamboo fiber were obtained from Cam Elyaf Sanayi AŞ and Karteks from Turkey. The activated carbon powder was purchased from Grafen Chemicals in diameter < 100nm (Figure 1), PAN (Mw=150000 g/mol) was purchased from Sigma Aldrich and N, N-Dimethylformamide (DMF) was purchased from Merck.

2.2 Production of samples and testing procedure

E-glass and bamboo fibers were processed in a laboratory-type carding machine (Mesdan Laboratory Carding Machine, 337A) and fibrous structures were produced. All fibrous structures were aimed to be produced in the same thickness. The production of the samples was made by spreading three layers of fibrous structures which were obtained from the carding machine. The thicknesses of E-glass and bamboo fiber structures were measured as 4.474±0.41 mm and 4.511±0.15 mm respectively.

The plasma treatment of fibrous structures was performed on Plasmatek device. Samples were placed in the plasma chamber and a vacuum of about 600-800 mTorr was provided. Samples were exposed to

O_2 (0.05 liters per minute) and Argon (0.5 liters per minute) gasses under 80 volts for 60 seconds. Both Oxygen and Argon plasma was used since both of them have an etching effect. The fibrous layered samples were prepared to have three layers. Only the surface of the uppermost layer of the samples G1P and B1P were treated by plasma; while the surfaces of the three layers of the samples G3P and B3P were treated by plasma application. ACP was deposited manually between only the first and second layers for the samples G1ACP and B1ACP and between all layers for the samples G3ACP and B3ACP. The amount of ACP within the fiber layered structures was tried to be kept at the percentages of 5% and 10% with one-layer and three-layer ACP treatments respectively. Demonstrations of the samples with plasma treatment, ACP, and PAN insertion were shown in Figure 1.



a b c d

Figure 1. Demonstration of samples a. with plasma treatment on one layer, b. with plasma treatment on three layers c. with one layer ACP/or PAN insertion d. with ACP/or PAN insertion between three layers

PAN was dissolved by Dimethylformamide (DMF) as 10 w% by using magnetic stirrer at 60 C°. Nanofiber webs were produced on a horizontal electrospinning apparatus, which was equipped with a syringe pump, a high voltage power supply and a grounded rotating collector covered by aluminum foil. DMF-PAN solution was added to a 20 ml syringe with a blunt needle and fed with the flow rate of 2 ml/h towards the tip of the needle. A voltage of 15.6 kV was applied to create an electrical field between the nozzle and the rotating cylindrical collector, where the distance was set to 12 cm. The average diameter of nanofibers within the web was found to be 198.2 nm. As in the case of ACP application, PAN nanofibers were put between the first and second layers for the samples G1PAN and B1PAN and; between all layers for the samples G3PAN and B3PAN.

The thermal resistance, which is an indication of the thermal insulation property of a material, and the thicknesses of the samples were measured using Alambeta Instrument according to ISO 11092:2014 standard [16]. Sound absorption coefficients (α) of the samples were measured by using TestSENS Soundtube testing device and TestSENS acoustic material testing software using ISO 10534-2 standard [17]. All the tests were performed under standard atmospheric conditions (20±2 °C and 65%RH).

3. RESULTS

The test results revealed that E-glass fiber layered structures have generally higher thermal resistance than that of bamboo fiber layered structures. This can be attributed to the lower thermal conductivity of E-glass materials when compared to the regenerated bamboo fiber materials [18,19]. In addition, Figure 2 supports that all the applications such as plasma treatment, application of nanofiber web, and presence of activated carbon powder resulted in an increase of thermal resistance values for both E-glass fiber and bamboo fiber layered structures.

When the effects of different applications are compared, it can be concluded that the greatest increase in thermal resistance property was achieved by the plasma treatment on three layers on the E-glass fiber based fibrous layered structures and by three-layer PAN nanofiber application on the bamboo fiber based fibrous layered structures.

Figure 3 shows the effects of plasma treatment, ACP, and PAN nanofiber applications on bamboo fiber based samples. It was observed that plasma treatment had a very slight impact on enhancing the sound absorption property for the bamboo fiber layered samples. However, the application of ACP and PAN nanofiber proposed greater improvements, and the most significant improvement was provided by PAN nanofiber for bamboo fiber layered structures. The effects of the treatment and applications were obvious at the frequency above 2000 Hz.

In Figure 4, the effects of plasma treatment, ACP, and PAN nanofiber applications on E-glass fiber based samples were shown. It was observed that ACP application had the least effect on improving the sound absorption property for glass fiber layered structure. On the other hand, plasma treatment resulted in a higher improvement on E-glass fiber, while PAN nanofiber application had the greatest improvement in sound absorption property. The improvements were observed at the frequency above 600 Hz.

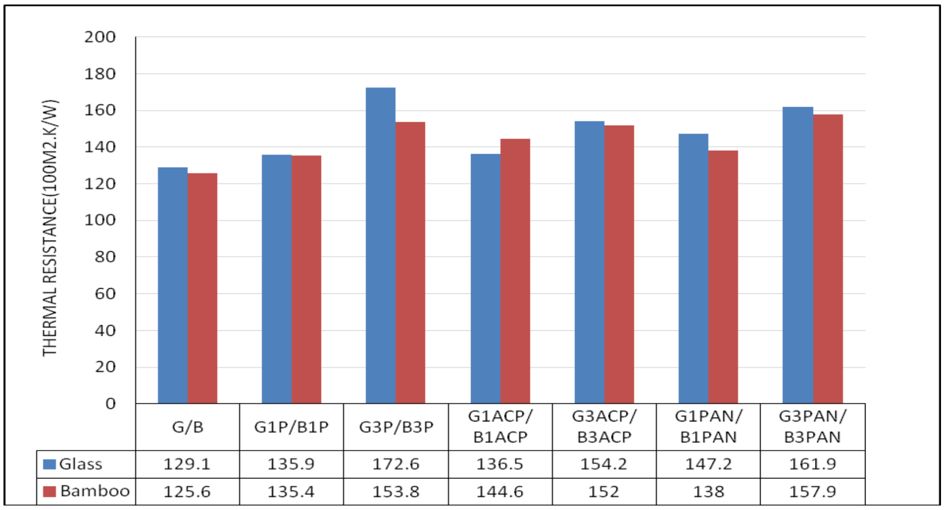


Figure 2. Thermal resistance values of E-glass fiber and bamboo fiber layered structures.

It was found that plasma treatment improved the sound absorption property of the layered samples, particularly at the frequency above 600 Hz, this may be attributed to the abrasion and increased roughness of the fiber surface due to the etching effect of plasma [20]. According to the results, it can be stated that activated carbon application positively affected the sound absorption property of the fibrous layered samples, regardless of the fiber type. The integration of pores into the fibrous layered samples by using activated carbon powder might have provided an increase in the sound absorption coefficient, as stated in previous studies [21,22]. The improvement in sound absorption properties with PAN application can be attributed to the higher surface area and lower fiber size of nanofibers [4] and highly porous structures with very small pore sizes [3,8]. In the literature [3], it has been pointed out that the incorporation of nonwoven materials with polyurethane and polyacrylonitrile nanofiber layers was stated to improve sound absorption performance.

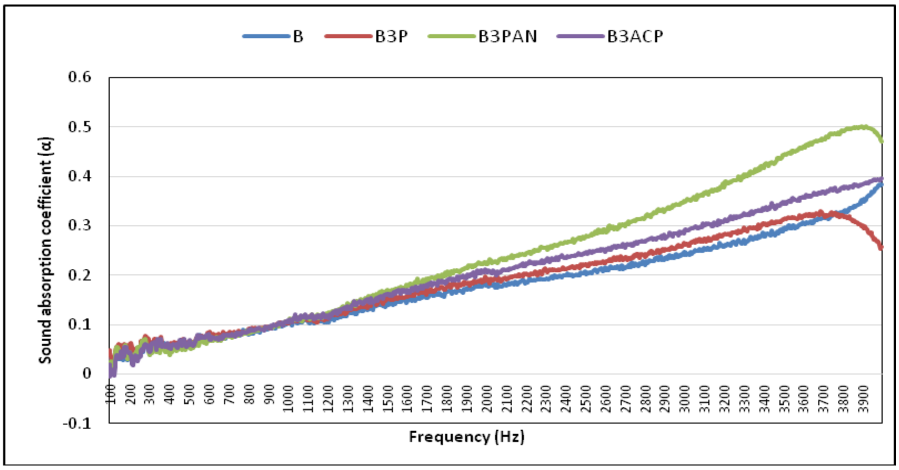


Figure 3. Comparative results for bamboo fiber samples.

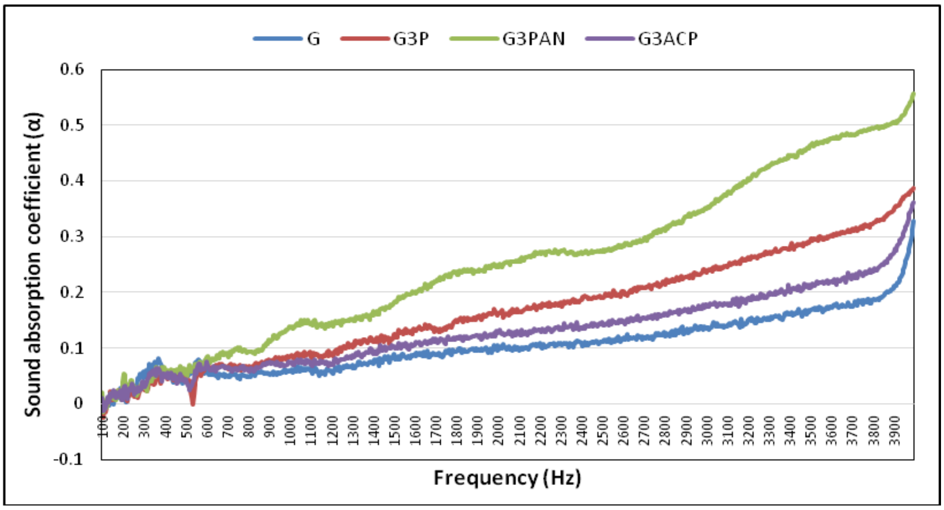


Figure 4. Comparative results for E-glass fiber samples.

Noteworthily, the results revealed that bamboo fiber based samples continued to perform better sound absorption properties when compared to the E-glass fiber based samples, except the sample G3PAN. The application of PAN between three layers of the E-glass fiber layered samples showed similar; even better performance when compared to the sample B3PAN. While plasma provides an improvement in sound absorption for both types of fiber, it is more effective for glass fiber than bamboo fiber. The positive effects of the treatment and applications were apparent mainly above the frequency of 600 Hz.

4. CONCLUSION

According to the results, it was observed that while E-glass fiber layered structures have slightly higher thermal resistance than that of bamboo fiber based, sound absorption of bamboo fiber layered structures have higher than that of E-glass fiber based. The addition of PAN nanofiber into the fibrous layered structure, independent of fiber type, can be suggested for improvement in thermal insulation and sound absorption. However, depending on specifically the fiber type, integration of activated carbon powder into the fibrous layered structure made of bamboo fiber can be suggested for a reasonable level of improvement; while plasma treatment can be suggested for the layered structure made of E-glass fiber. Based on the observations, the lighter bamboo fiber can be an alternative to E-glass fiber, especially in terms of sound absorption.

The fibrous layered structures proposed in the present study can be used in many areas where sound absorption and thermal insulation are needed. Choosing such materials with improved thermal resistance can be an effective solution for decreasing the energy demand for heating in buildings. Besides, for insulating the noise generated in vehicles and in industrial or household equipment and machines such as generators, compressors, and air pressure water tanks, fibrous structures with improved sound absorption properties can be used. The sound absorption property of such structures can make them efficient solutions in buildings for insulating noise through walls, floors, and ceilings. The ease of manufacturing and light weight of these fibrous structures can make them ideal substitutes for conventional and heavier products.

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REFERENCES

[1] Tascan, M., & Gaffney, K. L. (2012). Effect of glass-beads on sound insulation properties of nonwoven fabrics. *Journal of Engineered Fibers and Fabrics*, *7*(1), 155892501200700111.
[2] Rabbi, A., Nasouri, K., Shoushtari, A. M., & Haji, A. (2013). Fabrication of electrospun polyacrylonitrile and polyurethane nanofibers for sound absorption. *In 6th TEXTEH International Conference*: *October* (pp. 17-18).
[3] Wu, H., Fan, J., Qin, X., & Zhang, G. (2008). Thermal radiative properties of electrospun superfine fibrous PVA films. *Materials letters*, *62*(6-7), 828-831.
[4] Na, Y., & Cho, G. (2010). Sound absorption and viscoelastic property of acoustical automotive nonwovens and their plasma treatment. *Fibers and Polymers*, *11*(5), 782.
[5] Jiang, N., Chen, J. Y., & Parikh, D. V. (2009). Acoustical evaluation of carbonized and activated cotton nonwovens. *Bioresource technology*, *100*(24), 6533-6536.
[6] Jiang, G., & Shen, Y. (2017). Sound absorptive properties of activated carbon fibers. *In Activated Carbon Fiber and Textiles* (pp. 193-207). Woodhead Publishing.
[7] Nayak, R., & Padhye, R. (2016). Acoustic textiles: an introduction. *Acoustic Textiles*, 1-32.
[8] Park, S., Lee, Y., Kim, B. S., & Kim, I. S. (2012). Thermal insulation property of cu-metallized nanofibers. *Advances in Polymer Technology*, *31*(1), 1-6.
[9] Yang, W., & Li, Y. (2012). Sound absorption performance of natural fibers and their composites. *Science China Technological Sciences*, 55, 2278-2283.
[10] Ersoy, S., & Küçük, H. (2009). Investigation of industrial tea-leaf-fibre waste material for its sound absorption properties. *Applied Acoustics*, *70*(1), 215-220.
[11] Fouladi, M. H., Nor, M. J. M., Ayub, M., & Leman, Z. A. (2010). Utilization of coir fiber in multilayer acoustic absorption panel. *Applied Acoustics*, *71*(3), 241-249.
[12] Fouladi, M. H., Ayub, M., & Nor, M. J. M. (2011). Analysis of coir fiber acoustical characteristics. *Applied Acoustics*, *72*(1), 35-42.
[13] Ramis, J., Alba, J., Del Rey, R., Escuder, E., & Sanchís, V. J. (2010). New absorbent material acoustic based on kenaf's fibre. *Materiales de construccion*, *60*(299), 133-143.
[14] Koizumi, T., Tsujiuchi, N., & Adachi, A. (2002). The development of sound absorbing materials using natural bamboo fibers. *WIT Transactions on the Built Environment*, 59, 157-166.
[15] Thilagavathi, G., Pradeep, E., Kannaian, T., & Sasikala, L. (2010). Development of natural fiber nonwovens for application as car interiors for noise control. *Journal of Industrial Textiles*, *39*(3), 267-278.
[16] ISO 11092:2014 Textiles-Physiological effects-Measurement of thermal and water-vapor resistance under steady-state conditions (sweating guarded-hotplate test).
[17] ISO 10534-2:1998 Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2: Transfer-function method.
[18] Cao, X., Liu, J., Cao, X., Li, Q., Hu, E., & Fan, F. (2015). Study of the thermal insulation properties of the glass fiber board used for interior building envelope. *Energy and Buildings*, 107, 49-58.
[19] Karthikeyan, G., Nalankilli, G., Shanmugasundaram, O. L., & Prakash, C. (2016). Thermal comfort properties of bamboo tencel knitted fabrics. *International Journal of Clothing Science and Technology*, *28*(4), 420-428.

[20] Zhu, L., Teng, W., Xu, H., Liu, Y., Jiang, Q., Wang, C., & Qiu, Y. (2008). Effect of absorbed moisture on the atmospheric plasma etching of polyamide fibers. *Surface and Coatings Technology*, *202*(10), 1966-1974.

[21] Lim, Z. Y., Putra, A., Nor, M. M., & Yaakob, M. Y. (2015). Preliminary study on sound absorption of natural kenaf fiber. *Proceedings of Mechanical Engineering Research Day*, 95-96.

[22] Zulkifli, R., Nor, M. M., Ismail, A. R., Nuawi, M. Z., & Tahir, M. M. (2009). Effect of perforated size and air gap thickness on acoustic properties of coir fibre sound absorption panels. *European Journal of Scientific Research*, *28*(2), 242-252.

IN VITRO EVALUATION OF A THREE DIMENSIONAL (3D) KNITTED SCAFFOLD FOR TISSUE ENGINEERING

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ABSTRACT

Pile loop knit structures hold promising results for being used as a three dimensional (3D) biocompatible scaffold for regenerative medicine. In this study, the physical and mechanical properties of a half pile loop knit structure made up of non-intermingled textured polyethylene terephthalate (PET) multifilament yarn with a filament count of 48 were investigated to evaluate the host response for the seeded murine C2C12 myoblasts. The knitted structure had a pore network mainly consisting of macropores of 100-500 μm that were well interconnected with micropores (<90 μm). In addition, the mean values of the Young's modulus of the structures at 20% strain were 177.78 kPa in the warp direction, and 59.21 kPa in the weft direction, which can be claimed not to be far from those declared for the human heart muscle. According to the results of the WST-1 assay, the C2C12 cells were able to proliferate properly on the scaffold, which was visualized by SEM and confocal images. Furthermore, the cell viability values on day 7 of the half pile loop knitted scaffold were observed to be statistically significantly higher than those of the full pile loop knitted scaffold from the previous study. Multiple large pores in polygonal shapes, that is large pore sizes (pore diameters greater than 200 μm), in the half pile loop knitted scaffold appear to promote an efficient cell migration and proliferation. The outcomes of this research would assist in developing ideal pile loop knitted scaffolds especially for myocardial tissue engineering applications.

Keyword: *Pile loop knitted scaffold, C2C12 myoblasts, Myocardial tissue engineering*

1. INTRODUCTION

Coronary artery disease (CAD), where the first manifestation is acute myocardial infarction (AMI), remains a fatal health problem for human being. Although whole heart transplantation could be applied for patients with end-stage heart failure, this final therapeutic strategy has some handicaps including insufficient heart donors, post-transplantation immune complications, and risk of tumor formation [1,2].

Since 1990s cell transplantation therapy has been progressing with preclinical and clinical studies aiming to treat the scarred tissue in the infarcted area following AMI by targeting tissue regeneration [3]. One of the main challenges of this therapy is the fact that less than 10% of the cells survive one week after transplantation [4]. Thus, engineering a scaffold-based biocompatible patch using natural (e.g., fibrin) or synthetic (e.g., polycaprolactone) biomaterials on which the cells could be seeded, in other words producing a cardiac patch, has been considered as a viable approach to ensure long-term survival of cells [5,6].

D'amore et al. [7] fabricated a bi-layered scaffold by sequentially deposition of two layers, where concurrent electrospinning of poly(ester carbonate uretahne)urea (PECUU) and phosphate buffered saline (PBS) solution forms the first layer, and subsequently concurrent electrospinning of PECUU and ECM solution (from an intact porcine heart) forms the second layer. The bi-layered scaffold patch was observed to mitigate scar formation and left ventricular (LV) wall thinning as well as improving angiogenesis in a rat chronic myocardial infarction model [7]. Xie et al. [8] developed collagen monofilament yarns from rat tail tendons and manufactured rib knitted structures using a two-ply polylactic acid (PLA) yarn and PLA/collagen yarn consisting of one ply PLA and two plies of collagen. They showed that the degree of attachment, proliferation, and migration of cardiosphere-derived cells (CDCs) were higher in the PLA/collagen based knitted scaffold due to the superior biological performance of collagen yarns in comparison to the PLA based scaffold after seven days of culture [8]. Fakhrali et al. [9] produced polycaprolactone/Gelatin/graphene oxide (PCL/Gel/GO) hybrid nanofibrous scaffolds via electrospinning and seeded human cardiac myocytes (HCMs) on scaffolds. They demonstrated that the presence of peptides and oxide groups on the Gel and GO, respectively, and the electrical conductivity property of GO, improved cell adhesion and proliferation [9].

The overall aim of this research is to design an appropriate pile loop knitted scaffold for being used as a cardiac patch. In the previous study, a full pile loop knit fabric made up of 100 denier, non-intermingled, textured polyethylene terephthalate (PET) yarns that had 48 filaments in cross-section was used as a three dimensional scaffold for the culture of murine C2C12 cells [10]. It is referred to as full pile loop when ground and pile loops are knitted together at every round on the machine at full length of the fabric, and half pile loop when pile loops join the formation of knitting structure one in two rounds. In this paper, a half pile loop knit fabric with yarn properties identical to those used in the previous study [10] was investigated to evaluate the host response for the seeded murine C2C12 myoblasts. The Young's modulus, morphology, and contact angle of the half pile loop knitted scaffold were analyzed. The C2C12 cell adhesion and proliferation were evaluated by 2-(4-lodophenyl)-3-(4-nitrophenyl)-5-(2,4-disulfophenyl)-2H-tetrazolium (WST-1) assay.

2. EXPERIMENTAL STUDY

In this research, the drawn textured non-intermingled PET yarn of which theoretical number is 100 denier was used as a raw material. The PET yarn with the delusterant level of semidull consists of 48 filaments, and all filaments have round cross-sections. The properties of the yarn are given in Table 1.

Table 1. Properties of the PET yarn [10].

	Measured filament diameter (micron)	**Measured linear density (BSENISO2060) (denier)**	**Tenacity (BSENISO2062) (g/denier)**	**Elongation (BSENISO2062) (%)**	
Mean	20.7	102	4.45	27.35	
SD	1.3	0.13	0.28	2.15	
	Crimp Contraction (CC) (DIN 53840) (%)	**Crimp Modul (CM) (DIN 53840) (%)**	**Crimp Stability (CS) (DIN 53840) (%)**	**Shrinkage (DIN 53840) (%)**	**Oil Content (Extraction Method) (%)**
Mean	16.35	12.77	70.71	3.22	2.2
SD	0.053	1.62	0.76	0.061	<1

Note: SD: Standard Deviation

One-sided half pile loop knit fabric was produced in loose construction, on a circular knitting machine of 20 gauge, 34 inches in diameter, and 1.8 mm pile loop height. After the knitting process, the fabric was washed with water at 60°C for 20 minutes, and then subjected to heat setting at 150 ºC in an industrial machine. In Table 2, the mean values of the physical properties of the knit structure were shown.

Table 2. Dimensional properties of the fabric.

Loop length (cm)		Fabric thickness (ASTM D1777-96) (mm)	Areal density (BS EN 12127) (g/m^2)	Porosity (%)	Air permeability (ASTM D737) ($cm^3/(cm^2/s)$)	Linear dimensions	
l_g	l_p					wales/cm (w/cm)	courses/cm (c/cm)
0.426	0.736	1.15	101	93.62	392.99	8.6	10.3

The loop lengths of ground (l_g) and pile (l_p) yarns were calculated by applying the same method from the previous study [11]. The percentage porosity was calculated by measuring five specimens, and using Eq. 1:

$$\text{Porosity} = (1 - \rho/\rho_0) \times 100 \qquad \text{Eq. 1}$$

where ρ and ρ_0 are the density of the knitted scaffold and the density of the PET polymer (1.38 g/cm^3), respectively. The number of stitches per unit length (courses/cm) and unit width (wales/cm) were measured on the ground side of the fabric, where ten specimens were considered. All of the measurements were done from the middle part of the fabric to minimize the variability.

2.1 Uniaxial Tensile Test

The uniaxial tensile test of the pile loop knit fabric was done according to ASTM D 5035-11 (2019) [12], Standard Test Method for the Breaking Force and Elongation of Textile Fabrics, utilizing a crosshead speed of 10 mm/min, and an initial gauge length of 25 mm. Specimens were prepared by cutting the knitted fabrics to a length of 90 mm to be long enough to be clamped in the top and bottom jaws, and the width of the specimens was 25 mm.

Young's modulus (E) at 20% strain was calculated considering both engineering and true stress-strain values by using the following equations:

$$E_{eng} = \left(\frac{\sigma eng}{\varepsilon eng}\right)/1000 = \left(\frac{\frac{F}{Ao}}{\varepsilon eng}\right)/1000 \qquad \text{Eq. 2}$$

$$E_{true} = \left(\frac{\sigma true}{\varepsilon true}\right)/1000 = \left(\frac{\frac{F}{Ao}}{\varepsilon true}\right)/1000 \qquad \text{Eq. 3}$$

$$\varepsilon_{true} = \ln(1 + \varepsilon_{eng}) \qquad \text{Eq. 4}$$

$$\sigma_{true} = \sigma_{eng}(1 + \varepsilon_{eng}) \qquad \text{Eq. 5}$$

E_{eng}, E_{true}: Young's modulus (kPa)

F: Tensile force applied on the sample (N)

A_0: Initial cross-sectional area of the sample (m^2)

ε_{eng}: Engineering strain

ε_{true}: True strain

σ_{eng}: Engineering stress (kPa)

σ_{true}: True stress (kPa)

The tester was a uniaxial James Heal Titan Strength Tester, the load cell capacity was 1kN, and TestWise™ Software was used to record and analyze the results. Five specimens in each direction (warp and weft) were tested.

2.2 Knitted Fabric Morphology

Five scanning electron microscopy (SEM) images of each side, front (surface), and back side (Figure 1 (a), (b)), of the fabric sample were used for analyzing the pore diameters, and pore areas in polygonal shapes surrounded by filaments at different positions of the fabric via the trial version of Digimizer software, image analysis program. The distance between the two adjacent filaments (Figure 1 (a)) was considered as a pore diameter [13].

2.3 Contact Angle Test

Contact angle measurements were performed via the sessile drop method with 4 µl distilled water on a Theta Lite Optical Goniometer (KSV Instruments Ltd, Finland) to determine the wetting property of the knitted structure. Measurements were carried out after the water droplet came into contact with the surface of the fabric's back side for 10 seconds. The average of three different measurements were recorded.

2.4 Biological Sample Preparation

Knitted fabric sample was cut into 28 mm^2 circular slices and sterilized by autoclave. The scaffold specimens were placed in a non-treated polystyrene 96-well plates (Corning, USA) for the biological experiments. Fibronectin coating solution which was performed by using 10 µg/ml fibronectin (Sigma-Aldrich, USA) solution in 1 ml Fetal Bovine Serum (FBS)-free cell culture media, was added onto the scaffolds for 4 h. Then, all the media and fibronectin solution were aspirated and washed by phosphate-buffered saline (PBS, Biological Industries, USA) for three times.

5×10^4 C2C12 mouse myoblast cells (ATCC® CRL-1772™) were seeded onto the specimens in each group (day 3 and day 7). Cell culture media contained Dulbecco's Modified Eagle's Medium (DMEM, Sigma, USA; with 4500 mg/L glucose) supplemented with 10% FBS (Biological Industries, USA).

2.5 WST-1 Assay

For WST-1 test, a total of ten specimens were prepared, in which five specimens were used for day 3 of the WST-1 assay, and five for day 7 of the WST-1 assay. After 70 hours for the group of day 3, and after 166 hours for the group of day 7, cell proliferation reagent WST-1 (Takara, MK400) solution was added to each well at 10% of the well volume. Then, the culture plate was incubated for 2 hours in a 37ºC humidified CO_2 incubator. The absorbance values were read at 450 nm and 630 nm (Chromate 4300 Elisa Reader, USA). The percentage of cell viability was calculated as follows [14]:

$$\text{Cell Viability (\%)} = \frac{A450\ (Sample-Blank) - A630\ (Sample-Blank)}{A450\ (Positive\ Control-Blank) - A630\ (Positive\ Control-Blank)} * 100 \quad \text{Eq. 6}$$

where blank represents well with DMEM medium containing 10% FBS, without any cell; and, positive control means well including cells cultured in DMEM supplemented with 10% FBS, without any scaffold; considered as 100% viable. Furthermore, negative control (cytotoxicity control) was designated by treating cultured cells with hydrogen peroxide (H_2O_2) known as the most stable reactive oxygen species (ROS), at the concentration of 2% for 24 hours at day 2 for the group of day 3, and at day 6 for the group of day 7, without any scaffold.

2.6 Scanning Electron Microscopy (SEM) and Confocal Microscopy Imaging

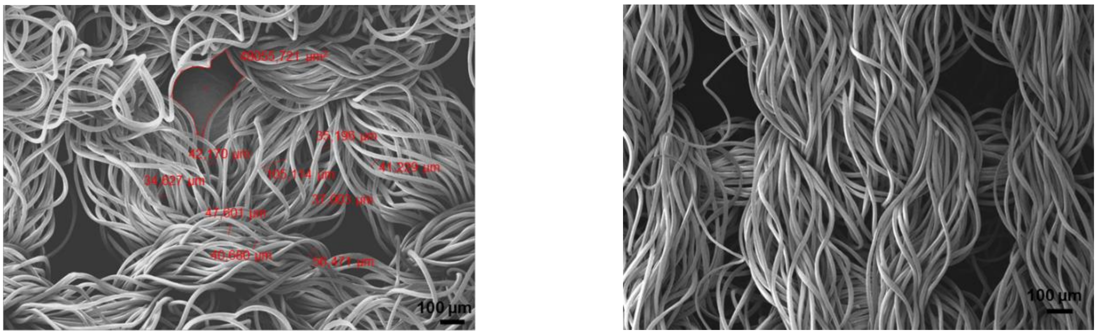
For SEM imaging, first, most of the culture media was removed, then, the cells were fixed using a fixative containing 4% glutaraldehyde (EMS, 16210) for 1 hour at 4ºC. Second, the specimens were washed three times with 500 µl PBS for 5 minutes each. Third, all the specimens were dehydrated through a series of ethanol concentrations (30, 50, 70, 90, 95, and 100%). Fourth, critical point drying was conducted by a critical point dryer (Leica EM CPD300). Fifth, the specimens were sputter coated with gold/palladium in a Leica EM ACE 600 sputter coater. The prepared PET scaffold specimens were then viewed in a Hitachi Regulus 8230 scanning electron microscope. For confocal imaging, after the removal of the culture media, each cell seeded scaffold specimen was treated with 100 µl NucBlue™ (DAPI: 4',6-diamidino-2-phenylindole) live staining dye (Invitrogen), and then incubated for 30 minutes. The specimens were observed using a Zeiss LSM 800 confocal laser microscope.

2.7 Statistical Analysis

The one-way analysis of variance (ANOVA) was used for statistical anaysis by utilizing the trial version of JMP® 16 statistical software. *p*-values smaller than 0.05 were considered significant.

3. RESULTS

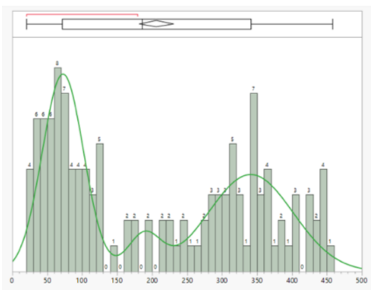
The morphology of the knitted structure is shown in Figure 1.



(a) (b)

Figure 1. Knitted structure (a) surface morphology, (b) back side morphology.

The structure was recognized to provide a pore network mainly consisting of macropores of 100-500 µm that were well interconnected with micropores (<90 µm) as shown in Figure 2. The mean pore area in polygonal shapes was measured as 83646.91 µm^2 (n=18).



	Mean	Standard Deviation
Gauss 1	72.42	29.55
Gauss 2	188.75	23.48
Gauss 3	340.98	60.81
Total entries (124)	206.19	139.18

Figure 2. Histograms of pore diameter distribution of the knitted scaffold.

The contact angle of the knitted structure, of which microscopic view is shown in Figure 3, was measured as 127º (standard deviation (sd): 2.86).

Figure 3. Microscopic view of the structure.

Figure 4 shows the stress-strain curves of the knitted scaffold in the direction of wales and courses.

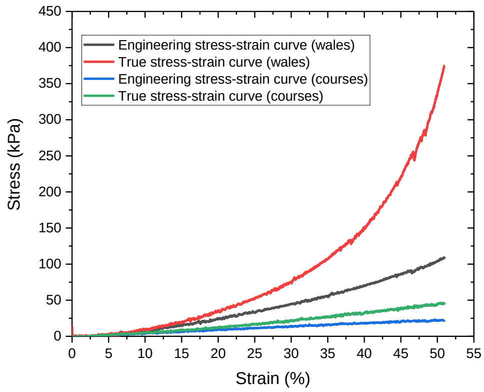


Figure 4. Stress-strain curves of the knitted scaffold.

In the stress-strain curves, the portions up to 20% strain are in the elastic region of the fabric, where for the linear regions, the coefficient of regression (RSquare) is approximately 98% both in the direction of warp and weft.

The values of the Young's modulus of the structure at 20% strain in the warp and weft directions were calculated by using both engineering and true stress-strain curves, which are shown in Table 3.

Table 3. Young's modulus of knitted scaffold.

	E_{eng} (kPa) at 20% strain		E_{true} (kPa) at 20% strain	
	Warp direction	**Weft direction**	**Warp direction**	**Weft direction**
Mean	115.63	49.24	177.78	59.21
Standard Deviation	18.49	8.40	20.19	12.81

WST-1 assay demonstrated that C2C12 myoblasts proliferated well on the scaffold (Figure 6). The mean cell viability value increased from 120.06% (sd: 6.81) on day 3 to 194.10% (sd: 3.36) on day 7, where the difeerence between the values on day 3 and day 7 was statistically important (p-value= 0.000 < 0.05). The mean cell viability of the negative control was 13.92% (sd: 1.25) both on day 3 and on day 7, where H_2O_2 had a significant cytotoxic effect in C2C12 cells [15].

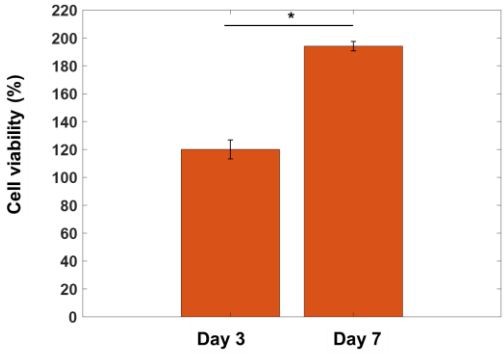
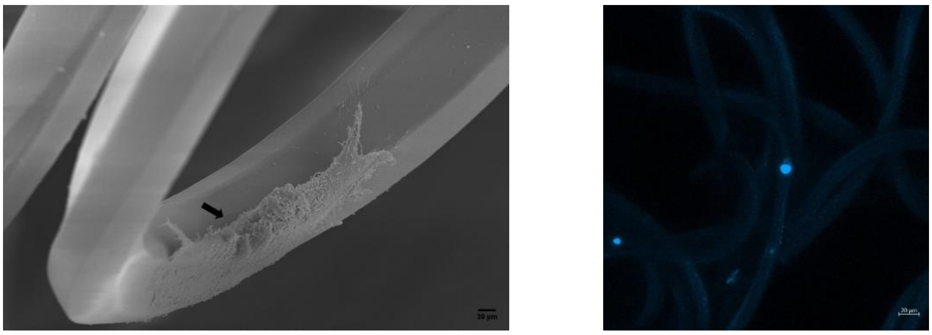


Figure 6. In vitro test of cell viability (%) on day 3 and day 7 by WST-1 assay.

Furthermore, the values of the cell viability of the half pile loop knitted scaffold on day 7 were found to be significantly higher than those of the full pile loop knitted scaffold from the previous study [10] (p-value= 0.000 < 0.05). In fact, full pile loop knitted scaffold is expected to have a higher proliferation due to its higher surface to volume ratio than that of half pile loop one [16]. Here, however, multiple large pores in polygonal shapes, that is large pore sizes (pore diameters greater than 200 μm), in the half pile loop knitted scaffold appear to promote an efficient cell migration and proliferation relative to the full pile loop one (mainly consisting of macropores of 100-200 μm) [17].

The SEM image visualized that the cells attached and grew along the surface of the PET filament (Figure 7 (a)), and confocal microscopy analysis demonstrated the presence of C2C12 cells on the scaffold, verifying the cell viability results (Figure 7 (b)).



(a) (b)

Figure 7. SEM and confocal microscopy imaging (a) SEM image of C2C12 cell attached to PET filament, 1500X (b) Confocal microscopy image of C2C12 cells on knitted scaffold stained with DAPI (blue).

This study showed that not only the high surface to volume ratio, but also the large pore sizes (pore diameters greater than 200 μm) and the number of large pores in the knitted structure influences C2C12 cell proliferation and viability on the scaffold.

4. CONCLUSION

In this paper, the physical and mechanical properties (e.g., morphology, wettability, Young's modulus) of the half pile loop knit fabric made up of 100 denier non-intermingled textured PET yarns with a filament number of 48 in cross-section were analyzed for myocardial tissue engineering application. The structure had a pore network mainly consisting of macropores of 100-500 μm that were well interconnected with micropores (<90 μm). Furthermore, the mean values of the Young's modulus of the samples at 20% strain were 177.78 kPa in the warp direction, and 59.21 kPa in the weft direction, on the basis of the results of the true stress-strain curves. Here, the values of the Young's modulus can be claimed not to be far from the reported values (50 kPa (healthy hearts) - 300 kPa (patients with heart failure) at about 15-22% strain) in the literature [18].

The half pile loop knitted scaffold was seeded with murine C2C12 cells, and the cell viability was evaluated by WST-1 assay. The C2C12 myoblasts were able to attach and grow along the surface of the PET filament, which was visualized by SEM and confocal images. Furthermore, the values of the cell viability on day 7 belonging to the half pile loop knitted scaffold were observed to be statistically significantly higher (p-value= 0.000 < 0.05) than those of the full pile loop knitted scaffold from the previous study (10). Here, multiple large pores in polygonal shapes, in other words large pore sizes (pore diameters greater than 200 μm), in the half pile loop knitted scaffold seem to encourage an impressive cell migration and proliferation relative to the full pile loop one (mainly consisting of macropores of 100-200 μm). Thus, not only the high surface to volume ratio, but also the large pore sizes (pore diameters greater than 200 μm) and the number of large pores in the knitted structure affects C2C12 cell proliferation and viability on the scaffold.

Finally, the outcomes of this research would assist in developing ideal pile loop knitted scaffolds and contribute future studies particularly in the field of myocardial tissue engineering.

ACKNOWLEDGMENT

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REFERENCES

[1] Bar, A., Cohen, S. (2020). Inducing Endogenous Cardiac Regeneration: Can Biomaterials Connect the Dots? Frontiers in Bioengineering and Biotechnology, 8, 126.
[2] Khush, K.K., Potena, L., Cherikh, W.S., Chambers, D.C., Harhay, M.O., Hayes, D. et al. (2021). The International Thoracic Organ Transplant Registry of the International Society for Heart and Lung Transplantation: 37th adult heart transplantation report—2020; focus on deceased donor characteristics. Journal of Heart and Lung Transplantation, 39(10), 1003–15.
[3] Zhang, J., Zhu, W., Radisic, M., Vunjak-Novakovic, G. (2018). Can we engineer a human cardiac patch for therapy? Circulation Research, 123(2):244–65.
[4] Yanamandala, M., Zhu, W., Garry, D.J., Kamp, T.J., Hare, J.M., Jun, H. et al. (2017). Overcoming the Roadblocks to Cardiac Cell Therapy Using Tissue Engineering. Journal of the American College of Cardiology, 70(6), 766–75.
[5] Gao, L., Gregorich, Z.R., Zhu, W., Mattapally, S., Oduk, Y., Lou, X. et al. (2018). Large cardiac muscle patches engineered from human induced-pluripotent stem cell-derived cardiac cells improve recovery from myocardial infarction in swine. Circulation, 137(16), 1712–30.
[6] Menasché, P., Vanneaux, V., Fabreguettes, J.R., Bel, A., Tosca, L., Garcia, S. et al. (2015). Towards a clinical use of human embryonic stem cell-derived cardiac progenitors: a translational experience. European Heart Journal, 36(12), 743–50.
[7] D'Amore, A., Yoshizumi, T., Luketich, S.K., Wolf, M.T., Gu, X., Cammarata, M. et al. (2016). Bi-layered polyurethane – Extracellular matrix cardiac patch improves ischemic ventricular wall remodeling in a rat model. Biomaterials,107, 1–14.
[8] Xie, Y., Chen, J., Celik, H., Akkus, O., King, M.W. (2021). Evaluation of an electrochemically aligned collagen yarn for textile scaffold fabrication. Biomedical Materials, 16(2), 025001.
[9] Fakhrali, A., Poursharifi, N., Nasari, M., Semnani, D., Salehi, H., Ghane, M. et al. (2021).

Fabrication and characterization of PCL/Gel nanofibrous scaffolds incorporated with graphene oxide applicable in cardiac tissue engineering. Polymer-Plastics Technology and Materials, 60(18):2025–41.
[10] Haroglu, D. (2022). In vitro evaluation of a pile loop knitted scaffold for myocardial tissue engineering using C2C12 cells. Tekstil ve Mühendis, 29(128), 199–207.
[11] Haroglu, D. (2022). Development of a three dimensional (3D) knitted scaffold for myocardial tissue engineering. Part I: mechanical performance of the knitted structures. Journal of the Textile Institute, 113(5), 882–94.
[12] ASTM (2019). *ASTM Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)*. Retrieved from: https://compass.astm.org
[13] Feng, J. (2017). Preparation and performance control of poly(lactic acid) fiber/polyurethane composite porous biomimetic-aligned scaffolds. Journal of Industrial Textiles, 46(6), 1297–318.
[14] Takara (2022). *WST-1 cell proliferation assay kit*. Retrieved from: https://www.takara.co.kr
[15] Siu, P.M., Wang, Y., Always, S.E. (2009). Apoptotic signaling induced by H2O2-mediated oxidative stress in differentiated C2C12 myotubes. Life Sciences, 84(13–14), 468–81.
[16] Haroglu, D., Eken, A., Gonen, Z.B., Bahar, D. (2022). Development of a three dimensional (3D) knitted scaffold for myocardial tissue engineering. Part II: biological performance of the knitted scaffolds. Journal of the Textile Institute, 113(5), 895–905.
[17] Stoppato, M., Carletti, E., Sidarovich, V., Quattrone, A., Unger, R.E., Kirkpatrick, C.J. et al. (2013). Influence of scaffold pore size on collagen I development: A new in vitro evaluation perspective. Journal of Bioactive and Compatible Polymers, 28(1), 16–32.
[18] Chen, Q.Z., Bismarck, A., Hansen, U., Junaid, S., Tran, M.Q., Harding, S.E. et al. (2008). Characterisation of a soft elastomer poly(glycerol sebacate) designed to match the mechanical properties of myocardial tissue. Biomaterials, 29(1), 47–57.

EXPLORING EFFECTIVENESS OF CELEBRITY ENDORSEMENT: CASE OF A TURKISH LUXURY FASHION BRAND

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ABSTRACT

Celebrity Endorsement (CE) strategy is an effective competitive measure to differentiate a brand's products from that of its competitors. However, there is a serious lack of prior research on assessing the effectiveness of celebrity endorsements on Turkish fashion industry. Given this background, the current research attempts to contribute to the existing theoretical understanding of CE as well as to discuss the effectiveness of CE on the sales of a Turkish luxury fashion brand which did engage Yonca Ebüzziya (Turkey's first brand ambassador) as its endorser. From a practical point of view this research demonstrates CE has a positive impact on the commercial performance of the luxury fashion brand under discussion, thereby suggesting that fashion marketers would benefit by the use of CE in their marketing communication activities.

Keyword: *Luxury fashion, Celebrity endorsement, Marketing*

1. INTRODUCTION

Celebrities are persons who enjoy public recognition among a large group of people due to their achievements in various fields such as sports [1]. The use of celebrities in marketing communication is not a recent phenomenon to popularize a brand among the public and the fashion industry is not an exception in that respect. Celebrity endorsement (CE) is a way of brand communication in which a celebrity acts as a spokesperson for a particular brand by certifying the brand's claims [2]. Ogunsiji suggests that the essence of strategic marketing is to set up a fitting relationship between the brand image of the company in the marketplace and the CE. Furthermore, Jain demonstrated that CE enhances brand equity and increases the brand value of products, and also suggests that CE is effective only to a certain extent and cannot always be used to endorse every product. However, most researchers agree that CE can help in brand promotion [3]. Wigley explains the types of CE in fashion by presenting a typology with four types of endorsement, namely PR-based, events-based, advertising-based and brand ambassador-based [4]. Togetherwith these typologies, the literature findings point out that celebrities have different aspects namely credibility (trustworthiness), attractiveness (likeability), familiarity and match up that can influence consumer purchasing behavior and perception on a fashion brand image. The literature also reveals that women are more influenced by expert advertising, opinion leadership and fashion innovativeness than their male counterparts [5]. In that respect, endorsement of the right gender for a brand or its collection/product etc. is quite important issue. Despite the broad celebrity endorsement literature, including CE in fashion industry [1-8], there is lack of study discussing CE as a marketing communication, on a leuxury fashion brand's sales performance from the perspective of the brand itself. Accordingly, the study aims to close this gap by discussing the case of Yonca Ebüzziya x MAKSU İstanbul Collection within that context. Maksu is a Turkish luxury fashion brand operating mainly in Spain. Although its presence and experience in European market becomes a solid asset for the brand, MAKSU continues to invest in increasing its public awareness as well as popularity in various markets all over the world. The aforementioned Collection which is based on CE is one of the brand's activities to strengthen its roots in the dosmestic market, i.e. Turkey.

2. RESEARCH METHOD

This research was purposed to configure the effectiveness of celebrities in increasing the MAKSU luxury fashion brand's public awareness as well as popularity in the domestic market in order to meet the marketing objectives and increase product sales. The celebrity chosen for this study is Yonca Ebüzziya who is the first brand ambassador of Turkey, a true Istanbulite, and art lover. When choosing the celebrity to endorse the brand, the attributes of credibility (trustworthy) with a high level of expertise, familiarity, and match-up with the brand's values were particularly taken into account. Maksu design team, together with the endorsed celebrity, designed and developed a 40 piece Yonca Ebüzziya x MAKSU collection (Figure 1). In doing so, the high quality stock fabrics were employed for 28 looks out of 40 in an attempt to emphasize the importance of sustainable material consumption.

Figure 1. Yonca Ebüziyya x MAKSU Collection.

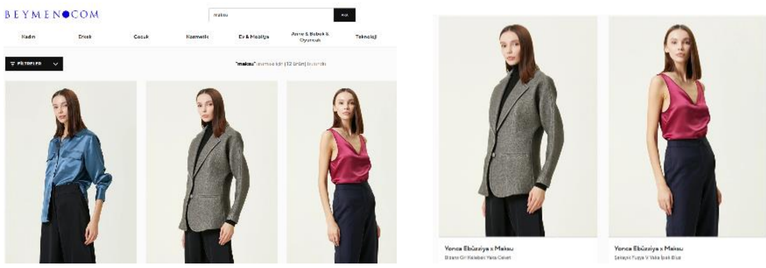

Figure 2. Yonca Ebüziyya x MAKSU Collection in Beymen.com [9].

3. RESULTS

After the collection was launched in September 2022, the sales of MAKSU did gradually increase and the average sales' increase was recorded as 34% in December 2022, which showed that choosing the right celebrity would be able to relate to the brand identity and communicate the message clearly to the consumers and ultimately influence them in their decision-making process. For the following months of the year, as was expected, the climax of the endorsement was diminished to some extent, and the average sales' increase ended by 13% when compared to MAKSU's general sales performance. But thanks to this endorsement, the MAKSU has been recognised as a luxury apparel brand in Turkey such that it was invited to sell its collections in Beymen.com in the second half of 2022 (Figure 2).

4. CONCLUSION

This study demonstrates the importance of CE for the luxury fashion industry and showing how useful it is for advertising, branding, and marketing a collection. The study concludes that focusing on recruiting well-known local celebrities as endorsers can help to strengthen a luxury brand's marketing communication and boost its sales.

REFERENCES

[1] Schlecht, C. (2003). Celebrities' impact on branding. Center on Global Brand Leadership, Columbia: Columbia Business School.

[2] Roll, M. (2006). Celebrity Branding in Asia. In Asian Brand Strategy (pp. 74-95): Springer.

[3] Ogunsiji, A. S. (2012). The impact of celebrity endorsement on strategic brand management. International journal of business and social science, 3(6), 141-145.

[4] Wigley, S. M. (2015). An examination of contemporary celebrity endorsement in fashion. International Journal of Costume and Fashion, 15(2), 1-17.

[5] Jain, V. (2011). Celebrity endorsement and its impact on sales: A research analysis carried out in India. Global journal of management and business research, 11(4).

[6] Chan T-J. and Selvakumaran D., (2021). The influence of celebrity endorser characteristics on brand image: A case study of Vivo. SEARCH Journal of Media and Communication Research, 13(3), 2021, 19-34.

[7] Hewage, V. H. and Ranaweera, H.R.A.T (2021). Exploring the Effectiveness of Celebrity Endorsement on Sri Lankan Fashion Industry. 12th International Conference on Business & Information ICBI, University of Kelaniya, Sri Lanka. ISSN 2465-6399 (pp. 001-013)

[8] Samson, T. (2015), Influence Of Celebrity Endorsed Advertisements On Consumers, Department of Business Administration and Marketing Research Project, The Copperbelt University School Of Business, India.

[9] https://www.beymen.com/search?q=maksu, Access Date: 15-02-2023

SYNTHESIS OF HYDROCORTISONE LOADED XEROGEL FOR DRUG DELIVERY

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ABSTRACT

There are various ways to develop and design a drug delivery system (DDS). In this study, silica xerogel as a drug carrier for hydrocortisone was produced. Drug release of prepared DDS was investigated. The results of in vitro drug release using ultraviolet–visible spectroscopy (UV-Vis) studies showed the capability of the silica xerogel to slow release the hydrocortisone making it suitable for incorporation into electrospun nanofibers as a controlled DDS. The results of in vitro drug release using ultraviolet–visible spectroscopy (UV-Vis) studies showed that the silica xerogel system released around 70% of the hydrocortisone drug carried within the silica xerogel in around 25 days. This is in line with a typical controlled drug release behavior.

Keyword: *Silica xerogel, Drug delivery system, Hydrocortisone, Drug release*

1. INTRODUCTION

Aerogels are mesoporous, open-cell solids with large internal porosity and low density [1-3]. The microstructure of aerogel such as high surface area, high mesoporosity make it an attractive drug carrier. An aerogel is simply produced by the replacement of the liquid inside a gel with a gas [4]. Silica aerogel synthesis consists of three main stages: gelation, aging and drying. Dyring is arguably the most critcial stage of this process as there are three different techniques, for drying the sol-gel and each one provides a different form of aerogel. In this study the focus will be on synthesizing xerogel which is dried at ambient tempreture unlike aerogels which are supercritically dried as well as cryogel which are freeze dried. Drug-delivery aims to develop an effective material for drug loading and its delivery to the targeted location [5]. This DDS should have the ability to retain the drug, release it to the targeted area, and being biocompatible [6]. This study aims to produce an silica xerogel working as a carrier of hydrocortisone to achieve a slow controlled realese of hydrocortisone.

2. EXPERIMENTAL STUDY

2.1 Materials

Ethanol (≥99.8 % gas chromatography (GC)), phosphate buffer saline 7.4 (PBS), were purchased from Sigma Aldrich (USA). For xerogel synthesis, tetramethyl orthosilicate (TMOS) (≥99%), methanol (≥99.8 % (GC)), ammonium hydroxide, 28-30 wt. % in water were purchased from Sigma Aldrich (USA) as well. For drug release studies, hydrocortisone was supplied by Sigma Aldrich (USA), dialysis tubing cellulose membrane (average flat width of 34 mm), consisting of regenerated cellulose, was purchased from Genesuz (Turkey).

2.2 Xerogel synthesis

Figure 1 describes the process of xerogel synthesis. Ammonium hydroxide stock solution was prepared by adding 4.86 g (5.40 mL) of concentrated ammonium hydroxide to 1000 mL of distilled water. Alkoxide solution was prepared by mixing 10.2 g (10.0 mL) of TMOS and 7.92 g (10.0 mL) of methanol in a beaker. Catalyst solution was prepared by mixing 5.0 g (5.0 mL) of ammonium hydroxide stock solution with 7.92 g (10.0 mL) of methanol. The sol solution was prepared by mixing the catalyst solution into the alkoxide solution.

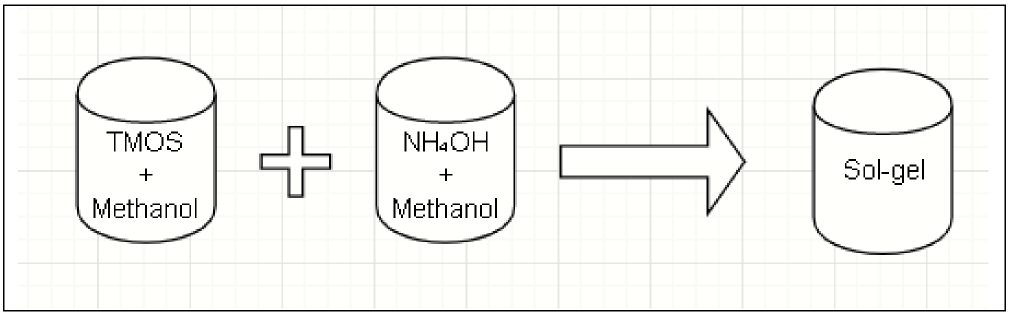

Figure 1. Xerogel synthesis.

The sol was later poured into cylindrical molds of around 2 to 3 cm long as it turned to a gel in approximately 2-4 min. The sol-gel was then dried in ambient temperature as the methanol evaporates resulting in cylindrical shaped xerogel as shown in Figure 2a.

2.3 Loading hydrocortisone acetate into the xerogel

Xerogel was then ball-milled at a frequency of 30 Hz for around 15 minutes to obtain a fine xerogel powder as shown in Figure 2b. After that, a (1%) hydrocortisone-ethanol solution was prepared, then approximately (50 mg) of the ball-milled xerogel powder was added to the hydrocortisone-ethanol solution. Finally, the drug loaded xerogel was filtered and dried at ambient condition.

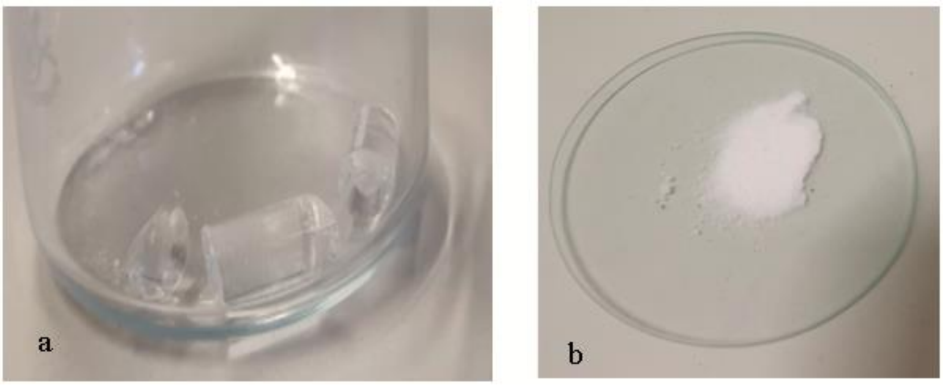

Figure 2. (a) Synthesized xerogel, (b) ball-milled xerogel.

2.4 Silica xerogel characterization

Brunauer-Emmett-Teller (BET) surface area analysis and Barrett-Joyner-Halenda (BJH) pore size and volume analysis were performed on the synthesized xerogel. BET analysis evaluate the specific surface area of the synthesized xerogel. This is done by using nitrogen multilayer adsorption measured as a function of relative pressure. This technique involves external area and pore area evaluations to determine the total specific surface area in m²/g. The results as shown in Table 1 indicated a high surface area and porosity which makes this synthesized xerogel a viable drug carrier.

Table 1. BET surface area analysis and BJH pore size and volume analysis.

ANALYSIS TECHNIQUE	RESULTS
Single point surface area (m²/g)	489,0177
BET surface area (m²/g)	505,1433
Single point pore volume adsorption (cm³/g)	0,480232
Single point pore volume desorption (cm³/g)	0,480995
BJH pore volume adsorption (cm³/g)	0,457467
BJH pore volume desorption (cm³/g)	0,513395
Adsorption average pore diameter (nm)	3,8027
Desorption average pore diameter (nm)	3,8088
BJH adsorption average pore width (nm)	3,8530
BJH desorption average pore width (nm)	3,4660

2.5 Preparation of calibration curve

Before determining the cumulative hydrocortisone release percentage of the xerogel carrier, a calibration curve was plotted. This was done by first dissolving (5 mg) of hydrocortisone in (10 mL) of PBS. This was used as a stock solution that was later diluted into concentrations of 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90 µg/mL using serial dilution. All of these solutions were tested using the UV-Vis spectrometer at a wavelength range of 200 to 400 nm with a recorded peak of 285 nm. Second, a calibration curve was plotted describing the relation between the concentrations (µg/mL) and the absorbance (nm). Slope and coefficient of determination (R^2) were calculated as well, as shown in Figure 3.

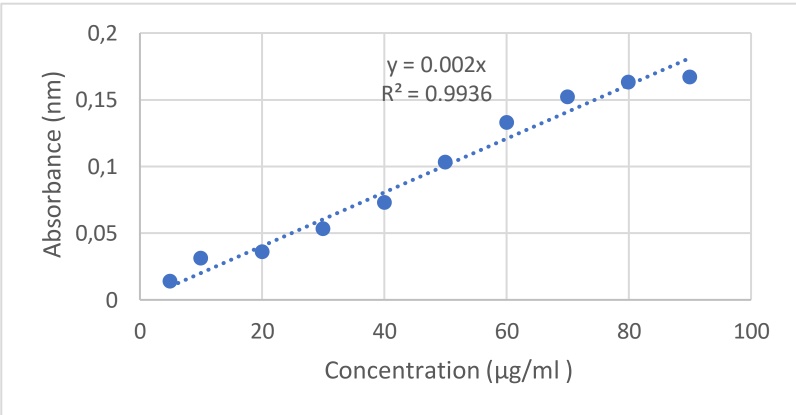

Figure 3. Calibration curve of hydrocortisone.

2.6 In vitro drug release studies with aerogel

The drug release of hydrocortisone was investigated. Xerogel powder loaded with hydrocortisone was placed inside a dialysis tubing which was sealed from both ends and then suspended in a flask containing the buffer solution (PBS), making sure that the hydrocortisone loaded xerogel was fully submerged in the buffer solution. The flask was then sealed and covered to avoid light passing through as demonstrated in Figure 4. Finally, the solution was stirred at 100 rpm and a temperature of 37°C. Due to the limited solubility of hydrocortisone and steroids in PBS, the time intervals at which samples were taken from the flask to be tested were long, precisely at 1, 2, 4, 8, 16 and 25 days respectively. Each sample was then scanned by UV-Vis spectrometer at wavelength 285 nm. Using the calibration curve, hydrocortisone concentration was determined and cumulative release percentage was calculated. Furthermore, a graph conveying the change of hydrocortisone cumulative release percentage across time in days was plotted.

Figure 4. In vitro drug release studies (A: xerogel loaded with hydrocortisone inside the dialysis tubing).

3. **RESULTS**

There are mainly three types of drug release. Conventional release or better referred to as immediate release where the release of the drug occurs immediately at a rapid pace hence named as immediate release. The second type is known as sustained release which is a slow release of drug over a period of time. Lastly there is controlled release in which releasing the drug is done according to a predictable and programmed rate. Controlled release does not differ from sustained release by much. The only key difference between them is that with controlled release the drug is released over time in correlation with concentration. This can be clearly apparent by measuring drug concentration in blood which is generally known as "plasma concentration" as shown in Figure 5.

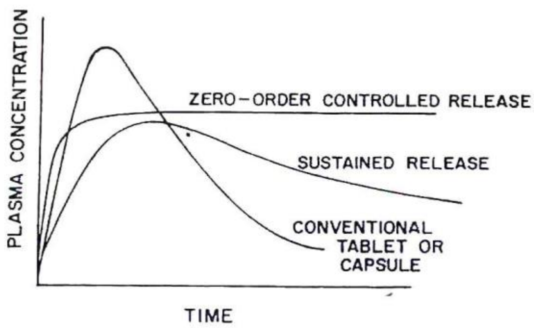

Figure 5. Plasma drug concentration for conventional, sustained and controlled drug release [7].

Furthermore, Figure 6 describes the amount of hydrocortisone released relative to the amount of the drug initially loaded. It shows that a large amount of hydrocortisone was released rapidly from xerogel at the initial stage but soon after that it started increasing at a slower and more sustained pace. After 1, 2, 4, 8, 16 and 25 days, 56%, 57%, 61%, 67% and 69% of the hydrocortisone were released from the xerogel, respectively. This means that about only 70% of the initial amount of hydrocortisone loaded in xerogel was released in around 25 days. The rate of the drug release strongly resembles the sustained/controlled drug release (Figure 5) which support the assumption that xerogel can work as a controlled drug carrier.

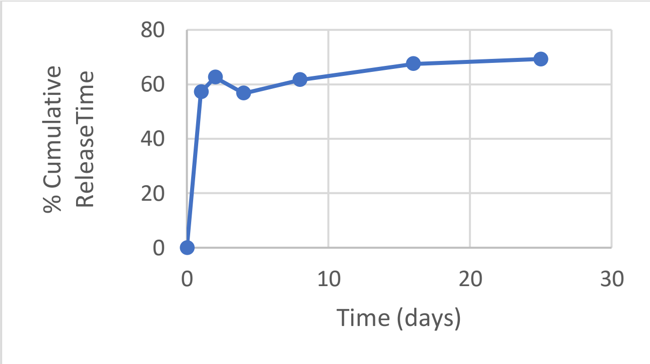

Figure 6. Cumulative release of hydrocortisone from xerogel.

4. CONCLUSION

In this study, the xerogel used as drug carrier was synthesized by the sol–gel process and its drug release characteristics were evaluated, with the ultimate goal of incorporating it into an elecrospun system that can be used for topical drug delivery applications. In vitro drug release studies were conducted and it showed that hydrocortisone was released at a rapid rate at first and then slowed down reaching a peak of 70% released of the initial loaded amount within 25 days showing promise to work as a controlled drug delivery carrier.

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REFERENCES

[1] S.S. Kistler, Coherent expanded aerogels and jellies, *Nature 127* (3211) (1931) 741.
[2] Hüsing, N. and Schubert, U. (1998), Aerogels—Airy Materials: Chemistry, Structure, and Properties. *Angewandte Chemie International Edition*, 37, 22-45.
[3] Pierre, A.C., & Rigacci, A. (2011). SiO 2 Aerogels., in: Aegerter, M. A., Leventis, N., & Koebel, M. M. (Eds.), *Aerogels handbook*, New York: Springer (pp. 21–45).
[4] C.A. García-Gonz´alez, T. Budtova, L. Dur˜aes, C. Erkey, P. Del Gaudio, P. Gurikov, M. Koebel, F. Liebner, M. Neagu, I. Smirnova, An opinion paper on aerogels for biomedical and environmental applications, *Molecules*, 24 (2019) 1815.
[5] Timko, B. P., Dvir, T., & Kohane, D. S. (2010). Remotely triggerable drug delivery systems. *Advanced materials* (Deerfield Beach, Fla.), *22*(44), 4925–4943.
[6] Arruebo M. (2012). Drug delivery from structured porous inorganic materials. *Wiley interdisciplinary reviews. Nanomedicine and nanobiotechnology*, *4*(1), 16–30.
[7] Goyal, S., Agarwal, G., Agarwal, S., & Karar, P.K. (2017). Oral Sustained Release Tablets: An Overview with a special emphasis on Matrix Tablet. *American Journal of Advanced Drug Delivery*, 5.

INVESTIGATION OF ENVIRONMENTAL LOAD OF TEXTILE RAW MATERIALS IN SOIL AFTER FINAL USE IN DIFFERENT FORMS AND NATURAL CONDITIONS

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ABSTRACT

Textile products are used in sectors such as clothing, home textiles, etc. by going through different processes as natural, regenerated, and synthetic fibers, 100% or as a mixture, in order to obtain the desired properties according to the area of use. Textile sector; Although it causes water and environmental pollution due to reasons such as the use of synthetic raw materials and non-environmental processes, it also produces waste products after final use. It is known that natural and regenerated raw materials biodegrade within 2-6 months under certain test conditions, but the biodegradation period of petroleum-derived synthetic fibers exceeds a thousand years. In this sense, within the scope of this study conducted with a multidisciplinary approach, considering that textile products released into the nature in an uncontrolled manner may be exposed to different climate and soil conditions, the dissolution behaviour and duration of textile surfaces in the form of yarn by burying in the soil in real nature conditions and the environmental load they create on the soil visually and morphologically were investigated.

Keyword: *Sustainability, Textile Raw Materials, Soil Burial Test*

1. INTRODUCTION

Textile products used for clothing and shelter, which are one of the most basic needs of human beings from past to present, are thrown away after being used for a certain period of time. These wastes both pollute the environment and cause the landfills in the world to fill up. The EPA estimates that only 15.2% of the 16.9 million tons of textile waste generated in the United States in 2017 was recycled, resulting in 11.2 million tons of textile waste going to landfills [1]. In addition, the United States Environmental Protection Agency (USEPA) states that textile waste covers 5% of landfills, while the textile recycling industry only recycles 15% of textile waste per year and dumps the remaining 85%. [2]. In Turkey, approximately 600 thousand tons of 1 million 800 thousand tons of products are wasted annually. Approximately 40 thousand tons of clothes are collected and separated for reuse annually, and 10 thousand tons of it can be recycled [3]. In the current situation, it is necessary to create more efficient and controlled waste sites by examining the behavior of the raw material types and forms used in order to ensure waste control in this sector, which is a burden to the nature due to the formation of many chemical wastes, carbon emissions, and water and energy consumption during the production of textile products. In this study, the dissolution behavior of tencel, viscose, bamboo and modal, which are in the regenerated fiber group, was investigated by applying the soil burying test under uncontrolled conditions in nature.

2. EXPERIMENTAL STUDY

2.1 Material

Within the scope of the study, yarn forms of tencel, viscose, bamboo and modal produced with ring short fiber technology in the regenerated fiber group were used. The fiber fineness of all raw materials is 1.33 dtex and the fiber length is 38 mm. The fiber strength of the viscose and bamboo fibers used is 1.47-2.26 gr/denier, the strength of the modal fiber is 3.96-5.09 gr/denier, and the strength of the tencel fiber is 4.75-5.42 gr/denier.

2.2. Method

The soil burying test was applied to the yarn forms of the raw materials used in the study under uncontrolled conditions in nature for 12 months. Sample controls were carried out at 4-month intervals by removing the samples from the soil, the weight was taken on a precision balance in the first two controls and visually examined.

3. RESULTS

Visual inspections of bamboo, viscose, modal and tencel yarn samples used within the scope of the study, made in 4-month periods, are given in Figure 1. The 1st control was done at the 4th month, the 2nd control at the 8th month and the 3rd control at the 12th month.

(a) 20/1 %100 Bamboo.

(b) 20/1 %100 Viscon.

(c) 20/1 %100 Modal.

(d) 20/1 %100 Tencel.

Figure 1. Visual **i**nspection of bamboo (a), viscon (b), modal (c), and tencel (d) yarns.

Within the scope of the study, it was observed that bamboo and viscose yarn dissolved at the highest rate, followed by modal and tencel samples, respectively, as can be seen from the images taken from regenerated fibers every four months.

The dissolution rates were calculated by measuring the weight of the yarn samples buried in the soil and these rates are given in Table 1.

Table 1. Weight and dissolution rates of yarns.

Sample Name	Weight before burial (gr)	1.Control (4. Month)	1.Control Dissolution Rate%	2.Control (8. Month)	2.Control Dissolution Rate%	3.Control (12. Month)	Total Dissolution Rate (%)
20/1 %100 BAMBOO	10	8,846 g.	11,54	2,056 g.	76,8	0.072 g.	%99,2
20/1 %100 VISCON	10	7,502 g.	24,98	1,312 g.	82,5	0,522 g.	%94,7
20/1 %100 MODAL	10	9,347 g.	6,53	6,637 g.	29,0	3,058 g.	%69,4
20/1 %100 TENCEL	10	9.121 g.	8,79	7,012 g.	23,1	3.618 g.	%63,8

Within the scope of the study, when the results of the burying test results of the yarns obtained from regenerated fibers after 12 months in uncontrolled real nature conditions were examined, bamboo yarn with 99.2% and viscose yarn with 94.7% were dissolved at the highest rate, followed by modal and tencel yarns with 69.4% and 63.8%, respectively. While these dissolution values are 8.79-24.98% after 4 months, it is seen to be between 23-82% after 8 months.

Longitudinal section microscope images taken at 20x size before and after burial of these yarns are given in Figures 2,3,4 and 5 respectively.

Figure 2. Microscope image of bamboo yarn before and after burial in soil.

Figure 3. Microscope image of viscon yarn before and after burial in soil.

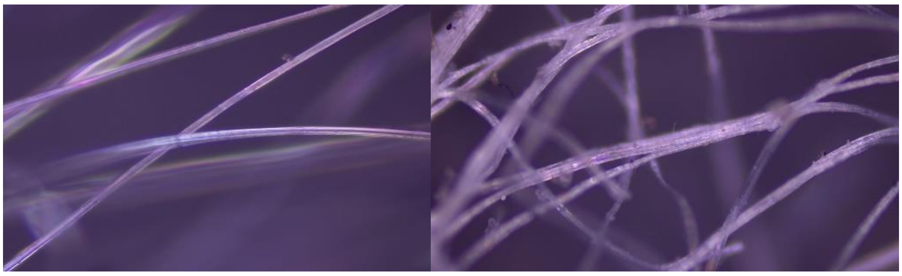

Figure 4. Microscope image of modal yarn before and after burial in soil.

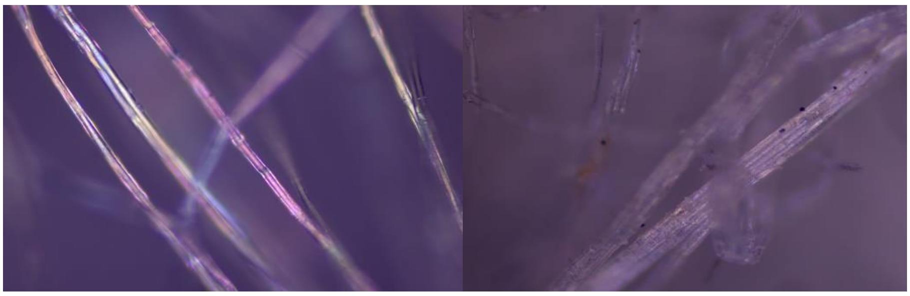

Figure 5. Microscope image of tencel yarn before and after burial in soil.

When the microscope images of the yarn samples were examined, it was seen that the bamboo fiber deteriorated in the form of fringing and the viscose fiber in the form of crystal particles. When the microscope images of the modal and tencel fibers were examined, it was observed that the fibers lost their shine and had a rough matte surface.

4. CONCLUSION

In this study, as can be seen from the images taken every four months, weight measurements and longitudinal section microscope images; It has been concluded that bamboo and viscose, which are yarns obtained from regenerated raw materials, dissolve at the highest rate in nature without controlling parameters such as temperature and humidity. Within the scope of the study, after 12 months, bamboo and viscose yarns dissolve at 99.2% and 94.7%, respectively, while modal and tencel fibers dissolve at 69.4% and 63.8%, respectively, it is predicted that it is the result of having bamboo and viscose fibers have 1.47-2.26 gr/denier fiber strength, modal fiber has 3.96-5.09 gr/denier and tencel fiber has 4.75-5.42 gr/denier fiber strength. It is aimed that this study will contribute to the reduction of water consumption and the achievement of 2050 zero carbon footprint targets by increasing the use of sustainable, non-nature-burdening raw materials and by spreading awareness about reducing the use of petroleum-derived raw materials. In addition, it is foreseen that it will play an active role in achieving the zero waste target with conscious and controlled waste generation by providing consumer information.

ACKNOWLEDGMENT

It will contribute to the literature by sharing the information obtained in this study, in which the environmental loads of yarns with regenerated cellulosic fiber group, carried out in Karacasu Tekstil R&D field, are examined on the platform realized by ITU. We would like to express our endless thanks to our Chairman of the Board, Mehmet Fethi Arifioğlu, our board members Deniz Arifioğlu Akbaş and Burak Orhan Arifioğlu, who created the field for us to carry out this research and provided all kinds of material and spiritual opportunities and ITU.

REFERENCES

[1] Advancing Sustainable Materials Management: 2017 Fact Sheet, November 2019. Retrieved from https://www.epa.gov/sites/default/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf

[2] Vadicherla, T., Saravanan, D., (2014), Textiles and Apparel Development Using Recycled and Reclaimed Fibers, in "Roadmap to Sustainable Textiles and Clothing Ecofriendly Raw Materials, Technologies, and Processing Methods", Ed: Muthu S.S., Springer Science-Business Media, Singapore.

[3] Tekstilde "geri dönüşüm" trend değil, bir zorunluluk, January 2022. Retrieved from http://www.tekstilisveren.org.tr/haberler/tekstilde-geri-doenuesuem-trend-degil-bir-zorunluluk.

A COMPERATIVE STUDY ON THE PERFORMANCE OF SIDE-BY-SIDE HOLLOW BICOMPONENT YARNS

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ABSTRACT

Using hollow yarns can change and improve many qualities of fabrics including thermal, acoustic, or mechanical properties. Using technical yarns in commercial textile products has been studied extensively to bring them some sort of functionality. In this study, side-by-side 50%/50% hollow bicomponent yarns made from different raw materials were tested and evaluated to determine their processing behaviour and performance characteristics. All yarns have coPET as one component where the other component is PET, recycled PET (rPET) and PA6, respectively. The mechanical and physical properties were evaluated by various tests, including unevenness, crimp testing, hollow ratio, and shear test. Their thermal and thermomechanical properties were also evaluated with DSC analysis. Same evaluations were done on the non-textured and textured state of the yarns to see the effect of the heat treatment.

Keyword: *bicomponent, hollow yarns, side-by-side, woven fabrics*

1. INTRODUCTION

The physical properties of textiles are critical for every imaginable sceneario, since they tend to dictate many factors, such as processability, usability, lifetime, etc. Recently, functional materials, such as bicomponent yarns, have been used in traditional and commercial textile products in order to add a new function or feature to the product. As such, their processing parameters and final properties are being extensively studied [1]. Bicomponent yarns can also be manufactured as hollow yarns by using two materials with different melting temperatures, and then melting the polymer with the lower melting point afterwards. Using hollow yarns in the structure enhances many properties, such as yarn strength, thermophysiological comfort, moisture and air permeability, and sound absorption [2–6]. Also, bicomponent fibers and yarns open the road for a more greener approach, where a recycled material can be combined with a higher strength material in order to maintain its strength while still being a more sustainable alternative [7].

In this study, three types of side-by-side hollow bicomponent yarns having different raw materials have been compared in terms of their physical, mechanical, and thermomechanical properties. All of these yarns are intended to be used in a commercial blackout curtain fabric, with the hollow yarns expected to enhance the sound absorbing quality of the fabric, so that it will be a bi-functional home textile product. Also, all the yarns were evaluated in both their textured and non-textured states in order to see the effect of the heat treatment on the yarn properties.

2. EXPERIMENTAL STUDY

Six different bicomponent yarn samples were evaluated. The yarns consist of PET/coPET, rPET/coPET, and PA6/coPET in both their nontextured and textured forms, making a total of six samples. Here, rPET denotes recycled polyester and coPET denotes co-polyester. The coPET components were dissolved by alkalization treatment. The properties of the raw materials were given in Table 1, and the compositions of the yarn samples are given in Table 2. All the samples are partially oriented yarns (POY). In the sample coding, samples that have "T" next to them are the textured yarns where the ones without the letter T were not texturized. The yarn counts for the non-textured yarns were taken before the dissolving of the coPET component and they are reduced to the desired yarn count by dissolving them in fabric form afterwards. The yarn counts were tested according to the TS 244 EN ISO 2060 standard and the number of filaments were determined by the firm accordingly to their in-house testing method.

Table 1. Raw material properties.

MATERIAL	VISCOSITY (DL/G)	MOISTURE (PPM)	MELTING POINT (°C)
PET	0,66	1477,99	252,7
COPET	0,685	1487,27	238,7
RPET	0,709	1572,14	253,6
PA6	2,4	891,42	218

Table 2. Sample properties.

SAMPLE ID	COMPOSITION	YARN COUNT (DN)	NUMBER OF FILAMENTS
1	50% PET & 50% coPET	248,48	72
1T	50% PET & 50% coPET	152,52	72
2	50% rPET & 50% coPET	248,48	72
2T	50% rPET & 50% coPET	157,47	72
3	50% PA6 & 50% coPET	251,23	72
3T	50% PA6 & 50% coPET	156,91	72

Afterwards, the nontextured and textured yarns were tested on their breaking force and elongation at break according to DIN EN ISO 2062, hot air shrinkages according to DIN EN 14621, and fat content by the NMR method. The nontextured yarns were also evaluated on their unevenness according to TS2394 standard and the textured yarns were additionally evaluated on their number of nips and nip stability, which was determined manually, and their crimp contraction and mechanical crimp retentions according to DIN 53840 standard. Their cross-sectional images were taken by Scanning Electron Microscope (SEM). The hollowness ratios of the yarns were determined with the help of a program written on MATLAB from the images taken from the SEM. The images taken from MATLAB can be found in Figure 1. As it can be seen, the alkalization treatment dissolved the coPET component completely in all samples. The hollowness ratio of the PET, rPET, and PA6 yarns after the coPET has been melted were determined as 24,61%, 18,15%, and 38,03% respectively.

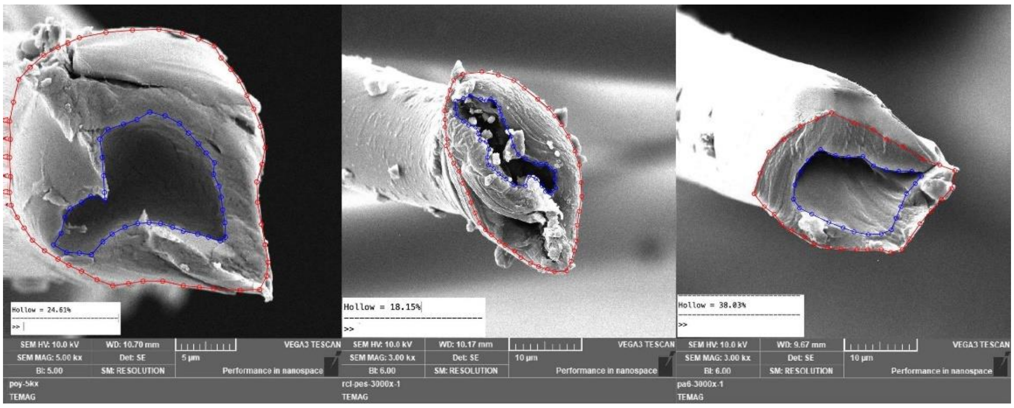

Figure 1. Hollowness ratios of the samples.

Also, Differential Scanning Calorimetry (DSC) analysis was done on all the samples to see the effect of the texturization process on the yarns in terms of their thermomechanical properties, as well as to see the different thermal behaviour of yarns having different raw materials. The test was carried out using a Perkin-Elmer DSC-4000 device and an average of 3mg of material. For the PET/coPET yarns, the samples were heated from 25°C to 300°C at a heating rate of 10°C/min and then the samples were cooled to 25°C at a rate of 10°C/min. The rPET/coPET yarns were heated from 0°C to 300°C at a heating rate of 10°C/min and then the samples were cooled down to 0°C at a rate of 10°C/min. The PA6/coPET yarns were heated from 20°C to 300°C at a heating rate of 20°C/min and then cooled back down to 20°C at a rate of 20°C/min.

3. RESULTS

The mechanical test results for the nontextured and textured yarns can be found at Table 3.

Table 3. Test results for textured and nontextured yarns.

ID	BREAKING FORCE (CN)	ELONGATION AT BREAK (%)	BOILING SHRINKAGE (%)	FAT CONTENT	UNEVENNESS (CV%)	NUMBER OF NIPS	NIP RETENTION (%)	CRIMP CONTRACTION (%)	CRIMP RETENTION
1	1,79	123,4	66,14	0,457	1,1	-	-	-	-
1T	3,16	22,8	12,67	1,245	-	80	46	33,06	53,09
2	1,79	123,4	66,14	0,457	1,2	-	-	-	-
2T	2,89	25,78	11,86	1,81	-	52	33	32,59	54,66
3	2,15	131,27		0,377	1,02	-	-	-	-
3T	3,86	27,57	12,96	1,526	-	82	60	27,98	63,24

Textured yarns have better dimensional resistance and improved strength when compared to their nontextured counterparts. The heating during the texturization improves crystallinity and density due to a greater number of immobile polymer chains with less elongation. This enhances strength while decreasing elongation. Alkalization however, causes a reduction in the fiber diameter which results in lower tensile properties due to finer fibers breaking apart from the structure easily. Nevertheless, the texturization seems to play a bigger role as the breaking force and elongation results show that the textured yarns are stronger than their nontextured counterparts.

The results of the DSC analysis for the PET/coPET sample, rPET/coPET sample and PA6/coPET sample can be found at Figure 21, Figure 3, and Figure 4 respectively. In all the figures, the graph on the left shows the results for the nontextured yarns and the graph on the right shows the results for the textured yarns.

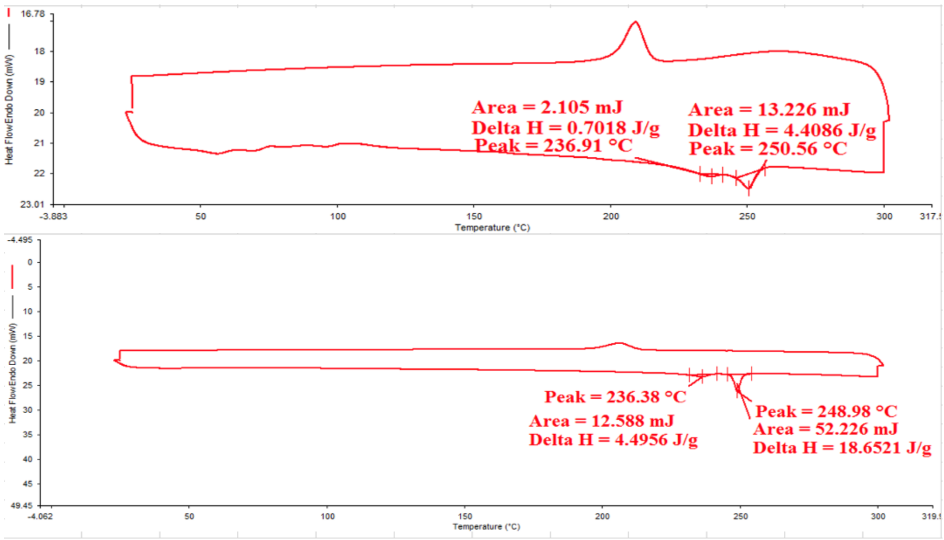

Figure 2. DSC results for nontextured and textured PET/coPET yarns.

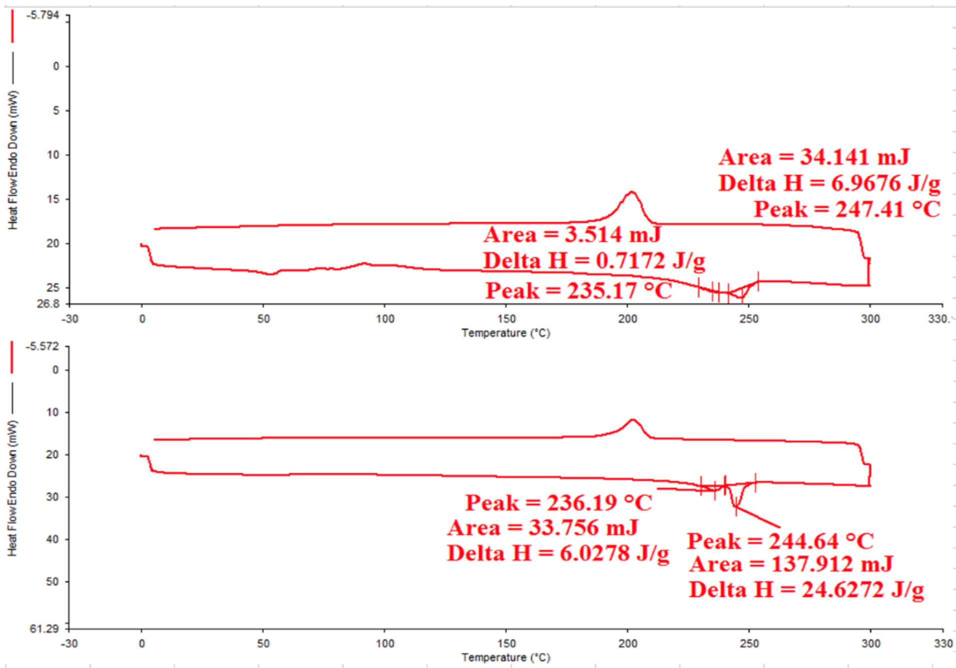

Figure 3. DSC results for nontextured and textured rPET/coPET yarns.

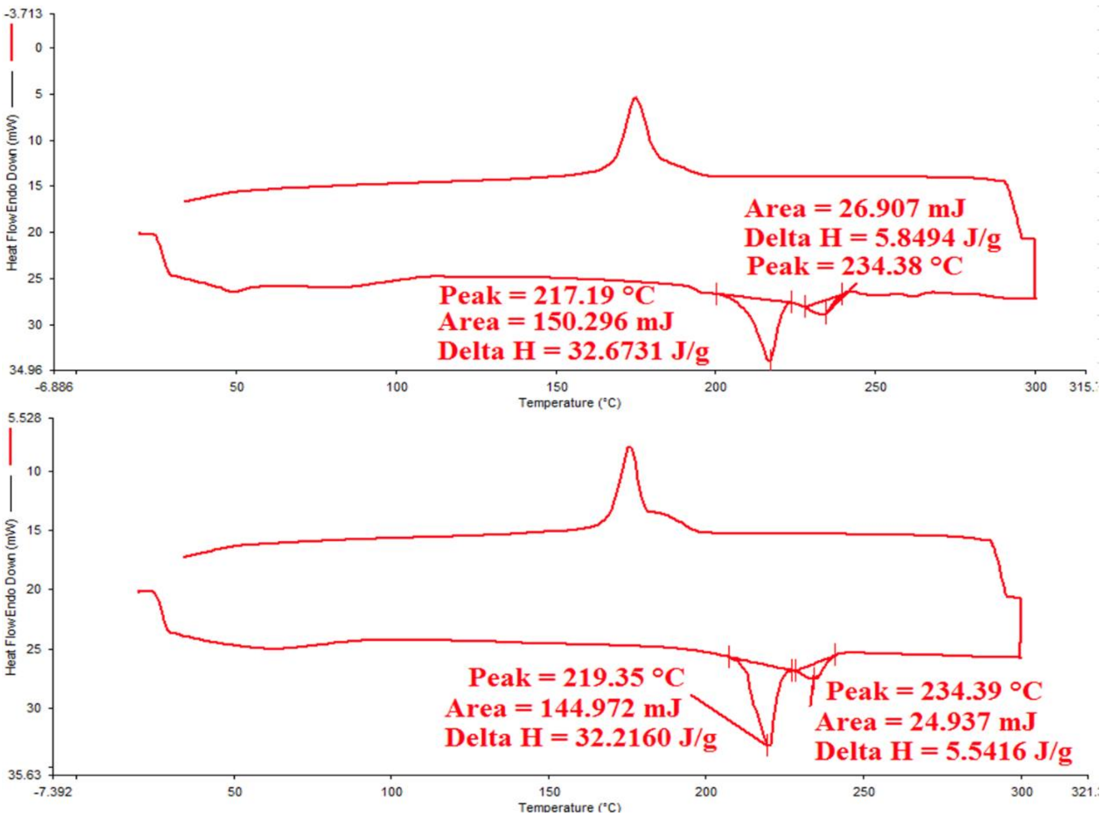

Figure 4. DSC Results for nontextured and textured PA6/coPET yarns.

DSC analysis performed on nontextured and textured yarns shows a double-peaked graph, as expected from bicomponent yarns. The melting properties of PET samples are very complex depending on the experimental conditions chosen for the measurements, isothermal temperature or non-isothermal crystallization conditions, thermal history and heating rate. The observed multiple melting endotherms are a result of the balance between melting and recrystallization and lamella thickness distribution present in the sample prior to heating. The presence of polymelt endotherms as observed with DSC is very common and is observed for many semicrystalline polymers, copolymers and blends. When two endotherms, I and II, are present, it is confirmed that they are due to the presence of a double lamella thickness distribution produced during crystallization. The peak points of the curves during the heating stage, thus the melting temperatures, of all four of the components were compatible with the polymer properties given in Table 1.

The enthalpy (ΔH) values have had a massive increase for all samples after the texturization. The enthalpy value is dependent on the polymer content of the sample. The heat treatment done by texturization indicates that the texturing process makes it difficult for the fiber to crystallize, which led to an increase in their ΔH values.

The endothermic curves also show different trends. For the nontextured samples, the melting peak is sharper and narrower, but the curve gets wider with the texturization process. The same trend can be observed for the re-crystallization during the cooling stage. Another observation is that for PET/coPET blend, the peak of PET is narrower whereas for the rPET/coPET blend, the rPET has a broader peak. This can be correlated to the thickness difference between PET and rPET materials. PET fibers' melting temperature is higher and is more peaked than rPET fibers. This difference can be attributed to the use of virgin raw materials and the absence of contamination in the PET/coPET sample. The smaller thickness of the rPET fiber crystallites is due to thermo-mechanical deterioration during the recycling and replication stages.

4. CONCLUSION

Hollow bicomponent yarns provide greater bulk with less weight. They are therefore, often used to make insulated textiles. Bicomponent hollow yarns are suitable candidates to replace their traditional counterparts, thanks to their modifiability, enhanced properties, and their availability for a more sustainable approach. In the future, with the development of new materials and new methods, the use and importance of bicomponent fibers and products made from these fibers will increase. This study evaluated and compared the mechanical and thermomechanical properties of three different bicomponent yarns in both their textured and nontextured stages. The results show that the chosen raw material carries its' intrinsic properties to the yarn stage and that both components of a bicomponent yarn can be chosen and modified according to the desired properties from the product. It also shows that the alkalization and texturization have great impact on the properties of the yarns. The result of this study shows the importance of choosing an appropriate raw material for bicomponent yarn production, since it greatly effects the properties of the final material.

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REFERENCES

[1] Oh, T. H. (2006). Melt spinning and drawing process of PET side-by-side bicomponent fibers. *Journal of Applied Polymer Science*, *101*(3), 1362–1367. https://doi.org/10.1002/APP.23287
[2] Uttam, D., Mukhopadhyay, A., & Ishtiaque, S. M. (2013). Modelling to predict thermophysiological properties of hollow/microporous yarn fabrics. *Journal of the Textile Institute*, *104*(4), 407–413. https://doi.org/10.1080/00405000.2012.737548
[3] Mukhopadhyay, A., Istiaque, S. M., & Uttam, D. (2011). Impact of structural variations in hollow yarn on heat and moisture transport properties of fabrics. *Journal of the Textile Institute*, *102*(8), 700–712. https://doi.org/10.1080/00405000.2010.515104
[4] Merati, A. A., & Okamura, M. (2000). Hollow Yarn in Friction Spinning. *Textile Research Journal*, *70*(12), 1070–1076. https://doi.org/10.1177/004051750007001206
[5] Yongfu, X., Zhang, Y., & Yuan, G. Y. (2020). Preparation and fuzzy evaluation of wool hollow yarn. *Textile Research Journal*, *90*(9–10), 1149–1156. https://doi.org/10.1177/0040517519884586
[6] Liu, X., Jiang, J., Tang, X., Han, R., Wang, Q., & Deng, Z. (2021). Sound absorption of hollow polyester woven fabric with honeycomb weave. *Applied Acoustics*, *180*, 108148. https://doi.org/10.1016/J.APACOUST.2021.108148
[7] Guo, Z., Warlin, N., Mankar, S. v., Sidqi, M., Andersson, M., Zhang, B., & Nilsson, E. (2021). Development of Circularly Recyclable Low Melting Temperature Bicomponent Fibers toward a Sustainable Nonwoven Application. *ACS Sustainable Chemistry and Engineering*, *9*(49), 16778–16785. https://doi.org/10.1021/ACSSUSCHEMENG.1C06302

WASTEWATER RECYCLING PRACTICES IN TEXTILE INDUSTRY AND CHALLENGES AHEAD

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ABSTRACT

This work is reviewing the current technologies practiced for wastewater recycling in textile industry. Wastewater recycling is the best solution for the industry to save water and to stop environmental pollution caused by the Textile wet processes. Recycling technology is mature enough for solving the textile industry's effluent problems but lack of environmental protection regulations and the concentrated discharge problem is the main issues which needs to be responded socially and scientifically. This work is reviewing the current technologies practiced for wastewater recycling in textile industry. Different filtration technologies will be discussed for textile wastewater recycling and advantages and disadvantages compared to the other advanced technologies available in the market is reviewed.

Keywords: *Wastewater recycling, Reuse, Textile wastewater, Zero liquid discharge*

1. INTRODUCTION

The Textile Industry is one of the industries that consumes huge amount of water. Textile industries can be also named as one of the largest generator of wastewater as large amount of water is used in coloring and finishing processes. The effluents released from textile industries contain biodegradable and non-biodegradable chemicals such as dyes, dispersants, leveling agents etc. These effluents are released into water bodies which can modify the physical, chemical and biological nature of the receiving environment [1].

Textile wastewater exhibits low biodegradability and high color, thus making it difficult to treat with normal physico-chemical and biological treatment methods making the wastewater treatment process costly and inefficient and very hard to guarantee its consistent performance. Therefore finding feasible, economical, compact and trustable methods for wastewater treatment in the textile industry is very crucial for controlling the environmental polluting potentials of the textile processes [2, 3].

There are not many successful example of wastewater recycling installation and plants which are affordable and feasible for use in small to medium size companies capable of recycling the Textile wastewater for re-use. Biological and Filtration techniques are promising because of their low running costs and the consistent quality of the treated water but not a single filtration system can handle all the diverse wastewaters discharged from different textile sectors and also the installation costs are very high and may not be affordable by most small scale Textile factories [4].

This paper reviews different techniques used for textile wastewater recycling and reuse and summarize advantage and disadvantages of them. Economical aspects, consumables and total efficiency of each technique will be listed and compared in order to provide an insight to the end users in different sectors of the Textile industry.

2. ADVANCED TECHNIQUES TO RECYCLE WASTEWATER

Local legislations obligate textile industries to treat their wastewater before discharging it into the water receiving bodies. In most countries, local discharge standards are more based on conventional parameters like Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). Unfortunately, not all the wastewater treatment procedures can produce an effluent with acceptable quality for reuse for turning the treatment system to a wastewater recycling unit. Chemicals such as lime and metal salts are usually used in conventional treatment systems to remove different dyes from the highly colorful wastewater. Adding these chemicals are increasing the hardness and the chance of interfering with the subsequent textile dyeing and finishing procedures. The textile effluent with a high pollution load must go through advanced treatment procedures such as oxidation, coagulation and filtration before it could be recycled again into the process.

The advanced treatment techniques mostly consist of chemical treatment, oxidation, absorption and finally a membrane systems, which have been in use in industries for water reuse applications. The pressure-driven membrane filtration process can remove both TDS and TSS but produces a highly concentrated discharge. For Reverse Osmosis (RO) filtration much higher pressure is needed to force the solute to pass through the membrane, Therefore, they are also very energy-intensive methods. Costs related to the installation and purchases, electricity costs, systems sensitivity to the change in the quality of the wastewater and temperature are some of the limitation and weaknesses incorporated with the filtration systems [5].

According to the ZDHC program which is a global industry initiative founded in 2011, not only use of hazardous chemicals are prohibited but also it introduces a new standard in wastewater discharge that goes beyond regulatory compliance. Table 1 shows some limits in the ZDHC Wastewater Guidelines where the standards are grouped into three categories: foundational, progressive and aspirational [3, 4]. The guideline contains hundreds of different chemical compounds which many are biodegradable but there is also a considerable number of non-biodegradable chemical compounds. In the aspirational level, the ZDHC Wastewater Guidelines is very difficult to achieve and may seem almost impossible to comply with, unless Zero Liquid Discharge (ZLD) technologies are used.

Table 1. Some selected parameters limit of the ZDHC guidline [6].

Parameter	Unit	Foundational	Progressive	Aspirational
Conventional parameters				
Temperature*1	°C	Δ15 /max. 35	Δ10 or 30	Δ5 or 25
Total suspended solids (TSS)	mg/L	50	15	5
Chemical oxygen demand (COD)	mg/L	150	80	40
Total Nitrogen	mg/L	20	10	5
pH		6.0 - 9.0		
Colour (spectral absorption coefficients at following wave lenghts: 436 nm; 525 nm; 620 nm)	1/m	7; 5; 3	5; 3; 2	2; 1; 1
Biochemical oxygen demand (BOD_5)	mg/l		15	5
Ammonium-N	mg/L	10	1	0.5
Total phosphorous (P)	mg/L	3	0.5	0.1
Adsorbable Organic Halogen (AOX)	mg/L	5	1	0.1
Oil and grease	mg/L	10	2	0.5

Conventional wastewater treatment practices can be listed into pre-treatment, primary, secondary and tertiary and advanced treatment which includes zero liquid discharge. Pre-treatment is mainly screening and primary treatment is sedimentation with or without chemical coagulation for settling down suspended particles. Biological treatments is known as secondary treatments which uses bacteria for decomposing biologically degradable matters in aerobic or anaerobic conditions. Tertiary treatments are mainly filtration, disinfection, and removal of microbes or salts using polymeric membranes. Advanced treatment are color removal, thermal or membrane based evaporation, and salt recovery systems [8].

In textile wastewater treatment industry, stability of the dyes and coloranats against oxidative biodegradation is the main challenge as it is one of the requirements expected from commercial dyes to whitstand fading caused by chemical and light induced oxidation. Another problem in the biological treatment of textile wastewater is the changing content of the effluent which causes problem for the microorganisem to cope with. Disperse and acid dyes can be removed in aerobic systems but reactive azo dyes are not degraded in aerobic treatment, whilst anaerobic systems can degrade reactive azo dyes to smaller aromatic amines which are still toxic and needing asubsequent aerobic systems to degrade theseby products. Power generation from anaerobic systems is an attractive opportunity if there is sufficient COD in the effluent [8].

Conventional secondary treatment including activated sludge process (ASP), Oxidation ditch, sequencing batch reactor (SBR), Trickling filters (TF), Moving Bed Bioreactor (MBBR) and Membrane bioreactor (MBR) are different biological treatment methods. MBR has attracted more attention in textile wastewater treatment based on its lower installation costs and space compared to normal ASP systems. These secondary procedures are not sufficient enough to guarantee the required effluent quality standards for discharging water to surface water bodies. Textile wastewaters usually require tertiary procedures to completely remove solids and organic matters, to remove color and nutrients like ammonia and phosphorous and to disinfect. The most common tertiary treatment applications practiced are filtration [9]. Filtration is a process in which passing a solid–liquid mixture through filter media retains the solids and allows the liquid filtrate to pass through.

3. FILTRATION TECHNIQUES FOR TEXTILE WASTEWATER RECYCLING

Textile colorants include soluble dyes and insoluble pigments and exceed 10,000 compounds which ends up in the final effluent because of their lack of 100% fixation on the textile materials. There are different dye groups like acid, basic, direct, disperse, mordant, pigment, reactive, solvent, sulphur and vat dyes. Some are anionic dyes like acid, direct, and reactive dyes and basic dyes are cationic. Disperse and solvent dyes and also pigments are nonionic and sparingly insoluble in water. Most mordant dyes are anionic. Most of the textile colorants have low biodegradability which are known as “recalcitrant compounds” as indicated by the ratio of BOD/COD. Reactive dyes are the most difficult colorants to treat because of their low BOD/COD ratio and high solubility. Therefore, for complete color removal more advanced treatment processes (including physical adsorption processes and/or chemical oxidation) are used in conjunction with biological processes. The common chemical processes are chlorination using sodium hypochlorite, calcium hypochlorite, sodium hydrosulfite, ozonation, hydrogen peroxide (H_2O_2) and advanced oxidation processes.

Ultrafiltration (UF) and nanofiltration (NF) are the main membrane based filteration techniqies used for color removal. Color removal from printing, washing, and dyeing effluents can be acheived by the UF and NF systems. As an example, in printing wastewater treatment, 90% of BOD and 100% of color can be removed. UF is capable of completely separating many dyes from the wastewater for recycling back the permeated water back to the process in dyeing with vat, acid, metal complex, disperse and direct dyes. NF can be used to separate cationic and reactive dyes from the brine. However, the main problem with membranes are their clogging by the dye compounds making them expensive if used in the absence of pre biological treatments [8, 9].

In wastewater recycling the effluent will be converted into water for reuse in the actual process previously produced the effluent. It is also possible to reuse some parts of the effluents if separated for toilet flushing or used within the process with or without further treatment. On the other hand, reclaimed water, is the water available from a wastewater after undergoing secondary, tertiary or advanced treatment for use as fresh water supplies.

Membranes are becoming gradually a popular choice in water reuse mainly because of significant costs reduction for membranes. There are four types of pressure driven membranes which their comparisons are shown in Table 2. Microfiltration (MF) and Ultrafiltration (UF) are low pressure applications given their larger pore size. Nanofiltration (NF) requires medium pressure, and Reverse Osmosis (RO), given the smaller pore size, requires significant pressure to push the solute through the membrane.

Table 2. Different types of pressure driven filtration tehchniques.

Process	Main objective	Typical fluxes (L/m²/h)[73]
Microfiltration (MF)	Suspended solids removal including microorganisms and colloids. Reduction in turbidity 90+%.	>50
Ultrafiltration (UF)	Elimination of long chain dissolved substances including colloidal, oil and fatty substances. Turbidity reduction 99%. Good for removal of metal hydroxides to 1 mg/L or less. In textile applications, COD removal is 21 – 77%, colour 31 – 76% and surfactants 32 – 94%. Requires NF or RO to polish the permeate further for dyeing lighter colours[89].	50 - 100
Nanofiltration (NF)	Selectively removing of charged ions including calcium and polar substances. Water softening applications and decolourisation. Prone to fouling from colloidal materials and polymers. COD removal 79 – 81%[73]	1.4 - 12
Reverse osmosis (RO)	Inorganic ions removal to very low concentrations used in de-salination. Very sensitive to fouling. Pretreatment required. COD removal 89 – 91%[73]	0.05 -1.4

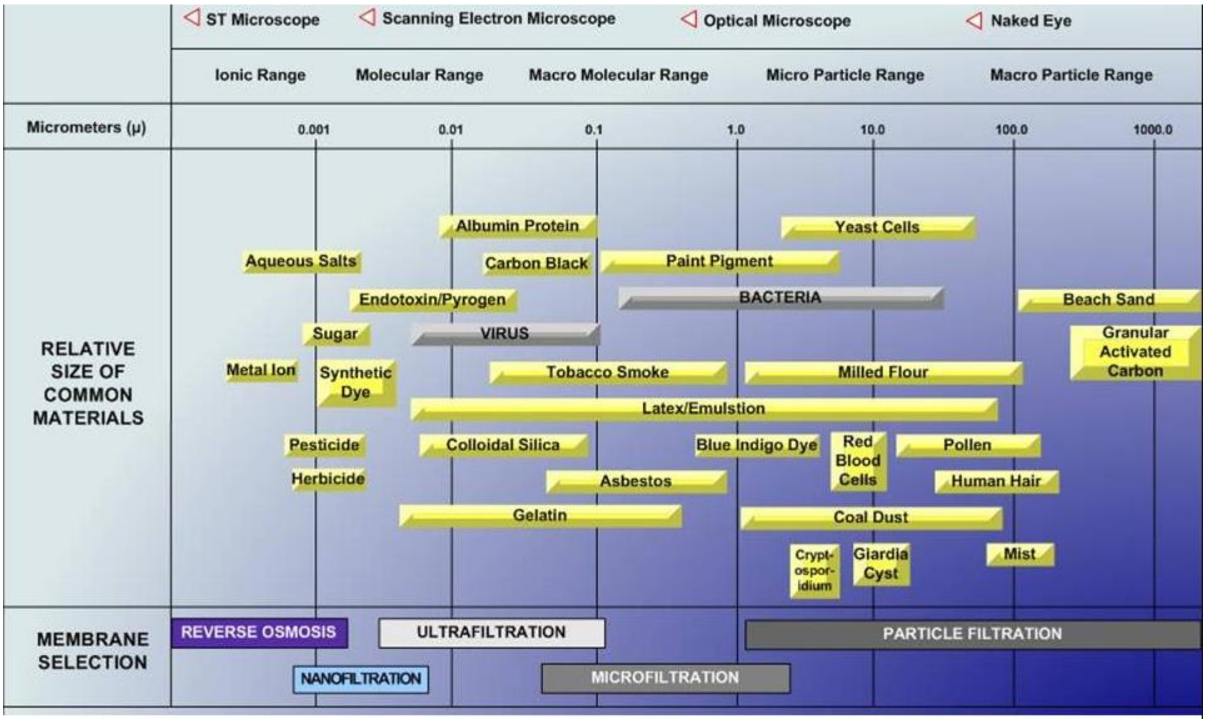

Figure 1. Filtration spectrum chart [10].

Filtration can perform in two modes, namely dead end and cross-flow. In dead end filtration, the flow is perpendicular to the media surface like macrofiltration in sand filters, cartridge and multimedia filters mainly used for removing suspended particles greater than 1 micrometer. Cross-flow membrane filtration is used for the removal of small particles and dissolved salts where a portion of the feed stream pressurized and passes through the membrane, known as permeate, and leaving behind the rejected particles in the concentrated remainder of the stream.

Membranes fouling which can happen reversibly and irreversibly is the main problem with all the filtration techniques. Suspended, biological and colloidal particles settling on the surface of the membrane or chemicals forming scale such as calcium carbonate causing reversible fouling. Reversible fouling can be removed by backwashing by acidic or alkaline chemicals. Once a membrane is fouled irreversibly the membrane needs to be discarded, since the fouling occurs in the interior of the membrane body. Some auxiliaries like cationic surfactants, quaternary ammonium based softeners and biocides can irreversibly foul the negatively charged membranes. Therefore, fouling potential which can cause membrane replacement is the main criteria in selection of the membrane systems suitable for wastewater treatments. Some very small fiber debris (<20µm) and particles released in chemical or enzymatic processes can pass through pre-filtration devices installed before an RO system causing fouling problems. As a solution, UF filters can be installed before RO membranes and where an MBR package precedes an RO plant the MBR can fulfill the necessary pre-filtration job. Fouling also increases the energy consumption significantly in all filtration processes. Average energy consumption of different treatment systems is shown in Table 3. As an example, brackish water RO energy consumption is much lower than sea water RO given the lower TDS. It also shows that the ZLD brine concentrators and crystallizers needs high energy consumption [5, 8].

Table 3. Energy consumption of different water and wastewater treatment systems [11].

Membrane process	Specific energy consumption kWh/m³
MF /UF	0.1 – 0.2
Electrodeionisation (EDI)	0.2 – 0.3
RO with feed water TDS <1000 mg/L	0.3 – 0.5
Brackish water RO (BWRO) with feed water TDS > 1,500 mg/L	0.6 – 1.0
High recovery BWRO with second stage RO, with feed water TDS> 1,500 mg/L	0.7 – 1.0
Immersed MBR as pre-filtration to RO	0.3 – 0.9
External MBR as pre-filtration to RO	2.0 – 4.0
Sea water reverse osmosis membrane (SWRO) with energy recovery	2.6 – 3.5
2 pass SWRO with energy recovery	3.0 – 4.0
ZLD – Brine concentrator	21 – 26
ZLD – Crystalliser	66 – 79

Disposal of rejected brine is another extremely problematic issue in RO membrane applications which is four to five times more concentrated than the feed. In the RO treatment of the brackish water which typically can deliver 65 – 85% of high quality water, the brine stream contains only around 15 – 35% of the feed water. In this cases and as the reject stream is concentrated using two or three passes the salt concentration in the reject stream upsurges intensely. This high salt concentration causes problem in discharging the rejected effluent into any kind of water receiving body and will leave the ZLD as the only practical option for disposal of the brine. Another option is solar evaporation. The Higher salt concentrations possesses greater osmotic pressure increasing the energy consumption in the filtration system to provide enough pressure to force the permeate to pass through the membrane.

4. CHALLENGES OF WASTEWATER RECYCLING

The major challenges of textile wastewater recycling are mostly related to the technologies and their economic feasibility. Although the technological advances in membrane design and application have reduced the cost significantly, the capital cost is still considerably high for small and medium scale industries and handling the highly concentrated discharge is another main problem. Evaporation techniques are always the final answer for getting rid of the polluted concentrated discharge which in turn adding to the costs and seen as a big disadvantage for the current users. If freshwater in that production region is very expensive, only then the advanced treatments are worth the investment.

5. CONCLUSION

We realize that textile wastewater should be treated before drainage. Upon discussed novel methods can be applied to remove different dye also hazardous materials from industrial effluents. Recycling is a perfect decision for both tackling the fresh water scarcity and environmental pollution. Advanced techniques including, chemical, electrochemical, oxidation and filtrations are together make it possible to recycle large amount of the wastewater for reuse in the actual production process. Concentrated discharge produced in the RO filtration procedures and final accumulation of pollutants in the recycled wastewater after cyclic use and reuse are the main causes for economical refusal by most factories for starting their recycling procedures which needs to be handled by the help of the governments.

REFERENCES

[1] Aksel, H.A., & Yukselen, S.G., & Sert, G., & Kahreman, Y., & Bidoki, S.M. (2022). Using 100% recycled Wastewater for Dyeing and Wet Processing of Cellulosic Fabrics, *in Akbaşlar Textile Company, 11th ULPAS Symposium*, Gebze Tech. Uni.
[2] Schönberger, H. (2018). Integrated Best Available Wastewater Management In The Textile Industry, https://elib.uni-stuttgart.de/bitstream
[3] Bidoki, S.M., & Demir, A. (2022). Development of a Water Recovery and Recycling System for the Air-jet Texturing Process, *11th ULPAS Symposium*, Gebze Tech. Uni.
[4] Sarker, K. (2022). Wastewater Recycling in Textile Industries, https://earth.org/wastewater-recycling-in-textile-industries/
[5] Sıngh, R.P., & Sıngh, P.K., & Gupta, R., & Sıngh, R.L. (2019). Treatment and Recycling of Wastewater from Textile Industry. *Advances in Biological Treatment of Industrial Waste Water and their Recycling for a Sustainable Future, Springer*, Singapore. https://doi.org/10.1007/978-981-13-1468-1_8
[6] ZDHC. (2023). Wastewater Treatment Technologies. *The Roadmap to Zero Liquid Discharge*, https://uploads-ssl.webflow.com
[7] (2022). *ZDHC Wastewater Guidelines*, Version 2.1, https://downloads.roadmaptozero.com/output/ZDHC-Wastewater-Guidelines
[8] Schönberger, H. (2018). Integrated Best Available Wastewater Management In The Textile Industry, https://elib.uni-stuttgart.de/bitstream
[9] Wang, X. & Jiang, J. & Gao, W. (2022). Reviewing Textile Wastewater Produced By Industries: Characteristics, Environmental Impacts, And Treatment Strategies. *Water Science & Technology*, *85*(7).
[10] (2023), Ultrapure Filtration Spectrum Chart, https://www.ultrapure.com.sg/images/
[11] Sıngh, R.P., & Sıngh, P.K., & Gupta, R., & Sıngh, R.L. (2019). Treatment and Recycling of Wastewater from Textile Industry. *Advances in Biological Treatment of Industrial Waste Water and their Recycling for a Sustainable Future,* Springer: Singapore. https://doi.org/10.1007/978-981-13-1468-1_8

DESIGN OF ALGINATE BASED ADVANCED WOUND DRESSING

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ABSTRACT

Today, wound dressings are not just a cloth covering open wounds, but they are advanced materials that take an active role in the wound healing process. Developing an active wound dressing that will shorten the wound healing time is the ultimate goal of this study. To achieve this goal, it is necessary to understand the wound healing process. The basis of the wound healing process is based on the proliferation of the new cells formed by the skin and the migrating of these cells to the lower layers. In this context, the wound dressing should facilitate the proliferation and migration of cells, and provide the oxygen and moist environment that cells need. For the development of such a structure, in this study, porous alginate films will be produced. Pore size will be controlled through controlling the solution concentrations. The biocompatible and biodegradable alginate films will provide the moist environment necessary for the healing of the wound, the porous film structure will provide a suitable ground for the proliferation and migration of fibroblast cells and will allow the wound to easily contact with oxygen. As a result of the studies to be carried out, modern wound dressings that play an active role in the wound healing process and shorten the wound healing period will be developed with the simple and inexpensive production method such as drop casting.

Keyword: *Poly (vinyl alcohol), Wound dressing, Porous Film*

1. INTRODUCTION

Since recent decade, it has been extensively demanding the usage of wound care materials from natural sources for many reasons. Films produced on biopolymers had been developed for wound dressing, having desirable characteristics such as non-toxicity, specific morphology etc. has many advantages of in terms of wound healing process.

Alginate is a natural, non-toxic, biodegradable, and biocompatible linear polysaccharide extracted from brown algae. This biopolymer has been widely used in wound dressings [1]. In some cases, the physico-chemical properties of *sodium alginate* (SA) need to be enhanced such as blending with another polymer. Poly (vinyl alcohol) (PVA) is a nontoxic water-soluble synthetic polymer, which is widely used in biochemical, medical, and industrial applications as a result of its compatibility with the human body. In literature, alginate-PVA films has been preferred for wound healing for their advantages [2].

In this study, porous alginate films have been developed via using PVA. PVA polymer has been benefited to create significantly porous structure to calcium-alginate film. The one of objective of PVA composition to alginate films is gaining of increased cell scaffolds compared to pure calcium alginate film and enhance cell adhesiveness via a porous structure.

2. EXPERIMENTAL STUDY

2.1 Materials and methods

Sodium alginate, poly (vinyl alcohol) and calcium chloride dihydrate were analytical grade. All solutions were prepared with distilled water.

2.2 Preparation of porous alginate films

To prepare porous alginate films, first of all PVA was dissolved at 80 ^{o}C under continuously magnetic stirring. After dissolution of PVA in water, the solution was cooled to room temperature. Sodium alginate was mixed in PVA solution until obtaining a homogeneous solution. The polymer mixture was poured in plastic Petri dish and completely dried to prepare SA-PVA films. The concentration of PVA was 0.5% (w/v) to produce a film. The films were cross-linked in calcium chloride solutions, and dried before characterization. Porous alginate films were prepared by dissolution of PVA in the cross-linking and washing steps of films. The porous structure composite films were analyzed using Scanning Electron Microscope (SEM) analysis in their dry states.

3. RESULTS

To investigate the effect of PVA on pore size of calcium alginate films, the films have been prepared, which are listed (Table 1). It is given in Table 1 that, 0.5% (w/v) PVA concentration, has been doped in alginate film solutions. After pouring the solution on Petri dishes, SA-PVA film have been prepared. To eliminate PVA from alginate polymer matrix and also cross-link the alginate by Ca^{2+} ions, the films have been waited in $CaCl_2$ solutions, and then rinsed with distilled water. Since PVA is water soluble, it has mostly been removed from SA-PVA film, while porous calcium alginate structure occurred.

Table 4. Formulation for calcium-alginate films.

Code of Films	PVA Concentration (%)	Molecular Weight of PVA (g/mol)
Film 1	0.5	67.000
Film 2	0	-

SEM analysis images of calcium alginate films have been shown in Figure 1 (A) and (B). Figure 1 (A) is representing PVA incorporated calcium-alginate film. Compared to non-porous calcium-alginate film (Figure 1 (B)) without PVA added, it can be clearly seen that, calcium-alginate films had been significantly altered their structure porously by the interaction of PVA with calcium-alginate. Besides, from the figure, it has been resulted that, a small and big sized pore structure has been formed by the 67,000 g/mol of PVA.

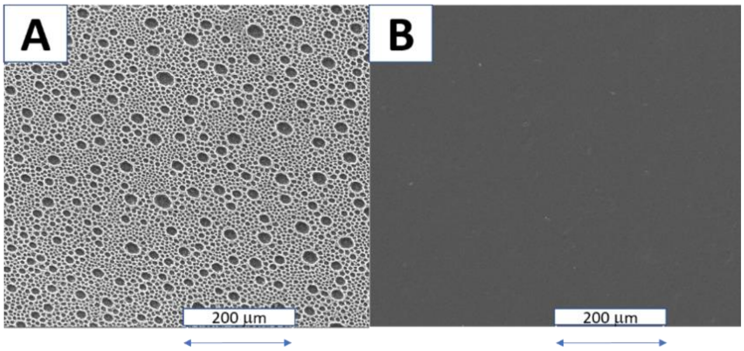

Figure 1. SEM image of 67,000 (g/mol) PVA (0.5% w/v) modified calcium-alginate film (A), calcium-alginate film (B). Scale bars in SEM images of (a) and (b), (c) are 200 µm, respectively.

4. CONCLUSION

Sodium alginate, which is a biodegradable and biocompatible polymer, combined with poly (vinyl alcohol) in SA-PVA film solutions. Following the removal of PVA from calcium-alginate films, highly porous films of alginate has been obtained. The prepared films by PVA doping provided porous and open cellular pore structured films with ant important degree of porosities. The modification by PVA of calcium-alginate films gained to the films an ideal pore size, which is demanded to be used in cell proliferation studies.

ACKNOWLEDGMENT

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REFERENCES

[1] Varaprasad, K., Jayaramudu, T., Kanikireddy, V., Toro, C. & Sadiku, E.R. (2020). Alginate-based composite materials for wound dressing application*:* A mini review. *Carbohydrate Polymers*, 236, 116025.

[2] Saraiva et al. (2023). Alginate/polyvinyl alcohol films for wound healing: Advantages and challenges. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, 111, 220-233.

NATURAL JUTE AND JUTE-COTTON FABRICS: FUNCTIONALIZED BY FLAME-RETARDANT FINISH

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ABSTRACT

The second most prevalent natural cellulosic fiber after cotton is the ligno-cellulosic Jute fiber. In this study, Pyrovatex CP New at 90% (owf), M:L: 1:7 concentrations was used to test the flame-retardance (FR) characteristics of pure jute and jute-cotton fabrics. The time it took to burn the full length (15 cm) of untreated jute and Jute-Cotton fabrics was 21 seconds and 28 seconds, respectively, after the ignition period. However, the flame spread time for the FR treated fabrics was zero seconds after that. In the Jute and Jute-Cotton fabrics, the length of the char during these times of flame propagation was 2.1 cm and 2.57 cm, respectively. The findings of this investigation point to the potential use of Pyrovatex CP New in jute-based materials.

Keyword: *Jute, Jute-Cotton, Flame-Retardancy, Pyrovatex CP New*

1. INTRODUCTION

Jute is a ligno-cellulosic fiber that mostly consists of cellulose (58–60%), lignin (12–14%), and hemicellulose (22-24%), as well as a few other minor components. Different components' thermal performance varies as a result of variations in their chemical composition. In earlier studies, [1–6] some exploratory study on thermal behavior and fire-retardant finishes was conducted. Jute carpet backing, decorative jute furnishing fabrics, and brattice cloth for mines have all been made fire-retardant to reduce the number of fire-related deaths and injuries. Today, a wide range of materials are utilized for fire-retardant purposes, including carpets, floor coverings, floor mats, military uniforms, hospital furniture, hospital curtains, and industrial ventilation, among others [7]. The main issues of treating fabrics with a jute-based fire-protective finish are increased chemical addition, a pronounced loss in tensile strength, and fading. Most of these fire-retardant compositions are also not long-lasting or even semi-long-lasting, and they require a lot of the right ingredients to function properly [4].

The first attempts to produce fire-resistant fabric were made in England in 1735. The earlier authors [8,9] explored the mechanism of the fire-retardant impact of several fire-retardant chemicals acting on cellulose. The flame-retardancy of cotton has been extensively studied, whereas jute has received less attention. A review study by Pal et al.[10] cited early studies on the temporary flame retardancy of Jute using potassium-sodium tartrate (Rochelle Salt) as a fire-retardant agent, ammonium sulfamate (AS) with urea to improve the flame-retardancy of Cotton [11] and Jute [12], and borax-boric acid with di-ammonium phosphate [3]. Halogenated, phosphorus-based fire retardants and sulfur-based flame retardants have been utilized to increase the flame resistance of wood [13,14], cotton [15], and synthetic[16–18] fabrics despite having substantial drawbacks. There have been few investigations on natural fibers other than cotton, but studies by Yusuf [19] linen, hemp, silk, and wool, as well as Mehta & Hoque [20] studies on the flame-retardancy of jute, are notable exceptions. Dorez et al. investigated how much cellulose, hemicellulose, and lignin was present in natural fibers and how it affected pyrolysis and combustion of those fibers [21]. In earlier studies [22–24], various organophosphates and other chemicals were applied to Jute, which was reported. In a more recent study, Samanta et al. successfully investigated the effect of nano-zinc oxide as a flame-retardant finish on Jute fabric [25], and Roy et al. reported the durable flame-retardancy on Jute [26].

Previous researchers conducted several studies on the application of Jute fibers in composites, but very few determined the flame-retardancy of Jute fabrics for the purpose of technical textiles. Therefore, this study aims to impart flame-retardant finishing on 100% Jute and Jute-Cotton fabrics treated with a phosphorous-based commercial flame-retardant (FR). Jute-Cotton fabric was selected for this study as there is no previously reported work citing the use of flame-retardants on Jute-Cotton.

2. EXPERIMENTAL STUDY

2.1. Materials

The two plain-woven textiles used in all of the studies were acquired from Mony Jute Company in Dhaka, Bangladesh, and were 100% Jute (290 GSM, EPI: 22, PPI: 16) and Jute-Cotton (340 GSM, EPI: 52, PPI: 26).

2.2. Chemicals

A phosphorous-based commercial flame-retardant chemical, PYROVATEX CP New (N-methylol dimethylphosphonpropionamide) and cross-linking agent KNITTEX FFRC (a modified dihydroxyethylene urea) were purchased from the local agent of Huntsman (Swiss Color, Bangladesh). All chemicals were used as received.

2.3. Flame-Retardant Finishing Treatment

According to our earlier research[27], 100% jute and jute-cotton fabrics were treated with Pyrovatex CP NEW using the exhaust method at 90% (owf) concentration with a material-to-liquor ratio of 1:7 in an open bath at room temperature for an hour. 30 g/L of the crosslinking agent KNITTEX FFRC was used. The pH was controlled using Phosphoric Acid (25%) (3.5-6). The treated samples were then air dried to finish.

2.4. Flammability Test

The untreated and flame-retardant (FR) treated fabrics were tested using a vertical flammability test. The specimen size was kept 15 cm in length and 5 cm in width and exposed to a standard flame at 90^{o} vertically using a Bunsen burner for 10 seconds of ignition time; the flame source is then removed and left for further burning. Afterwards, the flame spreading time, after glow time and char length was recorded.

3. RESULTS

3.1 Determination of Flammability

According to the results of our prior investigation (part I) [27], the treatment condition was best for a 90% (owf) concentration of Pyrovatex CP New on jute fabrics at a 1:7 material to liquor ratio. It appears that the Jute-Cotton fabric received the same treatment, and the effectiveness was evaluated. The digital photos of 90% Pyrovatex CP New (1:7) treated Jute and Jute-Cotton fabrics and their vertical flammability characteristics are shown below. In terms of flame-spread time and char length, both treated materials demonstrated strong FR capabilities. After the flame source was extinguished, it was found that the flame spread time on the FR treated Jute-Cotton fabric was less than one second, but it was zero on the FR treated Jute fabric. In contrast to the Jute-Cotton fabric, which had an after-glow time of two seconds, 100% Jute cloth did not exhibit any afterglow (Table 1).

Like that, a slightly longer char length (2.57cm) on the Jute-Cotton fabric than on 100% Jute was found (2.1cm). On the contrary, both untreated materials burned entirely (15.0 cm), spreading the flame for 21.6 seconds, after glowing for 14.6 seconds on pure jute, and for 28 seconds and 17.6 seconds, respectively, on Jute-Cotton fabrics. These findings confirm the earlier findings by demonstrating a significant improvement in flame-retardance in the Jute-based materials utilized in this investigation. As a result, they meet the requirements for decorative fabrics FR ability (B1 grade, 5s).

Table 1. Flame-retardance performance of Jute and Jute-Cotton fabrics.

	Flame Spread Time (sec)	After Glow Time (sec)	Char Length (cm)
Untreated Jute	21,6 (±1.15)	14,6 (±1.15)	15
FR Treated Jute	0	0	2,1 (±0.17)
Untreated Jute-Cotton	28 (±1.73)	17,6 (±0.58)	15
FR Treated Jute-Cotton	0,69 (±0.18)	2,1 (±.09)	2,57 (±0.06)

4. CONCLUSION

Both fabrics had considerable improvements in their FR and thermal stability. During the thermal decomposition and combustion stage, the FR-treated textiles showed improved char-forming capabilities. The flammability results show that both FR-treated Jute and Jute-Cotton fabrics had negligible flame-spread time than their untreated pairs. Jute-Cotton combination fabric can be an effective workaround to the problem, hence improving the handling and flame-retardant characteristic of the fabric. Jute fiber is also more cost-effective than cotton and its production is more hygienic. While producing jute involves using fewer chemicals and pesticides than producing cotton, cotton production consumes more water, chemicals, and pesticides overall. Additionally, since it grows during the monsoon season, jute farming does not require external water. Jute is still having trouble becoming commercially successful for future applications, though. The jute fiber is therefore more environmentally friendly and shows promise to fulfill the requirements for technical applications about the environmental aspect of these cellulosic fibers.

REFERENCES

[1] Varma IK, Anantha Krishnan SR, and Krishnamoorthy S (1988) Effect of Chemical Treatment on Thermal Behavior of Jute Fibers. *Textile Research Journal*. 58 (9), 486–494.

[2] Basak, R.K., Saha, S.G., Sarkar, A.K., Asha, M., Das, N.N., and Mukherjee, A.K. (1993) Thermal Properties of Jute Constituents and Flame Retardant Jute Fabrics. *Textile Research Journal*. 63 (11), 656–666.
[3] Banerjee SK, D.A.R.P. (1986) Fireproofing jute. *Textile Research Journal*. 56 (5), 338–339.
[4] Samanta, A.K. (1995) Chemical finishing of jute and jute blended textiles. *Colourage, 42, 37-37*. 42 37–42.
[5] Samanta, A.K., B.S.K., B.A., & B.R. (2011) Semi-durable fire retardant finishing of jute fabric and its thermal behaviour. *Journal of the Institution of Engineers*. 91 (1), 18–20.
[6] Samanta, A.K., B.A., & B.S.K. (2011) Fire retardant finishing of jute fabric and its thermal behaviour using phosphorous and nitrogen based compound. *Journal of Polymer Materials*. 28 (2), 149–158.
[7] Weil, E.D. and Levchik, S. v. (2008) Flame retardants in commercial use or development for textiles. *Journal of Fire Sciences*. 26 (3), 243–281.
[8] Horrocks, A.R. (1983) An Introduction to the Burning Behaviour of Cellulosic Fibres. *Journal of the Society of Dyers and Colourists*. 16 (7–8), 191–197.
[9] Barker, R.H., & H.J.E. (1979) Flame retardance of cotton and other naturally occurring cellulosic polymers. *Flame Retardancy of Polymeric Materials, USA*. 1–65.
[10] Pal, A., Kumar Samanta, A., Bagchi, A., Samanta, P., and Ranjan Kar, T. (2020) A Review on Fire Protective Functional Finishing of Natural Fibre Based Textiles: Present Perspective. *Current Trends in Fashion Technology & Textile Engineering*. 7 (1), 19–30.
[11] Lewin, M. and Mark, H.F. (1997) Flame Retarding of Polymers with Sulfamates. I. Sulfation of Cotton and Wool. *JOURNAL OF FIRE SCIENCES*. 15 (July/August), 263–276.
[12] Kumar Samanta, A., Bhattacharyya, R., and Chowdhury, R. (2015) Fire-retardant Chemical Finishing of Jute Fabric Using Sulfamate and Urea Mixture. *AASCIT Journal of Materials*. 1 (4), 98–110.
[13] Dobele, G., Urbanovich, I., Zhurins, A., Kampars, V., and Meier, D. (2007) Application of analytical pyrolysis for wood fire protection control. *Journal of Analytical and Applied Pyrolysis*. 79 (1-2 SPEC. ISS.), 47–51.
[14] Liodakis, S., Vorisis, D., and Agiovlasitis, I.P. (2006) Testing the retardancy effect of various inorganic chemicals on smoldering combustion of Pinus halepensis needles. *Thermochimica Acta*. 444 (2), 157–165.
[15] S. M. Mostashari* and and S. Z. Mostashari (2008) Combustion Pathway of Cotton Fabrics Treated by Ammonium Sulfate as a Flame-Retardant Studied by Tg. *Journal of Thermal Analysis and Calorimetry*. 91 (2), 437–441.
[16] Markarian, J. (2005) Flame retardants for polyamides-new developments and processing concerns. *Plastics Additives & Compounding* . 7 (2), 22–25.
[17] Chen, Y., Wang, Q., Yan, W., and Tang, H. (2006) Preparation of flame retardant polyamide 6 composite with melamine cyanurate nanoparticles in situ formed in extrusion process. *Polymer Degradation and Stability*. 91 (11), 2632–2643.
[18] Fei, G., Liu, Y., and Wang, Q. (2008) Synergistic effects of novolac-based char former with magnesium hydroxide in flame retardant polyamide-6. *Polymer Degradation and Stability*. 93 (7), 1351–1356.
[19] Yusuf, M. (2018) A Review on Flame Retardant Textile Finishing: Current and Future Trends. *Current Smart Materials*. 3 (2), 99–108.
[20] Mehta, R.D., & H.A.M. (Communication to the E. (1982) Flammability of Metal-Cation-Exchanged Jute Fabrics. . *Textile Research Journal*. 52 (9), 607–608.
[21] Dorez, G., Ferry, L., Sonnier, R., Taguet, A., and Lopez-Cuesta, J.M. (2014) Effect of cellulose, hemicellulose and lignin contents on pyrolysis and combustion of natural fibers. *Journal of Analytical and Applied Pyrolysis*. 107 323–331.
[22] Klingshirn, C.F. (2007) ZnO: Material, physics and applications. *ChemPhysChem*. 8 (6), 782–803.
[23] Matei, A., Cernica, I., Cadar, O., Roman, C., and Schiopu, V. (2008) Synthesis and characterization of ZnO-polymer nanocomposites. *International Journal of Material Forming*. 1 (1), 767–770.
[24] Reddy, K.M., Feris, K., Bell, J., Wingett, D.G., Hanley, C., and Punnoose, A. (2007) Selective toxicity of zinc oxide nanoparticles to prokaryotic and eukaryotic systems. *Applied Physics Letters*. 90 (21), 213902.

[25] Samanta, A.K., Bhattacharyya, R., Jose, S., Basu, G., and Chowdhury, R. (2017) Fire retardant finish of jute fabric with nano zinc oxide. *Cellulose*. 24 (2), 1143–1157.
[26] Roy, P.K., Mukhopadhyay, S., and Butola, B.S. (2018) A Study on Durable Flame Retardancy of Jute. *Journal of Natural Fibers*. 15 (4), 483–495.
[27] Begum, M.S., Kader, A., and Milašius, R. (2022) The Effect of Flame-Retardant Finish on Jute and Jute-cotton Fabrics. in: AUTEX 2022 Conference Proceedings - 21st World Textile Conference, pp. 20–24.

MOISTURE COMFORT ANALYSIS OF UNDERWEAR T-SHIRTS FROM SORPTION AND MOISTURE MANAGEMENT PROPERTIES

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ABSTRACT

Moisture management through underwear affects the wearer's perception of thermo-physiological comfort. The objective of this study is to understand and analyze the moisture mechanisms of the undergarment/skin interaction in a transient regime to design innovative textiles by maintaining an optimal skin moisture threshold to optimize the comfort of older adults. This research analyzed the moisture management properties of six single jersey knitted fabrics for everyday underwear. A skin model-derived measurement bench was set up to study the dynamic water transfers through the textiles, considering the microclimate layer's presence. This apparatus allowed the discrimination of textile samples based on their fiber composition. The transfer rate of water vapor molecules during desorption and the precise time at which this phenomenon begins to provide information about textiles' water management. In parallel, the study was also conducted at the fiber scale, using the dynamic vapor sorption (DVS) test, to determine the amount of water stored and released by textiles. Modeling the results provides an understanding of the water-fiber interaction mechanisms at a given moisture level. MMT was used to analyze liquid-moisture transfer at the fabric scale. All the methods developed in this study provide elements of understanding the results obtained when determining skin hydration and, more specifically, the ability of fabrics to dry or maintain a certain amount of moisture at the skin surface.

Keyword: *Textile comfort, Sorption, Moisture Management, Skin Model, Skin Hydration*

1. INTRODUCTION

Friction and shear forces, as well as moisture in the microclimate between the human skin and textiles, are critical factors in determining comfort. The type of textile influences the hydration of the skin [1]. For example, thicker fabrics have a higher thermal insulation performance so that the heat loss from the human body is slower, and the skin can sweat more quickly so that a water film is formed between the surface of the human skin and the fabric, which has the effect of retaining water .

Water sorption and desorption ability are one of the main criteria to consider for textile materials in the field of textile comfort. The textile layer must act as a barrier to regulate temperature and humidity within the microclimate and thus regulate the transfer of perspiration to the atmosphere to maintain thermal body balance. It is a complex mechanism that involves a structural modification of fiber materials during the uptake or desorption of water [2].

Sorption isotherms can describe the relationship between the moisture content in a material at a steady state and the surrounding relative humidity (RH) at a constant temperature. Nevertheless, the understandings of the various mechanisms implied in the process are often limited and lack a complete description to analyze the water activity in a textile substrate properly.

Corneometer tests have shown that skin drying or hydration varies according to the fabric composition. Some quickly drive the moisture or maintain a suitable %RH in the microclimate. Nevertheless, few studies have been published to explain this phenomenon. This study aims to provide additional information on the moisture management of single jersey knitted fabrics composed of synthetic, artificial, or natural fibers, such as cotton (CO) acrylic (PAN), polyester (PET), cellulose-based (VI), and moisture-sensible synthetic fibers (PAC).

2. EXPERIMENTAL STUDY

2.1 Textile samples

Four types of single jersey fabrics used for commercially available underwear, obtained from Damart (France) and designed for daily use, have been tested (Table 1). The selected samples were based on polyacrylic, moisture-sensible synthetic fibers blend, polyacrylic and viscose blends, and cotton and PES are blank samples. This selection was used to determine the effect of the viscose and PAC fibers and the moisture management properties.

Table 1. Description of tested samples.

Sample code	Fabric weight ($g.m^{-2}$)	Thickness at 0.1 kPa (mm)	Density ($g.m^{-3}$)	Porosity (%)	Air Permeability ($l.m^{-2}.s^{-1}$)	Moisture regain (%)
$CO_{95\%}$-$EA_{5\%}$-J	166±1	1.05±0.02	1.52	89.5±2.3	265±8	7.1±0.3
$PAN_{80\%}$-$PAC_{14\%}$-$EA_{6\%}$-J	158±2	1.02±0.02	1.23	87.4±3.2	785±46	4.4±0.1
$PAN_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J	138±5	0.71±0.02	1.29	85.0±5.6	1226±32	5.0±0.1
$PET_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J	141±3	0.82±0.02	1.41	87.8±4.4	1213±70	4.1±0.1

2.2 Methods

2.2.1 Porosity

The porosity is a static parameter defined as the total volume of void space within a specified area of the fabric. It is calculated according to Eq. (1).

$$P = (1 - \frac{m}{\rho \times e}) \times 100 \quad \text{Eq. 1}$$

With P is the relative porosity (%), m is the fabric weight according to BS EN 12127:1998 ($g.m^{-2}$), ρ is the density of the fibers ($g.m^{-3}$), and e is the fabric thickness according to ISO 5084:1996 (m).

2.2.2 Air permeability

Air permeability is defined as an airflow passing perpendicularly through a fabric area of 20 cm3 at a given pressure (100 Pa). The difference in airflow across the fabric test area is measured over time. The FX3300 device (Textest, Switzerland) is used for measurements according to ISO 9237:1995.

2.2.3. Vapor Water Sorption

Water sorption isotherms of the different fibers were determined at 35 ◦C using the dynamic vapor sorption analyzer (DVS Advantage, London, United Kingdom). The vapor partial pressure was controlled by mixing dry and saturated nitrogen using electronic mass flow controllers. The initial mass of the fabric samples was about 12mg. Each sample was pre-dried by exposure to dry nitrogen until the dry mass was obtained (m_0). A partial pressure of vapor (p) was then established within the apparatus, and the mass of the sample (m_t) was followed as a function of time. The mass of the sample at equilibrium (m_{eq}) was considered to be reached when the weight change was less than 0.005% per minute. Then, the samples were exposed to the following water activity (0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, and 98) before decreasing to 0 in the reverse order. The value of the mass gain at equilibrium (M) defined as $(m_t - m_0)/m_0$ for each water activity (a_w) allowed for plotting the water sorption and desorption isotherms for each sample.

3. ANALYSIS

The mathematical description of the sorption isotherms can bring helpful information concerning the sorption mode and the interactions involved in the process. To evaluate the accuracy of the following models in describing the experimental water sorption isotherms of the different fabrics sample, the mean relative percentage deviation modulus (E%) was used, and it is defined by Eq. (2).

$$E\% = \frac{100}{N} \times \sum_{i=1}^{N} \frac{|m_i - m_{pi}|}{m_i} \qquad \text{Eq. 2}$$

Where m_i is the experimental value, m_{pi} is the predicted value, and N is the number of experimental data. The parameters of the various equations were determined by fitting them using the software Origin 9.1. The E is widely adopted throughout the literature, with a value below 10% usually revealing a good fit.

The "Parallel Exponential Kinetics" (PEK) model (Eq. (3)) was used to analyze the kinetics of moisture sorption of these samples in more detail. An H-H and PEK model were used to understand the sorption mechanisms from the thermodynamic and kinetic points of view. With the help of the PEK model, the sorption/desorption kinetics were described by a fast and slow moisture sorption/desorption process. This model can be used in the range of about 0 to 98%RH for a relaxation-limited diffusion situation when the rate of diffusion is faster than the rate of relaxation.

$$MC_{t,\%RH_i} = MC_{1,\%RH_i} \times \left[1 - e^{\frac{-t}{t_1}}\right] + MC_{2,\%RH_i} \times \left[1 - e^{\frac{-t}{t_2}}\right] \qquad \text{Eq. 3}$$

With MC (%) as the moisture content at time t (min), MC_1 (%) and MC_2 (%) are, respectively, moisture content at time t_1 (min) and t_2 (min). The two terms in the PEK model represent fast and slow kinetic processes related to sorption or desorption sites present in the fibers. Water molecules can create a direct or indirect bond with hydroxyl or other groups on the fiber surface. Direct sorption/desorption of water molecules occurs on the material's outer surface, in amorphous regions, and on the inner surface of pores and crystallites. Indirect moisture sorption/desorption involves additional water molecules bound to the already sorbed molecules. Thus, the fast process is associated with easily accessible sites such as the outer surface of the fiber and amorphous regions. The slow process involves sites on the inner surface and crystallites that are difficult to access.

The HH (Hailwood-Horrobin) model allows us to analyze the sorption mechanisms of water vapor molecules in monolayer (Mh) and multilayer (Ms) (Eq. (4)). The monolayer sorption concerns the sorption on the surface of the fabric and in the pores with a single layer of water vapor molecules. Multilayer sorption is possible above the first layer of water molecules already placed on the fabric's surface and in the pores. It involves several layers of water vapor molecules stacked together.

$$M = M_h + M_S = \frac{1800}{W} \times \left[\frac{K_1 \times K_2 \times H}{100 + K_1 \times K_2 \times H}\right] + \frac{1800}{W} \times \left[\frac{K_2 \times H}{100 - K_2 \times H}\right] \quad \text{Eq. 4}$$

M0 (1800/W) is a specific property related to the moisture sorption of the materials. It indicates the moisture content corresponding to all available sorption sites occupied by water molecules in the monolayer. With M is the percentage of moisture content at a given RH (%), W is the molecular weight of cell polymer per sorption site, K_1 is the equilibrium constant of monolayer water formed from dissolved water and cell walls, K_2 is the equilibrium constant between water vapor and dissolved water. The values of K_1 and K_2 are determined by plotting H/M vs. H, which is predicted by H–H theory to give a parabolic relationship [3]. EMC is the sum of MC_1 and MC_2 at each humidity level. The parameters EMC (PEK model) and M (H-H model) corresponding respectively to the amount of water contained in the textile are correlated according to our previous study [4] in the form of equations (5 and 6).

$$M_h = \left[1 - \frac{\%RH}{100}\right] \times MC_1 + \left[\frac{\%RH}{100}\right] \times MC_2 \quad \text{Eq. 5}$$

$$M_S = \left[\frac{\%RH}{100}\right] \times MC_1 + \left[1 - \frac{\%RH}{100}\right] \times MC_2 \quad \text{Eq. 6}$$

4. RESULTS

The first part of the isotherm presents a concave form, which corresponds to the formation of the primary hydration sphere of the hydroxyl groups or sorption groups of fibers. The sorption and desorption isotherm curves for all fibers have a sigmoid or S-shape, corresponding to a type II classification of BET. The linear evolution of the mass gain observed in the moderate activity range was assigned to a random distribution of the water molecules. The convex part presented at high activity is attributed to the formation of water molecule clusters.

The mechanisms of sorption and desorption depend on the chemical constitution of the samples. The tests carried out during this study allowed us to put forward four distinct behaviors. For the most hydrophilic fibers, $CO_{95\%}$-EA_5%, the rapid sorption and desorption mechanisms dominate over the slow mechanisms whatever the RH% range considered. Thus, the sorption is located preferentially on the material's surface and in this one's amorphous zones. In addition, it is noted that the fast mechanism in sorption is superior to that in desorption, and the reverse is valid for the slow.

The desorption profile is similar for both samples, where the fast mechanism is more important than the slow mechanism. For viscose-based samples, the behavior is very similar. Only the RH% range differs. Thus, between 10 and 40 %RH for $PAN_{66\%}$-$VI_{28\%}$-$EA_{6\%}$ (or 10 and 30%RH for $PET_{66\%}$-$VI_{28\%}$-$EA_{6\%}$), MC_1=MC_2, the sorption takes place on the surface of the textile, in the amorphous zones as well as on the internal surface (pores, cavities, crystalline zones). At higher rates, MC_1>MC_2, the sorption is favored on the surface and in the amorphous zones.

The presence of polyacrylate fiber in the sample, $PAN_{80\%}$-$PAC_{14\%}$-$EA_{6\%}$, allows sorption in the core of the material by favoring the slow mechanism until saturation, which induces the fast mechanisms on the sample surface mainly initiate the desorption.

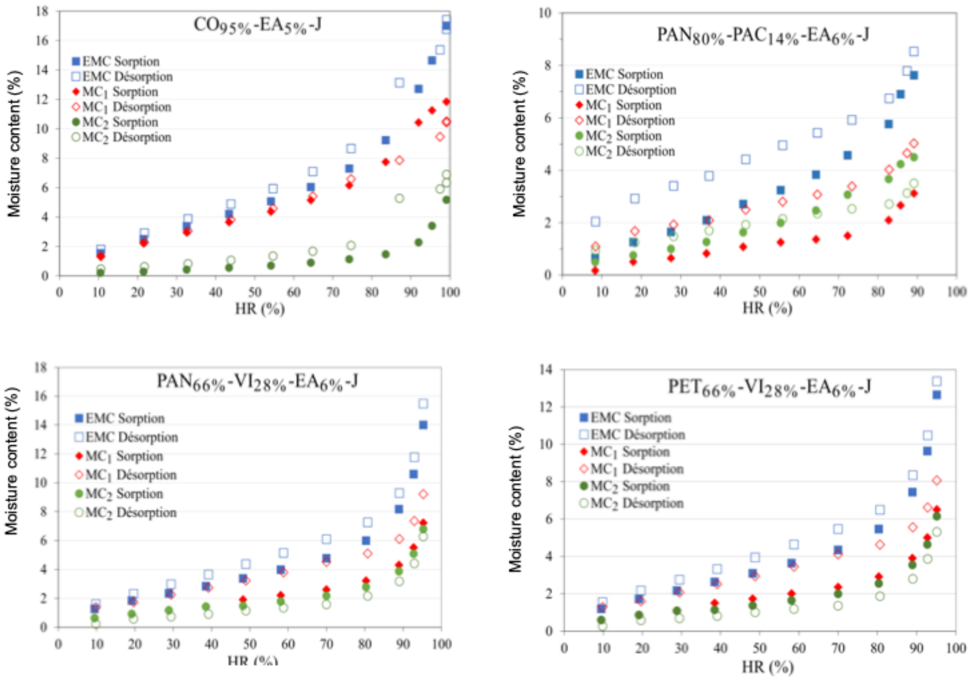

Figure 1. Moisture content for the amount of moisture (EMC), fast (MC_1), and slow (MC_2) sorption and desorption processes.

Table 2. Hailwood Horrobin fitting parameters.

Sample code	A	B	C	K_1	K_2	W	M_0	E (%)
$CO_{95\%}$-$EA_{5\%}$-J	4.28	0.26	0.002	8.26	0.82	588	3.06	2.0
$PAN_{80\%}$-$PAC_{14\%}$-$EA_{6\%}$-J	9.43	0.37	0.004	5.68	0.84	955	1.80	2.7
$PAN_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J	3.7	0.42	0.004	14.11	0.87	881	2.04	5.5
$PET_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J	3.78	0.47	0.004	9.61	0.80	971	1.85	5.0

The reduction of the moisture sensitivity of the sample fibers reflects a decrease in the available sorption groups at their surface and in their inner core. This decrease was quantified using the Hailwood Horrobin model (HH model). The experimental sorption isotherm curves were fitted using the HH model, and the inverse method identified the parameter values. The determined values are presented in Table 2. The difference between all the samples is mainly in the K_1 equilibria constant and M_0 parameter. K_1 is the constant between hydrate and dissolved water. Concerning the term M_0, the variation is directly attributed to reducing the number of available hydroxyl groups or sorption groups.

At high %RH, the M_h and M_s curves calculated for the sample $CO_{95\%}$-$EA_{5\%}$- J are similar to the HH curves model. For the other sample, a discrepancy is detected from 50 to 60 %RH. However, the results suggest that the sorption of water vapor molecules according to the fast (MC_1) and slow (MC_2) processes is performed simultaneously in monolayer and multilayer. The relative humidity intersection between the curve M_h representing the quantity of water taken in monolathe yer and the curve M_s in multilayer is the same range of value between 49 and 56 %RH, whatever the composition of the textile samples.

5. CONCLUSION

Corneometer tests indicate that $CO_{95\%}$-$EA_{5\%}$-J significantly dries the skin surface, while the $PET_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J sample has a neutral behavior for the skin. $PAN_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J and $PAN_{80\%}$-$PAC_{14\%}$-$EA_{6\%}$-J show similar behavior. Different characterization methods are performed to understand the mechanisms that justify the results obtained during wear. Thus, its high affinity for water molecules slowed the moisture transfer rate through cotton. A textile containing polyacrylate quickly desorbs moisture once the desorption process has begun. Viscose-based samples desorb water molecules to the external environment at an earlier stage and a moderate rate. A cotton-based fabric takes less time to create hydrogen bonds with water molecules on the surface than a viscose or polyacrylate-based sample. DVS tests were used to determine the contribution of fast and slow mechanisms derived from the PEK model on water vapor sorption/desorption from textiles. Water is mainly sorbed by the slow mechanism in sorption at 40%RH for $PAN_{80\%}$-$PAC_{14\%}$-$EA_{6\%}$-J and $PAN_{66\%}$-$VI_{28\%}$-$EA_{6\%}$-J. In desorption, for all materials, the fast mechanism predominates over the slow mechanism. In addition, the amount of water stored in the knitted fabric and the hysteresis are essential for very hydrophilic textiles compared to hydrophobic textiles.

The effect of the fabric on the skin hydration tests depends mainly on the ability of the fabric to rapidly create hydrogen bonds on the inner surface of the knit fabric in contact with the skin. A very hydrophilic textile will store more moisture inside the textile by drying the skin surface according to the fast mechanism.

REFERENCES

[1] Wang, Q., Lu, J., Jin, Z., Chen, K., Zhao, M., & Sun, Y. (2022). Study on the Structure and Skin Moisturizing Properties of Hyaluronic Acid Viscose Fiber Seamless Knitted Fabric for Autumn and Winter. Materials (Basel), 15(5). doi:10.3390/ma15051806.
[2] Das, B., Araujo, M. d., Kothari, V. K., Fangueiro, R., & Das, A. (2012). Modeling and Simulation of Moisture Transmission through Fibrous Structures Part I: Water Vapour Transmission. Journal of Fiber Bioengineering and Informatics, 5(4), 359-378. doi:10.3993/jfbi12201202.
[3] Hill, C. A. S., Norton, A., & Newman, G. (2009). The water vapor sorption behavior of natural fibers. Journal of Applied Polymer Science, 112(3), 1524-1537. doi:10.1002/app.29725.
[4] Marolleau, A., Salaün, F., Dupont, D., Gidik, H., & Ducept, S. (2018). Study and modeling of fabric hydric behavior to improve wearer comfort. Textile Research Journal, 89(17), 3632-3652. doi:10.1177/0040517518817030.

THE SERVICE QUALITY DIMENSIONS FOR DIFFERENT TYPE OF RETAILERS IN B2B INDUSTRY

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ABSTRACT

Turkey is an important player that provides a large variety of products for global retailers. The global retailers are usually sourcing from Turkey via sourcing offices as they give support services to their retailer customers at every step of the retail process, from creating the concept plans to customs and financial operations. Different types of retailers require particular types of service, and they place discriminating importance on different dimensions of service. Therefore, it is important to know the service quality dimensions in B2B services and which dimensions are much required by different retailers as increasing the customer satisfaction is directly dependent on this and satisfying the customers is the only way for the continuity of business. The purpose of this study is to identify the dimensions of service quality in the B2B industry and to determine which dimensions of service quality provided by the sourcing offices are more important for each retailer type.

Keyword: *Service quality, Retailer types, B2B, Sourcing offices, Satisfaction*

1. INTRODUCTION

The textile and apparel industry is a global business where retailers work with many suppliers from all around the world. The apparel retailers prefer global sourcing in order to reduce costs, maximize performance mitigate risks [1] and benefit many opportunities due to reaching many suppliers having different capabilities and different level of expertise. However, working with many suppliers from a far distance can be quite cumbersome, as control operations can be quite overwhelming. Therefore, the sourcing offices became active partners for global retailers in their production operations overseas.

The sourcing agencies primarily work with their customers at two stages, defined as the pre-production and bulk production stages [1]. Whereas the pre-production stage covers the search and selection of suppliers, the auditing of factories to ensure required quality levels and labor standards, and the design activities in regards to product development and specification; the bulk production stage covers the production flow/arrangements, the fulfillment of orders, inspections, and the execution of financial operations [2]. With the major aim of satisfying these tangible requirements, the main business of the sourcing offices is to provide services with intangible components.

Service quality was confirmed to be a prerequisite for business customer satisfaction [4, 5]. Moreover, it was stated that some dimensions or components of service quality has greater emphasis on customer satisfaction. There are some studies in literature proposed to measure B2B service quality, but none of these studies was specially dedicated for the textile and apparel industry. The ones in the textile and apparel industries have been limited in scope, which have only discussed the role of sourcing agencies in retail buying and the apparel business. In this respect, there is only one study that has aimed to measure the service quality dimensions for sourcing offices acting in the apparel industry [3]. On the other hand, the significance of each of the service quality dimensions for different types of retailers has not been discussed in detail in the literature. Therefore, the purpose of the study is to identify the dimensions of service quality in the B2B industry in apparel business and to determine which dimensions of service quality provided by the sourcing offices are more important for each retailer type.

2. LITERATURE REVIEW ABOUT SOURCING OFFICES, B2B CUSTOMERS AND B2B SERVICE QUALITY

The retail buying process begins with the concept plan and ends with the presentation of the products in the stores. Whereas the sourcing offices are responsible for providing an effective relationship between buyers and suppliers in general, they replace the buyer itself and perform most of the production activities from pre-production to post-production on behalf of the buyer, which can be specified as pre-production and bulk production stages. Specifically, in the pre-production stage, they establish a concept plan and decide about a product range, which is followed by product development, fabric selection, silhouette/pattern selection, sampling, pricing, and product engineering. This stage ends with final evaluation meetings and order confirmation. After the confirmation received in the pre-production stage, the bulk production stage begins with the approval of color works / print embroidery, the product fitting process, the control and approval of tests of fabric and garments, the sending of pre-production samples, which is followed by size grading, the production process, in-process and final product inspections. The bulk production stage ends up with the shipment, customs, and financial operations. In all these steps, the major aim of the sourcing offices is to make business customers sure that the production operations are under control and all the requirements are satisfied by the suppliers and other intermediaries. In this context, the major aim of the sourcing offices is to provide the required, continuous, and excellent service to various retailers.

The business customers in the textile and apparel industries are the retailers, and there are different types of retailers whose classification is made on different bases. As of this point, it is evident that retailers are classified based on their business structure, presentation method, price positioning, and product range [6]. There are five types of retailers namely independent retailers, chain stores, franchisers, leased store sections and consumer cooperatives according to the organizational structure [7]. Besides, two main retailer types can be identified as with or without store retailers according to presentation method [8]. On the other hand, the retailers may be classified as low end, medium end, and high end according to their price ranges, they may be classified as convenience stores, department stores, specialty stores, supermarkets and hypermarkets, discount stores, and stores that sell from catalogs according to the product range. Based on the classification specified, the identities, application areas, and accordingly, the requirements of the retailers from both suppliers and sourcing offices, vary. For instance, buying the products at a low cost is the most important expectation for low end retailers. Similarly, whereas the trendiness of products is important for a specialty store, the width of the product range is important for a department store. Accordingly, the expectations of each retailer in terms of service quality dimensions differ from the others. While a low end retailer expects sourcing offices to provide some flexibility in terms of financial payment, a business customer for a specialty store expects sourcing offices to be innovative.

“Service” as a concept is typically described as any action or activity that is fundamentally intangible that one party can provide to another and does not result in ownership [9]. It is also noted that service is a product that is easily wasted and cannot be standardized [10]. The concept of “service quality” has been established based on the definition of “quality” primarily, and it was defined as an organization’s capacity to satisfy the needs of its customers and even go beyond these expectations [11]. Service quality is one of the success parameters that distinguishes a company from its competitors. Businesses that provide superior customer service build long-term relationships with their customers, and they can attract new customers owing to favorable customer reviews. In this way, business profitability rises and reputation is enhanced. This is evidence for the significance of service quality for organizations; therefore, a systematic way of service quality measurement is needed.

Due to the requirement of service quality measurement, there are studies in the literature on the identification of its components and the overall measurement of service quality. Accordingly, one of the earlier studies defined the service quality dimensions as physical, interactive, and corporate quality [12]. The most widely known scale, SERVQUAL, defined five dimensions of service as tangibility, reliability, responsiveness, assurance, and empathy [13]. In another study, ten dimensions of service quality were defined as tangibles, reliability, responsiveness, competence, courtesy, credibility, security, access, communication, and understanding the customer [14]. Conducted researches revealed that there are differences between the B2B and B2C sectors in terms of understanding of service, and thus some components should be introduced specifically to the B2B sector. Finally, in the only study established in the textile and apparel industries, the B2B service quality expected from the sourcing offices was entitled as "credibility and reliability," "visualization and innovation," "trust for service efficiency," "intra-organizational communication," "technological and financial flexibility," "financial trust," and "knowledge" by Kavitaş Durgun [3].

Literature review revealed that there are different types of retailers as business customers in the textile and apparel industries, which have different types of requirements and, therefore, different types of expectations in terms of service quality. Moreover, the dimensions of service quality differ according to the sector or customer type.

3. METHOD

The service quality dimensions proposed by the study established by Kavitaş Durgun [3] were used in this study. The importance of each service dimension was measured with a survey conducted among merchandisers. Each service dimension was associated with a relevant question prepared using a 7-point Likert scale. The survey was conducted among 154 merchandisers working in the sourcing offices in Istanbul. Each participant responded the questions for their primary retailers after identification of the retailer type. The importance of each service dimension was calculated by taking the average values of the responses given by different retailers to questions dedicated to that dimension. One-way ANOVA was established to check if there are differences in the responses by different type of retailers about service quality dimensions. Some suggestions were made based on the analysis and the interpretation of the results.

4. RESULTS

In this study, the seven service quality dimensions derived by Durgun [3] were used, with the explanations given below:

Credibility and reliability is "good appreciation of service delivery (providing product with the right quality and quantity on time) and having a good reputation and honesty in operations with positive attitudes in delivery";

Intra-organizational communication is the "extent of communication between the interacting organizations and the speed of the information shared";

Technological and financial flexibility is "providing and accommodating the right services as per the changes in requirements in both technological and financial aspects";

Trust for service efficiency is "providing a smooth and consistent service with the convenient and effective use of staff, tools, techniques, and technology";

Knowledge is the "level of knowledge shared by the staff of sourcing agents in terms of textile materials, design, production, and trade";

Visualization and innovation is "providing service in an appealing environment or with innovative techniques in accord with the image of a brand";

Financial trust is "preserving financial trust between business partners with comprising timeliness, trustworthiness, financial strength, and minimum price items";

In all, 154 questionnaires were completed for the study. Based on the answers, five retailer types were determined: online retailers, chain stores, branded retailers, supermarkets, and department stores. Besides, a category called “other” was added to specify the retailers that fall into more than one category. The definitions of retailers in this study were given below:

Online retailer: These are the retailers that make their sales entirely or largely on their websites and/or mobile applications. This category includes retailers such as Asos, Zalando, and Trendyol. 18 responses were given for this retailer type.

Chain stores: As a type of specialty store, they are the retail organizations that have two or more stores generally owned by themselves. Retailers such as H&M, Zara, and LCWaikiki are in this category. 18 responses were given for this retailer type.

Branded retailers: As a type of specialty store, they are the retailers that follow fashion and have their own distinctive product lines. They usually sell in franchise and multi-department stores as well as in their own stores. Retailers such as Diesel, Tommy Hilfiger, and Lacoste are in this category. 18 responses were given for this retailer type.

Supermarkets: These are the retailers that offer low-cost, low-margin, high volume shopping opportunities in a wide area. Along with the apparel products, they also provide products for nourishment, cleaning, health, beauty, and basic household needs. Retailers such as Migros, Sainsbury’s, Aldi, and Carrefour are in this category. 18 responses were given for this retailer type.

Department stores: These are the large-scale sales organizations, usually serving in multi-storey buildings. Their product range includes different product groups for women, men, and children, as well as cosmetics and home decoration. Retailers such as Boyner, Selfridges, Galleries LaFayette, and Macy’s are in this category. 18 responses were given for this retailer type.

Others: Retailers falling in either two of the mentioned categories above were assessed in this category. 18 responses were given for this retailer type.

A one-way ANOVA test was applied to observe the differences between the significance of the service dimensions for the retailer type, whose results are summarized in Table 1 below. As it can be seen from the ANOVA test results in Table 1, it is possible to state that only two dimensions, namely “technological and financial flexibility” and “knowledge”, differ significantly for different types of retailers. Specifically, the “technological and financial flexibility” requirement is different for branded retailers, department stores, and online retailers, and the “knowledge” requirement is different for online retailers and supermarkets.

To get further insight, the arithmetic average of the importance given by each retailer for each dimension of the service quality mentioned above was calculated and shown in Table 2 below.

Table 2 revealed that “trust for service efficiency,” “intra-organizational communication,” and “credibility and reliability” are the most popular service quality dimensions for all types of retailers, whereas “technological and financial flexibility,” “financial trust,” and to some extent “knowledge” are the least popular dimensions.

Table 1: The results of one-way ANOVA test.

		Σ of squares	df	Mean square	F	Significance
Credibility and reliability	Between groups	1.053	5	0.211	0.241	0.943
	Within groups	129.070	148	0.872		
	Total	130.123	153			
Visualization and innovation	Between groups	6.296	5	1.259	1.201	0.312
	Within groups	155.225	148	1.049		
	Total	161.521	153			
Trust for service efficiency	Between groups	1.399	5	0.280	0.733	0.600
	Within groups	56.531	148	0.382		
	Total	57.930	153			
Intra-organizational communication	Between groups	5.243	5	1.049	1.680	0.143
	Within groups	92.367	148	0.624		
	Total	97.610	153			
Technological and financial flexibility	Between groups	18.262	5	3.652	3.283	0.008
	Within groups	164.640	148	1.112		
	Total	182.902	153			
Financial trust	Between groups	3.097	5	0.619	0.757	0.582
	Within groups	121.088	148	0.818		
	Total	124.185	153			
Knowledge	Between groups	7.219	5	1.444	2.180	0.059
	Within groups	98.030	148	0.662		
	Total	105.249	153			

Table 2. Average values for each factor according to retailer types.

	Online retailer	Chain stores	Branded retailers	Super markets	Department stores	Others
Credibility and reliability	6.22	6.24	6.21	6.47	6.08	6.22
Visualization and innovation	5.86	5.66	5.87	5.32	6.33	5.86
Trust for service efficiency	6.29	6.17	6.06	6.05	6.44	6.05
Intra-organizational communication	6.26	6.13	5.96	6.21	6.38	6.07
Technological and financial flexibility	4.31	5.24	5.39	4.63	5.11	5.26
Financial trust	6.07	5.69	5.68	5.88	6.33	5.85
Knowledge	6.38	6.16	5.72	5.73	5.93	6.23
Total number of respondents	**18**	**76**	**19**	**17**	**6**	**18**

Considering the average values for "online retailers" in Table 2, "knowledge" has the highest average value, and it is followed by "trust for service efficiency," "intra-organizational communication," and "credibility and reliability". "Technological and financial flexibility" became the least important service quality dimension.

In view of chain stores, it has been seen that the "credibility and reliability" of the sourcing offices is a priority for these retailers. The "knowledge" level of the sourcing office employees about the business area, "trust for service efficiency," and "intra-organizational communication" are of almost equal importance. It has been observed that, similar to online retailers, "technological and financial flexibility," "financial trust," and "visualization and innovation" have the least importance in the scope of service received from sourcing offices.

From the average values of branded retailers, it has been understood that "credibility and reliability" is one of the most important factors, as it is for chain stores. It is followed by "trust for service efficiency" and "intra-organizational communication". The most notable difference for branded retailers is that the average values are close to each other in terms of significance.

When supermarket type retailers are examined, it is seen that “credibility and reliability” is the most important dimension. “Intra-organizational communication” is observed to be placed in the upper ranks compared to the other retailer types.

Lastly, when department stores are considered, “visualization and innovation” and “financial trust” factors are noticed to be at higher levels, making them different from other retailer types. In addition, it is seen that the most important factor is ‘trust for service efficiency’.

The overall evaluation of the retailer types in regards to the importance of particular service quality dimensions showed that the branded retailers, chain stores, and to some extent, online retailers, have similar requirements for service quality dimensions. The ranking of the requirements of the department stores shows a different pattern, comparatively.

5. CONCLUSION

The results showed that the service components are very important to business customers, but there are differences in terms of their significance for particular retailers. Specifically, the overall evaluation of findings showed the most and least significant service quality dimensions, as well as the ones that differ in terms of ranking for different types of retailers. Moreover, the retailers having similar tendencies and patterns have been found out.

The study provided minimum information about the retailers classified as “other”, which fell into more than one retailer type, however. Therefore, it can be advised to establish a future study with a larger number of participants and make the classification of the retailer type compulsory.

Nonetheless, the findings outlined above are believed to be able to raise awareness among the sourcing offices working in this industry, and the service quality dimensions provided here might be used for making a differentiation between different retailer types. Moreover, the findings might provide a foundation for future research aimed at improving the satisfaction level in terms of meeting these requirements.

REFERENCES

[1] Lee, M., & Oh, K. (2010). Buying office as a catalyst in global apparel sourcing: A case study in Korea. *Journal of Global Fashion Marketing*, *1*(4), 250-256.

[2] Towers, N., & Xu, K. (2016). The influence of guanxi on physical distribution service quality availability in e-commerce sourcing fashion garments from China. *Journal of Retailing and Consumer Services*, *28*, 126-136.

[3] Kavitaş Durgun, Z. (2018). *Hazır giyim sektöründe satın alma ofislerinin rolü ve hizmet kalitesinin değerlendirmesi / The role of buying agencies in apparel retail industry and the evaluation of service quality,* Master of Science Thesis, ITU

[4] Chumpitaz, R., & Paparoidamis, N. G. (2004). Service quality and marketing performance in business-to-business markets: exploring the mediating role of client satisfaction. *Managing Service Quality: An International Journal*, *14*(2/3), 235-248.

[5] Chen, J. V., Chen, Y., & Capistrano, E. P. S. (2013). Process quality and collaboration quality on B2B e-commerce. Industrial Management & Data Systems.

[6] Kunz, G. I. (2015) Perakende Planlama: Uygulmalı ve Teorik Merchandising, Istanbul: Skala Yayıncılık (2. Basım)

[7] Classification of Retail Formats, (t.y.) Institute of Business Management, http://www.iibmindialms.com/library/management-basic-subjects/retailmanagement/ classification-retailing-formats/ erişim tarihi 27.01.2018

[8] Koumbis, D. (2014) Fashion Retailing: From Managing to Merchandising, New York: Fairchild Books

[9] Balin, S., & Giard, V. (2006). A process oriented approach to the service concepts. https://doi.org/10.1109/ICSSSM.2006.320562
[10] Sayım, F., & Aydın, V. (2011). Hizmet sektörü özellikleri ve sistematik olmayan risklerin sektör menkul kıymetleri ile etkileşimine dair teorik bir çalışma. *Dumlupınar Üniversitesi Sosyal Bilimler Dergisi*, *29*, 245-262.
[11] Odabaşı, Y. (2004). Satış ve pazarlamada müşteri ilişkileri yönetimi. 4. Baskı, İstanbul, Sistem Yayıncılık.
[12] Lehtinen, U., & Lehtinen, J. R. (1982). Service quality: a study of quality dimensions. Service Management Institute.
[13] Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). Servqual: A multipleitem scale for measuring consumer perc. *Journal of retailing*, *64*(1), 1
[14] Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1985). A conceptual model of service quality and its implications for future research. *the Journal of Marketing*, 41-50.

ECOFRIENDLY PRODUCTION OF FUNCTIONAL FACE MASKS

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ABSTRACT

The high-performance nanofiber membrane filters fabricated by electrospinning technology enhance the filtration efficiency of traditional filters due to their high surface area and small inter-fiber pore sizes. Suported by the advantages of environmental sustainability, biocompatibility, and biodegradability together with antibacterial functional properties; this filter will be a good candidate to substitute traditional PP based synthetic filters. The aim of this work is to develop a biodegradable electrospun functional nanofiber air filter on account of its ecofriendly superiority.

Keyword: *Air filters, eco-friendly, biodegradable, functional, sustainable*

1. INTRODUCTION

The most common properties of nanofibers that attract researchers are extremely fine fiber diameter size, high surface area to volume ratio, and controllable porosity [1]. All of the these properties also make nanofibers appropriate for air filtration usage. A layer of nanofibers possessing mi-nute diameter sizes below 1 micron can act as a sieve for straining particulate matter (PM) that are of similar small sizes. High surface area to volume ratio denotes that the nanofiber layers can be of light-weight and can provide numerous contact points for a large number of particles in the air stream. Controlling the porosity of the nanofiber mesh plays a huge role for the permeability of air particles and prevention of undesirable PMs such as dust, pollen, or even bacteria. As a result, these properties allow nanofibers to be a model specimen for air filtration theory.

Whilst there are a number of ways to produce nanofibers, electrospinning is the most popular and robust technique that allows users to produce functional materials with one step mechanism.

The end-product of this process is a mesh of nanofibers deposited on the target electrode. This mesh is actually a network of many nanofibers randomly oriented with a particular thickness and porosity that can act as a filter layer.

2. EXPERIMENTAL STUDY

2.1 Materials and Methods

In this study; the ingredients given in Table 1 have been used to conduct the optimization of the solution with an eco-friendly process.

In electrospinning process; polymeric solutions are influenced under high voltage (typically in a range of several kV) and consequently accumulate charge. These highly charged and energetic solutions are dispersed out of a needle/nozzle then proceed to form strands of jets. These jets travel and solidify while being attracted towards the oppositely/neutrally charged target electrode as the given schematic in Figure 1.

2.1.1. Tables and Figures

Table 1. The materials used for this study.

Materials	Purpose
PHB, PCL, PLA etc.	Polymeric material in granule form
Acetic Acid, DMSO, 1-4 Dioxane, THF, DMF etc.	Potential solvents
TBAC, Triton 100X, LiCl	Additives
Lavender oil, Lemon Grass Oil, Cinnamon oil etc.	Functional materials

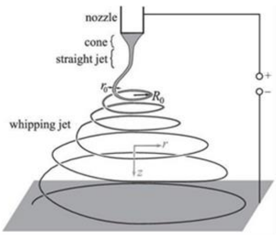


Figure 1. Diagram showcasing the electrospinning mechanism [2].

3. RESULTS

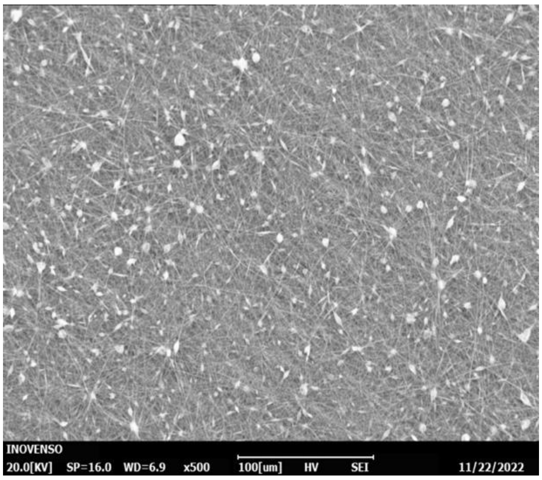
A series of trial recipes have been processed and the samples obtained by a stable and continuous spinning process have been examined under SEM to examine the morphologies. The candidate solutions that have stable, continuous process were coated on 35 GSM PET spun bonded substrates with varying thicknesses for filtration measurements and some of the samples gave promising filtration results meeting all the requirements of EN149 standard. The SEM image, fiber diameter analysis and the filtration performance of one of the candidate recipes are given below in Table 2 and Table 3 respectively.

Table 2. The filtration measurements of the membranes with respect to the thickness.

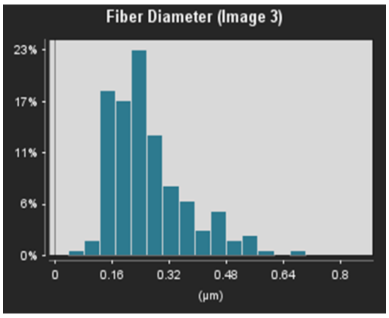
Solution Numbers	Filtration Eff (%)	Press. Drop(mbar)	Flow Rate (L/min)
Thickness – 0.5 GSM			
Replicate 1	95.01	1.32	85.2
Replicate 2	95.31	1.34	85.2
Thickness – 0.6 GSM			
Replicate 1	96.13	1.46	84.9
Replicate 2	95.51	1.46	85.3

Table 3. The SEM image and the fiber diameter analysis of a 0.6 GSM membrane.

SEM Image



Fiber Diameter Analysis



Sample ID	Fiber Diameter (µm)		
	Average	Std Dev	Median
R13	0.260	0.113	0.240

The study will continue with addition of functional materials in the potential membrane recipe and the tests for antibacterial activity will be run to optimize the minimum amount of active ingredient required for the functionality.

4. CONCLUSION

The current commercial masks are made of non-renewable resources and are non-biodegradable. After one-time use, they turn to harmful microplastic disposals, which is destructive towards the environment [3]. There is a great potential in the manufacturing of air filtration membrane materials using biodegradable, ecofriendly materials modified with multifunctional properties like antibacterial activity etc. in the market. In this work, we will manufacture a bio-based air filter which meet all these advantageous properties.

ACKNOWLEDGEMENT

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REFERENCES

[1] Balamurugan, R., Sundarrajan, S., Ramakrishna, S. (2011). Recent trends in nanofibrous membranes and their suitability for air and water filtrations. Membranes, 1(3), 232-248.
[2] Stepanyan, R., Subbotin, A., Cuperus, L., Boonen, P., Dorschu, M., Oosterlinck, F., Bulters, M. (2014). Fiber diameter control in electrospinning. Applied Physics Letters, 105(17), 173105.
[3] Torres, F., & De-la-Torre, G. (2021). Face mask waste generation and management during the COVID-19 pandemic: An overview and the Peruvian case. Science Of The Total Environment, 786, 147628.

DEVELOPMENT OF BANANA FIBERS BLENDED YARN AS AN ECO-FRIENDLY ALTERNATIVE TO COTTON YARNS FOR CLOTHING

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ABSTRACT

Bananas are one of the most popular fruits in the world. The plant of banana has rich number of fibers in its leaves and stem. The fibers can be extracted from banana plant and can be used as an alternative to other cellulosic fibers in textiles. In this study, the banana fibers were extracted and treated mechano-chemically to obtain spinnable banana fibers. These spinnable banana fibers were blended with cotton in various ratios on conventional ring & rotor spinning processes to develop cotton/banana blended yarns. Moreover, the cotton/banana blended yarn was used to prepare woven fabric. The mechanical and comfort properties of cotton/banana woven fabric were analyzed to check the performance developed fabric. The results showed that the properties of developed fabric were comparable to conventional cotton fabric. Therefore, cotton/banana woven fabric can be used to prepare various kinds of clothing.

Keyword: *Banana fiber, agro-waste, yarns, fabrics*

1. INTRODUCTION

The textiles manufacturing is among one of the largest industrial sectors in the world and employs 250 million people around the world. However, the various kinds of textiles manufacturing industries are producing 2-7% of total green house gas emissions in the world. Morover, 20-25% water pollution and 35-40% microplastics are caused of textiles manufacturing processes [1-3]. Among all the textiles manufacturing processes, the effect of textile fibers/raw materials production is highest on envirnment. The most abandanly used textiles fibers such polyester and cotton are not eco-friendly. Cotton consumes lots of water and pesticides during its growth. Therfore, there is need to find the alternative textiles fibers which are more eco-friendly and can reduce the polluation [4-6]. In recent years, a number of studies have been conducted to use alternative natural fibers other than cotton such as sisal, flax, corn, begasse, banana and many others to prepare yarns and fabrics for textiles [7,8].

Banana is an important food crop which is currently grown in more than 130 countries. The crop of banana is cultivated over 5.5 million hectares globally, with 114 million tons banana production [9]. The stems and leaves of banana plants are usually burnt as a waste material after getting the fruit. These stems and leaves are important source of cellulosic fibers. These fibers have good strength and moisture absorbency. However, the harsh feel of these fibers limits their applications in various fields such as textiles [10,11]. Therefore, there is need to prepare soft and spinnable banana fibers from raw extracted fibers which can be used as an alternative to other cellulosic fibers such as cotton, viscose, and bamboo etc. for textiles. A number of studies have been conducted to improve the feel/handle of extracted banana fibers. In these studies, various kinds of chemicals such as acids, alkalis and enzymes were used to enhance the softness of extracted banana fibers [12,13]. Another challenge to process banana fiber to make yarn and fabric was its processability on conventional existing machinery setups. The objectives of this work are to prepare spinnable banana fiber from agro-waste (stems of banana plants) with enhanced softness and use these fibers to prepare yarns and fabrics. In this study, firstly a new process was developed to obtain soft spinnable banana fibers from extracted raw banana fibers. Later, these spinnable banana fibers were blended with cotton fibers. The blend of cotton and banana was processed on conventional ring and rotor yarn manufacturing technologies to prepare yarns. Afterwards, the woven fabrics were prepared by using developed cotton/banana blended yarns. The physical, mechanical and comfort properties of these developed yarns and fabrics are promising and comparable with other conventional fabrics.

2. EXPERIMENTAL STUDY

2.1 Materials

The extracted Pakistani banana fibers of were purchased from the local market. The chemical 1 and chemical 2 were obtained from Sigma-Aldrich in their pure form.

2.2 Methods

Firstly, the raw banana fibers were cut into length of 38 mm. These fibers were placed in prepared solution of chemical 1 and chemical 2 [14] for 6 hours in heating chamber at 40 °C. After chemical treatment, the fibers were dried and subject to specially designed beater. After beating, the opened fibers were blended with cotton fibers and passed through the conventional blowroom line (Toyoda Ohara) and carding machine. The blended sliver of cotton/banana was produced at card machine which was fed to drawing machine for parallelization. A simplex machine (Toyota FL-16) was used to prepare the cotton/banana roving which delivered to conventional ring frame (Rieter K44) to spin the yarns of 10/1 Ne and 20/1 Ne. These yarns were used to prepare woven fabrics on conventional warping and weaving machinery setups. The single fiber strength of banana fibers and tensile strength of prepared yarns were measured. The air permeability, bending length and thermal resistance of developed cotton/banana fabrics were analyzed by using standard testing methods.

3. RESULTS

3.1 Physical properties of cotton/banana yarn

The treated fibers are flexible with good softness which are shown in Figure 1. The fibers have strength in the range of 300 cN/tex whereas the elongation is 2 to 2.5 % which means that the fibers can be used to prepare yarn. The properties of prepared blended yarn are given in Table 1. The strength of developed yarn (8/1 Ne to 20/1 Ne) is in the range of required yarn strength for fabric manufacturing. The yarn appearance was excellent with few protruding ends of banana fibers.

Table 1. Properties of cotton/banana yarn.

Sample No.	**Lea strength (lbs)**	**CLSP**
1	255	1800
2	255	1924
3	254	1867
4	254	1856
5	252	1902
S.No.	Tenacity CN/Tex	Elongation (%)
Average	11.65	5.40
S. No.	Neps +200	IPI
Average	1000.00	1500

3.2 Comfort properties of cotton/banana blended fabric

The appearance of prepared woven cotton/banana blended fabric was like pure cotton fabric whereas the feel/handle was little bit rough as compared to pure cotton fabric. The thermal conductivity and air permeability of cotton/banana blended fabric are given in Table 2. The prepared fabric has comparable thermal conductivity and air permeability with pure cotton fabric which may be due the fact that the banana fibres were evenly blended and regular inside the blended structure of yarn.

Table 2. Properties of cotton/banana fabric.

Fabric Type	**Thermal Conductivity(W/mK)**	**Air permeability($cm^3/cm^2/s$)**
Pure Cotton	0.065	227
Banana/cotton (20:80)	0.061	219
Banana/cotton (30:70)	0.059	214

4. CONCLUSIONS

The spinnable banana fibers with good softness were developed successfully. The cotton/banana blended yarn of 8/1 Ne and 20/1 Ne were prepared on conventional yarn manufacturing machinery setups. The yarns have good physical and mechanical properties which were employed successfully to develop woven fabrics. The comfort properties such as thermal conductivity and air permeability of cotton/banana blended woven fabric were comparable with pure cotton woven fabric.

ACKNOWLEDGMENT

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REFERENCES

[1] Franco, M. A. (2017). Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. Journal of Cleaner Production, 168, 833-845.
[2] Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. Journal of Cleaner Production, 259, 120728.
[3] Chen, X., Memon, H. A., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021). Circular Economy and sustainability of the clothing and textile Industry. Materials Circular Economy, 3, 1-9.
[4] Chen, H. L., & Burns, L. D. (2006). Environmental analysis of textile products. Clothing and textiles research journal, 24(3), 248-261.
[5] Egan, J., & Salmon, S. (2022). Strategies and progress in synthetic textile fiber biodegradability. SN Applied Sciences, 4, 1-36.
[6] Periyasamy, A. P., & Militky, J. (2020). Sustainability in regenerated textile fibers. Sustainability in the Textile and Apparel Industries: Sourcing Synthetic and Novel Alternative Raw Materials, 63-95.
[7] Mohanty, A. K., Misra, M., & Drzal, L. T. (Eds.). (2005). Natural fibers, biopolymers, and biocomposites. CRC press.
[8] Karimah, A., Ridho, M. R., Munawar, S. S., Adi, D. S., Damayanti, R., Subiyanto, B., ... & Fudholi, A. (2021). A review on natural fibers for development of eco-friendly bio-composite: Characteristics, and utilizations. Journal of materials research and technology, 13, 2442-2458.

[9] World banana production Retrieved from https://knoema.com/atlas/World/topics/Agriculture/Crops-Production-Quantity-tonnes/Bananas-production

[10] Ortega, Z., Morón, M., Monzón, M. D., Badalló, P., & Paz, R. (2016). Production of banana fiber yarns for technical textile reinforced composites. Materials, 9(5), 370.

[11] Hossain, M. B., & Begum, H. (2017). Investigation of spinnability of banana fibers through yarn formation along with analysis of yarn properties. American Journal of Engineering Research, 6(1), 322-327.

[12] Englund, K. (2009). Tribology of natural fiber polymer composites. Materials Today, 12(3), 45.

[13] Tholkappiyan, E. (2016). A preliminary study for improving the banana fibre fineness using various chemical treatments. Global Journal of Researches in Engineering, 16(3/1), 17.

[14] Patent: A mechano-chemical method to prepare spinnable banana fibers, (Application no. 707/2021, Dated 30/09/2021)

DESIGNING AND PRODUCING A WOMEN'S UNDERWEAR BASED ON HOSIERY KNITTING MACHINE

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ABSTRACT

In this research, there is the idea of producing a different product apart from the production of hosiery, which has been produced in hosiery knitting machines from past to present. The main purpose of the project is to produce woman underwear-panty- from a hosiery knitting machine. The hosiery is consisting of body (panty), legs and feet. In the project, a suitable process has been developed by separating the body part of the pantyhose from this natural structure in order to produce panties only from the machine that produces socks. No similar product was found in the literature research. During the product development process have some criteria such as being as thin and flexible as possible, being able to offer different sizes with a single product -one size-, comfortable and not showing any traces of product on the clothes were taken into consideration. In addition, a lower cost product was obtained compared to the seamless woman underwear on the market. In the process of the project, texture and surface tests were carried out on hosiery knitting machines, followed by cutting and sewing studies and fit activities. A patent application was made to the Turkish Patent and Trademark Office with the application number TPE 2022/020037 for the production process and product within the scope of the project. As a result of the project, an underwear product has been developed that is as thin as hosiery and does not show any traces, and that is lower cost than seamless underwear suitable for all sizes.

Keyword: *one size woman underwear, hosiery knitting machine, one size seamless woman underwear, woman underwear*

1. INTRODUCTION

In the literature researches, it has been seen that there have been different studies on hosiery knitting machines since the 1860s [1]. With industrialization, socks as of the beginning of the 19th century; started to be produced and exported in factories with large amounts of capacity. Glen Raven Mills company launched the first seamless pantyhose in 1965. This garment, which combines panties and stockings, attracted great attention and spread rapidly in the 1960s, especially with the miniskirt fashion it triggered, and took the place of nylon stockings. The spread of pantyhose has also led to a decrease in the use of corsets and garters. In the same period, the invention of elastane yarn made pantyhose more comfortable and stylish [2]. Studies on hosiery knitting machines appear as mechanical designs and electronic designs. Studies in the field of mechanics focus on determining design parameters and improving machine performance [3]. Studies in the field of electronics have focused on patterning and computer programming systems [4]. Comfort features come to the fore in studies on woman underwear products [5]. There are studies on stretchable fabrics in the field of clothing [6]. These studies are mainly aimed at providing comfort in wearable technologies. There are one size seamless woman underwear products with a fabric suitable for different sizes [7]. Studies on hosiery knitting machines in the literature are about producing hosiery as a product, and no work has been found on a woman underwear product developed from a hosiery knitting machine.

2. EXPERIMENTAL STUDY

Within the scope of the project, in order to create underwear-panty in hosiery knitting machines, experiments were made on surface, texture and underwear size and shape in various knitting, pattern and yarn structures.

At the beginning of the project, to tested the creation of the panty pattern on the tube fabric and in order to see this pattern clearly, knitting was done with the combination of Single Cover Yarn and Sim Yarn. In this study, the elasticity of the single cover yarn and the visuality of the sparkle yarn was benefited. The panty pattern is created with sparkle yarn the knitted on tube fabric which knitting with 63 dtex single cover and 66 dtex sparkle yarn. In the part that will go to fabric waste in the tube fabric, sparkle yarn is not included in the knitting. The tube fabric is knitted in a plain knit structure, which is the maximum width of 46 centimeters. As a result of the clothing trials of the first prototype panties obtained in this way, the flexibility and comfort properties were not found sufficient and it has been decided that this yarn combination is not suitable. In the first prototype study, the process of waist rubber to the waist part of the panties was applied with sewing as adding. This process increased labor and material costs. At the same time, the rubber added to the waist of the panties that panties leave a trace on garment. For this reason, it was decided to add rubber knitting to the tube fabric at the knitting stage. In this way, 18% reduction in cost was achieved.

Figure 1. a) One size product b) Silverly product c) Jacquard product.

Jacquard knit structures are used extensively in the production of hosiery. With this knitting structure, unlimited patterns can be created. Panty production trials were carried out with the jacquard knit structure in this study. Samples were prepared in selected patterns. It was observed that the panties prepared with jacquard knit structure could not reach sufficient flexibility in the clothing trials.

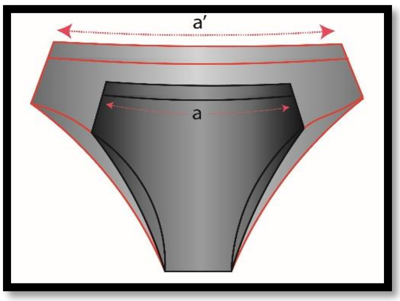

Figure 2. Stretching the product.

It has been decided to continue working with the knitting structure of the sock named "My Size One Size", which was previously developed and commercialized by Penti Socks R&D Center in order to ensure its flexibility. This sock is in plain knit structure. This sock is knitted with gipe which has the high breaking elongation property. This sock is obtained by combining 2 separate knitting tubes and the socks have a crotch seam. In this study, no stitching is required in the middle of the panty so panty was designed a single tube fabric. The panties are knitted with single cover yarn, which is obtained by covering with 44 dtex textured yarn of 44 dtex elastane consisting of '44EL LS/44/34T' yarn combination. '44 EL LS' elastane, which is used in single cover yarn production, has 460% break elongation. This feature has eliminated the flexibility problem of the panty sample. Although there is a more flexible knit types than plain knit structure, plain knit structure is used because of the other knit types create a problem of leaving marks on the garment. There are panties and wastage parts in the tube form fabric knitted in the knitting machine. In the garment stage, the tube fabric is brought to the form of panties with the sewing process and the waste part is separated. This separation is achieved by changing the knitting structure of the part that will go to waste in the first stage. The difference in the knitting structure disrupts the structure of the tube form. For this reason, different studies have been directed. The color of the marking yarns used can be changed according to the color of the tube fabrics. In this way, the visibility of the marking yarns on the tube-shaped fabric can be preserved.

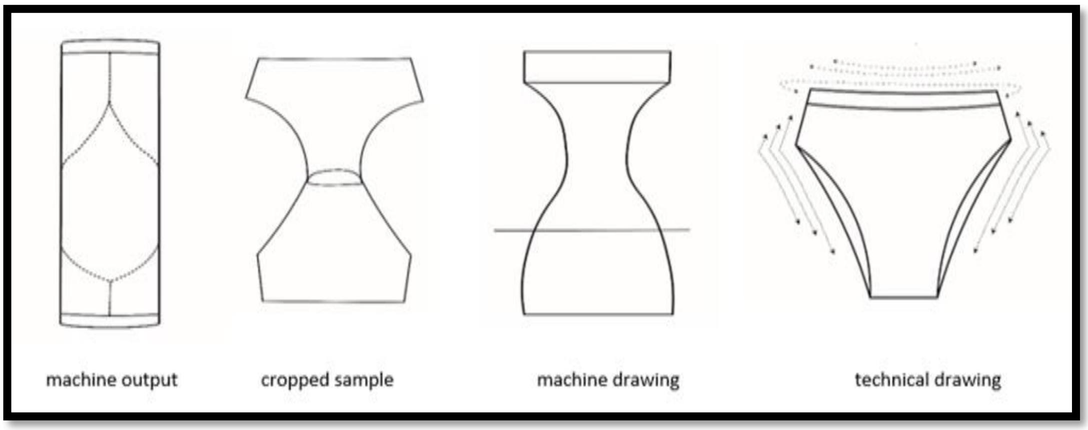

Figure 3: Product design stages.

In the second study, the area that was form the panties for the separation of wastage and panty pattern was marked on the tube fabric with 1x1 knitted marking lines. Tube fabrics are dyed before sewing processes. Metal complex dyestuffs were used in the dyeing process of fabrics. The fabrics dyed in the rotary dyeing machine are dried after dyeing and made ready for sewing processes. After the tube fabric is dyed, the marking lines has not been visible enough. Therefore, it was decided to change the marking lines. In the last study, the waste parts and the panty parts in the panty section were separated with different colored threads. Polypropylene yarn was used as marking thread. Thus, since the visibility of these yarns is very high, both the cutting process has been facilitated and the tube fabric form is preserved.

Figure 4. Separation with mesh structure.

Figure 5. Separation with sign yarn.

When the prepared product comes out of the knitting machine, it is in the form of a tube. This tube form is cut in half with using guillotine cutting machine to get open with fabric form. In order to cut the products in the form of underwear before the sewing process on the cut, the overlock machine without the sewing thread was applied for cutting purposes by following the hem edge traces instead of the traditional cutting processes. In sewing operations; Overlock stitching on the edge of the gusset piece, fixing the gusset piece on the panty edge with stitching, hem edge stitching in an overlock sewing machine with piping apparatus, side joining in a flatlock machine and edge reinforcement with bartack stitches were applied.

In the international clothing size standard, the difference between sizes in transverse measurement is ±4 cm for underwear. One size clothes must meet the +12 cm measurement difference in order to be compatible from size S to size XL. Many prototype underwears were produced according to the choices during the project process, and the first fitting tests were carried out on a live model. When the design, which was revised according to the fit trial results, was finalized, it was given to 15 different people in the XS-L size range, and the results of daily use were followed. And the panties developed in the project has met this size range.

3. RESULTS

Thanks to the project, a new workflow related to the production of panties in the sock knitting machine has been revealed, this innovation is based on the application of a different cutting method than the existing one, in order to develop the fabric of women's panties in the sock knitting machines and make them suitable for ready-made garments. As a result of many trials and tests, in order for the project to result in a product that can be commercialized, a flat knitted panty with a 460% stretch feature, a self-elastic waistband, and a non-marking panty that adapts to the S-XL size range was produced. As a result of the project, one size woman panty design and production with the hosiery knitting machine was successfully completed. The developed product has a similar appearance with one size woman seamless underwear and reflects the effect of thin hosiery in terms of delicacy and comfort. The product does not show any traces on the clothing when worn. The product has a 20-25% cost advantage over the one size seamless underwear product. Patent databases were searched for the product and production method developed within the scope of the project. Since no similar product or method has been found, a patent application has been made.

4. CONCLUSION

It has been noticed that the developments in socks machines in the literature are naturally on the production of socks and that these machines were not used to produce any other garments other than their purpose before. In the project, the production and design of women's panties were carried out by evaluating the hosiery machine in order to obtain a product different from its purpose. With different yarn choices, knitting structures, and panty models, a technique that is open to diversity has been put forward. The study laid the groundwork for new product trials in the future, such as underwear in the form of shorts, children's underwear and bikini bottoms.

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REFERENCES

[1] Felkin, W. (1967). *A history of the machine-wrought hosiery and lace manufacturers*. Burt Franklin.
[2] *Çorabin TARİHÇESİ. Çorabın Tarihçesi - Çorap Sanayicileri Derneği. (n.d.). Retrieved from http://www.csd.org.tr/corabin-tarihcesi*
[3] Marmaralı, A., & Encan, B. C. (2018). Pressure comfort of sock welts produced on single cylinder Sock Machine. *IOP Conference Series: Materials Science and Engineering*, *459*, 012052. https://doi.org/10.1088/1757-899x/459/1/012052
[4] Zhang, Z., Bai, S., Xu, G.-shen, Liu, X., Wang, F., Jia, J., & Feng, Z. (2020). Research on the Knitting Needle Detection System of a hosiery machine based on machine vision. *Textile Research Journal*, *90*(15-16), 1730–1740. https://doi.org/10.1177/0040517519899173
[5] Wu , X., Li, Y., Tian, J., Li, Z., Zhang, M., & Pan, J. (2022). Analysis of wearing comfort and permeation resistance of menstrual underwear. *Wool Textile Journal*, *50*(10), 107–112.
[6] Deng, P., Li, X., Wang, Y., He, Z., Zhu, W., Zhang, Y., Schalm, G. M., & Li, T. (2022, October 28). *Highly stretchable ionic and electronic conductive fabric - advanced fiber materials*. SpringerLink. Retrieved from https://link.springer.com/article/10.1007/s42765-022-00208-w
[7] Ning, D. A. I., Jiachao, Z. H. O. U., Laihu, P. E. N. G., Jiajia, T., Xudong, H. U., & Huimin, M. (2019). Research on grouped self-diagnosis control of seamless underwear machine solenoid valve. *2019 6th International Conference on Information Science and Control Engineering (ICISCE)*. https://doi.org/10.1109/icisce48695.2019.00169

THE EFFECT OF ALTERNATIVE LAMINATION MATERIALS ON THE AIR PERMEABILITY OF AUTOMOTIVE SEAT FABRIC STRUCTURES

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ABSTRACT

Automotive seat cover fabrics traditionally consist of woven or knitted face fabric, lamination foam and backing scrim. The usage purpose of the lamination foam is to increase the feeling of comfort by meeting the required resilience properties. Lamination foam is generally produced based on polyurethane, as this material successfully meet the low-cost expectations and necessary technical features. Although PU-based lamination foams generally meet automotive technical requirements, it is observed that they are not sufficient in terms of air permeability. For this reason, the sector has led to the need to research air permeable lamination material solutions for seats which are equipped with active ventilation devices. For this reason, open-cell lamination foam, reticulated foam, specially designed perforated foam, and multi-knit nonwoven structures that can be replaced traditional lamination foam may a place in the sector. In this study, the air permeability properties of the above-mentioned alternative lamination materials were evaluated, and a comparison was made with the traditional lamination foam.

Keyword: *Automotive seat cover, PU foam, Ventilated seat, Air permeability, Lamination materials*

1. INTRODUCTION

Automotive seat cover fabrics are traditionally produced as 3-component composite structures. These 3 components are the woven or knitted fabric on the upper surface, the lamination foam in the interlayer, and the circular or warp knitted backing scrim fabric on the backing layer [1]. It is aimed to meet the technical and aesthetic properties required for automotive in the production of upper surface fabrics. In order to meet these properties and provide cost advantage, PET-based yarns are generally used. The purpose of use of the lamination material in the interlayer is to increase the feeling of comfort by meeting the necessary resilience properties. Polyurethane foams are widely used as lamination material due to their ease of production, low cost and high resilience property. The purpose of use of the backing scrim fabric on the backing layer is to provide ease of trimming by reducing the friction forces during the trimming of the seat cover fabric to the seat foam. PET or PA yarns generally used of the production of this layer [1,2]. The most commonly used method for the lamination of the mentioned 3 separate components is the flame lamination technique. In the flame lamination technique, the upper and lower layers of the lamination foam are melted using flame and become sticky, so that the 3 components are strongly bonded to each other [2,3].

Today, rapidly developing technology has been created expectations for the development of comfort features as well as the technical and aesthetic features expected from automobile seats. Considering that

¼ of the passengers' bodies are in contact with the seat in the interior of the car, heat and humidity increason in the seats are the factors that disturb the people. Therefore providing thermal comfort is an important factor in terms of users' comfort satisfaction [4]. In order to increase the thermal comfort of the passengers, vehicles are equipped with heating, ventilation and air conditioning systems. Air conditioners generally aims to heat or cool the general environment of vehicle's cockpit. That logic doesn't aim to heat or cool directly the driver of passengers. It takes some time for the car to warm up or cool down, and if there are less than four people in the car, the idle areas are also heated or cooled. This means both a waste of time and a waste of extra energy. Therefore, active ventilation systems have become a good alternative in order to eliminate time loss, unnecessary energy consumption [5,6]. Active ventilation system uses a fan device which is placed inside the automotive seat cushion or backrest foam or under the seat. After the fan system is turned on, air is blown through the diffusion layer [7]. In vehicles which's seat are equipped with active ventilation system, a more porous and high air permeability construction should be used between ventilation devices and passenger contact area [5]. It has been observed that the PU lamination foam traditionally used in automotive seat covers does not have sufficient air permeability.

Today, materials with higher breathability and alternative to PU lamination foam have been the subject of research in order to make ventilated seat systems work more effectively [8]. Lamination materials that may have higher air permeability compared to traditional PU lamination foams are reticulated foams , open-cell foams, perforated foams and nonwovens. Open-cell and open-cell reticulated foams have more open structured than traditional PU foam. The pore sizes of these structures can be adjusted regarding to their utilization area. These products are mostly used for filtering fluids such as air or water which can can fully pass through [9]. Another method for the production of foam with high air permeability is the perforation process. Desired size holes are created in the foam structure with special blades or laser [10]. In recent years, nonwoven fabric has been used as an alternative to PU foam in order to ensure 100% recyclability in seat cover production. The nonwoven structure, which is aimed to be used instead of PU foam, should have similar mechanical properties with foam, especially in terms of resilience, and should meet the needs of the automotive industry in terms of weight, application and cost. Since 3D stitch-bonded (multiknit) nonwovens provide suitable resilience properties thanks to the piles in their structure, it is more suitable to use instead of foam than other nonwoven structures [11]. Within the scope of this study, airpermeability tests were performed on opencell foam, reticulated foam, perforated foam, multiknit nonwoven structures, and the traditional lamination foam. According to the test results, air permeability properties of 4 different lamination materials relative to each other and to PU foam were compared.

2. EXPERIMENTAL STUDY

2.1 Materials

In this study, PU-based open-cell foam, PU-based reticulated foam, PU-based perforated foam and PET-based multi-knit nonwoven materials that can contribute to air permeability of seat cover structure were used. These materials were supplied from manufacturers which serve to the automotive industry. Traditional PU lamination foam produced by Martur Sünger ve Koltuk Tesisleri A.Ş. was used to compare with alternative lamination materials which mentioned above.

Figure 1. PU lamination foam, perforated PU lamination loam, open-cell PU-based foam, reticulated PU-based foam, multiknit PET- based nonwoven.

2.2 Physical Properties of the Materials

The materials to be performed test were preferred with similar thicknesses in order to make an accurate comparison. The thickness and weight information of each material is given in the table below. These values are specified by products datasheets received from their suppliers.

Table 1. Thickness, density information of the used materials.

Material	**Thickness** (mm)	**Density** (Dens)
PU Lamination Foam	4.1	30
Perforated PU Lamination Foam	4.1	30
Open-Cell PU-based Foam	4	35
Reticulated PU-based Foam	4	35
Multiknit PET- based Nonwoven	3.8	65

2.2 Method

2.2.1. Thickness Measurement

Thicknesses have been measured to confirm the thickness information of the materials supplied and produced in accordance with DIN EN ISO 5084. The thickness (mm) was determined using thickness gauge for textile structures .The averages of five specimens were calculated for both measurements.

Figure 2. Thickness gauge.

2.2.2. Air Permeability Test

In order to determine the air permeability properties of five different materials, air permeability test was performed according to DIN EN ISO 9237 test standard. The air permeability values of the materials were determined by measuring the pressure of 200 Pa from a test area of 20 cm² in the test device. The test specimen is fixed to the air permeability device with one side facing the air inlet. Air is sucked from the test material. The air flow is adjusted to reach the expected pressure drop. The averages of five specimens were calculated for both measurements.

Figure 3. Air permeability machine.

3. RESULTS&DISCUSSIONS

According to the thickness measurement results given in Table 2 below, a major difference was not seen from the comparison to thickness values given by the suppliers.

When the air permeability test results were checked, it was determined that the most air permeable material was reticulated foam. After reticulated foam, the most air permeable materials are multiknit nonwoven, opencell foam and perforated foam. The air permeability of the traditional lamination foam was lower than each alternative material.

Table 2. Thickness measurement of 5 different lamination materials

Measurement Type	Traditional PU Foam	Perforated PU Foam	Opencell PU Foam	Reticulated PU Foam	Multiknit Nonwoven
Thickness (mm)	4,14	4,12	4,01	4,04	3,68
	4,14	4,13	3,98	3,74	3,89
	4,15	4,12	4,12	3,96	3,87
	4,18	4,09	4,03	4,16	3,68
	4,21	4,03	4,02	4,17	3,85
Average value	**4,16**	**4,09**	**4,03**	**4,01**	**3,79**
CV%	0,65	0,89	1,19	3,92	2,47

Table 3. Air permeability test result of 5 different lamination materials

Measurement Type		Traditional Foam	Perforated Foam	Opencell Foam	Reticulated Foam	Multiknit Nonwoven
Air Permeability (l/m²/s)		855,86	930,28	3901,28	3901,28	1892,65
		857,85	925,65	3968,12	3968,12	1816,62
		860,03	928,86	4202,12	4202,12	1804,48
		858,01	927,35	3758,35	3758,35	1726,37
		857,96	925,98	3972,53	3972,53	1814,74
	Average value	**857,942**	**927,624**	**1312,30**	**3960,48**	**1810,97**
	CV%	0,15	0,18	0,21	3,62	2,91

4. CONCLUSION

Within the scope of this study, four different lamination materials, which are able to be a good alternative in terms of air permeability to traditional polyurethane foam were compared. When the results are evaluated, each alternative materials to PU foam shows that higher air permeability. The air permeability of reticulated foam is the most successfully meets the required air permeability values. The usage of multiknit nonwoven as lamination material also can be a good alternative to PU foam air permeability.

In this study, air permeability measurements of lamination materials used in automotive seat cover structures were evaluated. The effect of the upper surface fabric and lamination method was not considered. The upper surface fabric and lamination method may have an effect when it is considered that traditional automotive seat cover fabrics are used with combination of face fabric and its lamination materials by processing it with a convenient lamination process.

REFERENCES

[1] Omerogullari Basyigit, Z., (2019). Improvement of Multifunctional Automotive Textile. *Textile and Apparel*, *29*(2), 113-120.
[2] Siyao, M., Liu, S., Peihua, Z., & Hairu, L. (2020). Functional Investigation on Automotive Interior Materials Based on Variable Knitted Structural Parameters. *Polymers*, *12*(11), 2455.
[3] Aksoy, S., Işılak, C., Ertürk, S., Oylar, S. & Mecit, D. (2021). Investigating the Effect of Fabric and Lamination-Foam Properties on the Air Permeability of Laminated Headrest Fabrics. *Textile and Apparel*, *31*(4), 235-241. doi: 10.32710/tekstilvekonfeksiyon.812489
[4] Berber, R. Ö., Marmaralı, A., & Ertekin, G. (2014). Otomobil Döşemeliklerinde Yüksek Isil Konfor Sağlayacak Sünger Ve Astar Özelliklerinin Belirlenmesi.
[5] Jadhav, O. A., & Chaitanya, S. V. (2018). Next Generation Automotive Seat Cover to Improve Thermal Comfort Using Thermoelectric Effect. *Journal of Manufacturing Engineering*, *13*(4), 236-240.
[6] Cengiz G., Babalık F. (2006). Klimalı otomobil sürücü koltuğunda termal konforun vücudun aynı transversal ve aynı vertikal eksendeki noktalarında deneysel incelenmesi. *Endüstri Mühendisliği*, *17*(1), 2 - 12.
[7] Anonim, https://blog.toyota.com.tr/koltuk-isitma-koltuk-sogutma-sistemleri-nasil-calisir/)
[8] Mazari, F. B., Mazari, A., Cirkl, A., Havelka, A. (2020). Comparison of different interlining materials of car seat cover under repeated loadings. *Industria Textila*, *71*(3), 199-203.
[9] https://urosan.com.tr/en
[10] Mazari, F. B., Chotebor, M., Naeem, J., Mazari, A., & Havelka, A. (2016). Effect of perforated polyurethane foam on moisture permeability for car seat comfort. *Fibres & Textiles in Eastern Europe*, (6 (120), 165-169. doi: 10.5604/12303666.1221752
[11] Handbook of nonwovens Edited by S. J. Russell.

3D GARMENT SIMULATION AS A TOOL TO ACTUALIZE THE DESIGN IDEAS OF FASHION STUDENTS

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ABSTRACT

This study explores how fashion design students perceive using 3D garment simulation to create their design ideas. As a part of an elective course taught in Fall 2022, twelve students were given a project to prepare virtual and physical garments of their design. The study had two parts: First was understanding students' expectations about 3D garment simulation before starting the project, and second was understanding students' experience after completing the project and comparing their before and after project experiences. Accordingly, a structured questionnaire measured on a seven-point Likert scale was applied to the students before starting their project to see their self-confidence of using 3D garment simulation, and after the project to understand their self-evaluations of their performance and difficulties they encountered during the project. The first part of the study presented here shows that students had a high self-confidence (M=5.16) that they will successfully apply their project digitally and it will be similar to their physical garment (M=5.50). Still, they were not so confident if the digital garment would be visually satisfying (M=4.92). Students were highly convinced that using 3D garment simulation is very useful (M=6.42) to visualize their projects before starting to work on it and they had high intention (M= 6.00) to use it in the future. After project results showed that students self-evaluated their performance higher than before project expectations. Students' evaluations for the perceived usefulness of 3D garment simulation to visualize their project and intention to use it in the future dropped after the project (M= 6.17 and M=5.75, respectively). Finally, students had the most difficulty creating the patterns and achieving the correct digital fit.

Keywords: *3D garment simulation, Digital fashion, Design education, Self-confidence, Technology acceptance model*

1. INTRODUCTION

Even though 3D garment simulation has existed commercially for over a decade, its use in the fashion industry widened in the last two to three years. Parallel to it, fashion design educators had to adopt using digital tools to retain teaching the courses which were normally studio-based in nature. 3D garment simulation was already being used by some universities, but the need has drastically increased after the COVID-19 pandemic. Nowadays, students and instructors are adapting to 3D garment simulation as a tool for designing clothes instead of or together with flat pattern making, draping, and tailoring. Traditionally, in fashion design education, students start with a design idea, followed by technical and artistic sketches and prototyping. However, due to the pandemic, many restrictions of this process outstood for students to actualize these traditional design steps. For instance, many students didn't have patternmaking tools, a dress form, or a sewing machine in their homes. Moreover, they couldn't go out to buy fabrics. However, 3D garment simulation allowed students to create patterns using a keyboard, sew them digitally, and use digital fabrics from a digital library. Many fashion design departments are now transforming to fully or partially digital fashion design education. However, research [1-3] is ongoing to understand students' expectations of this transformation.

The primary research purpose of this study was to measure students' attitudes toward using 3D garment design software to actualize their design ideas. To do so, twelve fashion design students who took the class 3D garment design during the 2022 Fall semester were asked to participate in the experiment. The 3D garment design course was conducted remotely; however, the midterm project and final project presentations were done face to face. The students' project consisted of two parts. In the first part, students were asked to design a women's garment to achieve a casual look. After getting confirmation from the instructor about their sketches, they started to study the creation of the digitals of the garments. In the second part, students were asked to prepare the actual clothes. The comparison between a real and virtual prototyping process from the students' perspective was evaluated as an experimental study. On the other hand, the technical difficulties during the digital prototyping process and how it was handled by the students and the instructor were addressed.

2. EXPERIMENTAL STUDY

The students used Browzwear VStitcher 3D Garment Simulation Software 2021.2 version for their digital projects. In the first ten weeks of the semester, students joined the online classes to learn how to use the program and how to improve their 3D design skills. In addition to this teaching process, students were granted full access to Browzwear University, which has all the necessary information to create a digital garment from basic to advanced. Besides, a three-hour workshop was organized with a VStitcher expert to advance students' 3D skills. At the end of this training period, students reached a certain level of knowledge about the program and were ready to create their digital projects.

At the beginning of the project, students created technical and artistic sketches of their project and brought the trims and fabrics they planned to use to get the instructor's approval. The instructor guided the students about how they could achieve the desired look in 3D as a starting point. Later, students were asked to bring fabric samples for physical testing in FAB (Fabric analyzer instrument developed by Browzwear to test bend, shear, and stretch of the fabrics) and visual testing in Vizoo (a texture creator instrument that works with scanning principle) to achieve the best images for the digital garment. The test results obtained from FAB and Vizoo were shared with students for use in their projects.

In addition to the digital design process, students produced their real garments by preparing the patterns (either directly on VStitcher, or manually by using flat pattern making or draping technique and digital table). Students were not limited to designing the digital first and the real garment after or vice versa. However, the deadline for creating the digital garments was earlier than the submission of physical garments, which encouraged students to develop the digitals first, like industrial applications. The project started on November 2022 and took approximately two months to finish.

To achieve the research goal of this study, descriptive research as the quantitative method was followed. The data were collected via structured questionnaires that consisted of multiple-choice questions (seven-point Likert Scale) and open-ended questions that were designed to measure constructs of students' satisfaction with using 3D garment simulation for fashion design education and practices, challenges of using 3D garment simulation as a design tool, the comparison of actual and digital prototyping process in terms of production time, visual quality of the end product, costs of the prototyping process.

Besides, a comparison of students' self-confidence in the tasks of the project before starting the project and their outcomes after the project were compared. To do so, two questionnaires (before and after project) were applied online using Google Forms.

3. RESULTS

All registered students agreed to participate in the research study; therefore, the sample number in the study was twelve. The first questionnaire was applied to the students before they started their project but after they had completed their training. According to the results of this first questionnaire, the majority of the students (n=5) more or less agreed that they could create the digital garments successfully; however, four of them doubted if it would be visually satisfactory, but still, more than half (n=7) of the students thought, at different extends that they would achieve a good visual standard. Most students (n=10) expected, to different extents, that their physical and virtual garments would be similar. Students' confidence that they could produce digital garments successfully was lower (M=5.17) than their confidence in making their physical garments successfully (M=5.50). The results showed that most of the students were committed to the project. Only one student hasn't done research before starting the project by looking at the trims and fabrics offered by the software or browsing the internet to see what the program provides for designers. The other students had done research to different extents before starting the project. While choosing their project ideas, most students (n=10) considered the difficulty/easiness of creating the patterns, and almost all of them (n=11) chose fabrics and trims like the ones in the library of software.

The second questionnaire was applied after students finished their projects. According to the results of this second questionnaire, most students (n=9) think they created digital garments successfully. However, four students were neutral as to whether they were satisfied with their project's visual quality, while eight were satisfied to different extents. Most students (n=10) thought, to different extents, that their physical and virtual garments were similar at the end of the project.

On the other hand, this study questioned if students would use the 3D garment creation software in the future. Before the project and after the project results were different. Agreement to use 3D garment creation software in the future was lower for after project results than before project results (M= 5.75 and M=6.00, respectively). Similarly, agreement for the usefulness of creating digital garments to visualize the imagined garments before its production was lower for after project results than before project results (M= 6.17, M=6.42, respectively).

Table 1. Before and after project evaluations of the students.

	Item	**Mean (Standard Deviation) (1: Completely disagree, 7: Completely agree)**
Performance	(Before project) I can apply my project digitally VStitcher successfully.	5.17 (0.94)
	(After project) I applied my project digitally VStitcher successfully.	5.42 (1.24)
	(Before project) I can produce the garments that I have designed for my project successfully.	5.50 (1.31)
	(After project) I produced the garments that I designed for my project successfully	5.83 (1.11)
	(Before project) The digital project I will design in VStitcher will be visually satisfying	4.92 (1.16)
	(After project) The digital project I designed in VStitcher is visually satisfying	5.50 (1.17)
	(Before project) The digital garment that I will create will be similar to the real garment that I will produce	5.50 (1.00)
	(After project) The digital garment that I created is similar to the real garment that I produced	5.75 (1.22)

Perceived usefulness	(Before project) I think that creating digital garments is very useful to visualize the products we have imagined in our mind even before its production	6.42 (0.67)
	(After project) I think that creating digital garments is very useful to visualize the products we have imagined in our minds even before their production	6.17 (1.03)
Intention to use digital garment creation	(Before project) I think that I will use digital garment creation in the future as well	6.00 (0.95)
	(After project) I think that I will use digital garment creation in the future as well	5.75 (1.54)

Moreover, to understand the difficulties that students had while creating their digital garments, additional questions were asked. According to the answers given in Table 2, students struggled most with creating the digital patterns (M=4.58) and least with creating the fabric texture (M=3.00). According to the answers to the open-ended question of the same query, "fitting" was the most used word by students to point out the most significant problem they had during digital garment creation, followed by the phrase "digital stitching."

Table 2. Difficulties encountered by students during the creation of the digital garments by using VStitcher as the 3D garment simulation software and the mean scores measured.

	Item	Mean (Standard Deviation) (1: Completely disagree, 7: Completely agree)
1	Creating digital patterns was difficult.	4.58 (1.88)
2	Fitting the digital garment was difficult.	4.25 (1.06)
3	Creating the simulation was difficult.	4.25 (2.01)
4	Creating the styling was difficult.	3.58 (1.08)
5	Creating the visual details (light, pose, shadows, etc.) was difficult.	3.67 (2.02)
6	Creating the fabric texture was difficult.	3.00 (1.04)
7	Creating the trims; zippers, buttons, accessories, etc. was difficult.	4.33 (1.97)
8	Digitally stitching the garment was difficult.	3.83 (2.17)

The money spent to produce the physical garments was asked in the after project survey. Students spent 25 USD on average to prepare their physical garments (Min: 7.5 USD, Max: 100 USD). Also, the time spent on the digital and physical projects was asked. However, the answers to this open-ended question didn't give any reliable and measurable results (i.e., approximately two weeks, more than a month, etc.) since students spread finishing the project over two months. However, a subject-by-subject comparison of the time spent on digital and physical garments showed that students spent more time on physical projects than digital ones (except three students). For example, the student who spent three days on his digital project said he prepared the physical garment in two weeks.

a. b.

c.

Figure 1. Physical and digital clothes examples from three different students' projects.

Besides the matters that students self-acknowledged, the instructor observed some additional points. The first observation was about the fabric's physics and texture. Even if the fabrics had been tested via FAB and Vizoo, some students were not satisfied with the drape and/or the fabric texture obtained from the test instruments. They preferred to use the available fabrics in the program library and modify them according to their own fabric. The second observation was about the accessories that were not in the program's library (i.e., safety pins, special design buttons, etc.) or any complicated details such as laced back. Students would have found/created these accessories through additional sources (i.e., other 3D object creation programs, the internet offering already created 3D objects). However, instead of this option, students preferred to change their designs even if they would get a lower grade upon any changes made to the initial design (See Figure 1.c where the lacing at the back and the bones at the front of the corset have been canceled on the digital look). The final observation was about the fabric folds and drapes. As given in Figures 1a, 1b and 1c, the folds and the wrinkles of the real garments were more visible than the digitals, the digitals had a very flat and smooth look, flawless even, and this issue was also addressed by one student.

Finally, Table 3 shows students' answers to the fashion design curriculum-related questions.

Even though students almost completely agreed (M=6.42) that 3D garment simulation is a useful tool to visualize their design ideas (Table 1), they disagreed that this tool could neither replace the real garment-making process nor replace the flat patternmaking class that is traditionally though in fashion design education (Table Y). On the other hand, students were more positive towards replacing 2D digital patternmaking teaching with 3D garment design teaching (M=3.75).

Table 3. Mean scores obtained from after project survey to fashion design curriculum-related questions.

	Item	Mean (Standard Deviation) (1: Completely disagree, 7: Completely agree)
1	Creating digital garments instead of real garments is enough for fashion design education.	2.50 (1.24)
2	3D virtual garment design class can replace the flat patternmaking class).	2.58 (1.16)
3	3D virtual garment design class can replace the 2D digital patternmaking class (i.e., Lectra, Gerber, etc.)	3.75 (2.01)

4. CONCLUSION

According to the analysis of the results, some points stood out to be discussed further. As given in Table 1, before and after project answers of the students differed. Before starting the project, students had lower confidence in whether they could successfully create the digital look, if the digital clothes would be visually pleasing and similar to the physical one. However, upon completing the project, their answers to the same questions showed that their satisfaction levels exceeded their expectations. Bandura (1977) described self-confidence as a person's confidence in his/her capabilities to accomplish a task [4]. People's self-confidence depends on many variables, including expertise on the topic, previous experiences of success and failure, and task difficulty [5]. In this study, students' self-confidence for items listed in Table 1 was higher (M>5.00) than the average (M=4.00). This might be related to students' gained experience due to the ten weeks of the training session they have received.

As documented well by Druckman et al., 1994, self-confidence is an essential mediator in performing towards achieving a goal [6] which simply can be translated as self-confidence helps people reach their goals [7]. When this relationship is assessed for this study, the students' high (M>5.00) self-confidence in that they could apply the digital project and produce the garment successfully might have reflected on their performance. However, it should be noted that the performance measured in this study was students' self-evaluation of their own performance. On the other hand, subject by subject comparison of students' project grades (instructor's evaluation) and their self-confidence on the measured constructs (success of the digital clothes, physical clothes, their visual quality and their similarity to each other) showed that students with higher self-confidence performed better which supports the earlier findings [7].

On the other hand, interestingly, students' belief in the usefulness of 3D garment simulation to visualize their project ideas and their intention to use it in the future had dropped. The relationship between a new technology and its acceptance is well documented by the Technology Acceptance Model (TAM) which shows the perceived usefulness and perceived ease of use of a technology, translating to a behavioral intention to use it [8]. The study results reported in Table 2 and answers to open-ended questions showed that students had some difficulties (perceived ease of use) while preparing their digital projects. This issue might have lowered their evaluations of the usefulness of the technology and their intention to use it in the future.

As given in Table 2, preparing the digital patterns and fitting them on the avatar was the most challenging aspect of the program, according to students. Even if the software shows the fit changes instantly when a pattern is altered, students have difficulty achieving the correct fit. According to the instructor's observation, this was related to the lack of students' patternmaking knowledge and expertise to analyze fit problems and offer solutions to solve them rather than the technical insufficiency of the program. On the other hand, most of the students had different design details or accessories they initially wanted to use. Still, they later decided not to use them as they struggled to create them digitally. However, more committed students (measured according to the self-reported time spent on the project and research done by the student before starting the project) achieved the desired details (trims or patterns) even if it required searching for community help to solve the problems. Although the program, VStitcher 2021.V2, offers a limited set of trims and accessories in the library and every new version of the software library being upgraded, many alternative ways exist to find/create/modify the desired look in case enough time is spent on it. One of the advantages of 3D garment simulation software is the shortening of the prototyping process. However, this advantage becomes vague if the garments have some design details, such as complicated patterns or some unusual accessories. On the other side, in this study, the advantage of 3D garment simulation programs to reduce the costs of garment making was confirmed since 25 USD average production cost which is high for a student (5% of the minimum wage as of Feb 2023) for doing the project has been omitted for its digital twin.

This study was an exploratory study to understand students' attitudes towards using 3D garment simulation software to actualize their design ideas during their university education.

This study can benefit educational institutions that are inevitably incorporating 3D garment design education into their curriculum after the pandemic to understand students' expectations, self-evaluations, and difficulties they encountered while working with 3D garment simulation software. One of the conclusions of this study was that even if students were convinced of the usefulness of the 3D garment simulation technology and had a high intention to use it in the future, they opposed it could replace traditional pattern-making education. During the COVID-19 pandemic, 3D garment simulation was offered as an alternative to studio-based courses in fashion design education and after the pandemic, many digital fashion design bachelor's courses have been established [9]. Even if 3D garment simulation was a temporary solution for education to continue in extraordinary conditions, this study showed that it is not a replacement for studio-based pattern making and garment-making courses according to the students, and the results of this study showed that merely a digital fashion education would not be favorable for students.

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REFERENCES

[1] Baytar, F. (2018). Apparel CAD patternmaking with 3D simulations: impact of recurrent use of virtual prototypes on Students' skill development. International Journal of Fashion Design, Technology and Education, 11(2), 187–195.

[2] Adams, M., & Alexander, L. (2018). Technology and studio classes: Teaching flat pattern in a digital world. International Journal of Design Education, 13(2), 21–27.

[3] Gu, L., & Liu, X. (2019). Online Fashion Design Education Supported by Digital Three Dimensions Technologies. Advances in Social Science, Education and Humanities Research, 286 (Seiem 2018), 575–577.

[4] Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84(2), 191–215.

[5] Bandura, A. (1986). Social Foundations of Thought and Action: A Social Cognitive Theory. Englewood Cliffs, NJ: Prentice Hall.

[6] Druckman, D., & Bjork, R. A. (1994). Self-Confidence and Performance. In Learning, remembering, believing: Enhancing human performance (pp. 194–195). essay, National Academy Press.

[7] Woodman, T., & Hardy, L. (2003). The Relative Impact of Cognitive Anxiety and Self-Confidence upon Sport Performance: A Meta-Analysis. Journal of Sports Sciences, 21, 443-457.
[8] Davis, Fred & Davis, Fred. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly. 13. 319-. 10.2307/249008.
[9] Barrera, T. (2022, May 31). The best 3D & Digital Fashion Design Courses in 2022. The Tech Fashionista. Retrieved February 18, 2023, from https://thetechfashionista.com/best-digital-fashion-courses/

INVESTIGATION OF r-PET FIBERS AND FILAMENTS TO BE USED IN OUTDOOR TEXTILE PRODUCTS

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ABSTRACT

Outdoor textiles need to be resistant to harsh environmental conditions. It is observed that textile materials used outdoors lose their properties, degrade and lose their structural integrity in a short time, especially with the effect of oxygen, UV and humidity. It is also an important problem that the colors fade with these external factors. In this project, first of all, color masterbatches were created with dyes and stabilizers that can offer superior color fastness, and the properties of the sample fabrics to be produced from them were examined to ensure color fastness standards. The results of sea water fastness, color fastness to chlorinated water and color fastness to light are given in detail in the article.

Keyword: *Outdoor Textiles, r-PET, color fastness, sea water fastness, chlorinated fastness*

1. INTRODUCTION

Textile products have been an indispensable part of our lives throughout the history of humanity. It has been widely used for personal or objective warming, cooling, drying and aesthetic purposes. It can facilitate human survival, growth and development through personal thermoregulation, such as human skin and the surrounding environment, and blocking the cold wind in winter and sunlight in summer. However, global warming and extreme weather conditions have become increasingly severe over the past century due to the accumulating greenhouse effect, leading to increased demand for advanced functional textiles that can provide better personal comfort, health and safety.

UV radiation, which is generally caused by the sun's rays we encounter in outdoor environments, has negative effects on many products. The negative effects of daylight, when combined with other outdoor conditions such as temperature and humidity, create permanent effects on the chemical and mechanical properties of organic materials [1].

The protection factors of the fabrics depend on the fiber type, yarn type, surface structure, color, moisture content, the finishing process and the wear condition during use. These are important factors affecting UV transmittance. The degree to which any fabric reflects, transmits and absorbs UV rays determines its sun protection properties. In other words, permeability, reflectivity and absorption depend on fiber, fabric structure (thickness and porosity) and finishing [2].

The usage rates of textile materials, which add visuality and comfort to daily life, have increased considerably in recent years, as well as indoors, outdoors such as gardens, restaurants, hotels, where they are constantly exposed to sunlight, rain, sea and pool water [3]. Accordingly, studies have started to develop alternative products to acrylic fibers, which show UV resistance due to their structure. In particular, PET fibers have started to come to the fore in this market with the use of masterbatch products to provide various structure modifications and production processes that create cost advantages. However, more importantly, it gives the properties of color fastness to artificial light, sea water fastness and color fastness to chlorinated water to the filament and fabric obtained from PET wastes released after industrial and personal use.

When the behavior of textile products against external effects is examined, exposure times to sunlight and some artificial lights have a negative effect on their lifetime. UV radiation causes the chemical bonds in polymeric structures to break down. This phenomenon is called photodegradation. The term photodegradation refers to the reactions that take place in an oxygen-free environment, photooxidation, and the changes that occur in polymers under the influence of light in an atmosphere with oxygen [4].

At the molecular level, many polymers have bond energies in the wavelength range of 290-400 nm. They are severely affected by this range of wavelengths of solar radiation. Photodegradation begins with the absorption of photon energy by the polymer and activation of the molecular chain [5]. In some cases, UV radiation is absorbed by photoinitiators rather than directly by the polymer. Photoinitiators initiate degradation by converting to free radicals in the presence of UV radiation. The reason for the complex changes observed in the physical and chemical properties of the material as a result of degradation is the combination of UV radiation, oxygen, temperature, humidity, wind and other environmental factors [1]. Sunlight, air and pollutants initiate photodegradation, but water, organic solvents, temperature and many mechanical factors accelerate this process.

In this study, r-PET filament with increased resistance to UV radiation by using zinc oxide (ZnO), filament and fabric with high color fastness and UV resistance, resistant to environmental conditions, were developed in outdoor textiles. Finishing chemicals are applied to these fabrics. Applications have been made to outdoor textile products by treating the surface covered by the textile product with finishing materials to protect it from sea and chlorinated water. Then, color fastness to artificial light, sea water fastness and color fastness to chlorinated water were analyzed.

2. EXPERIMENTAL STUDY

In this study, UV masterbatch composites were formed by adding 3% by weight of polybutylene terephthalate (PBT) polymer and zinc oxide to obtain the masterbatch. The created UV masterbatch composites were mixed with r-PET flake and colored masterbatch composite at certain ratios (Table 1). This mixture was worked in the sample filament forming machine at 12-18 rpm engine speed and 2.5 rpm melt pump speed. The temperature values of the extruder are 130 °C, 285 °C, 285 °C, 285 °C, 295 °C and 295 °C, respectively. Godet speeds are 600 rpm, 650 rpm, 1900 rpm and 2050 rpm, respectively. Godet 2 is 100 °C, Godet 3 is 130 °C. The winder speed is 2090 rpm. The obtained filaments were brought into fabric form in the sample knitting machine. The tension of the machine is 4 and the speed is between 40-60 rpm.

Table 1. Mixing ratios of sample filaments.

	COLOR MASTERBATCH (%)	UV MASTERBATCH (%)	R-PET FLAKE (%)
00	0	0	100
01	0	2	98
02	3	3	94
03	3	5	92
04	3	7	90
05	3	9	88

After the color intensity of the sample was determined, the color was kept constant at 3%. UV masterbatch additive was added as 2%, 3%, 5%, 7% and 9% quantitatively. The remaining part is completed with r-PET fake.

Finishing chemicals (RD - AD729) were applied to the knitted fabrics at the rates of 5%, 10% and 15% to increase sea and pool water fastness. It was then dried in stenter at 150 °C.

Color fastness to light is made with Xenon arc lamp according to EN ISO 105-B02 test standard. Made with Atlas BETA Xenon lamp light fastness device. The withering cycle was performed according to the A1 (Temperate zone) condition. Color fastness to chlorinated water was made with 20 ppm active chlorine according to ISO 105 E03 test standard. Sea water fastness is made according to EN ISO 105-E02 standard.

3. RESULTS

6 different types of samples, coded 00, 01, 02, 03, 04 and 05, were prepared in the sample filament machine. 72x2 filament round spinneret was used as a spinneret. These samples were studied in the machine under equal working conditions. The effect of color masterbatch and UV masterbatch added into it on the working process has been observed. No negative effect was observed on the working process as the UV masterbatch ratio increased. The resulting filament is 3 denier.

00, 01, 02, 03, 04 and 05 coded samples were knitted on a circular knitting machine at a tension of 40 and 60 rpm. While preparing the sample knit fabrics, unevenness was observed in some parts of the fabrics with difficulties due to the high denier of the filaments. However, this problem has been overcome by taking samples from suitable places while analyzing color fastness to light, color fastness to chlorinated water and seawater fastness.

Samples coded 01, 02, 03, 04 and 05 were cut in dimensions of 20 cm x 10 cm. Then the weights of these samples were measured. A solution of 5%, 10% and 15% was prepared with the chemical RD-AD729. Samples 01, 02, 03, 04 and 05 were applied to these solutions.

Color fastness to light, color fastness to chlorinated water and seawater fastness analyzes of the chemically applied samples were performed. Color fastness to light analysis was performed according to the EN ISO 105-B02 test standard. Atlas BETA Xenon lamp light fastness device was used in this analysis. The withering cycle was performed according to the A1 (Temperate zone) condition. Color fastness to chlorinated water was determined according to ISO 105 E03 test standard. Analysis was done with 20 ppm of active chlorine. Sea water fastness is made according to EN ISO 105-E02 standard.

When the seawater color fastness results were examined, it was seen that all of the fabrics formed from the filaments obtained from the PET wastes released after industrial and personal use were 4-5 (Table 2).

Table 2. Color fastness to sea water.

	01	**02**	**03**	**04**	**05**	
FASTNESS	4-5	4-5	4-5	4-5	4-5	CA
	4-5	4-5	4-5	4-5	4-5	CO
	4-5	4-5	4-5	4-5	4-5	PA
	4-5	4-5	4-5	4-5	4-5	PES
	4-5	4-5	4-5	4-5	4-5	PAN
	4-5	4-5	4-5	4-5	4-5	WO
	4-5	4-5	4-5	4-5	4-5	*

When the color fastness results against chlorinated water were examined, it was seen that all of the fabrics formed from the filaments obtained from the PET wastes released after industrial and personal use were 5 (Table 3).

Table 3. Color fastness to chlorinated water.

	01	02	03	04	05
FASTNESS	5	5	5	5	5

The results of color fastness to light were examined. Here the results are compared with the reference blue wool (4/4). When the results were examined, it was seen that all of the fabrics formed from the filaments obtained from the PET wastes released after industrial and personal use were 5 (Table 4).

Table 4. Color fastness to light.

	01	02	03	04	05
FASTNESS	5	5	5	5	5

4. CONCLUSION

The aim of this study is to develop products that can be used outdoors, the filament and fabric obtained from PET (r-PET) wastes released after industrial and personal use. For this purpose, r-PET filament with increased resistance to UV radiation by using zinc oxide (ZnO), filaments and fabrics that are resistant to environmental conditions and have high color fastness and UV resistance have been developed in outdoor textiles. Applications have been made to outdoor textile products by treating the surface covered by the textile product with finishing materials to protect it from sea and chlorinated water. Then, color fastness to artificial light, sea water fastness and color fastness to chlorinated water were analyzed. As a result of these analyzes, the color fastness to artificial light, sea water fastness and color fastness to chlorinated water of fabrics formed from r-PET filaments are successful.

REFERENCES

[1] Yılmaz, N. D. (2020). *Ultraviyole Işınlara Karşı Dayanımı Arttırılmış Polietilen Tereftalat (Pet) Ipliklerin Dış Ortam Şartlandırma Testi Sonucunda Mekanik Özelliklerindeki Değişimin Incelenmesi* (Doctoral dissertation, Bursa Uludag University (Turkey)).
[2] Yıldırım, Ş. (2006). *Mayoluk Kumaşlarda UV-Absorblayıcılarının Uv Geçirgenliğine, Koruma Faktörüne, Hava Geçirgenliğine Isı Geçirgenliğine Ve Diğer Kumaş Özelliklerine Etkisi* (Doctoral dissertation, Marmara Universitesi (Turkey)).
[3] Serpil, K. O. C., & YILMAZ, N. D. (2020). HPT türevi UV absorblayıcıların PET iplik ve kumaşların UV dayanımı üzerine etkilerinin incelenmesi. *Avrupa Bilim ve Teknoloji Dergisi*, 276-282.
[4] DEMİR, A., Oektem, T., & Seventekin, N. (2008). The Effect of UV absorbers on light fastness of reactive dyed cotton fabrics. *Textile and Apparel*, *18*(3), 211-220.
[5] Rabek, J. F. 1995. Polymer Photodegradation Mechanisms and Experimental Methods.Chapman & Hall Publishing, London, UK, 664 pp.

INFLUENCE OF CARBON FIBER NON-CRIMP FABRICS STITCHING PARAMETERS ON THE OUT-OF-PLANE PERMEABILITY IN LIQUID COMPOSITE MOLDING PROCESS

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ABSTRACT

The widespread use of carbon-fiber-reinforced plastics (CFRP) has attracted many industries such as defence, aerospace as well as in sailboats, automotive, rotor-blades, where high strength-to-weight ratios are required. For the aerospace and defence customer today, the importance is no longer just on minimum weight and therefore performance, but primarily on cost of ownership. Textile manufactured composites, particularly of non-crimp fabric (NCF) type offer significant cost savings in terms of reduced labor time and higher deposition rates over the unidirectional prepreg tape which is the most traditional method. Vacuum assisted infusion method is the most used production technic in CFRP parts which also offers high fiber ratios. The most important goal is the impregnation of carbon fiber package in through-the-thickness direction to get good quality parts in infusion. The behaviour of the impregnability depends mainly on the out-of-plane permeability of the fabric. The fiber type, orientation of the fibers, and the stitching parameters, mainly influences the permeability of the fabric. In this study, the influence of textile parameters on the out-of-plane permeability of UD (unidirectional) carbon fiber NCF was investigated. The stitching yarn parameters (stitch pattern, stitch tension and stitch length) were varied to see the influence on the out-of-plane permeability. The out-of-plane permeability was measured using a tailored visual flow front monitoring method by measuring resin flow distance on X and Y axes of the fabric during infusion. The results show that the out-of-plane permeability of the UD (0°) carbon fibre NCF are significantly affected by the stitch pattern, stitch tension and stitch length.

Keyword: *CFRP, NCF, Stitch, Permeability*

1. INTRODUCTION

Due exceptional properties such as its high-temperature resistance, mechanical characteristics, and relatively lower price, the demand for carbon fiber has been increasing over the past years. Carbon fiber is the most used fiber in the defense & aeronautical fields due to its stiffness and resistance combined with a low specific weight. The most traditional method for the production of complex parts is to use unidirectional fiber prepreg tapes arranged in a suitable lay-up in a mold and cured in an autoclave. This process has been successful and widespread until now in these industries. However, this manufacturing system represents one of the most important cost items in the production of components in composite materials. In addition, the prepreg materials are expensive and require storage in freezers and accurate control of exposure times at room temperature [1]. As the defense & aerospace industries, move to consider larger structural parts, alternative and cheaper, manufacturing approaches are increasingly sought for commercial applications. Therefore, interest has increased in the use of dry fabrics that allow the construction of preforms of varying complexity coupled with manufacturing based on liquid composite molding (LCM) methods. Liquid composite molding consists of a variety of composite manufacturing processes where the liquid state matrix material (e.g., epoxy resin) is forced into the dry reinforced reinforcing material (e.g., carbon fiber fabric). LCM methods comprise resin transfer molding (RTM), vacuum-assisted infusion, and injection compression molding (ICM).3 The main goal is to achieve complete impregnation as the resin flows between the bundles of fibers [2].

Non-Crimp Fabrics (NCF), whose structure leads to a synergetic effect of high material properties and excellent drape performance, has received much attention over recent years (Figure 1). The NCFs show some reduction in performance as compared to those derived from pre-pregs mainly because of the lower fiber volume fractions and the use of lower-performance resins suitable for infusion. The fiber over resin percentage may be enhanced by reducing the tow spacing and by improving the stitching architecture as well the overall manufacturing process, leading to a product of comparable performance but cheaper than those from pre-pregs [3, 4].

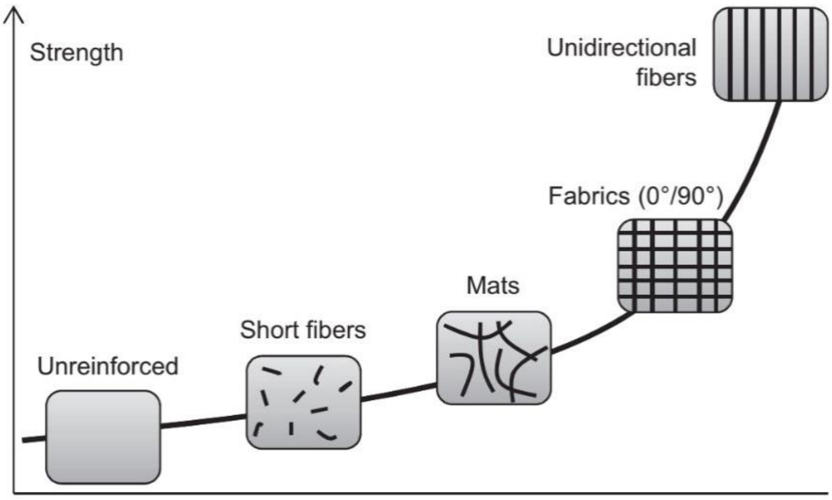

Figure 1. Strength comparison of reinforcements.

Non-crimp fabric (NCF) composites are built from multiaxial textile preforms with fiber tows stitched or warp-knitted together into a directionally oriented structure (Figure 2.).

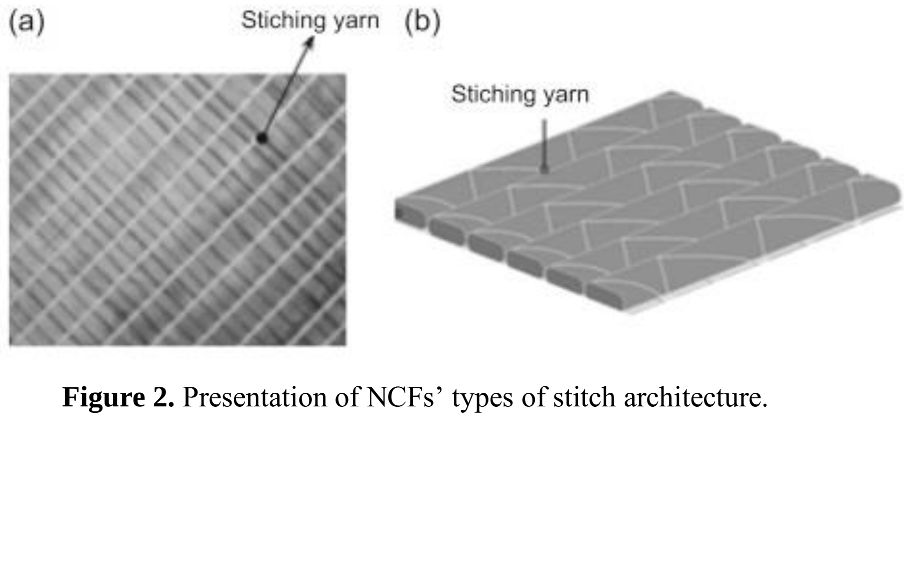

Figure 2. Presentation of NCFs' types of stitch architecture.

The goal of the study is the selection of an optimized stitching architecture in carbon fiber UD NCF, regarding impregnation behavior during permeability test [5-8]. Therefore, the cycle time for impregnation of the textile can be shortened.

2. EXPERIMENTAL STUDY

2.1 Materials

In this study the out-of-plane permeability of carbon fiber UD NCF is presented. The stitching parameters to investigate influence on permeability were chosen as stitch pattern, stitch length and stitch tension, in this study. Stitch parameter details are presented in Table 1. All NCFs have a 620 g/m² total areal weight consisting of 3750 tex (50K tow) carbon fiber on 0° direction, 68 tex E-Glass fiber on 90° direction and 7,5 tex polyester stitching yarn. As the matrix material epoxy resin is used.

Table 1. Investigated **s**titching parameters.

STITCH PATTERN	STITCH LENGTH	STITCH TENSION
Pillar	3,1mm	LOW
Tricot	3,3mm	MEDIUM
Pillar-Tricot	3,6mm	HIGH

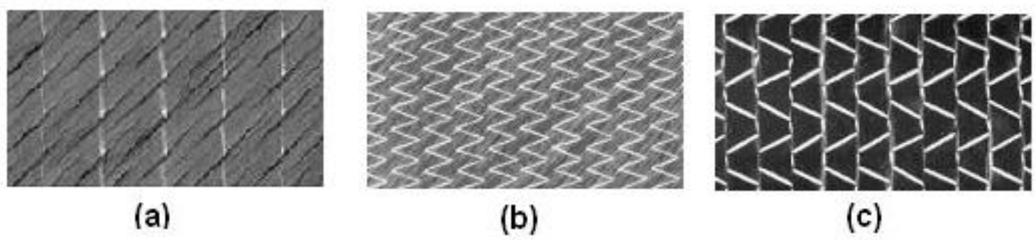

Figure 3. Examples of stitching patterns for non-crimp fabrics: chain stitched (a), tricot stitched (b) and tricot-chain stitched (c). (Copyright Katleen Vallons [9]).

2.2 Test system set-up

The permeability was measured via vacuum infusion method with central resin feeding, surrounded vacuum channel placement. 10 layers of fabric were placed on center of prepared area then covered with transparent vacuum film. After vacuum applied, visual track of the flow front was performed while the resin moves from center to the edges through the fiber stack. The infusion parameters such as mold temperature, vacuum pressure, resin feeding positions are constant for all measurements.

Figure 4. Representation of permeability test system set-up.

2.3 Calculation

The resin track distance were measured periodically on X, X', Y, Y' axes by getting the origin as the starting point. Flow front charts were created with distance-time curves for X and Y axes for comparison. The thickness and fiber percentages also measured and included in comparison tables.

3. RESULTS

Permeability test shows that tricot stitch pattern has higher resin flow speed then those of pillar tricot and pillar, See Figure 5.

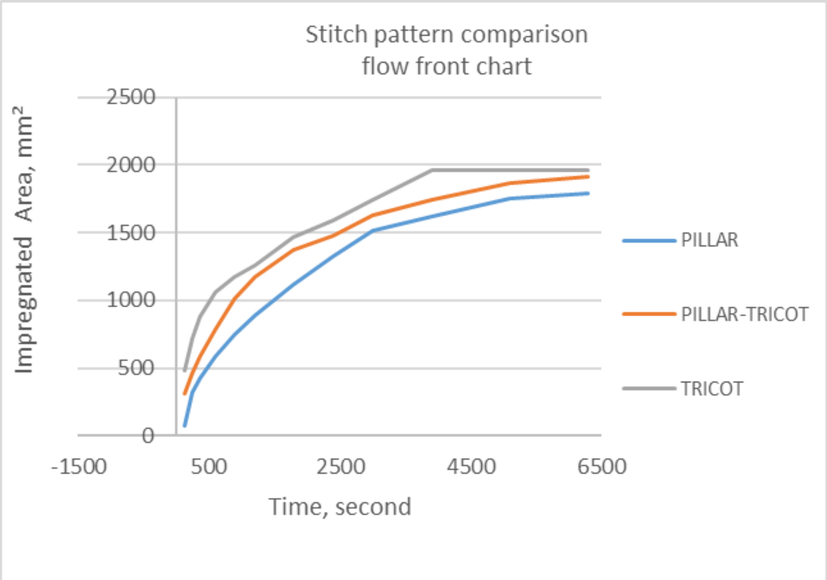

Figure 5. Stitch pattern flow front chart.

In the comparison of stitch tension tests tricot stitched UD NCFs were used. While low stitch tension is giving the lowest resin flow speed, Medium and High tensions shown higher flow speed and close flow front properties each other, See Figure 6. To see the stitch tension influence on fiber content, fiber weight ratios were measured and compared. Although it was observed that stitch tension differences did not have the most significant effect on the fiber ratio, it was observed that high stitch tension decreased the fiber ratio, while low tension had an effect in the direction of increasing the fiber ratio, See Figure 7. Both results can be associated with the fact that the gaps between the fiber bundles that might be created by stitch tension can create paths through which the resin can pass and accelerate the flow. Figure 8. is the schematic presentation how the gaps between fiber bundles might be formed due to stitch tension [5].

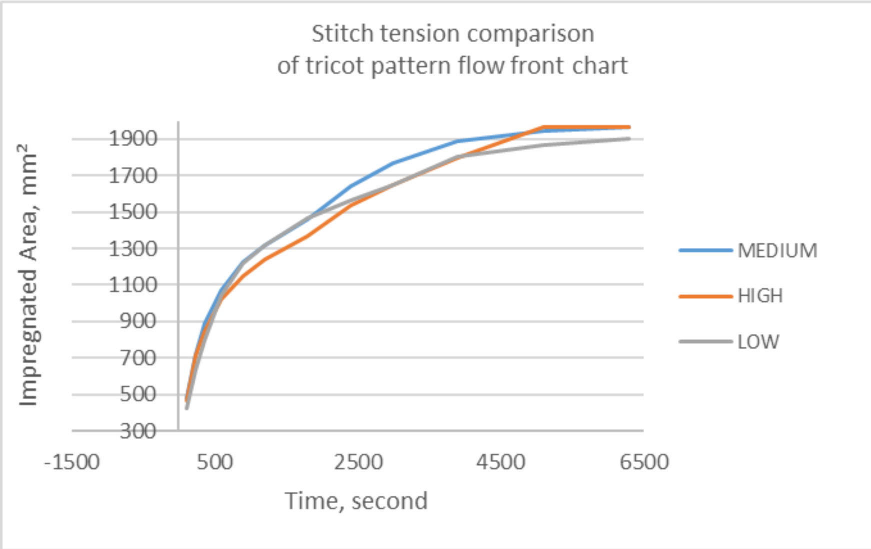

Figure 6. Stitch tension flow front chart.

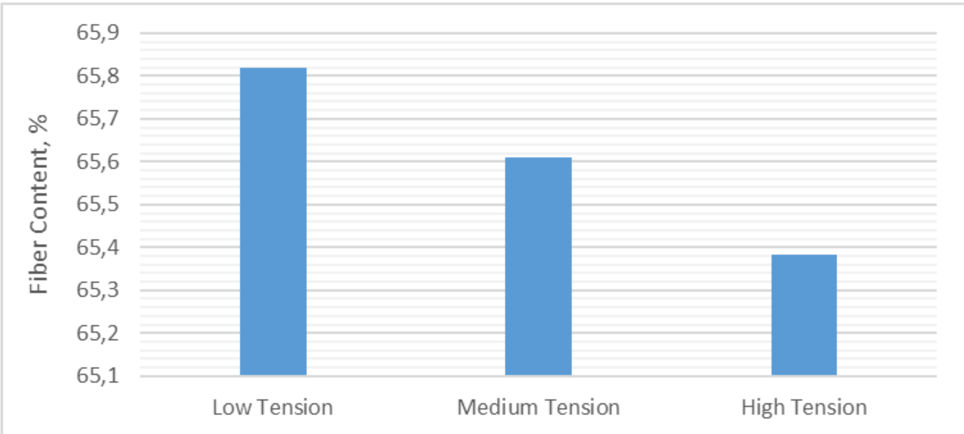

Figure 7. Stitch tension effect on fiber weight content in composite part.

a) b) c)

Figure 8. Presentation of gap formation between bundles due to stitch tension in NCF high tension b) medium tension c) low tension.

There is no dramatic effect observed on In the stitch length trials, on X axis direction larger stitch length (3,6 mm) shown the highest speed, while there is no much significant difference between other lengths respectively 3,1 mm and 3,3mm, see Figure 9. In Y axis trial, larger stitch length (3,6 mm) shown the highest speed and the 3,1 mm stitch length shown very low flow speed with 3000 seconds to impregnate all fiber stack area, see Figure 10.

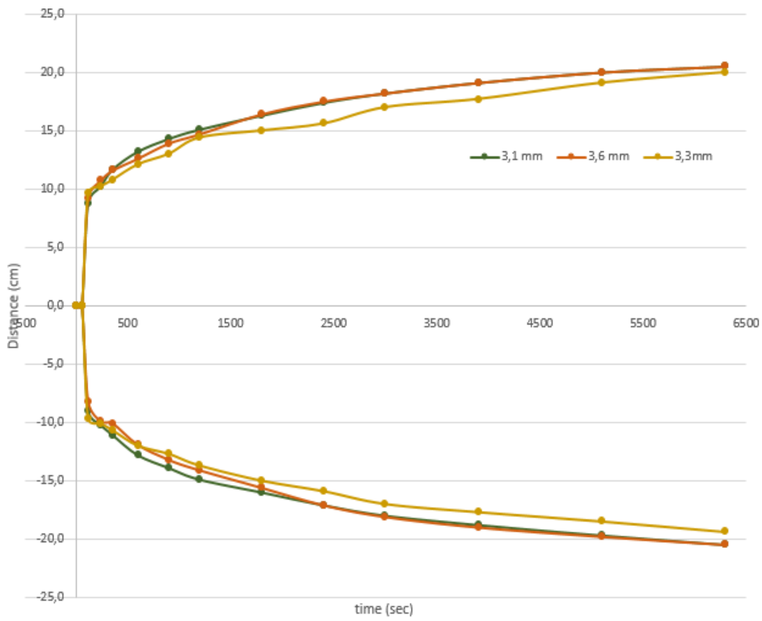

Figure 9. Stitch length X, X' axis flow front.

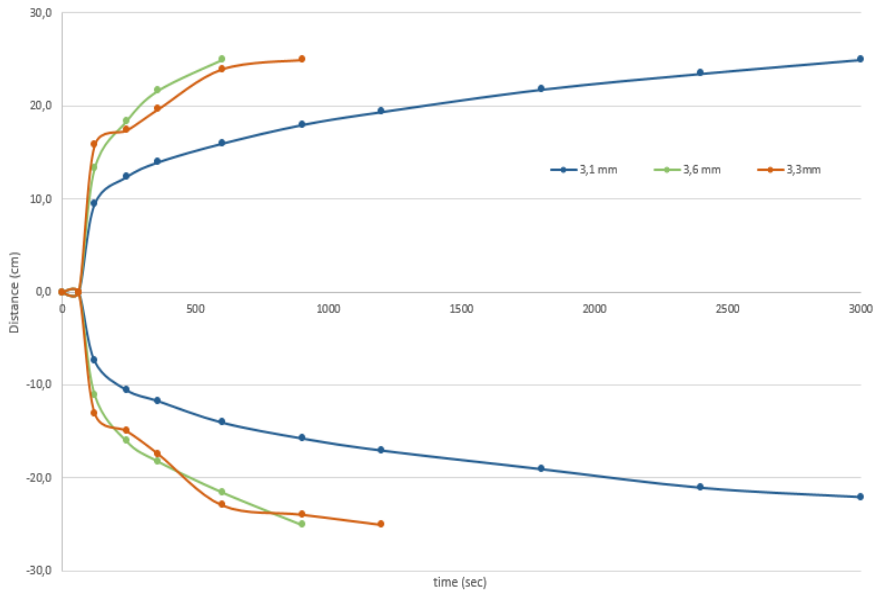

Figure 10. Stitch length Y, Y' axis flow front.

4. CONCLUSION

This paper presents an experimental investigation on the effects of stitch pattern, stitch length, and tension, on the permeability of unidirectional carbon fiber NCFs during vacuum infusion process.

The results imply that impregnation quality of NCF is not affected from stitching architecture. In contrast, the permeability speed is sensitive to the stitch pattern, stitch length and stitch tension, respectively.

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REFERENCES

[1] Ekuase O. A., Anjum N., Eze V. O. and Okoli O. I. (2022). A review on the out-of-autoclave process for composite manufacturing: Journal of Composite Science 6, 172.
[2] Lepore M., Ferrante L., Sanguigno L., Malign A. (2021). A non-crimp fabric mechanical characterization for the production of aerospace components: Material Design & Processing Communications 3(4): Wiley Report.
[3] Carvelli V., Lomov S. (2015). Fatigue of Textile Composites (chapter 12: Fatigue of Non crimp fabric composites., pp. 274-278).
[4] Bel, S., Hamil, N., Boisse, P. (2017). *Characterization of non-crimp fabric deformation mechanisms during preforming.* LaMCoS 2017, 18th International Conference on Composite Materials, INSA-Lyon, France.
[5] Colin D., Bel S., Hans T., Drechsler H.&K. (2020). Virtual description of non-crimp fabrics at the scale of filaments including orientation variability in the fibrous layers: Applied Composite Materials, 27, 337-355.
[**6**] Leif E. A, Edgren, F., & Sjögren, A., (2004). Effects of stitch pattern on the mechanical properties of non-crimp fabric composites. Engineering, Paper 6.
[**7**] Tanaka K., Tokura D., Katayama T., (2014). Effect of stitch tension of non-crimp fabric on the mechanical properties of CFRTP. Engineering, 331-335
[8] Arnold, M., Gortner, F., Cojutti M., Wahl M., Mitschang P. (2016). Influence of Textile parameter on the out of plane permeability of carbon fiber non-crimp fabrics. Advanced Composites Letters, 25(5), 121-126.
[9] Vallons K. (2009). *The behaviour of carbon fibre epoxy NCF composites under various mechanical loading conditions. Advanced Composites Letters* [Katholieke Universiteit Leuven].

WOVEN FABRIC DESIGN WITH KNITTING SEERSUCKER EFFECT

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ABSTRACT

Nowadays, the increasing social consciousness on the protection of nature and, at the same time, the seeking for comfort and easiness caused by the pandemic, increase the interest in easy-to-use, comfortable textile products produced with natural raw materials. Seersucker woven fabrics are highly preferred in recent years due to their features such as providing wearing comfort and being user-friendly by not requiring ironing. However, in order to provide the three-dimensionality/wrinkle effect in woven seersucker fabrics in the currently used methods, it is necessary to use elastane in the weft/warp or to use double beams during production. At this point, it is not possible to produce completely natural fabric in the method using elastane, and in the other method, a special several warp and machine requirements are emerging. In this study, the literature on seersucker fabrics was reviewed and experimental seersucker weaving applications were carried out. Studies have been carried out in order to produce fabrics using completely natural raw materials (cotton), to improve production efficiency and to increase design possibilities. In this context, instead of the traditional methods used in seersucker fabric creation, seersucker fabric production was carried out with a single beam on the weaving machine by using different weaves in the dobby for fabric design. In this way, it has been provided that the seersucker weaving process can be performed with a single beam on any desired machine by using existing direct warps without the need for a special warp preparation.

Keyword: *Woven Fabrics, Seersucker Fabrics, Elastane Free Seersucker Fabrics*

1. INTRODUCTION

Seersucker fabrics are thin, lightweight, comfortable fabrics with a striped appearance and a wrinkled, textured surface, usually produced by the combined use of cotton and synthetic yarns [1,2]. Some researchers qualify these fabrics as 3D fabrics [3].

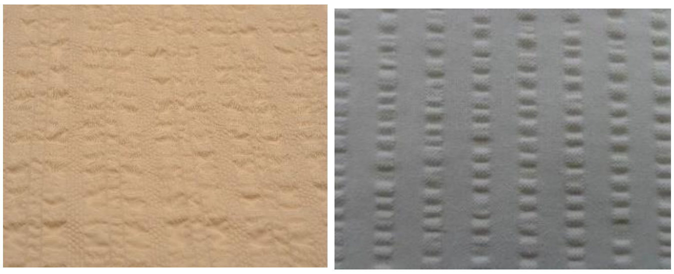

Figure 1. Seersucker Fabric Samples [3,4].

Since these fabrics are lightweight, have a wrinkled appearance, and have different moments woven loosely and tightly, they are generally used in the production of summer clothing. The puffy parts on the fabric surface create air pockets and keep the wearer cool in hot weather. Seersucker fabrics are ideal fabrics for the production of skirts, summer dresses, blouses and shirts [1,5]. In recent years, studies have been carried out to improve the surface and comfort properties of seersucker fabrics [6-8].

Currently, several different methods are used in seersucker fabric production. Usually, as a result of combined weaving of two warp yarns of different tensions or weft and warp yarns of different tensions, wrinkle effect is obtained on the surface by the tension differences between them. [1,2]. In the method where two warp beams with different tension are used, one beam carries the warp yarns that will form the flat (basic) strip appearance and the other beams carry the warp yarns that will form the shirred strip appearance. During the weaving process, the warp yarns that will create the shirred appearance are adjusted so that they are fed faster than the other warp yarns. This causes different tension of the warp threads and subsequently, a localized wrinkling of the fabric occurs in the areas with fast-feeding yarns. As a result, shrinking and flat strips are formed on the fabric surface in the warp direction. This kind of shrinkage on the fabric surface is called the seersucker effect. This type of fabric cannot be produced on conventional weaving looms with a single beam [2,5]. For this method, a special weaving loom that can be worked with double beam is required [1]. The use of elastane yarn in seersucker fabric production is also a method that has been widely used in recent years. Apart from these, seersucker effect can be created on fabrics with some finishing and printing processes after weaving [9].

In the study, it is aimed to produce fabrics with seersucker effect with completely natural raw materials without the necessity for double beam and without using elastane. In this context, fabrics using different weave values in dobby were designed, the trials of these designed fabrics on the template loom were carried out in the product design department of Akın Tekstil AŞ., and sample production was carried out by Akın Tekstil AŞ. for the model study in which the seersucker effect was obtained visually, and post-washing shrinkage, washing fastness, dry/wet rubbing and strength tests were applied.

2. EXPERIMENTAL STUDY

In the study, three different knitting compositions were designed to give this effect on the fabric surface in order to create the Seersucker effect. Trials of these three different compositions were produced on template looms. Figure 2 and Figure 3 illustrate the examples of fabric experimentations with different compositions.

Figure 2: Fabric trials with different weave composition.

(P1) (P2) (P3)

Figure 3: Different prototype studies produced on hand loom.

Wrinkle effect was obtained on the fabric surface in all experiments. However, in one of them (P3), a surface appearance having the surface appearance of the fabric produced by other conventional methods was obtained. The fabric (P3) in the knitting composition, in which the desired seersucker effect is achieved; Ne50/1 and Ne30/1 combed cotton yarns were woven on 2022 model Picanol Optimal weaving machines using a single beam. Raw and finished fabric samples are illustrated in Figure 4.

(a) (b)

Figure 4: (a) Raw seersucker fabric sample (b) Finished seersucker fabric sample.

Post-washing dimensional change, washing fastness, dry and wet rubbing fastness, rupture and tear strength tests were performed on the produced fabrics. Dimensional change measurements of the samples were made by washing under "delicate" conditions and “line drying” application in accordance with AATCC 135 standard. Washing fastnesses were measured in James Heal Gyrowash 1615 device according to AATCC 61 standard. Tensile strength test was performed on James Heal Tinius Olsen apparatus in accordance with ASTM D5034 standard and tear strength test was performed on James Heal ElmaTear apparatus in accordance with ASTM D1424 standard.

3. RESULTS

It was possible to obtain a wrinkle effect on the fabric surface in each of the different experiments carried out in line with the design studies. However, in one of them, the fabric surface was obtained in the usual seersucker image and this work was produced in finished form. There was no change in the seersucker appearance of the fabric after dyeing and finishing. The washing, rubbing and strength test results were complied with the standards and the fabric weight obtained was within the desired values. The values of the test results are given in Table 1 below.

Table 1: Test results for the finished seersucker fabric.

Dimensional Change (%)		**Washing Fastness**	**Rubbing Fastness**		**Tensile Strength (kg)**		**Tear Strength (g)**	
Warp	Weft		Dry	Dry	Warp	Weft	Warp	Weft
-4	-2,5	5	4/5	4/5	62,8	61,5	1675	1330

4. CONCLUSION

Seersucker fabrics have been in increasing demand in recent years due to their features such as being light, having good comfort properties, not requiring ironing thanks to their wrinkled surface appearance and thus being user-friendly. However, the increasing level of consciousness in the society about sustainability and the desire of consumers to return to natural lifestyles lead to the preference of products produced with natural raw materials in textile products. Seersucker fabric production is currently possible with different methods. However, in these methods, it is required either to use elastane yarns produced with synthetic raw materials or to have a special machine park that can work with double beam. In this study, it is aimed to produce seersucker fabrics without elastane and without the need for double beams. For this purpose, different fabric compositions were designed and sample productions of the designed fabrics were carried out. As a result of the experiments, it was seen that the seersucker effect was realized to the expected extent in the designed fabrics. The fabrics designed with the use of completely natural raw materials can be produced and commercialized. At the same time, seersucker production can be carried out on every machine when necessary with the method put forward in the study and the designed fabric weave compositions, and thus production efficiency can be increased. As such, the study offers an alternative method and design proposal to the methods currently used in seersucker fabric production. It is believed that the study will be a source for future academic and sectoral studies.

REFERENCES

[1] Maqsood, M., Nawab, Y., Javaid, M.U., Shaker, K. & Umair, M. (2015) Development of seersucker fabrics using single warp beam and modelling of their stretch-recovery behaviour, *The Journal of The Textile Institute*, *106*(11), 1154-1160. doi: 10.1080/00405000.2014.977542

[2] Matusiak, M., & Frączczak, Ł. (2016). Influence of kind of weft yarn on properties of the seersucker woven fabrics. *AUTEX Research Journal, 16*(4), 214-221. doi: 10.1515/aut-2016-0021

[3] Frączczak, Ł., Rafał, D., Piotr, Z., & Matusiak, M. (2019). Parameterization of seersucker woven fabrics using laser techniques. *Autex Research Journal*, *19*(3), 243-249. doi: 10.1515/aut-2018-0042

[4] Kumaş Fırsatı Web Sitesi, Gofre Kumaş Örneği, (2022, December 28). Retrieved from: https://www.kumasfirsati.com/tr/gofre-kumas-bej/u/37194

[5] Matusiak, M. (2021) *Comfort-Related Properties of Cotton Seersucker Fabrics. AUTEX Research Journal*. doi:10.2478/aut-2021-0049

[6] Matusiak, M., & Bajzik, V. (2021). Surface characteristics of seersucker woven Fabrics. *Autex Research Journal*, *21*(3), 284-292. doi: 10.2478/aut-2019-0079

[7] Frączczak, Ł., & Matusiak, M. (2021). Influence of the structure of seersucker woven fabrics on their friction properties. *Autex Research Journal*, *21*(1), 85-91. doi: 10.2478/aut-2019-0063

[8] Matusiak, M. (2022) Investigation of Surface Geometry of Seersucker Woven Fabrics. *AUTEX Research Journal*. doi: 10.2478/aut-2022-0023

[9] Ghahraman, F. G., Tavanai, H. & Hosseini, S. A. (2010). A qualitative assessment of seersucker effect through spectral density and angular power spectrum function algorithms, *The Journal of The Textile Institute*, *101*(3), 276-281. doi: 10.1080/00405000802399536

[10] AATCC 135 (2018t). Test Method for Dimensional Changes of Fabrics after Home Laundering.

[11] ASTM D5034 (2021).Standard Test Method for Breaking Strength and Elongation of Textile Fabrics.

[12] ASTM D1424-21 (2021). Standard Test Method for Tearing Strength of Fabrics by Falling-Pendulum (Elmendorf Type) Apparatus.

[13] AATCC 8 (2016e). Test Method for Colorfastness to Crocking: Crockmeter.

[14] AATCC 61 (2020). Test Method for Colorfastness to Laundering: Accelerated.

FABRICATION OF BIODEGRADABLE NANOFIBROUS MEMBRANES OF PLA/PBAT POLYMER BLENDS

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ABSTRACT

In this study, morphological and thermal characteristics of biodegradable polylactide (PLA)/ poly(butylene adipate-co-terephthalate) (PBAT) based nanofibrous membranes were investigated. To prepare electrospinning solutions, PLA grades of 4032 and 6252, having different melt flow rates (MFR), were blended with PBAT at a concentration of 10% (wv^{-1}) and dissolved in a solvent system of dichloromethane (DCM)/ dimethyl sulfoxide (DMSO). The prepared solutions were electrospun by using a single syringe electrospinning setup. The morphological and thermal structure of the nanofibrous membranes were characterized via Scanning Electron Microscopy (SEM) and Differential Scanning Calorimetry (DSC), respectively. In morphological analysis, it was observed that PLA4032/PBAT blends produced smooth fibers, whereas the fiber production from PLA6252/PBAT polymer blends could not be achieved due to an insufficient number of entanglements in the polymer solution. DSC results showed that the glass transition temperature of the PLA did not change with an addition of 25% wt. PBAT, indicating the immiscibility of PBAT and PLA. In addition, cold crystallization temperature was decreased approximately 10°C, which could be related to the presence of more free volume created by PBAT molecules initiating cold crystallization of PLA earlier. However, crystallization degree of PLA reduced with an addition of PBAT into the structure.

Keyword: *PLA, PBAT, biodegradable, nanofibrous membranes, electrospinning*

1. INTRODUCTION

Since it is derived from natural resources, and hence is biodegradable, polylactide (PLA) has increasingly drawn much interest in the development of sustainable materials. PLA can be used by blending it with soft polymers to overcome its brittleness, which is one of the major drawbacks. Poly(butylene adipate-co-terephthalate) (PBAT), a flexible and biodegradable polymer [1], is a suitable candidate for use in a blend with PLA. PLA/PBAT blends have been extensively studied in the production of polymeric films [2,3]. However, the use of PLA/PBAT blends in the electrospinning process has not been studied until 2018. In the first study in this field, Khatsee et al. [4] reported the solvents in which the PLA/PBAT blends dissolved properly, and the most uniform fiber morphology was obtained. Then, the effect of polymer concentration and polymer blend ratios on the thermal and mechanical properties of the produced nanofibrous mats were investigated. Followingly, four more studies on the use of PLA/PBAT blends in the electrospinning method were published between 2018-2021 [5-8]. However, in these studies, instead of blending PLA and PBAT polymers during the production, a polymer containing 55% PBAT and 45% PLA by weight, commercialized by BASF under the name Ecovio®, was used. While the high cost of this polymer limits its use for large-scale industrial applications, the constant blending ratio of the polymers in its content does not allow for different designs to be made during the production to improve the final properties [9]. In this study, PLA grades of 4032 and 6252, with different MFR values, were blended with PBAT at different weight ratios in dichloromethane (DCM)/ dimethyl sulfoxide (DMSO) binary solvent system. The morphological and thermal characteristic of the produced nanofibrous membranes were reported.

2. EXPERIMENTAL STUDY

2.1 Materials

Semicrystalline PLA grades with low D-lactide content (%) were supplied from NatureWorks LLC (USA). PBAT Ecoflex F Blend C1200 was supplied from BASF (Germany) (Table 1). Dichloromethane (DCM, 99% purity, ISOLAB) and dimethyl sulfoxide (DMSO, 99% purity, ISOLAB) were used as solvents (Table 2).

Table 1. Properties of the polymers.

Grade	D-content (mol %)	Melt flow rate g/10min (210^{o}C)
PLA 4032	1.4	7-10
PLA 6252	1.4	70-85
PBAT C1200	-	2,7-4,9

Table 2. Properties of the solvents.

Solvent	Boiling Point (°C)	Dielectric constant (ε)
DCM	40	8.93
DMSO	189	46.7

2.2 Methods

The polymer solutions were prepared by dissolving PLA/PBAT polymers (10% wv^{-1}) in DCM/DMSO solvent system for 3.5 hours at 30°C using a magnetic stirrer according to the determined polymer solution parameters and levels (Table 3). An electrospinning device (Inovenso Nanospinner24) was used to produce nanofibrous membranes. The voltage, tip-to-collector distance and feed rate were 20 kV, 13 cm and 1.3 ml/h, respectively.

The morphology of the produced nanofibrous mats were analyzed using Tescan Vega3 scanning electron microscope (SEM). Before imaging, samples were coated with gold (Au)/palladium (Pd) for 2 min. The diameter of nanofibers were measured using ImageJ software. 100 measurements were taken on each sample, and mean nanofiber diameters were calculated.

A differential scanning calorimetry (DSC), Perkin Elmer DSC400, was incorporated to analyze the thermal and crystallization behavior of the electrospun mats. The sample weight was kept constant around 4 mg for all samples. The samples were heated from 20°C to 200°C at a heating rate of 10°C/min and then cooled to 25°0 at a rate of 5°C/min, then re-heated to 200°C at a rate of 10°C/min. The initial temperature for the electrospun mat comprising PBAT polymer was -40°C. Crystallization and melting enthalpies were calculated and the degree of crystallinity was calculated using equation (1). In the equation, ΔHm is the melting enthalpy and ΔHcc is the cold crystallization enthalpy, and the Xc% value gives the percentage of crystallinity. A 100% crystalline melting enthalpy (ΔH_0) was taken as 93 J/g for PLA.

Table 3. Factors and levels.

	Levels	
Factors	**Low Level (1)**	**High Level (2)**
Polymer blend	PLA4032/PBAT	PLA 6252/PBAT
PLA/PBAT ratio	75/25	100/0
DCM/DMSO ratio	75/25	100/0

$$X_c\,(\%) = \left[\frac{\Delta H_m - \Delta H_{cc}}{\Delta H_0}\right] \times 100 \qquad \text{Eq. 1}$$

3. RESULTS

3.1. Morphological Analysis

SEM images of the produced nanofibrous membranes were given in Figure 1, whereas the mean fiber diameters with the sample numbers were given in Table 4. As could be compared in the SEM images (4, 5 and 8), when PLA6252, with a high MFR value, was used, the fiber production was achieved only for sample 8. It could be related that at the polymer concentration of 10 wt%, a sufficient number of entanglements did not form in the polymer solutions prepared from PLA6252 due to the high MFR of the polymer. Therefore, it would be better to increase the polymer concentration in the solutions, containing PLA6252, above 10%. On the other hand, at the same polymer concentration, all polymer solutions comprising PLA4032, with a low MFR value, produced fibers. As could be compared in Table 4, the mean fiber diameter of sample 1 is lower than that of sample 3 since the addition of DMSO, with a high dielectric constant (Table 2), into the polymer solution resulted in the polymer jet carrying more free charge and stretching more under an electric field. On the other hand, even if the mean fiber diameter of the samples 6 and 7 were quite similar to each other, the SEM image of sample 7 displayed bead formation due to its polymer solution prepared by using 100% DCM, having a low dielectric constant (Table 2).

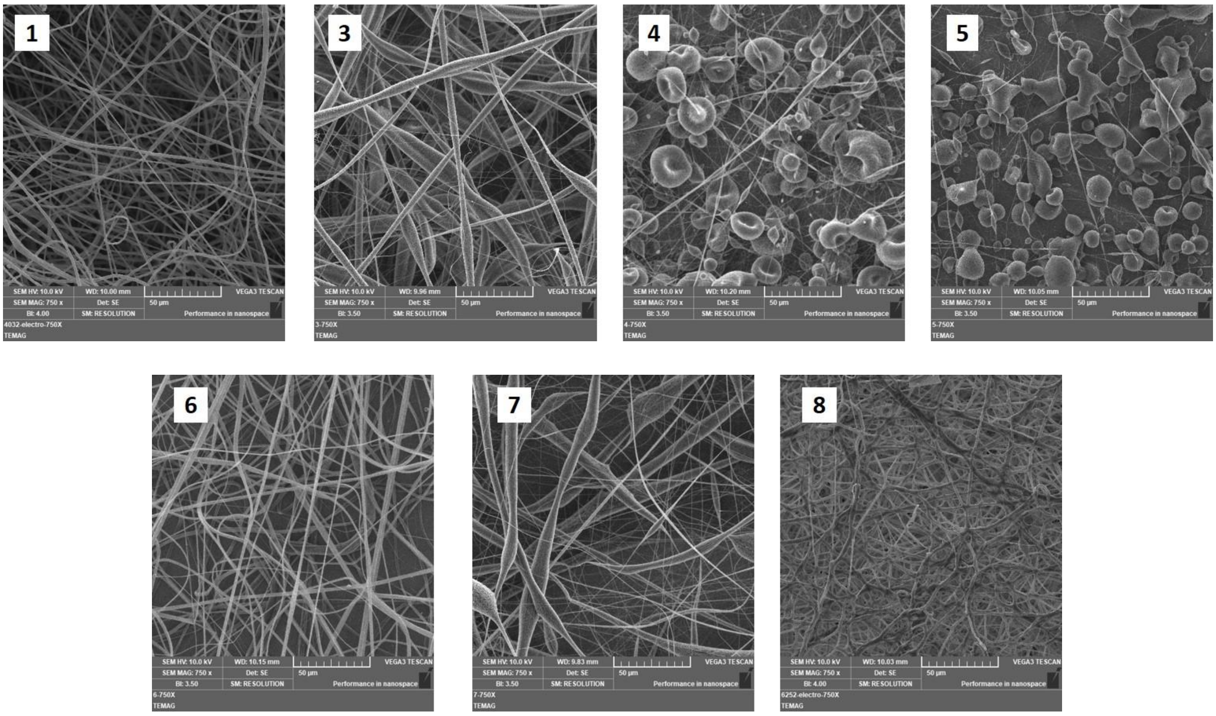

Figure 1. SEM images of the samples.

Table 4. Samples with mean fiber diameter values.

Sample No	Sample Code	Polymer blend	PLA/PBAT ratio	DCM/DMSO ratio	Mean fiber diameter
1	100 PLA4032/ 0 PBAT-75DCM-25DMSO	PLA 4032/ PBAT	100/0	75/25	1349±200 nm
2	75 PLA6252/ 25 PBAT-75DCM-25DMSO	PLA 6252/ PBAT	75/25	75/25	No fiber production
3	100 PLA 4032/ 0 PBAT-100DCM-0DMSO	PLA 4032/ PBAT	100/0	100/0	3752±300 nm
4	75 PLA 6252/ 25 PBAT-100DCM-0DMSO	PLA 6252/ PBAT	75/25	100/0	Full bead
5	100 PLA 6252/ 0 PBAT-100DCM-0DMSO	PLA 6252/ PBAT	100/0	100/0	Full bead
6	75 PLA 4032/ 25 PBAT-75DCM-25DMSO	PLA 4032/ PBAT	75/25	75/25	1806±231 nm
7	75 PLA 4032/ 25 PBAT-100DCM-0DMSO	PLA 4032/ PBAT	75/25	100/0	1737±290 nm
8	100 PLA 6252/0 PBAT-75DCM-25DMSO	PLA 6252/ PBAT	100/0	75/25	1900±150 nm

3.2. Thermal Analysis

Based on the results of the morphological analysis, thermal characterization was performed on the electrospun mats that were produced from PLA4032/PBAT polymer blends. The results for the glass transition temperature (Tg), the cold crystallization temperature (Tcc) and enthalpy (ΔHcc), melting temperature (Tm) and enthalpy (ΔHm), and degree of crystallinity (%Xc) were summarized in Table 5. DSC results show that the Tg of the PLA barely changes with an addition of 25% wt. PBAT, which indicates that PBAT is not miscible with PLA [3]. If the amorphous regions of the PBAT and PLA are miscible, according to the rule of mixing there should be a shift in the Tg of the blend.

All samples showed Tcc peaks, suggesting the presence of crystallizable amorphous regions in the electrospun fibers. On the other hand, when 25% of PBAT was added into PLA (75%), Tcc was decreased approximately 10°C, from 111°C to 99°C. The cold crystallization began at lower temperatures for the PLA/PBAT blend compared to neat PLA, which could be related to the presence of more free volume created by PBAT molecules initiating cold crystallization of PLA earlier [10]. However, it was observed that crystallization degree of PLA reduced with an addition of PBAT into the structure. This could be related to the relatively large molecular segments of PBAT that limited the arrangement of the PLA segments [4]. On the other hand, Tm of blend electrospun mats was not changed indicating that low amount addition of PBAT into PLA has no effect on Tm of PLA.

Table 5. Thermal properties of electrospun mats (second heating scan).

Sample No	Sample Code	Tg(°C)	Tcc(°C)	ΔHcc (J/g)	Tm(°C)	ΔHm (J/g)	X_{PLA}%
1	100 PLA4032/ 0 PBAT-75DCM-25DMSO	61.4	111.2	17.6	165.8	35.8	19.5
3	100 PLA 4032/ 0 PBAT-100DCM-0DMSO	62.1	115.1	11.5	164.5	33.1	23.2
6	75 PLA 4032/ 25 PBAT-75DCM-25DMSO	-31.9 61.65	99.2	16.3	165.2	24.1	11.2
7	75 PLA 4032/ 25 PBAT-100DCM-0DMSO	-32.1 62.0	99.6	18.5	165.6	24.5	8.6

4. CONCLUSION

In conclusion, biodegradable PLA/PBAT polymer blends were used for fabrication of nanofibrous membranes through electrospinning technique. The effect of MFR values of PLA, blending ratio of PLA/PBAT polymers and DCM/DMSO solvents on morphology and thermal-crystallization behaviour of the produced nanofibrous membranes were investigated and discussed. It is foreseen that the proposed biodegradable PLA/PBAT-based electrospun mats can be tailored with various additives for application in tissue engineering, drug delivery, and active/intelligent food packaging.

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REFERENCES

[1] Nofar, M., Oguz, H., & Ovalı, D. (2019). Effects of the matrix crystallinity, dispersed phase, and processing type on the morphological, thermal, and mechanical properties of polylactide-based binary blends with poly[(butylene adipate)-co-terephthalate] and poly[(butylene succinate)-co-adipate]. Journal of Applied Polymer Science, 136(23), 1–11.

[2] Pietrosanto, A., Scarfato, P., & Maio, L. Di. (2020). Development of eco-sustainable PBAT-based blown packaging applications. Materials, 13, 5395.

[3] Wang, L. F., Rhim, J. W., & Hong, S. I. (2016). Preparation of poly(lactide)/poly(butylene adipate co-terephthalate) blend films using a solvent casting method and their food packaging application. LWT - Food Science and Technology, 68, 454–461.

[4] Khatsee, S., Daranarong, D., Punyodom, W., & Worajittiphon, P. (2018). Electrospinning polymer blend of PLA and PBAT: Electrospinnability–solubility map and effect of polymer solution parameters toward application as antibiotic-carrier mats. Journal of Applied Polymer Science, 135(28), 1–19.

[5] Rosenberger, A. G., Dragunski, D. C., Muniz, E. C., Módenes, A. N., Alves, H. J., Tarley, C. R. T., … Caetano, J. (2020a). Electrospinning in the preparation of an electrochemical sensor based on carbon nanotubes. Journal of Molecular Liquids, 298.

[6] Rosenberger, A. G., Hardt, J. C., Dragunski, D. C., da Silva, F. F., Bittencourt, P. R. S., Bariccatti, R. A., … Caetano, J. (2020b). Use of experimental design to obtain polymeric microfibers with carbon nanotubes. Advanced Manufacturing: Polymer and Composites Science, 6(3), 115–126.

[7] Rossin, A. R. de S., Caetano, J., Zanella, H. G., Bariccatti, R. A., Gaffo, L., Muniz, E. C., … Dragunski, D. C. (2021). Obtaining and characterization of PBAT/PLA fibers containing zinc phthalocyanine prepared by the electrospinning method. Journal of Thermal Analysis and Calorimetry, 147(7), 4579.

[8] Schneider, R., Mercante, L. A., Andre, R. S., Brandão, H. de M., Mattoso, L. H. C., & Correa, D. S. (2018). Biocompatible electrospun nanofibers containing cloxacillin: Antibacterial activity and effect of pH on the release profile. Reactive and Functional Polymers, 132, 26–35.

[9] Su, S., Duhme, M., & Kopitzky, R. (2020). Uncompatibilized PBAT/PLA blends: Manufacturability, miscibility and properties. Materials, 13(21), 1–17.

[10] Sarul, D.S., Arslan, D., Vatansever, E., Kahraman, Y., Durmus, A., Salehiyan, R., & Nofar, M. (). Preparation and characterization of PLA/PBAT/CNC blend nanocomposites. Colloid and Polymer Science, 299, 987–998

DENIM FABRIC PRODUCTION WITH ENHANCED ANTI-OXIDANT ACTIVITY

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ABSTRACT

This paper introduces denim fabric samples with anti-oxidant activity. The method for the assessment is described and samples which also dyed by natural dyes and treated by in-house finishing bath were evaluated in terms of anti-oxidant performance.

Keyword: *Denim, natural dye, anti-oxidant activity*

1. INTRODUCTION

Denim is a popular woven fabric type for clothing industry. The global denim market was valued at around 70 Billion USD in 2021 and expected to reach a value of around 107 Billion USD. This huge market resulted with R&D demands to add functionalty, increase mechanical performance and develope sustainable process and denim products. Maritaş Denim, as one of the leader denim fabric producer in Turkiye, introduced various denim fabric qualities recently to the market regarding to meet those demands. Terra, a branded denim fabric by Maritaş Denim, is developed by intense R&D studies to utilize natural mineral-based dyestuff ro replace indigo and commercialized succesfully. Natural dyes are known to have various advantages in textile industry, inherent anti-oxidant performance is one of them [1,2]. Anti-oxidant performance of chemicals is strongly related to defeat free-radicals which are responsible for breaking down the collagen and HLA of skin, muscle damages and inflammation [3,4]. It is possible to apply anti-oxidant performance to next-to-skin fabrics to help the fight with free-radicals [5]. However, the biggest setback is the difficulty to analyse the anti-oxidant performance of textile surfaces. This paper introduces not only a method to assess the anti-oxidant performance of a fabric but also showing an in-house finishing application to enhance that property. By this study, it was possible to highlight the inherent anti-oxidant activity of Terra denim fabrics but also to increase the performance by a spesific wet treatment.

2. EXPERIMENTAL STUDY

Denim fabric sample (11 onz, %100 cotton) of which warps were dyed by mineral-based natural dye (Terra Raw) were used in the study. Then the fabrics were subjected to finishing treatment via lab scale foulard by:

a) Commercially available emulsion which is blend of co enzyme Q10 and sweat almond oil (Terra R1)

b) In-house emulsion which is blend of Gum Arabic and pomegrante seed oil (Terra R2) [6].

c) 1:1 v:v mixture of the emulsions used in Terra R1 and R2 (Terra R3)

d) 1:10 reduced concentration of Terra R2 (Terra R4)

The samples were dried at 100 ^{0}C for 6 minutes, then an in-house anti-oxidant activity measurement (Quencher-DPPH method) was applied. In this method, methanolic DPPH reagent was applied into a centrifuge tube and certain amount of fabric sample were put in. The mixture was vortexed and mixed on a rotator, then filtered and absorbance values were measured at 517 nm. The absorbance values in the blank solution and in the presence of sample were recorded and used to calculate Total Anti-oxidant Capacity (TAC). The higher the TAC, the higher anti-oxidant activity the sample has.

3. RESULTS

Table 1 shows the TAC values of the samples (average of three measurements). The results first indicated the inherent anti-oxidant activity of Terra denim (Terra Raw) which is dyed by natural dyestuff. This finding supported the advantage of natural dyes in textiles in terms of inherent anti-oxidant activity. Also, it was reported that the in-house treatment increased the anti-oxidant performance of denim samples.

Table 1. TAC values of the samples.

Sample	TAC (Q-DPPH)	% Inhibition
Terra R1	0,91 ± 0,03	15,72 ± 0,60
Terra R2	2,93 ± 0,07	48,90 ± 1,60
Terra R3	2,51 ± 0,09	41,74 ± 1,80
Terra R4	0,96 ± 0,02	15,91 ± 0,80
Terra Raw	0,81 ± 0,01	13,51 ± 0,50

4. CONCLUSION

This study describes a method to measure the anti-oxidant activity of the fabrics. Thus, it would be possible to address the skin-friendly performance of those fabrics. The method revealed the inherent anti-oxidant activity of Terra denim and increased performance after the application of an in-house emulsion.

REFERENCES

[1] Patel, N., et al. (2020). Antioxidant And Antimicrobial Potentials Of Some Plant-Based Natural Dyes. International Journal of Biology, Pharmacy and Allied Sciences, 9 (9), 2090 – 2101.
[2] Tereucan, G., et al. (2021). Stability of antioxidant compounds and activities of a natural dye from coloured-flesh potatoes in dairy foods. LWT, 144, 111252.
[3] Dahmane, R.G. and Poljsak, B. (2011). Free radicals and intrinsic skin aging: Basic principles. Healthmed, 5 (6), 1647-1654.
[4] Biswas, S. et al. (2017). Role of free radicals in human inflammatory diseases. AIMS Biophysics, 4 (4), 596-614.

[5] Baaka, N., et al. (2017). Optimisation of the recovery of carotenoids from tomato processing wastes: application on textile dyeing and assessment of its antioxidant activity. Natural Product Research 31 (2), 196-203.
[6] Rojo-Gutierrez, E., et al. (2021). Evaluation of green extraction processes, lipid composition and antioxidant activity of pomegranate seed oil. Journal of Food Measurement and Characterization, 15, 2098-2107.

CHEMICALS MANAGEMENT IN THE TEXTILE INDUSTRY: CHALLENGES AND POSSIBLE STRATEGIES FOR A TRANSPARENT AND SUSTAINABLE SUPPLY CHAIN

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ABSTRACT

The focus of the paper is to examine the challenges of chemicals management in the textile supply chain and possible strategies for a transparent and sustainable textile industry. For this purpose, the results of the status quo analysis of the textile market are presented and the currently changing European chemicals policy is explained. The chemicals management of selected clothing companies is examined along with the interfaces to occupational safety and health and environmental protection in order to identify important insights and recommendations for action. The objective is to highlight the need for a multi-criteria approach to chemicals management in the apparel industry and to discuss the necessary measures.

Keyword: *Sustainability, Environment, Chemicals Management, Supply Chain, Occupational Safety and Health (OSH)*

1. INTRODUCTION

The resource-intensive textile and clothing production has extensive impacts on the environment and human health. Along the complex textile supply chain, a large number of chemicals are used in the various production steps. Beyond the analysis of the resulting environmental impacts, such as energy consumption, waste and wastewater, the studies show that the scope of analysis of chemicals management must also include a detailed consideration of occupational safety and health. Especially during the labour-intensive production steps in the finishing of textiles, where chemicals are used intensively, many employees are exposed to harmful substances. Here, the negative effects for employees arise primarily from the unsafe production processes [1]. According to the organization ChemSec, approximately 3,500 different substances are used in the production of textile and clothing products. Even though chemicals used in textile production are not all necessarily hazardous, 750 of these substances used are already assessed as hazardous to human health and 440 as hazardous to the environment. In addition, it is assumed that about 20% of global water pollution is caused by textile finishing processes, which in turn also result in negative consequences for the health and habitat of the local population [2]. Especially in production countries in the Global South, a risk is posed by the improper storage of chemicals, insufficient personal protective equipment (PPE), and a lack of risk assessment and substitution solutions for the chemicals [3].

The legal framework for distributing chemicals in the European Union is provided by the REACh Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals) and the Globally Harmonised System of Classification, Labelling and Packaging of Chemicals (GHS) [4]. With the new supply chain laws and the Chemicals Strategy for Sustainability of the EU Green Deal, there is now the challenge of creating transparency about the utilised chemical substances, as the shift of textile production to the global south has also shifted the chemical problem to countries outside the legal frameworks. For this reason, organisations, initiatives and alliances such as the Greenpeace Detox Campaign, among others, are trying to achieve a commitment to implement European standards in chemicals management in international supply chains. This endeavour is supported by numerous international organisations such as the ZDHC Foundation (Zero Discharge of Hazardous Chemicals), which are working intensively on these issues, pushing legislation as well as supporting companies in voluntary measures [5]. The European Corporate Sustainability Due Diligence Directive (CSDDD), which has not yet been formally adopted, forms the European framework for the supply chain laws of the individual EU states [6]. So for instance, the German Supply Chain Due Diligence Act (LkSG), which was passed in June 2021, forces certain companies to comply with the specified human rights due diligence requirements. From the beginning of 2023, companies with more than 3000 employees will be affected, and from 2024, companies with more than 1000 employees. The fulfilment of the due diligence obligations laid down in the law must be published annually by the companies concerned in a report for the previous business year. In addition to submitting the report to the Federal Office no later than four months after the end of the business year, they must also be publicly accessible free of charge via the company websites [7]. The EU Directive represents a tightening of e.g. the German Supply Chain Act, as it also covers indirect suppliers, i.e. suppliers with whom there is no contractual relationship, but whose supplies are nevertheless necessary for the production of the product or for the provision and use of the service [8].

However, the still ongoing Covid 19 pandemic also shows that efforts to improve working conditions in the production countries are weakening. There is an increase in health and safety violations and safety in the production plants is increasingly disregarded, especially in the production steps where chemicals are used intensively [9].

In order to identify the relation between the use of chemicals and occupational safety and health and environmental protection, it is essential to determine the terms of toxicology. Toxicology can be divided into different areas, such as human toxicology, reproductive toxicology, toxicokinetics, toxicogenetics, ecotoxicology and particle and fibre toxicology. The link between toxicology and textile and clothing production is illustrated by looking at the relevant potential release patterns of chemicals from textiles. The release pathways are summarised in the following figure:

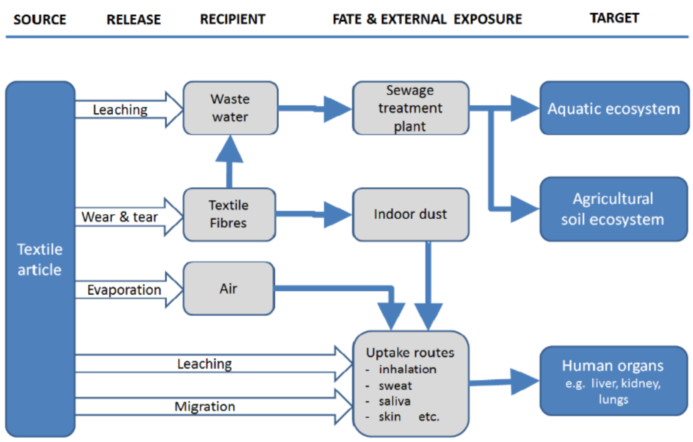

Figure 1. Potential release pathways of chemicals from textiles [10].

As illustrated, chemical substances present in textiles can be released in different ways both during manufacture and during subsequent use, thereby posing a risk to humans (human toxicology) and the environment (ecotoxicology). The possible forms of release are migration, leaching, evaporation and release of particles. These depend on the inherent chemical and physical properties of the chemical substance, its form of use, the type of fibre and the handling of the textiles by consumers. Exposure to chemicals in textiles is mainly through skin contact, but the pollutants can also be released from the textiles, i.e. lead to exposure through inhalation or accidental ingestion of dust. In the context of textiles and chemicals, the terms PBT substances (persistent, bioaccumulative, toxic) and vPvB substances (very persistent and very bioaccumulative) are often used. Here, persistent refers to the property when a chemical substance can remain in the environment for a long time, and bioaccumulation when the chemical substance can accumulate in an organism, especially along the aquatic food chain. This danger is particularly prevalent in wastewater management in developing countries, as often the chemicals washed out are either discharged directly into the environment or, if present, are not sufficiently degraded in municipal wastewater treatment plants. In addition, the spread of sewage sludge on the soil can lead to exposure of organisms in terrestrial ecosystems [10].

2. CASE STUDY METHODOLOGY

A status quo analysis is carried out and the chemicals management of selected clothing companies is examined with the help of the case study methodology. The company selection for the case study analysis results from the methodology of a thesis, which includes a comprehensive status quo analysis of the German clothing market and the evaluation of the companies according to their relevance to the research question at hand. The aim of this analysis is to explore how the implementation of chemical management differs in practice, that is, the approach of clothing companies along international value chains. In the following, the main highlights from the challenges and strategies of the five case studies are summarised.

3. RESULTS

3.1 Challenges of Chemicals Management

The research proves on the basis of the comprehensive analysis that the companies have several overlaps in their strategies. However, it is already clear from the examination of five case studies that the amount of information regarding the companies' chemicals management differs greatly.

Companies rarely allow public access to their RSL (Restricted Substance List) or MRSL lists (Manufacturing Restricted Substances List). As the lists contain extensive technical data and require a certain knowledge of chemicals, it can be assumed that they are not included in the public sustainability reports. In addition, chemical names are not particularly revealing to most industry players, so chemical industry information systems for labelling chemicals are not yet optimal for downstream users in the textile and apparel industry and can lead to challenges in supply chain communication [11]. Another important point regarding chemical restricted lists is that due to the creation of the lists by the companies themselves, a large number of different RSLs circulate in the supply chain, making it difficult to achieve transparent and sustainable chemicals management [12].

Among the challenges that emerge from the analysis include the current negative impact of the pandemic on working conditions and environmental protection in the garment industry. It is also noted that despite the efforts of the companies, there are still suppliers who do not publish their chemical inventory list. A challenge mentioned several times is the use of chemicals in tanneries and textile finishing, in particular the still inadequate wastewater management systems of those processes. The analysis also shows that in some case studies, the overlap between chemical use and occupational health and safety is underreported. It should also be noted that the increasing awareness of the importance of chemical management and therefore the stricter environmental standards can lead to increased costs. These include, above all, the costs of audit and certification processes as well as wastewater and chemical tests, which are mostly covered by the production sites and suppliers.

3.2 Possible Strategies of Chemicals Management

The following is a summary of the individual companies' strategies for chemicals management.

Table 1. Overview of the chemicals management strategies of the examined case studies.

Topics of Chemicals Management	Strategies and Measures
Production	▪ RSL as a mandatory element in B2B contracts ▪ Use of ZDHC: MRSL List ▪ Supplier evaluation according to ZDHC audit protocol ▪ Entry of suppliers' inventory lists in the ZDHC gateway ▪ Testing of chemical residues in external laboratories & monitoring ▪ Keeping the number of producers low for more individual support with strategic and long-term production cooperation ▪ Development of best practice guidelines for chemical management for the suppliers ▪ Sustainable Product Design ▪ Life Cycle Assessment (LCA)
Environmental Protection	▪ Monitoring of wastewater management (e.g. through ZDHC modules) ▪ Environmental management system ISO 14001 ▪ Random laboratory tests and self-initiated chem. tests for harmful substances ▪ Pollutant testing
OSH (Occupational Safety and Health)	▪ Training and education on chemicals focused on suppliers with wet processes ▪ Risk analysis and hazard assessment ▪ Safety Data Sheets (SDS) ▪ Hazard reporting system ▪ Occupational safety guidelines ▪ Social standards in the procurement process: ILO, SAI
Reporting	▪ The chemical audits at the production sites are not reported as an absolute number of factories audited, but as a KPI in % for the suppliers' expenditure ▪ Publication of annual KPIs on audits and wastewater investigations ▪ Transparency through publication of supplier list
Legislation	▪ RSLs visible and references to REACh requirements ▪ Compliance with national and EU textile labelling law, EU Chemical Law (REACh, CLP, Biocide, POP)
NGOs Partnerships and Cooperation Certification	▪ Monitoring of good housekeeping through external environmental certificates ▪ Cooperation with textile associations ▪ Dialogue and exchange with industry stakeholders ▪ ZDHC ▪ High Index Facility Environment Module (FEM) ▪ amfori BEPI ▪ WRAP ▪ bluesign
Innovation	▪ Development of a chemical assessment process ▪ CleanChain tool ▪ EIM Score - software for the environmental impact assessment of textile finishing companies ▪ bluesign® bluefinder-Tools ▪ Innovative production technologies (e.g. water-free finishing) ▪ Green Chemistry

4. CONCLUSION

The research shows that the key challenges include differences in chemical knowledge, the multitude of different limit values (Restricted Substances List (RSL), Manufacturing RSL (MRSLs)) and the human toxicological impact on workers in the supply chain. Many chemical management systems and certifications focus on the technical aspects and on the reduction or substitution of hazardous chemicals, but less on the occupational health and safety aspects. As many European companies have relocated their production to the global south, they do not provide reports on chemicals management, as their own operations are not affected. Also, little information is provided on voluntary chemicals standards, such as ZDHC, GOTS, bluesign etc., which should be used in the supply chain. The few exceptions include large companies such as Adidas, which also report on working conditions and occupational safety and health in their supply chain. With the requirements from the various due diligence acts and laws in Europe, significant changes are to be expected in the future.

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REFERENCES

[1] ILO (Ed.) (2021). Exposure to hazardous chemicals at work and resulting health impacts: A global review. Geneva, Switzerland (pp. 39).
[2] ChemSec (Ed.) (2021, June 13). What goes around, Enabling the circular economy by removing chemical roadblocks. Retrieved from https://chemsec.org/app/uploads/2021/02/What-goes-around_210223.pdf
[3] Solidaridad (Ed.) (2021, June 30). Wet Processing Guidebook. Retrieved from https://www.solidaridadnetwork.org/wp-content/uploads/2021/03/Solidaridad-Guidebook-Wet-Processing-151220.pdf, pp. 33.
[4] Richter, S. (2009). Fortschrittsbericht zur nationalen Umsetzung des Strategischen Ansatzes zum Internationalen Chemikalienmanagement. (SAICM). Umweltbundesamt (Ed.). Dessau-Roßlau, Germany.
[5] Cobbing et al. (2020). Einführung der erweiterten Herstellerverantwortung für das Chemikalien-Management globaler Lieferketten, Die Fallstudie Detox und Textilien. Greenpeace (Ed.). Hamburg, Germany.
[6] Heinen, A. (2021). Schutz der Arbeits- und Menschenrechte in globalen Wertschöpfungsketten – rechtlicher Rahmen und aktuelle Entwicklungen. *Zeitschrift für Arbeitswissenschaft 75*, 155-161.
[7] Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA) (2023, January 5). *Lieferketten.* Retrieved from https://www.bafa.de/DE/Lieferketten/Berichtspflicht/berichtspflicht_node.html
[8] Lanfermann, G. (2023). Corporate Governance und Nachhaltigkeitsberichterstattung. In: Zwick, Y., Jeromin, K. (eds) *Mit Sustainable Finance die Transformation dynamisieren*. Springer Gabler, Wiesbaden. Retrieved from https://doi.org/10.1007/978-3-658-38044-1_17
[9] Scheper, C. (2020). Synthesebericht: Auswirkungen von COVID-19 auf die Textilindustrie, Femnet e.V./ INKOTA-netzwerk e.V./ SÜDWIND e.V. (Ed.), Bonn/ Berlin, Germany.
[10] Kemi (Ed.) (2014). Chemicals in textiles – Risks to human health and the environment, *Report from a government assignment, 6*(14), Stockholm, Sweden.
[11] Roos et al. (2020). A Function-Based Approach for Life Cycle Management of Chemicals in the Textile Industry, *in Sustainability 2020, 12*(3), 1273.
[12] Schäfer, Thomas (2017). Integriertes Chemikalienmanagement entlang der textilen Kette, in: Forschungs- und Entwicklungsinstitut für Industrie- und Siedlungswasserwirtschaft sowie Abfallwirtschaft E.V. (FEI) (Ed.), *Chemikalienmanagement und Umweltschutz in der textilen Kette,* München, (p. 29 – 46).

CHALLENGES IN THE ADAPTATION OF CLOTHING PRODUCTION COMPANIES TO INDUSTRY 4.0: A CASE STUDY

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ABSTRACT

Digital revolution, known as Industry 4.0, is coming to manufacturing industry, which means the integration of virtual and physical worlds and the creation of an interoperability platform between business and operation technologies through cyber-physical systems. It is possible to create a "smart" production environment by using automation and data processing systems together. Smart factories are flexible and can cope with real-time changes in demand. Competitive advantage, efficiency and flexibility are key benefits to Industry 4.0 adoption. This study identifies the challenges that clothing production companies face on their journey to Industry 4.0. The adaptation of clothing production companies to Industry 4.0 presents numerous challenges, including the need for investment in new technologies and infrastructure, the acquisition of new skills and competencies, and the management of organizational and cultural changes.

Keyword: *Industry 4.0, Clothing Production, Digital Transformation, Smart Manufacturing*

1. INTRODUCTION

Clothing was typically produced by hand before the First Industrial Revolution. Each clothes being produced individually by skilled craftsmen. This process was slow and labor-intensive, and the resulting products were often expensive [1].

The clothing production industry has seen many improvements in technology since second industrial revolution [2,3]. The sewing machine was a significant technological advancement that revolutionized the clothing production industry. Sewing machines allowed for much faster and more efficient production of clothing [4]. Improvements in needle design and materials have continued throughout the 20th centuries, with the development of various types of needles for different sewing tasks, such as quilting, embroidery, and topstitching, as well as the use of new materials such as stainless steel and titanium [5].

Industry 3.0, also known as the Digital Revolution or the Third Industrial Revolution, refers to the current period of technological advancement and digitalization that is transforming many industries, including the clothing production industry. Some of the key technology improvements that have taken place in the clothing production industry in recent years include: Computer-aided design (CAD) and computer-aided manufacturing (CAM), Automation of Sewing Machines, Material Requirement Planning and Enterpirese Resource Planning softwares [6,7].

Overall, these and other technological advancements help to transform the clothing production industry, making more efficient, flexible and sustainable.

Industry 4.0, also known as the Fourth Industrial Revolution is defined as "Industrie 4.0 will involve the technical integration of CPS (Cyber Physical Sytems) into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes." [8]. In the field of Clothing Production, this trend has led to the development of new technologies that are transforming the way clothing is designed, produced, and distributed. These technologies range from smart factories, smart products and procedures in production lines and smart logistcis systems [9–11]. Theoretical framework of Industry 4.0 technologies shown in Figure 1 are described briefly.

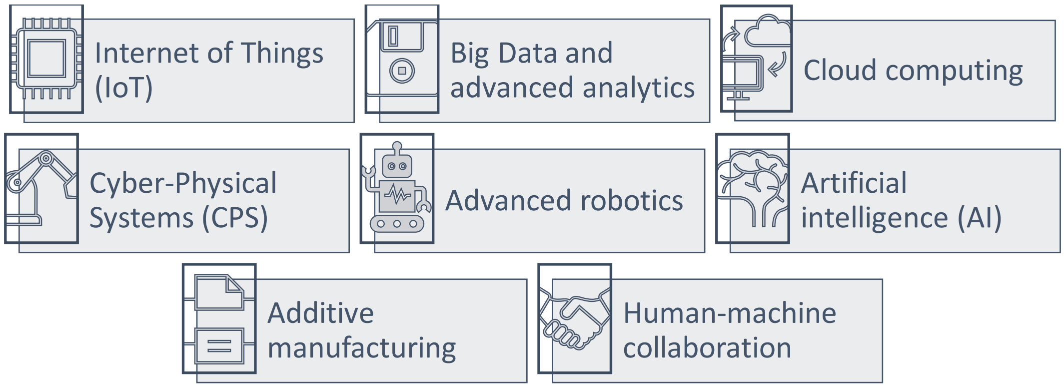

Figure 1. Theoretical framework of Industry 4.0 technologies.

Internet of Things (IoT), which refers to the network of physical objects that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. Smart fabrics, Intelligent manufacturing, Iot and blockchain supported supply chain management and customer engagement are ways of Iot usage in Clothing Industry [12,13].

Big Data and advanced analytics, which involve the collection, processing, and analysis of large and complex datasets to uncover insights and support decision making. Clothing industry uses Big data in Market research and trend analysis, supply chain optimaztion, Customer engagement and sustainablity and enviromental impact [14].

Cloud computing, which provides on-demand access to a shared pool of computing resources, such as networks, servers, storage, and software, over the internet. Cloud computing provides convenience. data storage ans management, collaboration and communication, product design and development [15].

Cyber-Physical Systems (CPS), which refer to the integration of physical and digital technologies in the design and operation of manufacturing systems, such as robots, sensors, and control systems. CPS are allows them to monitor and control the clothing production process in real-time. Also CPS allows to track and monitor the movement of raw materials, components, and finished products throughout their supply chain [16].

Advanced robotics, which encompasses a range of technologies and techniques for the design, development, and deployment of intelligent, autonomous, and adaptable robots that can perform a wide variety of tasks in manufacturing, transportation, healthcare, and other sectors [17].

Artificial intelligence (AI) and machine learning, which refer to the ability of computers to learn from data, make predictions, and take actions without being explicitly programmed. Clothing manufacturers can uses machine learning to create and test new product designs more quickly and easily, automate the inspection and testing of finished products for defects and other quality issues and optimize their supply chain operations [18].

Additive manufacturing, also known as 3D printing, which involves the use of 3D printing technologies to create physical objects by adding layer upon layer of material, based on digital designs [19].

Human-machine collaboration, which involves the integration of humans and machines in the design, operation, and maintenance of manufacturing systems, in order to enhance productivity, quality, and safety [20].

The clothing industry has been technologically labor-intensive since the invention of the sewing machine. Although sewing machines have automation systems, they have never fully been able to remove human control. With Industry 4.0, it is now possible to collect real-time data from clothing production lines, make decisions, and use smart data analysis to reduce waste and increase efficiency [21,22]. Therefore, the clothing production industry, which is referred to as the fourth industrial revolution, is now an important topic of discussion in terms of using automation to the least extent possible with human power and realizing digital transformation and full automation. This situation requires clothing production companies to work on infrastructure for Industry 4.0. Businesses face many different challenges. This study identifies the challenges that clothing production companies face on their journey to Industry 4.0.

2. EXPERIMENTAL STUDY

The integration of base technologies allows for the creation of smart, connected, and flexible production lines that can adapt to changing customer demand, production conditions, and other factors in real-time. It also enables the optimization of production processes, the improvement of product quality, and the reduction of waste and other inefficiencies.

A textile company was chosen as an example for Industry 4.0 adaptation. The industry 4.0 adaptation process was analysed through face-to-face interviews and field observations with department managers, production engineers, quality engineers, production chiefs and IT employees in this company. In these interviews and analyses, industry 4.0 adaptation, qualified workforce requirement, industry 4.0 transformation cost, basic technology components were examined. The infrastructure needs of a business for the theoretical framework of Industry 4.0 and the base technologies (Internet of Things (IoT), cloud computing, big data analytics) required for Industry 4.0 were examined. The business infrastructure was analysed in terms of hardware, network, and internet infrastructure for the base technologies within the scope of Industry 4.0.

3. RESULTS

3.1. Base Technology Structure of Industry 4.0 for Clothing Production

Base technologies of industry 4.0 have challenges for the clothing production companies. It is a difficult process to keep up with technology while continuing production on the one hand. We tried to identify the problems that the clothing production companies will encounter in their adaptation to the industry 4.0 basic technologies and to offer solutions according to the needs.

Clothing production is carried out on assembly lines where many machines and operators work. Production processes need to be planned in each assembly line. Workload planning (line balancing) of manpower and machines should be done according to the workflow of the product to be produced. Making these plans depends on the fact that time and method studies have been done beforehand. In the planning and management of this process, which is briefly explained, the working time of the operator, the working time of the machine, the number of products produced etc. a lot of data is generated.

The structure prepared from the Tao's model for clothing production lines (Figure 2) shows the sources of obtaining data in the production line for clothing production companies. Data from Sewing Operator, Sewing Machine, Product, and Production Management can be collected and managed in real-time from the production line with IoT devices. These real-time and historical data are stored in a structured manner [23].

3.2. Cloud Computing

The use of cloud systems for data storage ensures that the data is stored at low cost, low energy consumption, and in a secure manner. Production data is processed, and incomplete, duplicated, or dirty data is separated. This production data is provided as feedback to the production line in the form of graphs, tables, and queries. IoT devices on each machine or large screens on production lines are used in this process. In addition, demand forecasting, machine and human workforce planning on production lines, and quality assurance work are carried out with this data [15].

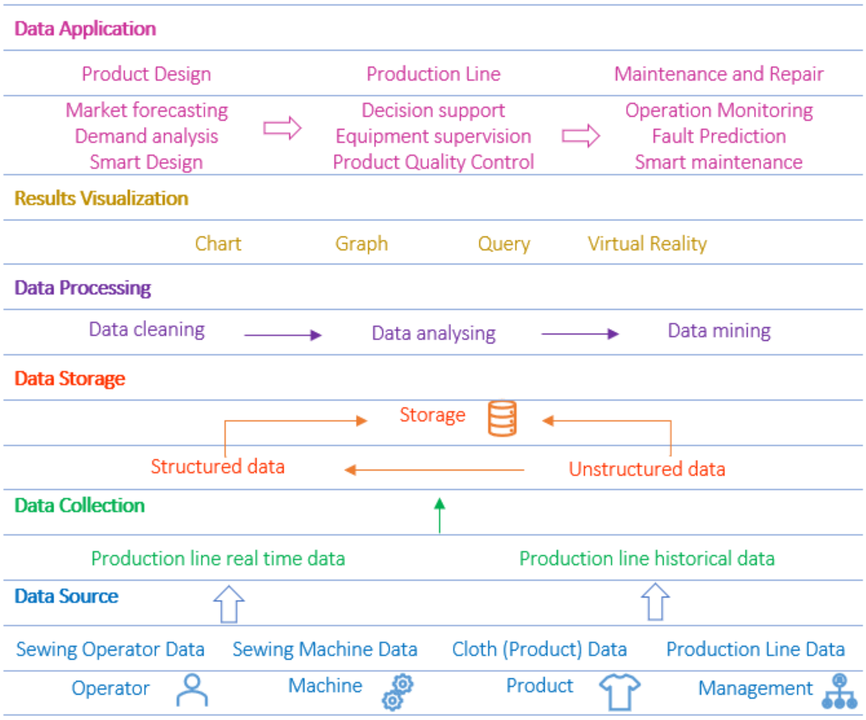

Figure 2. Clothing production line data structure (reproduced from Tao et. al) [23].

3.3. Internet of Things for Data Collection

Clothing production companies should use IoT devices to collect data on their production lines. These devices can be connected to the network either by cable or wirelessly. Since there are many machines in clothing production lines, connecting these devices with cables will add an extra burden to the lines carrying energy, lighting, compressed air, and other systems. Additionally, there is a high degree of product model variation in production lines, which results in changes in machine placement. In this case, connecting each machine to the network with a cable makes the situation complex. Therefore, strengthening the infrastructure of the wireless network is one of the first challenges that clothing production companies encounter. Furthermore, when setting up a wireless network, factors such as metal shelves, metal machine components, and the length of production lines should be taken into consideration.

It is necessary to plan IoT devices to collect real-time data, in a way that allows data input for every process flow used in the production line. This device can be SBM's (single board computers). Nowadays SBM's are low-cost, very low-energy-consumption devices, with multiple data inputs and outputs, and the ability to work with many operating systems. The operating system is an important point of IoT devices. A touch screen support and open-source operating system will increase the benefit from the software. The devices can have a screen to not only input data but also serve as a performance indicator. The devices transmit production data to the database that is part of the enterprise resource planning software located in the cloud system.

3.4. CPS (Cyber physical systems) for Data and Process Integration

Clothing production companies should have interfaces that are suitable for real-time data collection in the enterprise resource planning software they use. The fact that the software is cloud-based, suitable for entry data from mobile devices, can be accessed through a browser on many operating systems, and has a current programming language that provides data integration is crucial in creating the basic technology infrastructure for Industry 4.0. It is important for enterprise resource planning software to provide integration capability to receive and send data produced by the businesses in the supply chain, audit firms, and government agencies for software flexibility.

3.5. Security

The use of IoT devices with wireless systems and the fact that many devices generate real-time data within the production line make cybersecurity an important element. To ensure data security and control, it is important to prepare user accounts within a standard, perform authorizations in a controlled manner, and continuously monitor devices that have access to the network.

3.6. Human Resources

In the context of Industry 4.0, adapting to the technologies implemented is also one of the important issues for human resources. In the clothing production industry, it is important for operators to be able to enter data correctly and completely through IoT devices located at the endpoint, to ensure that data is collected correctly from the production line. Therefore, providing basic information technology education to human resources is an important issue for the clothing production industry.

4. CONCLUSION

The results of this case study suggest that clothing production companies face several challenges in their adaptation to Industry 4.0. One of the main challenges identified was the need for significant investment in new technologies and infrastructure. This includes the acquisition of new hardware and software, as well as the upgrade of existing systems to be compatible with Industry 4.0 technologies such as the Internet of Things (IoT) and cloud computing.

Another challenge was the need for companies to acquire new skills and competencies to effectively implement and use Industry 4.0 technologies. This includes the need for training and development programs for employees, as well as the hiring of new employees with the necessary expertise.

In addition, the case study identified organizational and digital cultural challenges related to the adoption of Industry 4.0. This includes the need to manage changes in processes and systems, as well as the need to adapt company digital culture and management practices to support the use of Industry 4.0 technologies.

In conclusion, the adaptation of clothing production companies to Industry 4.0 presents numerous challenges, including the need for investment in new technologies and infrastructure, the acquisition of new skills and competencies, and the management of organizational and cultural changes. This study contributes as a practical analysis and evaluation of the challenges as a case study encountered by clothing production companies on their journey to Industry 4.0.

However, the successful implementation of Industry 4.0 can bring numerous benefits, including increased efficiency, flexibility, and competitiveness. It is therefore important for clothing production companies to carefully consider the challenges and opportunities presented by Industry 4.0 and to develop strategies for successful adaptation. This may require the support of external expertise and resources, as well as the participation and commitment of all levels of the organization. By addressing these challenges and embracing the opportunities of Industry 4.0, clothing production companies can position themselves for success in the digital age.

REFERENCES

[1] Thanhauser, S. (2022). *Worn: A people's history of clothing*. Pantheon.

[2] Yin, Y., Stecke, K. E., & Li, D. (2018). The evolution of production systems from Industry 2.0 through Industry 4.0. *International Journal of Production Research*, *56*(1–2), 848–861. https://doi.org/10.1080/00207543.2017.1403664

[3] Gregory, J. M. (2006). A History of the Sewing Machine to 1880. *Transactions of the Newcomen Society*, *76*(1), 127–144. https://doi.org/10.1179/175035206X105249

[4] Uri M. Kupferschmidt. (2019). The Social History of the Sewing Machine in the Middle East. *Die Welt Des Islams, New Series*, *44*(2), 195–213. https://www.jstor.org/stable/1571315

[5] Jana, P. (2015). 11 - Sewing equipment and work aids. In R. Nayak & R. Padhye (Eds.), *Garment manufacturing technology* (pp. 275–315). Woodhead Publishing. https://doi.org/10.1016/B978-1-78242-232-7.00011-4

[6] Luca, D., & Dolga, V.-I. (2021). From Industry 3.0 to Industry 4.0. *The International Journal of Engineering and Science*, *10*(9), 44–49. https://doi.org/10.9790/1813-1009014449

[7] Jiang, Z., Yuan, S., Ma, J., & Wang, Q. (2022). The evolution of production scheduling from Industry 3.0 through Industry 4.0. *International Journal of Production Research*, *60*(11), 3534–3554. https://doi.org/10.1080/00207543.2021.1925772

[8] Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). *Recommendations for implementing the strategic initiative industrie 4.0: Securing the future of german manufacturing industry; Final report of the Industrie 4.0 Working Group*.

[9] GTAI. (2013). Smart Manufacturing for the Future. *Industrie 4.0*, 1–40. https://doi.org/10.1007/978-3-642-36917-9

[10] Shi, Z., Xie, Y., Xue, W., Chen, Y., Fu, L., & Xu, X. (2020). Smart factory in Industry 4.0. *Systems Research and Behavioral Science*, *37*(4), 607–617. https://doi.org/10.1002/sres.2704

[11] Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34. https://doi.org/10.1016/j.compind.2017.04.002

[12] Manglani, H., Hodge, G. L., & Oxenham, W. (2019). Application of the Internet of Things in the textile industry. *Textile Progress*, *51*(3), 225–297. https://doi.org/10.1080/00405167.2020.1763701

[13] Majeed, M. A. A., & Rupasinghe, T. D. (2017). Internet of things (IoT) embedded future supply chains for industry 4.0: An assessment from an ERP-based fashion apparel and footwear industry. *International Journal of Supply Chain Management*, *6*(1), 25–40. https://doi.org/10.1016/j.tim.2005.09.005

[14] Sun, N., & Cao, B. (2022). Production Scheduling Optimization of Garment Intelligent Manufacturing System Based on Big Data. *Computational Intelligence and Neuroscience*, *2022*, 1–8. https://doi.org/10.1155/2022/2293473

[15] Kim, S., & Yu, H.-S. (2022). Production Equipment Monitoring System Based on Cloud Computing for Machine Manufacturing Tools. *Journal of Korea Multimedia Society*, *25*(2), 197–205. https://doi.org/10.9717/KMMS.2022.25.2.197

[16] Lee, J., Bagheri, B., & Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

[17] Tantawi, K. H., Sokolov, A., & Tantawi, O. (2019). Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration. *2019 4th Technology Innovation Management and Engineering Science International Conference (TIMES-ICON)*, 1–4. https://doi.org/10.1109/TIMES-iCON47539.2019.9024658

[18] Jan, Z., Ahamed, F., Mayer, W., Patel, N., Grossmann, G., Stumptner, M., & Kuusk, A. (2023). Artificial intelligence for industry 4.0: Systematic review of applications, challenges, and opportunities. *Expert Systems with Applications*, *216*, 119456. https://doi.org/10.1016/j.eswa.2022.119456
[19] Khajavi, S. H. (2021). Additive Manufacturing in the Clothing Industry: Towards Sustainable New Business Models. *Applied Sciences*, *11*(19), 8994. https://doi.org/10.3390/app11198994
[20] Schuh, G., Potente, T., Varandani, R., Hausberg, C., & Fränken, B. (2014). Collaboration Moves Productivity to the Next Level. *Procedia CIRP*, *17*, 3–8. https://doi.org/10.1016/j.procir.2014.02.037
[21] Gökalp, E., Onuralp Gökalp, M., & Erhan Eren, P. (2018). Industry 4.0 Revolution in Clothing and Apparel Factories: Apparel 4.0. In *Industry 4.0 from the MIS Perspective* (pp. 169–183). Peter Lang. https://www.researchgate.net/publication/332410328
[22] Zhou, K., Taigang Liu, & Lifeng Zhou. (2015). Industry 4.0: Towards future industrial opportunities and challenges. *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, 2147–2152. https://doi.org/10.1109/FSKD.2015.7382284
[23] Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of Manufacturing Systems*, *48*, 157–169. https://doi.org/10.1016/j.jmsy.2018.01.006

STUDY ON TENSILE PROPERTIES OF COMPRESSION SOCKS ANKLE CUT-STRIPS AT FIXED EXTENSION

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ABSTRACT

Compression socks are used for treatment of venous disorders. The main function of this socks is exertion of compression pressure, and this is strongly related to tensile properties of compression socks. Current research work contains an analysis exercising effect on force decay [N] at fixed extension, it also relates the how the tensile indices value interacts to force at fixed extension and experimental compression pressure. Results showed that force decay value due to exercising of class I cut-strips undergoes more force decay as compared to class II and class III cut-strips due to their lower structural stability and stiffness characteristics. Also results portray that significant relationship between force at fixed extension and compression pressure compared to tensile indices values.

Keyword: *Compression Socks, Durability, Force Decay, Tensile indices, Force at Fixed Extension*

1. INTRODUCTION

Compression socks are used for the prophylaxis and treatment of venous disorders in the human lower extremities [1]. Extensibility and elastic recovery of compression garments are the most important operational characteristics. During the wearing of compression garments, the hysteresis of fabric and dynamic elastic properties are also of great significance and affect the intensity and durability of compression stockings [2]. It is observed that there exist different modalities to be considered for the tensile properties of compression socks. It includes mainly elasticity, stiffness, hysteresis, pressure level, pressure delivery mode, materials, and fabrication technology [3–5].The main purpose of current research is to investigate the tensile properties of compression socks using cut-strips detached from the ankle part of the socks.

2. EXPERIMENTAL STUDY

2.1 Material and Method

A total of 13 commercially available socks samples were purchased exhibiting compression class levels (class I, 2.40~2.80 kPa; class II, 3.06~ 4.27 kPa and class III, 4.53~ 6.13 kPa. Most of the socks (11 samples) exhibited (1×1 laid-in plain Knit) while 2 class I samples exhibit (1×1 laid-in- mesh knit). All the samples were evaluated for their built-in physical specifications as shown in table 1 and with great precision and accuracy under standard atmospheric conditions RH, 65±5%, temperature, 20±2˚C as per CEN 15831:2009, and RAL-GZ 387/1 (Medical compression hosiery quality assurance).

2.2 Marking and slicing of cut-strips (ankle portion) and testing

Wooden leg is used for marking the cut-strips. This leg exhibits the requisite specifications a cB (circumference at ankle; 240 mm) and ℓB (position of the ankle from the sole of foot along the leg, 12 cm). A sock sample was put onto a wooden leg and drawn a mark of dashed-line corresponding to main-grooved-line engraved on the face of the wooden leg. After marking the mean-dashed line (-). socks were put-off and a square of 5×5 cm was marked keeping the drawn dashed line (-) as the mean line of the square. In this scientific research, all detached cut-strips were investigated for their tension behavior using a constant rate of extension based Testometric tensile testing machine with the set maximum load of 5kN, a set extension rate at 100 mm/minute under standard testing conditions according to ASTM D1775-04. For tensile characterization, all linearized cut-strips were extended to fixed extension level (65%) corresponding to gauge length/initial length (50 mm) and then relaxed to zero position repeating the cycle five times for each sample.

Table 1. Physical specifications of compression socks.

Code	**Thickness [mm]**	**Fabric Weight [g/m^2]**	**Course density [per cm]**	**Wales density [per cm]**	**Stitch density [stitches/ cm^2]**	**Fiber [%] PU/ PA**	**Main yarn** Type	**Inlaid yarn** Type	**Class**
A1	0.40	139.44	22.4	19.21	430.43	30/70	MF*	DCV*	CCLI (2.40–2.80 kPa)
A2	0.46	134.00	24.6	16.20	398.52	31/69	ACV*	DCV*	
A3	0.54	149.28	18.20	20.00	360.00	28/72	MF*	DCV*	CCLII (3.06–4.27 kPa)
B1	0.90	291.60	22.00	18.00	396.00	33/67	ACV*	SCV*	
B2	0.75	298.00	22.60	18.27	412.90	30/70	MF+ACV*	DCV*	
B3	0.64	306.08	23.20	22.06	511.79	25/75	MF+ACV*	DCV*	CCLIII (4.53–6.13 kPa)
C1	0.69	281.60	20.80	22.41	466.12	50/50	MF+ACV*	SCV*	
C2	0.68	265.20	21.80	20.34	443.41	45/55	MF+ACV*	SCV*	
C3	0.65	296.00	21.00	23.44	492.24	38/62	MF+ACV*	DCV*	
C4	0.86	360.56	19.20	19.00	364.80	28/72	MF+ACV*	DCV*	
C5	0.70	298.44	24.00	22.00	528.00	40/60	MF+ACV*	DCV*	
C6	0.87	312.80	16.80	24.48	411.26	32/68	MF+ACV*	DCV*	
C7	0.72	384.88	22.60	26.00	587.60	45/55	MF+ACV*	DCV*	

*MF=multi-filament yarn, *ACV=Air covered yarn, *SCV=Single covered yarn, *DCV= Double covered yarn

3. RESULTS

In this scientific research work, the tensile properties of the compression socks were analyzed. These properties include comparison of force at practical extension and experimental pressure (Ps), exercising effect on force decay [N], combined effect of force at fixed extension (65%) and hysteresis (H), loading energy [mJ], unloading energy [mJ], tensile resilience (TR) and tensile linearity on experimental pressure (Ps).

Table 2. Tensile properties of compression socks' cut-strips.

Code	Hysteresis	Loading energy [mJ]	Unloading energy [mJ]	Tensile resilience [%]	Tensile linearity	Force at fixed extension [N]
	H	W	W'	RT%	LT	F_F
A1	50.764	146.604	95.84	65.373	1.09	8.242
A2	88.248	182.86	94.612	51.740	1.11	10.12
A3	17.286	81.356	64.07	78.753	1.19	4.22
B1	44.381	172.917	128.536	74.334	1.25	8.486
B2	41.64	162.623	120.983	74.395	1.29	7.76
B3	47.794	203.096	155.302	76.467	1.30	9.658
C1	38.303	208.203	169.9	81.603	1.21	10.634
C2	40.144	188.624	148.48	78.717	1.24	9.33
C3	37.16	176.688	139.528	78.969	1.16	9.348
C4	48.595	248.055	199.46	80.410	1.25	12.222
C5	44.183	222.91	178.727	80.179	1.29	10.642
C6	44.201	232.325	188.124	80.974	1.29	11.04
C7	56.326	304.059	247.733	81.475	1.26	14.842

3.1 Force decay due to exercising

Figure 1 represent the exercising effect of cut-strips undergoing the decrease in their tensile force when extended to a maximum 65% context to gauge length. A decrease in tensile force due to cyclic loading and unloading is named force decay due to exercising explained by BS EN 14704-1.

In this Figure 1 (see the class I cut-strips: A1, A2, A3) it is revealed that samples A2 and then A1 is highly deformed; with a loss of force value of about (8.834%) and (7.536%) which is due to their lower thicknesses, lower areal densities and mesh knitted structures while sample A3 undergoes minimum force decay that is 3.347% which portrays A3 cut-strips are more stable as compared to A1 and A2 cut-strips due to the highest value of thickness, areal density, and plain knit structures respectively. Similarly, decay in force value of class II cut-strips due to five cyclic loading and unloading has been ordered as B2 (3.969 %) >B1 (3.70%) > B3 (2.941%). The difference in force decay between the samples is not too much but observed there is a small force value decrement occurs because of varying physical internal specifications shown in Figure 1.

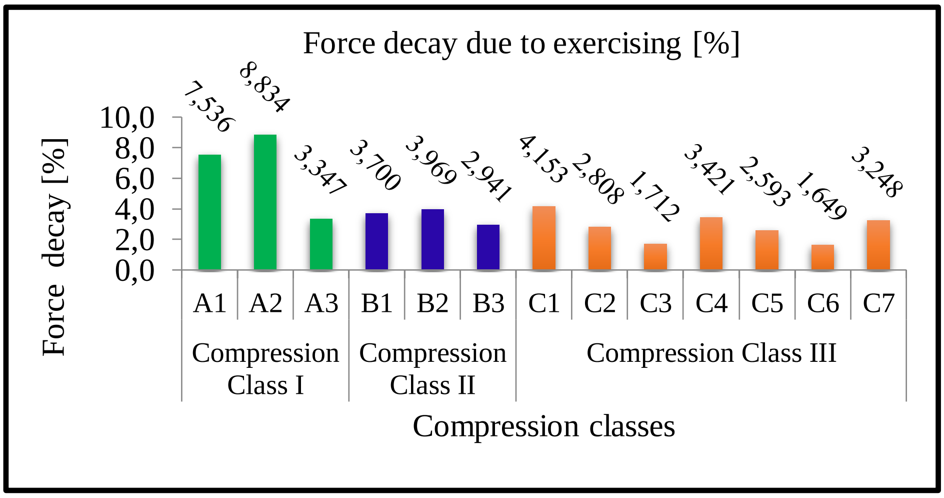

Figure 1. Force decay due to exercising [%].

3.2 Elastic hysteresis

Figure 2 illustrates the 3D surface plot between the two independent variables; force at fixed extension (F_F) and hysteresis (H) and one dependent variable; experimental pressure (P_S).
Compression class I cut strips show the increasing trend of elastic hysteresis (H) values arranged in decreasing order; A2 (88.248) >A1 (50.764)>A3 (17.286) shown in Table 2. This trend of elastic hysteresis (H) values of cut-strips is due to their knit structure as well as the decreasing trend of areal density A2 (134.00) >A1 (139.44) >A3 (149.28). This also portrays that the areal density of the cut-strips sample is inversely proportional to hysteresis values of cut-strips.

Table 2 also portrays the hysteresis values of class II cut-strips in increasing order B3 (47.794) > B1 (44.381) > B2 (41.64). The reason for the highest value of hysteresis of B3 cut-strip is due to its minimum thickness and highest wale density that cause the stitches to deform and deteriorate the internal friction between them. Elastic hysteresis (H) value of the class III cut-strips coded as above also undergoes varying deformation depending on their physical characterization.

Table 2 portrays that C3 (37.16) cut-strip undergoes a minimum loss of energy (hysteresis) due to five times cyclic loading while cut-strip C7 (56.326) loses maximum energy after cyclic loading and unloading processes. The reason for such a maximum loss of energy of sample C7 is due to the highest areal density (384.88 g/m2) as well as the stitch density (587.60 stitches/inch2) that causes the displacement of loops ultimately decreasing the internal friction between the loops.

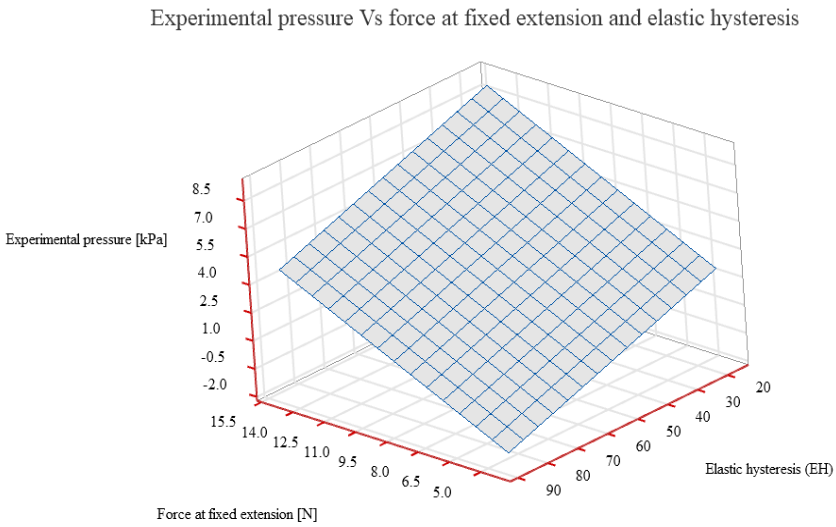

Figure 2. Elastic hysteresis and force at fixed extension compared to experimental pressure.

3.3 Loading energy

Loading energy (L_E) is the capacity of the material to withstand the force or it can also be defined as the area under the tensile curve. Figure 3 represents the 3D surface plot relationship between the force of extension (F_F), loading energy (L_E), and experimental pressure (P_S).

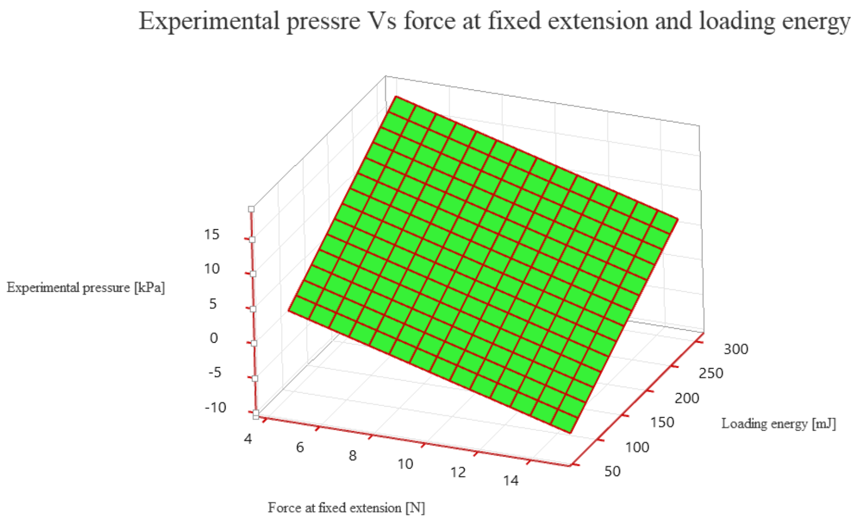

Figure 3. Loading energy and force at fixed extension compared to experimental pressure.

Figure 3 quantifies that how much force at fixed extension (F_F) and loading energy (L_E) influence the intensity of compression pressure. As the loading energy increases, the area under the loading curve increases which increases the intensity of experimental pressure (Ps). The greater the tensile energy and tensile strain, the easier the fabric deforms in stretch loading. Higher deformation causes higher recovery of fabric to return to its original position ultimately increasing the intensity of compression pressure.

3.4 Unloading energy

Figure 4 represents the relationship with the decreasing of the stretch loading, the return curve formed reflects the tensile resilience energy (W') of the fabrics. It is also calculated by measuring the area under the unloading curve also called as resilience curve. Figure 4 reflected the relationship between unloading energy (UE) and force at fixed extension (F_F) on experimental pressure (Ps) of all of the 13 socks samples including class I, class II and class III. Figure 4 also replicated that unloading energy (UE) has a direct relationship with the experimental pressure (Ps) which means as the unloading energy (UE) increases the compression pressure (P_S) value increases.

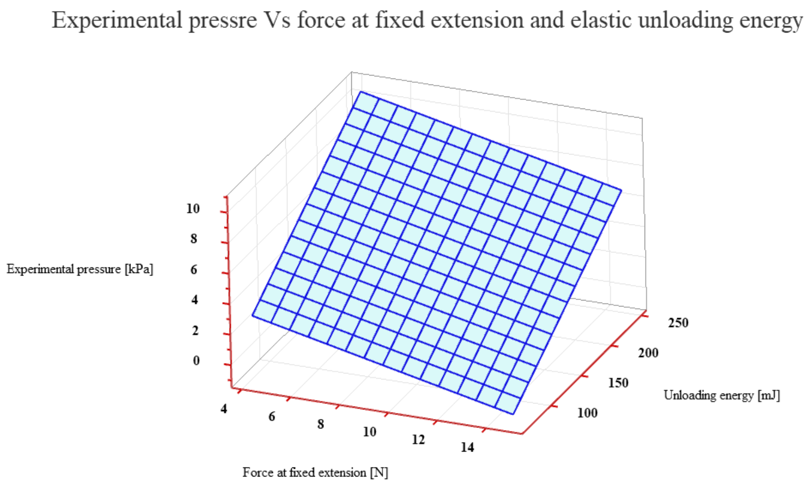

Figure 4. Unloading energy and force at fixed extension compared to experimental pressure.

3.5 Tensile resilience

Figure 5 represented that by increasing the value of the tensile resilience (TR), the pressure value (Ps) exerted by the cut strips increases while the force of fixed extension (F_F) has also a direct relationship with compression pressure.

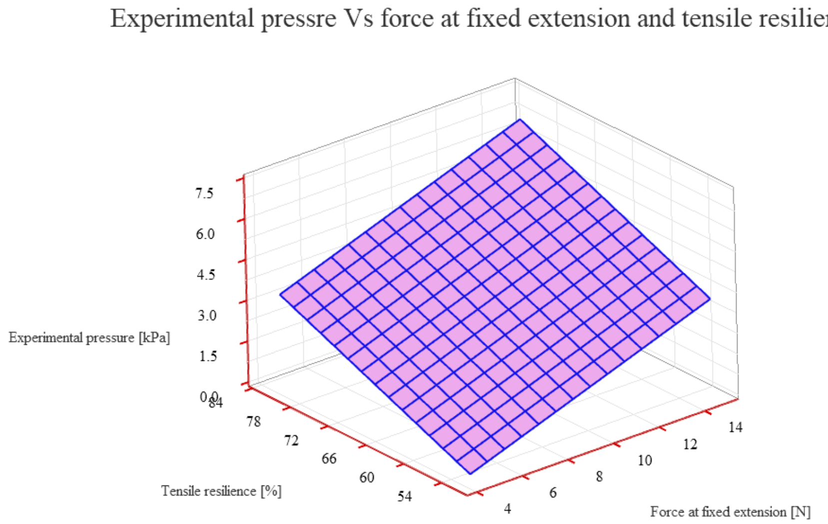

Figure 5. Tensile resilience and force at fixed extension compared to experimental pressure.

3.6 Tensile linearity

Figure 6 comprised of the relationship between forces at fixed extension [N], tensile linearity, and experimental pressure of all of the cut-strips belonging to class I, class II and class III. To understand their mutual relationship, a 3D surface plot was graphed and analyzed which tells that tensile linearity has an indirect relationship with experimental pressure. As the tensile linearity value decreases, the compression pressure value increases. Figure 6 also portrays that by increasing the force at fixed extension [N] compression pressure also increases.

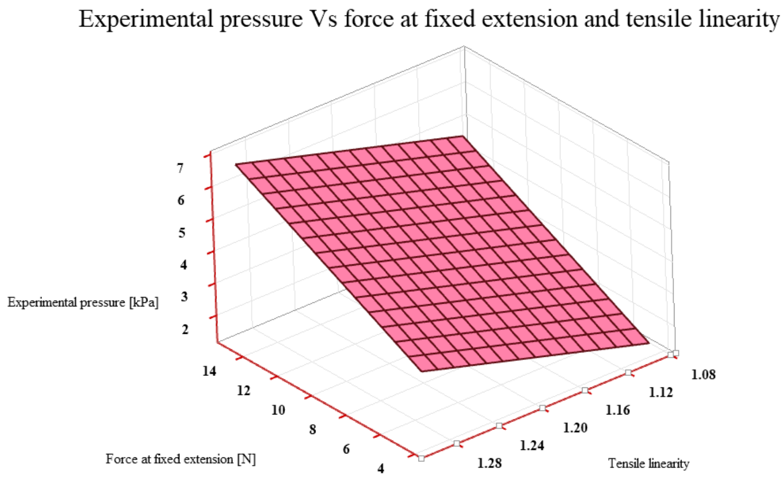

Figure 6. Tensile linearity and force at fixed extension compared to experimental pressure.

4. CONCLUSION

Tensile properties of the compression socks is of great importance that helps to understand the engineering of these and how these play a role to exert adequate pressure to avoid the insufficiency and reversibility of blood flow.

Force decay value due to exercising of class I cut-strips undergoes more force decay as compared to class II and the class III cut-strips due to their lower structural stability and stiffness characteristic. The 5 times cyclic loading and unloading for all samples belonging to each class undergoes varying force decay from a minimum of 1.649% to a maximum of 8.834%. Conclusively, class III samples; C3 and C6 undergoes least force decay being structurally more stable while Class I sock cut-strips especially; A1 and A2 undergo more force decay 7.536% and 8.834% simultaneously.

Force at fixed extension has a direct relationship with experimental pressure (Ps) while the elastic hysteresis (EH) values have an indirect relationship with the intensity of exertion of interface pressure. Higher the values of elastic hysteresis values lower will be the intensity of exertion of compression pressure.

Loading energy (LE) effect combined with force at fixed extension (F_F) on experimental pressure (Ps) undergoes a strong relationship. Unloading energy (UE) and force at practical extension (F_P) has a significant influence on the intensity of the experimental pressure (Ps).

Tensile resilience (TR) and force at fixed extension (F_F) have a direct relationship with each other. Tensile linearity (TL) and force at fixed extension (F_F) have a significant influence on the intensity of the compression pressure.

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REFERENCES

[1] Flaud, P., Bassez, S., & Counord, J.-L. (2010). Comparative In Vitro Study of Three Interface Pressure Sensors Used to Evaluate Medical Compression Hosiery. *Dermatologic Surgery*, *36*(12), 1930–1940. https://doi.org/10.1111/j.1524-4725.2010.01767.x

[2] Xiong, Y., & Tao, X. (2018). Compression Garments for Medical Therapy and Sports. *Polymers*, *10*(6), 663. https://doi.org/10.3390/polym10060663

[3] van der Wegen-Franken, C. P. M., Tank, B., Nijsten, T., & Neumann, H. A. M. (2009). Changes in the pressure and the dynamic stiffness index of medical elastic compression stockings after having been worn for eight hours: A pilot study. *Phlebology*, *24*(1), 31–37. https://doi.org/10.1258/phleb.2008.008037

[4] Van Der Wegen-Franken, K., Tank, B., & Neumann, M. (2008). Correlation Between the Static and Dynamic Stiffness Indices of Medical Elastic Compression Stockings. *Dermatologic Surgery*, *34*(11), 1477–1485. https://doi.org/10.1111/j.1524-4725.2008.34312.x

[5] Liu, R., Guo, X., Lao, T. T., & Little, T. (2017). A critical review on compression textiles for compression therapy: Textile-based compression interventions for chronic venous insufficiency. *Textile Research Journal*, *87*(9), 1121–1141. https://doi.org/10.1177/0040517516646041

THE REDUCTION OF SIZE CONSUMPTION WITH NOVEL PRE-WETTING BOX

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ABSTRACT

The aim of this study is to point out all advantages of prewetting, and differences from conventional sizing process. Different type of yarns is analysed by using row and dyed ring spun and open-end cotton. After water application the yarn is squeezed by high pressure. So that residual moisture takes place only around centre of the yarn. The sizing will carry out with the wet yarn which has fully cleaned surface. After size application, the most important parameter is to know the percentage of water content out of total size pick up inside the yarn. The moisture content in the material is determined by Pleva unit which has microwave measuring sensor. The result of this research has been revealed that prewetting process has a great contribution of saving sizing and desizing agents and increasing weaving efficiency.

Keyword: *pre-wet sizing, size pick-up, weaving*

1. INTRODUCTION

The new prewetting size box subject to study named as wet-on-wet sizing process. The wet-on-wet technology makes it possible to treat rough and fine yarns as well as coloured yarn of different materials due to a specially suited way of running between feeding liquor and proportional squeezing pressure. By a volume-constant dosage in connection with an intermediate buffer situated between rollers it is possible to keep the bath concentration constant (from the first to the last meter) and to automate, display and control all the possible running conditions. In the study, the novel sizing technique is investigated for increasing the sizing efficiency. This new box is designed by ProSMH R&D teams. While testing of the box, the efficiency is measured and compared with conventional one.The conventional size box can be seen in Figure 1.

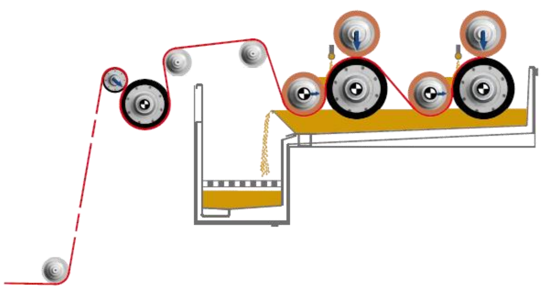

Figure 1. Conventional size box.

In Figure 3, the new compact size box can be seen wit prewetting application desing by PROSMH R&D teams.

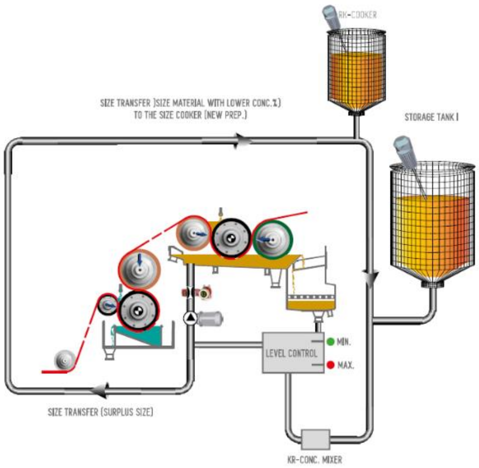

Figure 2. Prewetting application at size box.

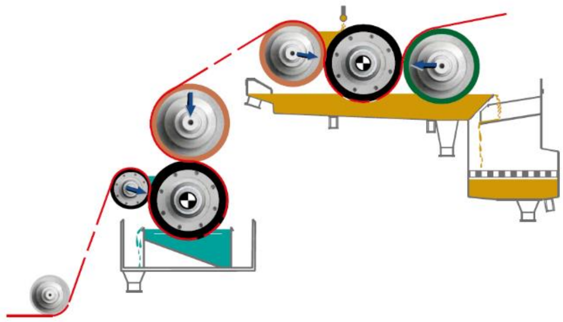

Figure 3. New compact size box with prewetting.

Figure 4. Conventional size box.

Figure 5. Prewetting application at size box.

2. EXPERIMENTAL STUDY

In the study, sizing process is performed at both size boxes (conventional and novel) by NeB 30 Ring and NeB 30 Open-End yarns and dyed yarns in order to measure the water / sizing absorption and size pick-up. The formulas that we used for the calculation of these parameters can be seen below as equation 1-2-3.

WA (%): Water Absorption

SA (%): Sizing Absorption

K (%): Concentration

B (%): Size Pick up

V(m/min): speed

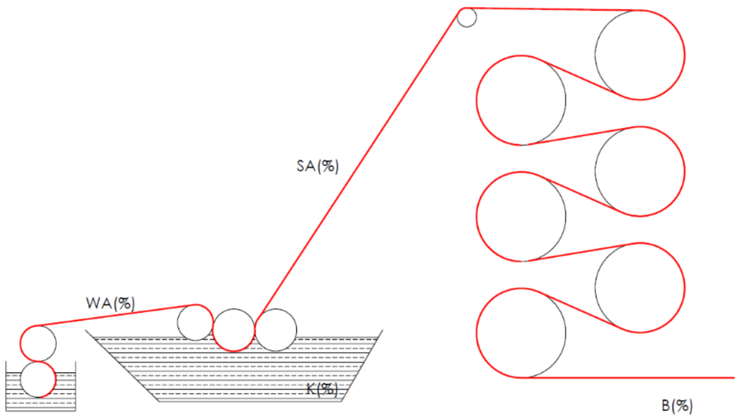

Figure 6. The principle of the sizing.

In the study, first, water pickup WA (%) is measured and defined for the different production speed. During the test by pure water the squeezing pressure is kept as 65 kN fixed. There is no size inside the box during that water test.

$$B(\%) = \text{WA}(\%) * \text{K}(\%)/(100 - \text{K}(\%)) \quad \text{Eq. 1}$$

$$B(\%) = [\text{WA}(\%) + B(\%)] * K(\%)/100 \quad \text{Eq. 2}$$

$$B(\%) = \text{SA}(\%) * \text{K}(\%)/100 \quad \text{Eq. 3}$$

The experimental study values taken from the bulk production can be seen in Figure 7.

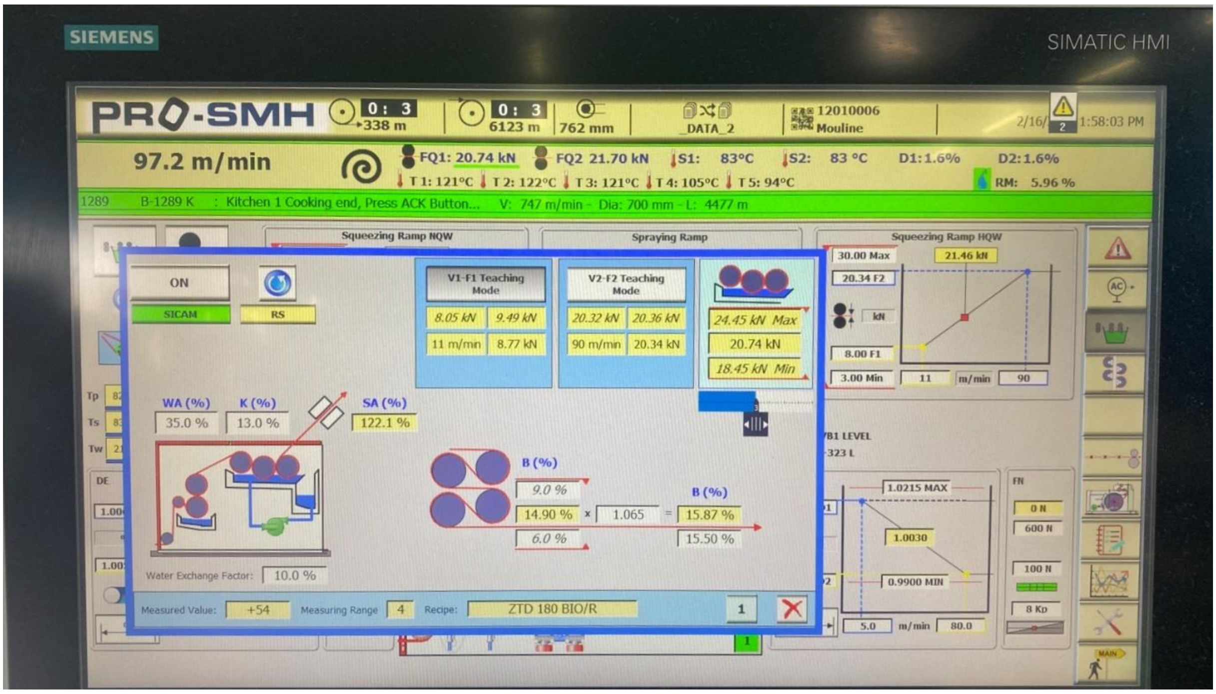

Figure 7. HMI image.

3. RESULTS

According to Table 1, water absorption WA% of OE, Ring and Dyed yarn (OE or Ring) is respectively %45, %25 and %55 for 80 m/min production speed; 24%, 20% and %55 for slow speed. Referring that information, we should similarly define the squeezing pressure ramp according to speed changes to have equal size pick-up for any speed. Absorption Results according to the speed changes for OE Yarn is having logarithmic increase more than Ring Yarn whereas Dyed Yarn is having no ramp. Size concentration should be considered a bit more for prewetting application due to exchange factor is around 10% in size box. In Table 2, comparing size pick-up B (%) values of above mentioned yarns for conventional and pre-wetting application. According to the Table, the efficiency and saving effect of new method can be seen clearly. The saving of 26,67%, 11,5% and 45% were calculated for OE, Ring and Dyed OE yarns, respectively.

Table 1. Water absorption WA (%).

Ne 30/1 Open End		**Ne 30/1 Ring**		**Dyed yarn OE or R**	
V (m/min)	WA (%)	**V (m/min)**	WA (%)	**V (m/min)**	WA (%)
20	24	**20**	20-21	**30**	56-54
40	29-32	**40**	23-20	**50**	52
60	40	**60**	26	**75**	54
80	45	**81**	26	**90**	56-51

Table 2. Size pick-up B (%).

Ne 30/1 Open End		Ne 30/1 Ring		Dyed yarn OE or R	
Conventional	Novel Box	**Conventional**	Novel Box	**Conventional**	Novel Box
10.8%	7,92%	10,4%	9,24%	8,8%	4,84%

Graphics taken from SICAM system developed by Prosmh and shown in Figure 8-9-10. The size pick up of conventional size application of OE yarn can be seen in Figure 8.

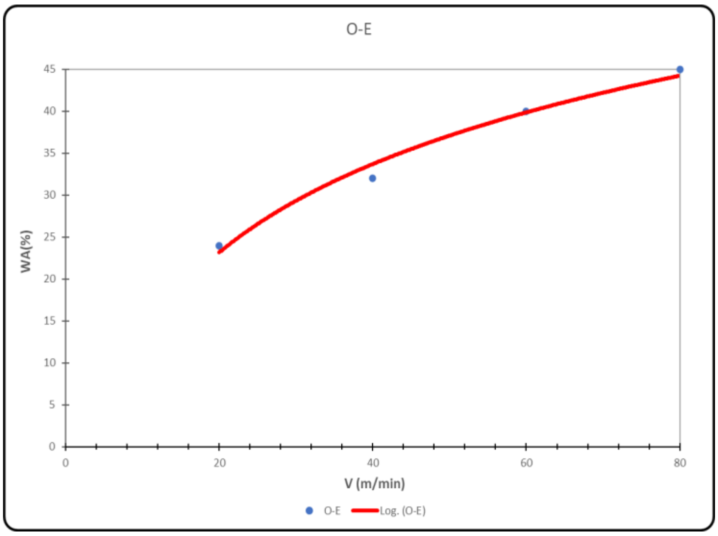

Figure 8. Size pick up of conventional size application of OE yarn.

The size pick up of conventional size application of ring yarn can be seen in Figure 9.

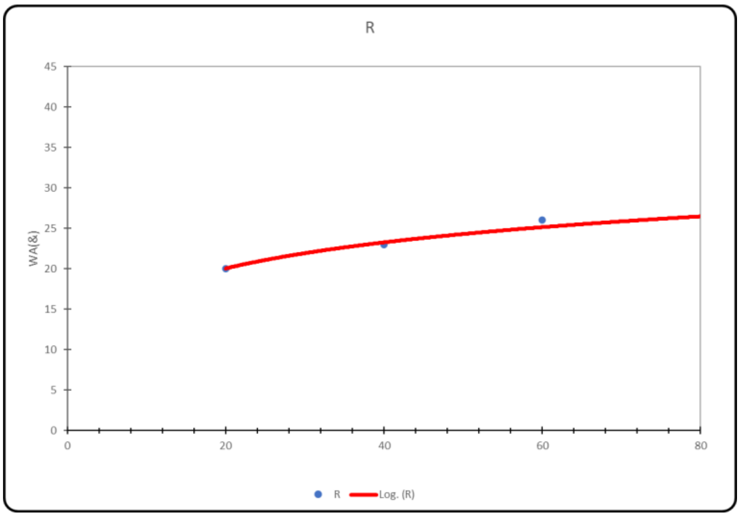

Figure 9. Size pick up of conventional size application of ring yarn.

The size pick up of conventional size application of dyed yarn can be seen in Figure 10.

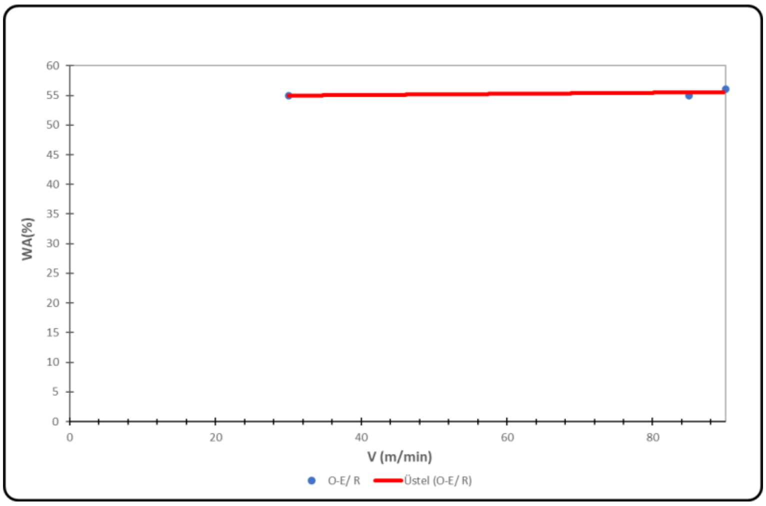

Figure 10. Size pick up of conventional size application of dyed yarn.

4. CONCLUSION

According to the results, it is found out that, the construction of the size box and pre-wetting application is having positive effect on the consumption of sizing materials. Water content in the centre of the yarn causes decrease of the consumption. Thus, sizing and desizing agents are saved by prewetting process.

Yarn types for prewetting application:100% Cotton OE yarns has no restriction.100% Cotton ring yarns up to Nm 100 or Ne 60 medium to long-stapled carded yams and compact yarns. Cotton ring yarns is having only a slight saving of size agent, however, prewetting application helps improving weaving efficiency due to less abrasion. Cotton / PES OE mixed 30/70 up to Nm 50 or Ne 30Cotton / PES ring mixed 50/50 up to Nm 50 or Ne 30 medium to long-stapled yarns are having restricted operative range.

Water absorption during pre-wetting max. 60%.

In conventional sizing increase of the efficiency up to 1%, in individual cases could be more, saving potential of size agent with SICAM controlup to 10%. In prewetting technology for 100% Cotton OE Increase of the efficiency up to 5 points and saving potential of size 10% to 30%, depending on yarn characteristics and sizing recipe for 100% Cotton ring yarns, Cotton / PES mixed, 100 % PES Increase of the efficiency up to 3 points and saving potential of size up to 10%, depending on yarn characteristics and sizing recipe. Increase of the efficiency should be regarded with priority in the weaving mill, as it brings along the most considerable cost advance. The saving of size is a supplementary contribute.

REFERENCES

[1] Gudlin Schwarz I., Kovacevic S., Dimitrovski K.; Comparative Analysis of the Standard and Pre-wet Sizing Process. FIBRES & TEXTILES in Eastern Europe 2011, Vol. 19, No. 4 (87) pp. 135-141.
[2] Johnen A.: Experiences in wet-in-wet sizing, Melliand International, Vol. 11 (March), 2005, pp. 34-36.
[3] Nejib Sejri[1, 2,] Ömer Harzallah[1], [*,]Prerre Vialier[1], Sami Ben Amar[2]ve Sassi Ben Nasrallah[2]. [1]LPMT UMR 7189 CNRS-UHA, ENSISA, 11 rue Werner,68093 Mulhouse Cedex, Fransa, [2]LESTE, ENIM, Avenue Ibn El Jazzar, 5019 Monastir,Tunusia

DURABILITY ASSESMENT OF DIGITAL PIGMENT INKJET PRINTING ON PLASMA PRETREATED NATURAL LEATHER FOR CAR INTERIOR DESIGN

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ABSTRACT

For this work, two semi-finished leather products and one finished leather were used in the experiment, for surface pretreatment with ecologically favorable plasma technology followed by digital inkjet printing technology. For ecological as well as technical reasons, the printing process was carried out without primer as well as without polyurethane primer in order to achieve high printing quality. Semi/finished products made of chrome or synthetically tanned bovine leather with different degrees of finishing. The samples are pretreated with oxygen and argon plasma and then printed using digital inkjet pigment printing (direct and transfer). The effectiveness of plasma pretreatment on the durability of digital pigment inkjet printing was characterized by analyzing the surface morphology with a scanning electron microscope, while the coverage of the printing surface was analyzed with a Dino-lite microscope. It was found that the surface of the samples was cleaner but rougher, with accentuated and open grooves and the presence of granulated segments on the pretreated leather surface. The effect of the (pre)treatments on the hydrophilicity, friction resistance, flexural resistance and ageing resistance after exposure to artificial light were performed under controlled laboratory conditions. After 25.000 cycles, almost all of the samples had excellent flexural resistance, as they did after 75 hours of artificial light irradiation, indicating that the samples printed with transfer printing had the highest values, regardless of the type of tanning agent or the type of plasma pretreatment working gas. Due to the spread of pigment ink on the surface during direct printing, it was not possible to apply the primer to semi-finished products. In this case, the only finished sample printed with primer using the direct printing process has the highest score, which is the best score for the direct printing process compared to transfer printing.

Keyword: *Bovine leather, Low-pressure plasma, Digital inkjet printing, Print fastness*

1. INTRODUCTION

Natural leather, as a unique biological material, has exceptional physical-mechanical (it is a very durable and resistant, elastic and breathable material characterized by high strength, elasticity, abrasion resistance, good air permeability, softness and suppleness) and aesthetic properties, and is one of the most expensive, but also most sought-after natural materials for car interiors. Due to its high price and extremely good properties, genuine leather is mainly installed in more expensive cars, where the customer wants a special and individual design of the interior [1,2]. Due to its efficiency and quality, digital printing technology is increasingly used in the textile industry. Plasma pretreatment, as an environmentally friendly technology, has helped to achieve better printing applied with digital inkjet technology to determine the possibility of using these two innovative technologies for the production of materials with potential application in the automotive industry [3,4]

2. EXPERIMENTAL STUDY

In this work, two hypotheses, namely that (i) plasma pretreatment will improve the durability of digital printing on semi-finished and finished leather and that (ii) the application of direct digital inkjet printing on semi-finished and finished leather will result in good service properties, were made in order to determine the possibility of applying these two innovative technologies in the production of materials with potential application in the automotive industry.

2.1 Materials and Methods

The tests were carried out on two different semi-processed bovine leathers - chrome tanned leather (labelled as UN/Cr) hydrophobic leather full of natural face, thicknes of 1.1-1.3 mm and leather tanned with synthetic tanning agent (Cr-free, labelled as UN/CrFree) non-hydrophobic leather, thicknes of 1.1-1.3 mm, and one finished Cr tanned leather (labelled as UN/Cr-black), hydrophobic and dyed with black dyes; thicknes of 1.6 -1.8 mm. All samples printed with direct inkjet print are labelled with D (or primer+direct inkjet print labelled as PD), with transfer print are labelled with T, and preatreated with oxygen and argon plasma are labelled depend gasses were used - Ar/ O_2 caption.

2.1.1. Plasma Pretreatments

Plasma pretreatments were realized using oxygen and argon gases (high purity 99.998%, by Messer) at a defined parameters of pressure and gas flow rate, at constant frequency of 40 kHz in a low-pressure plasma system (Nano LF-40kHz, Diener electronic GmbH), Table 1.

Table 1. Argon and oxygen plasma pretreatment conditions.

	Gas	P [W]	t [min]	q [cm^3/min]	p_0 [mbar]	p_1 [mbar]
UN/Cr *UN/CrFree*	Ar/O_2	500	20	200	0.20	0.32

p_0 [mbar]- initial pressure; p_1 [mbar]- working pressure

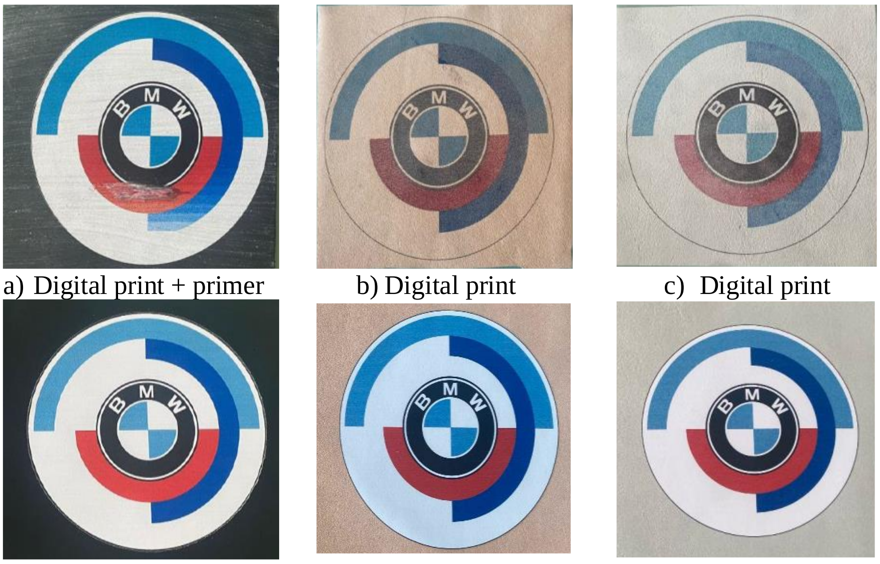
2.1.2. Digital and Transfer Pigment Inkjet Printing

Digital printing (Brother GTX Pro, Figure 1.) by digital inkjet printer with piezoelectric droplet forming was performed. For comparison, untreated and treated samples of leather samples were printed. After completion of printing, the print was fixed in a dryer at a temperature of 80 ºC for 3 minutes.

Figure 1. Digital inkjet printer Brother GTX Pro [6].

2.1.3. Optimization of printing process

For priming, the agent "Flor Leather primer FLLP1GTX" was used according to the manufacturer's recommendation. The agent was also sprayed on the surfaces according to the manufacturer's instructions. During the application of the primer, uneven absorption occurred on the sample. Following the hologram, the sample was dried in a dryer at a temperature of 80 °C for 3 minutes, which resulted in excessive drying of the sample. Due to the poor absorption of the primer, the white ink was not printed evenly on the surface and overflow occurred. After drying in a heat press at a temperature of 120 °C for 3 minutes, the sample was completely deformed. Because of the excessive temperature sensitivity of the semi-processed leather samples and the impossibility of further processing, a non-plasma-treated sample of finished black-leather was selected. Primer applied to the surface after drying remained visible in the form of undesirable rough residues, so that the print did not turn out evenly (Figure 2a). In the next step, direct printing without primer was possible, provided that a white background was not used. The results can be seen in the picture (Figure 2b,c). The color saturation of the patterns printed with an inkjet printer depends on the color of the background on which they are located.



a) Digital print + primer b) Digital print c) Digital print

d) Transfer print e) Transfer print f) Transfer print

Figure 2. Digital and transfer printing on three leather samples.

Thermal transfer film (Figure 2 d,e,f) was first printed using the inkjet printing method and then transferred to the leather samples under the action of temperature and pressure. The advantage of this method is that it does not require a primer as a base.

2.2. Testing Methods

- *The hydrophilicity* of untreated and treated leather samples was tested using the drop test in accordance with AATCC 79-2000. The behavior of the drop is observed and the time of absorption or spreading of the drop per sample is measured.
- *The analysis of the surface* of the tested leather samples was performed using an scanning electron FE-SEM microscope (Tescan Mira *II LMU*), precisely scanning the surface of the tested sample with a focused electron beam. The samples are prepared by covering their surface with a thin layer of metal (Cr) for 20 minutes (for leather samples) to ensure the conductivity of the sample. To determine the coverage of the surface of the samples after inkjet digital printing, a morphological analysis of the surface of the samples was performed using a Dino-Lite Pro AM-413T5 digital microscope at a magnification of 65x.
- *Testing the color fastness* of leather samples *to friction* using a Crocmeter ME198B, (Mesdan-Lab) according to HRN EN ISO 105-X12:2016 [7]. The tested sample is rubbed with a dry or wet cotton fabric in warp and weft direction, while the color change of the cotton fabric is evaluated according to the gray scale (grades from 1 to 5).

- *The flexural strength* of the leathers was tested according to the standard HRN EN ISO 5402-1:2017 [8] using a Flexometer (Pegasil from Zipor, EL-18/6). Before the test, samples were taken according to HRN EN ISO 2418:2017 [10]. The flexural strength test of the dry sample was performed under laboratory conditions at a temperature of 21°C and a relative humidity of 61%. A number of cycles of 25.000x was selected for testing the flexural strength of leather in dry conditions.
- *Ageing resistance of prints after exposure to artificial light* according to both standards ISO 105-B02 + A1:2013 with change of filter to B04 using the Xenotest (by SDL Atlas) were performed under controlled laboratory conditions [9]. The conditions according to the standard are given in Table 2. Before the test, a blue scale must be prepared to evaluate the resistance of the color, and the samples are exposed to the specified conditions in the xenotest together with the blue scale.

Table 2. Testing conditions in simulated conditions.

Parameters	Testing conditions	Blue scale
Lite time, t	75h	
Irradiance control, λ	300 - 400 nm	
Filter system	B04	
Energy - E	42 W/m^2	
CHT – chamber temp.	32 °C	
BST – standard temp.	47 °C	
RH	40%	
Spray	NO	
Fan speed	2000 Rpm	

Completion of the test in the exposure device is assessed by comparing the grey scale (not placed in the apparatus) with the blue wool reference illuminated together with the samples. Sunbathe until the blue scale rating is 3/4 according to the grey scale. If the rating is 4, 4/5 or 5, the sun exposure must be prolonged. Sun-exposed samples are compared with the sun-exposed blue scale and graded from 1 to 8.

3. RESULTS AND DISCUSSION

3.1. Hydrophilicity of the Tested Samples

Hydrophilicity testing was performed on semi-processed leather samples after pretreatments with oxygen and argon plasma using the simple drop test. The results are shown in Table 3.

Table 3. Time of absorbing water drop on the surfaces of tested samples.

Label of sample	Absorbtion time, t/s
UN/Cr	/
O_2/Cr	83
Ar/Cr	154
UN/CrFree	78
O_2/CrFree	43
Ar/CrFree	104

/ - hydrophobic after 2 hours

In general, O_2 plasma pretreatment shows a better effect on the wettability of the hydrophobic leather surface than Ar pretreatment, which can be attributed to the nature of the gases. The change in terms of better surface wettability after 20 minutes is important for the chrome tanned sample, which is extremely hydrophobic before plasma pretreatment. However, to achieve uniform wetting of the surface, additional plasma treatments must be performed, which improves the application possibilities for further treatments such as printing.

3.2. Analysis of Morphology of Leather Surfaces

The effectiveness of plasma pretreatments was characterized by analyzing the surface changes caused by the oxygen and argon plasma, with the aim of achieving better opacity and durability of the inks applied with digital printing technology (Figure 3.), while the coverage of the printing surface area was studied with a Dino-lite microscope (Figure 4.).

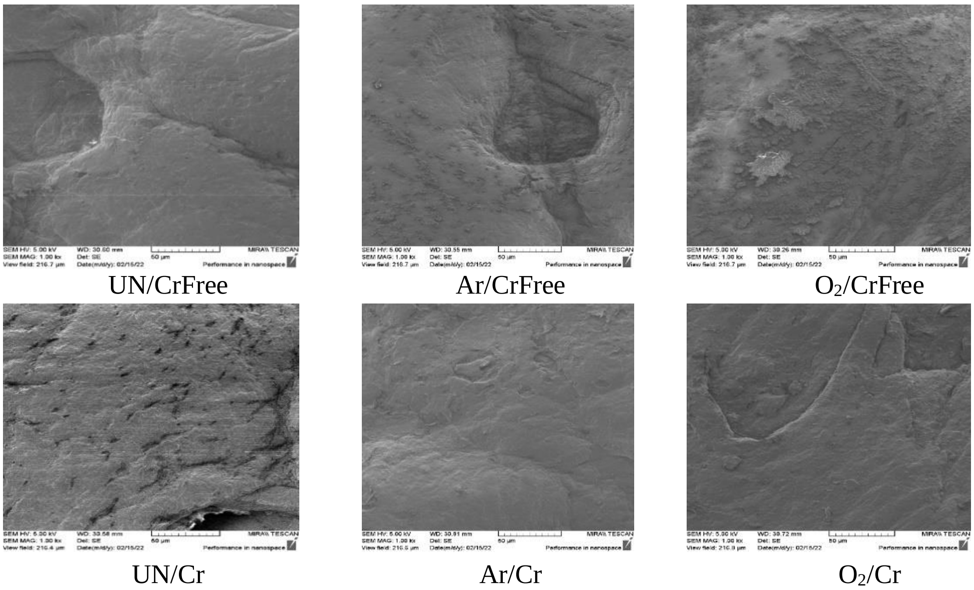


Figure 3. Micrographs images of treated Cr and CrFree leather samples, magnifications of 1000x.

After plasma pretreatments the surface of the samples was cleaner and more rougher (especially after oxygen pretreatment of the chrome free tanned leather, with open grooves and the presence of granulated segments on the pretreated leather surface. The surface consists of impurities on the face as a result of treatment with oxygen plasma. Such results are in correlation with results obtained in previous paper [5]. The results obtained correlate with the improved hydrophilicity, as the wetting time of the sample is 43 seconds, compared to the untreated sample, which requires 78 seconds.

3.3. Coverage of Printing Area Analysed by Dino Lite Microscope

Morphological analysis of the surface of the leather samples was performed using a Dino-lite microscope at a magnification of 65x. By analysing the surface morphology in this way, it is possible to consider the behaviour of the print. The results of individual samples are shown in Figure 4.

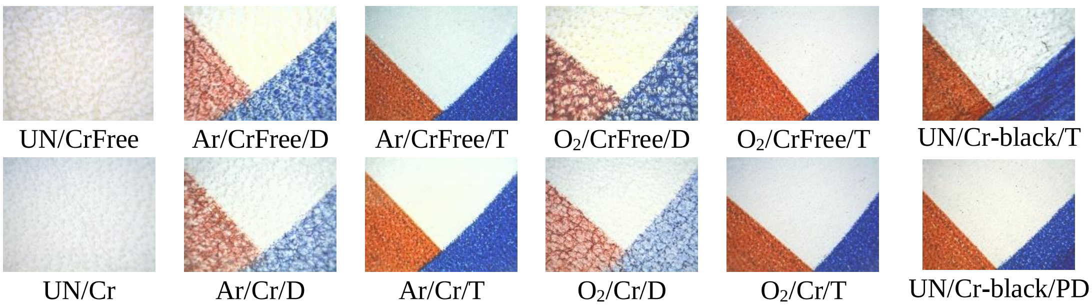


Figure 4. Coverage of the surface of leather samples (D - direct inkjet print; T - transfer print).

Plasma pretreatment resulted in an increase in surface hydrophilicity of the leathers, but because pigment ink contains some water, direct printing resulted in a characteristic bleeding of the ink in areas of greater relief of the leather surface. With transfer printing, this effect is not so pronounced and the surface is evenly covered with ink. Visually, the opacity is much better, as is the mixing of the process colors. The UN/Cr-black/PD sample is the only sample that contains a primer substrate, and uniform coverage of the surface is observed on it.

3.4. Results of Color Fastness of the Leather Samples to Friction Resistance

Results of durability assessments of printing of leather samples against friction were presented in Table 4. The color change of the cotton fabric is evaluated according to the gray scale (1-5). Wet print stability is worse for almost all samples regardless of the type of pressure, while the results of the dry friction test are very good. The best results (5/4-5) are shown by the chrome tanned sample pretreated with argon plasma and printed by digital transfer print. The worst result (3-4/1-2) was obtained for the untreated, chrome tanned and black dyed sample printed by the direct printing process with a primer.

Table 4. Assesment of friction resistance of the printed samples.

	UN/Cr Free	Ar/CrFree/D	Ar/CrFree/T	O_2/CrFree/D	O_2/CrFree/T	UN/Cr	Ar/Cr/D	Ar/Cr/T	O_2/Cr/D	O_2/Cr/T	UN/Cr-black/T	UN/Cr-black/PD
Grey scale dry/wet friction	5/5	3/2-3	3-4/3	4-5/4-5	4-5/4-5	5/5	4/4	5/4-5	3/2-3	4-5/4-5	4-5/3	3-4/1-2

The general conclusion visible on the basis of the obtained results shown in Table 4. indicates that the results do not depend so much on the plasma pretreatments carried out as on the printing method, where the grades are better for transfer printed samples. No clear results were obtained, making it difficult to determine whether plasma pretreatment improves the durability of the print or whether the results obtained with transfer printing are generally better than those obtained with direct digital inkjet printing.

3.5. Results of Flexural Resistance of the Leathers

The flexural resistance of the semi-processed and finished leather samples was tested using the Flexometer method. The three specimens exhibited poor flexural strength, where "cracks in the finish were observed without propagation of damage through one or more layers of the finish". This damage was observed after 5000 bending cycles for the Ar/Cr/T, after 11460 cycles for O_2/Cr/T, and after 16730 cycles for a UN/Cr-black/ PD sample. Excellent results are shown of all other tested samples, without any destroying the digital prints and surface even after 25.000 bending cycles.

3.6. Results of Ageing Resistance of Prints after Exposure to Artificial Light

The results of the color fastness of artificially aged specimens in the Xenotest according to the blue scale (grades from 1 to 8) are shown in Table 5.

Table 5. Results of the color fastness of artificially aged specimens according to blue scale.

	UN/Cr Free	Ar/CrFree/D	Ar/CrFree/T	O_2/CrFree/D	O_2/CrFree/T	UN/Cr	Ar/Cr/D	Ar/Cr/T	O_2/Cr/D	O_2/Cr/T	UN/Cr-black/T	UN/Cr-black/PD
Evaluation according to the blue scale (red/blue)	4	6/5	7/7	6/6	7/7	6	6/6	7/7	1/6	7/7	7/6	7/7

After 75 hours of exposure to sunlight and atmosphere, high values were obtained i.e., there are no significant changes in the appearance of the printed patterns. The values obtained for the red and blue patterns are mostly correlated and have equal values. The results show that the samples printed with the transfer printing process obtain the best scores regardless of the type of tanning and the type of gas used for plasma pretreatment (7/7). For the O_2/Cr/D sample, the lowest score (1/6) was obtained in the red part of the printed sample. This result is due to the fact that the direct printing pigment was spilled on the surface because the primer could not be applied. At the finished sample UN/Cr-black/PD, where the primer was used in the direct printing process, the highest rating (7/7) is visible, which is the best rating for the direct printing process.

4. CONCLUSION

According to obtained results and discussion, it can be concluded that the application of environmentally friendly cold plasma technologies and digital inkjet printing is essential for the development of sustainable materials and the sustainability of textile technology to reduce environmental pollution and the generation of unnecessary waste, and that research should be continued to fully optimize the parameters for the preprocessing of leather from natural sources to achieve better performance characteristics and quality of the material obtained. In this sense, the hypotheses established can be partially accepted, although additional tests and analysis are required.

ACKNOWLEDGMENT

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REFERENCES

[1] Rogina-Car, B. & Kovacevic, S. (2019). Natural leather car upholstery - characteristics and sewing challenges, Koža & Obuća**,** 68, 34-37.
[2] Li, Z., Paudecerf, D., Yang, J. (2009). Mechanical behaviour of natural cow leather in tension, *Acta Mechanica Solida Sinica*, **22** (1) 37-44.
[3] Štěpánová, V. et al. (2017). Surface modification of natural leather using diffuse ambient air plasma, International Journal od Adhesion and Adhesives, **77,** 198-203.
[4] Glogar I. M. (2019). All the challenges of inkjet digital textile printing, *Textile Print magazin*, **6** (4), 18-21.
[5] Ercegović Ražić, S., Akalović, J., Ivanković, T., Ludaš A., & Ištef, K. (2021). Modification of Leather Surface Using Low-Pressure Plasma and Antimicrobial Reagent, E3S Web of Conferences, 327, 03004. Retrieved from https://doi.org/10.1051/e3sconf/202132703004
[6] https://garmentprinter.global.brother/de-emea/products/all-dtg/dtg/gtx-423, accessed 10 July 2022.
[7] HRN EN ISO 105-X12:2016 Textiles - Color fastness test - Part X12: Color fastness to friction.
[8] HRN EN ISO 5402-1:2017 Leather - Physical and mechanical tests - Determination resistance to bending by the flexometer method
[9] https://www.ttf.unizg.hr/xenotest-440/1002, accessed 12.9.2022.
[10] HRN EN ISO 2418:2017 Leather - Chemical, physical, mechanical and durability tests - Sampling point.

PERFORMANCE PROPERTIES OF FIREFIGHTER FLAME RETARDANT UNDERWEAR FABRICS

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ABSTRACT

Nowadays, occupational health and safety is important and thermal protective clothing is used in many sectors where thermal hazards are available. Within the scope of the study, performance properties of knitted fabrics which can be used for firefighter flame retardant underwear clothes were investigated. For this aim, Ne 24/1 yarn samples were produced with the blend of different fibers namely Panox, FR Modacrylic, FR Viscose and conventional Viscose fiber by vortex spinning system. Yarn strength, elongation and unevenness tests were carried out on yarn samples. Then, single jersey and pique knit type fabrics were produced from these yarns and the sample knitted fabrics were dyed. Performance properties of vertical flame resistance, bursting strength, air permeability, dimensional stability and fastness were determined. In case of flame resistance performance, it was observed that FR Modacrylic blended fabrics were better than other samples.

Keyword: *Flame retardancy, Knitted fabric, Firefighter underwear, Air permeability, Vertical flame resistance*

1. INTRODUCTION

Firefighters are the occupational group which mostly exposed to the thermal hazards. Considering the high level of radiant heat and flame that firefighters are exposed to it can be concluded that serious threats are available. Firefighter suits are manufactured to protect personnel against radiant heat and flame. Nevertheless, effective protective clothing structure may not be not sufficient in most cases. Although the firefighters' suit is not deformed, burns may occur on the firefighter's skin. This situation shows the importance of protection level of clothing which is in contact with the human skin.

Today, there are various studies on flame retardancy. These studies are based on the principle of obtaining flame retardancy from fiber spinning, synthesizing new polymers and using them as flame retardant materials, and applying flame retardant finishing during finishing processes.

Parmar et al. [1] studied on Aramid and Modacrylic fiber types in order to improve the comfort parameter with natural flame retardant fibers, FR Viscose-containing woven fabrics were evaluated in terms of durability, safety (heat and flame) and comfort properties. Özcan [2] determined that the most important parameters which affects the flammability of knitted fabrics are fiber type, blend ratio, fabric design and weight. It is also concluded that the open-end yarns ignites faster. Ksenija Varga et al. [3] investigated the effectiviness of Lenzing FR® fibers by different analytical methods in comparison to different protective fibers. Şardağ [4] investigated the comfort properties of knitted fabrics containing different blend ratios of cotton, tencel and meta-aramid fibers. Erkut [5] investigated the comfort properties and burning behavior of knitted fabrics obtained from meta aramid, para aramid and FR viscose fibers with different blend ratios. Hyun et al. [6] examined the flame retardancy, antistatic property and wear comfort of knitted fabrics produced from blends of Modacrylic, antistatic PET, cotton and Excel fibers. The Excel knitted fabric showed better flame retardancy, antistatic property and thermal comfort in comparison to cotton blended and 100% cotton fabrics. Regarding the wear comfort, wickability and fast drying properties of the Excel fabric was superior to those of the cotton blended and 100% cotton ones. The thermal conductivity of the Excel fabric was lower than that of the cotton blended and 100% cotton ones. The water vapor permeability of the Excel fabric was lower than that of the 100% cotton one. The Excel fabric had an inferior tactile hand compared to the cotton blended and 100% cotton fabrics because of its less extensibility, lower compressibility, higher bending and shear rigidity. Stygienė et al. [7] examined the protective fireproof underwear regarding wear comfort. In this study, flammability and thermal comfort properties of two-layer knitted fabrics containing aramid and flame retardant (FR) viscose fiber. Liquid moisture management, water vapor permeability, air permeability and thermal resistance were examined. Jamshaid et al. [8] studied on flame retardancy of knitted fabrics with meta-aramid, FR-Viscose, FR-modacrylic, FR-polyester and carbon fibers with different blend ratios. It was reported that the fabric produced from the sample containing FR-polyester and FR-viscose fiber provides optimum flame retardancy and comfort. Alaybeyoğlu et al. [9] examined the flame retardancy properties of some biodegradable fibers obtained from different sources. Flame retardancy properties of knitted fabrics containing PLA, cotton, lyocell, and chitosan fibers were studied by analyzing the LOI values and burning behaviors. Single jersey knitted fabrics composed of 100% PLA, 100% Lyocell, 95% PLA-5% Chitosan, 95% Cotton-5% Chitosan, 95% Lyocell-5%Chitosan, 80%PLA-15%Cotton-5%Chitosan, 80%PLA-15%Lyocell-5%Chitosan were produced. As a result of the study, it is concluded that the highest flame retardancy was obtained with 95% PLA 5% Chitosan and the lowest flame retardancy was obtained for 100% Lyocell knitted fabric.

Within the scope of this study, knitted fabric samples were developed for firefighter flame retardant underwear clothes with inherently flame retardant fibers namely FR Viscose, FR Modacryclic, Panox and conventional viscose fiber.

2. EXPERIMENTAL STUDY

In the scope of the experimental study, Ne 24/1 vortex spun yarns were produced with the blend of different fibers as Panox, FR Modacrylic, FR Viscose and conventional Viscose fiber. Yarn unevenness and yarn faults were tested with Uster Tester 5 device. Yarn breaking strength and elongation measurements were tested using Uster Tensojet device. Yarn strength and quality parameters are given in Table 1.

Table 1. Strength and quality parameters of sample yarns.

Samples	%U	%CVm	-50% Thin	+50% Thick	Neps +280%	Strength, cN/tex	Elong., %
70% Viscose – 30% FR viscose	11.88	15.04	25.0	59.2	58.3	13.90	10.33
70% Viscose – 30% FR Modacrylic	9.09	11.44	1.7	9.2	10.8	15.92	13.16
70% Viscose – 30% Panox	10.02	12.65	2.5	153.3	28.3	14.79	11.24
100% Viscose	9.30	11.75	2.0	14.5	5.0	18.34	12.34

Knitted fabric samples were produced with two different knit structures namely single jersey and piquet from these sample yarns. Single jersey fabric samples were produced with 32 inches diameter 26 fein circular knitting machine, pique fabrics were produced with 26 inches diameter and 28 fein circular knitting machine. Eight different knitted fabric samples were obtained and then tests were done to determine the performance properties. Before testing and measurements, all fabric samples were conditioned according to TS EN ISO 139 [10]. The tests carried out in a standard atmosphere of 20±2 ℃

temperature and 65±4 % relative humidity. Fabric structural parameters of loop length, number of loops, fabric thickness, fabric weight properties were determined according to standards of TS EN 14970 [11], TS EN 14971:2006 [12], TS 7128 EN ISO 5084 [13] and TS EN 12127: 1999 [14], respectively. The structural parameters of the knitted fabric samples are given in Table 2.

Table 2. Structural parameters of sample fabrics.

Sample	Knit type	Loop Length, mm	Number of courses, loops/cm	Number of wales, loops/cm	Fabric Thickness, mm	Fabric Weight, g/m^2
70% Viscose – 30% FR viscose	**single jersey**	0.30	10	16	0.50	169
	piquet	0.29	9	6	0.79	197
70% Viscose – 30% FR Modacrylic	**single jersey**	0.31	11	14	0.45	159
	piquet	0.31	9	6	0.77	185
70% Viscose – 30% Panox	**single jersey**	0.30	10	16	0.52	172
	piquet	0.29	7	5	0.86	201
100% Viscose	**single jersey**	0.30	10	16	0.50	164
	piquet	0.29	10	6	0.73	202

Dyeing processes of sample fabrics in black color were applied separately. Fabrics knitted from FR Viscose/Viscose, Viscose and FR Viscose/Panox blends were dyed in black color with one-step dyeing. Panox fiber is originally black in color and does not need to be dyed. Fabrics knitted from FR Modacrylic/Viscose blended samples were dyed in two steps. Then the performance tests were applied to dyed fabric samples namely vertical flame resistance, bursting strength, air permeability, dimensional stability, pilling resistance according to the standards of ASTMD 6413-08 [15], TS 393 ISO 13938-2 [16], TS 391 EN ISO 9237 [17], TS EN ISO 6330 [18], TS EN ISO 12945-2 [19], respectively. Fastness performance of the sample fabrics were tested according to standards of ISO105 E04 [20], ISO105 E01 [21], ISO105 X12 [22], ISO105 C06 [23].

3. RESULTS

3.1. Vertical Flame Resistance

Vertical flame resistance test results of samples are given in Table 3.

It is observed from the vertical flame resistance that Viscose and Viscose / FR Viscose blended fabric samples have very low flame resistance that all the tested specimens turned into ash thoroughly. Regarding the Panox blended fabric samples, it can be concluded that Panox fiber provided moderate flame resistance to the fabric that after the tests specimens can maintain their structural integrity. On the other hand, FR Modacrylic fiber provided a very good level of flame resistance that glowing occurred during the test and flame was not observed. It was observed that when the heat source removed, FR Modacrylic blended specimens self-extinguish and carbonize up to 7.5 cm.

Table 3. Vertical flame resistance test results of sample fabrics.

Sample	Knit type	After flame time, sec	After glow time, sec	Observation
70% Viscose – 30% FR viscose	single jersey	16	-	turned into ashes
	piquet	17	-	turned into ashes
70% Viscose – 30% FR Modacrylic	single jersey	-	10	7 cm burned distance
	piquet	-	10	7,5 cm burned distance
70% Viscose – 30% Panox	single jersey	32	-	40 cm burned distance
	piquet	20	-	40 cm burned distance
100% Viscose	single jersey	25	-	turned into ashes
	piquet	24	-	turned into ashes

3.2. Air Permeability

Air permeability test was applied to sample fabrics regarding the thermal comfort property. Air permeability test results are given in Figure 1.

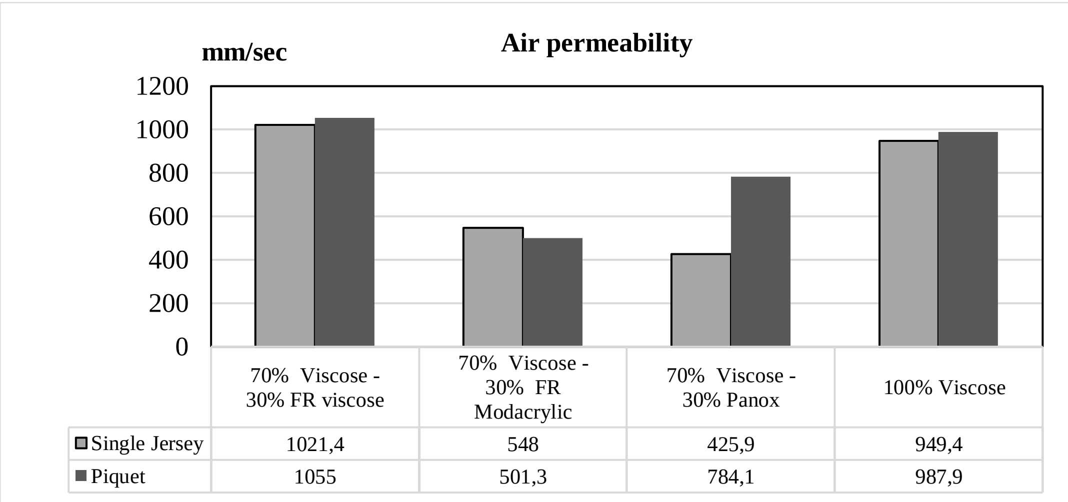


Figure 1. Air permeability performance of sample fabrics.

Considering the air permeability as a thermal comfort property, higher air permeability is desirable for the samples which were produced for firefighter underwear clothes in the scope of this study. As it can be seen from Figure 1, Viscose/FR Viscose blended and Viscose fabric samples had the highest air permeability whereas FR Modacrylic and Panox availability had a decreasing effect on air permeability. On the other hand, knit type has no consistent effect on air permeability. Also knit type has a considerable effect on air permeability for only Viscose/Panox samples. It can be concluded that Viscose/FR Viscose samples had convenient air permeability among the samples.

3.3. Bursting Strength

The bursting strength test was applied to sample fabrics to assess the durability of the sample fabrics. Bursting strength test results of the samples are given in Figure 2.

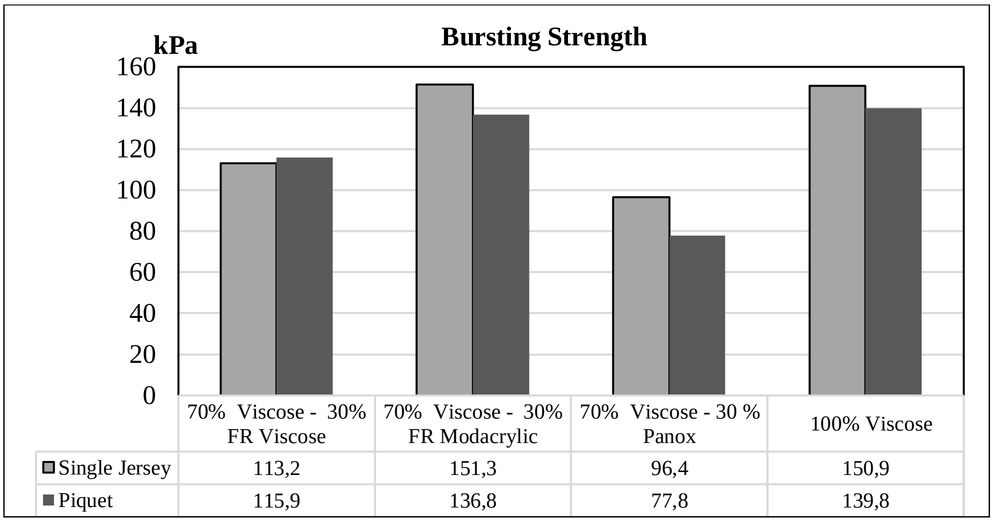


Figure 2. Bursting strength performance of sample fabrics.

When bursting strength test values given in Figure 2 are examined, it can be concluded that Viscose/FR Modacrylic and Viscose samples had the highest bursting strength values. Samples which have Panox fiber had the lowest bursting strength value. Piquet knit type samples have lower bursting strength values than single jersey ones. Viscose/FR Modacrylic samples can be selected regarding higher durability.

3.4. Pilling Resistance

Within the scope of this study, the Martindale Pilling test was applied to sample fabrics. The pilling resistance assessment was carried out after 2000 cycles of the test device using the Pilliscope, by comparing the tested samples with ASTM standard photographs under standard lighting conditions. Pilling resistance test results are given in Table 4.

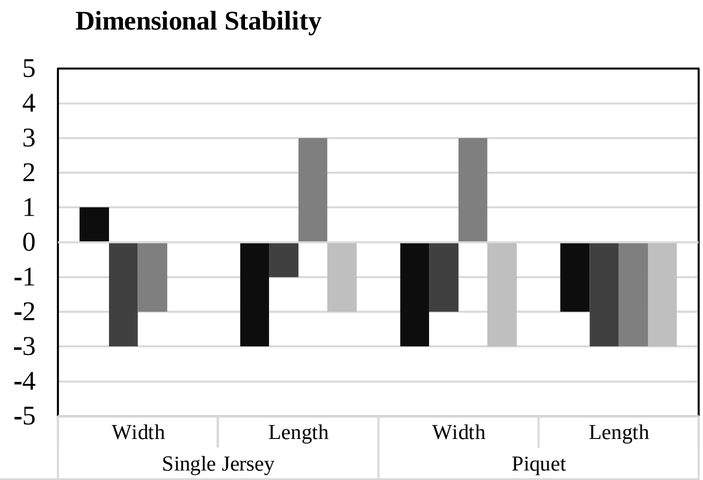
Table 4. Pilling resistance of sample fabrics.

	Knit type	
Samples	**single jersey**	**piquet**
70% Viscose – 30% FR viscose	4	4
70% Viscose – 30% FR Modacrylic	4	4
70% Viscose – 30% Panox	4	4
100% Viscose	3	4

As it can be seen from the pilling resistance evaluation that fiber type and knit type has no considerable effect on pilling resistance of sample fabrics. Additionally, all of the samples have a good level of pilling resistance.

3.5. Dimensional Stability

The dimensional stability of the single jersey and piquet fabrics in widthwise and lengthwise fabric samples are given in Figure 3.



	Single Jersey Width	Single Jersey Length	Piquet Width	Piquet Length
70% Viscose - 30% FR Viscose	1	-3	-3	-2
70% Viscose - 30% FR Modacrylic	-3	-1	-2	-3
70% Viscose - 30% Panox	-2	3	3	-3
100% Viscose	0	-2	-3	-3

Figure 3. Dimensional stability of sample fabrics.

When Figure 3 is examined, it can be seen that there is no consistent tendency of dimensional change for different fiber types. Dimensional change values were within the commercial acceptable limits.

3.6. Fastness

Single jersey and piquet knit type sample fabrics produced from Viscose, FR viscose, FR Modacrylic and Panox yarns dyed in black color and their different fastness properties tested. Results of fastness tests given in Table 5.

As it is seen from Table 5, knit type had no considerable effect on fastness properties. Besides, fastness to perspiration (acid and alkaline), fastness to water and fastness to domestic and commercial laundering results are similar for all samples. Also, these fastness levels are within the acceptable commercial limits. But there is an important decrease for fastness to wet rubbing of both Panox blended single jersey and piquet samples. This result may cause an important level of deterioration for usage performance owing to the situation of the underwear fabric will be in contact with the wetted skin after perspiration.

Table 5. Fastness performance of sample fabrics.

		Single Jersey						Piquet					
	Multifiber	**Acid**	**Alkaline**	**Water**	**Dry**	**Wet**	**Wash**	**Acid**	**Alkaline**	**Water**	**Dry**	**Wet**	**Wash**
70% Viscose - 30 % FR Viscose	**Wool**	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Acrylic	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Polyester	4	4	4	4/5	3/4	4	4	4	4	4/5	3/4	4
	Nylon	4	4	4			4	4	4/5	4			4
	Cotton	4	4	4			4	4	4	4			4
	Acetate	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
70% Viscose - 30% FR Modacrylic	**Wool**	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Acrylic	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Polyester	3/4	3/4	4	4	3/4	3/4	3/4	3/4	3/4	4	3/4	3/4
	Nylon	3/4	3/4	3/4			3/4	3/4	3/4	3/4			3/4
	Cotton	4	4	4			4	4	3/4	3/4			4
	Acetate	4	4	4			4	4	4	4			4
70% Viscose - 30% Panox	**Wool**	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Acrylic	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Polyester	4	4	4	4	2	4	4	4	4	4	2	4
	Nylon	4	4	4			4	4	4	4			4
	Cotton	4/5	4/5	3/4			3/4	4/5	4	3/4			3/4
	Acetate	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4
100% Viscose	**Wool**	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Acrylic	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5
	Polyester	4/5	4/5	4/5	4/5	3/4	4/5	4	4	4	4/5	3/4	4
	Nylon	4/5	4/5	4/5			4/5	4	4	4			4
	Cotton	4/5	4/5	4/5			4/5	4	4	4			4
	Acetate	4/5	4/5	4/5			4/5	4/5	4/5	4/5			4/5

4. CONCLUSION

In the scope of this study, it is aimed to investigate the performance properties of some commercially available inherently flame resistant fibers with viscose fiber blend aiming to determine the best fiber type for producing firefighter underwear fabric. So, the foremost performance property that is investigated in this study was flame resistance. The highest flame resistance was observed for FR Modacrylic fiber blend that the sample exhibited no flame during vertical flame resistance test and a very low afterglow time and short distance of decomposing was observed. FR Modacrylic blended samples provided higher bursting strength that can provide better durability during usage. On the other hand, air permeability of FR Modacrylic sample was low that can be contributed as lower thermal comfort property. Also, pilling resistance, color fastness and dimensional stability of the FR Modacrylic sample are within the acceptable commercial limits. Consequently, FR Modacrylic fiber can be contributed as the most convenient fiber type within the fiber types investigated in this study. Furthermore, as a skin contact fabric as underwear, further investigation is needed to optimize the FR Modacrylic fiber content.

REFERENCES

[1] Parmar, M.S., Sonee, N., Sisodia, N. (2020). Thermal and flame retardant properties of FR viscose fibre and its blends. Journal of The Textile Association, May-June, 19-28.
[2] Özcan, G. (2002)**.** *Effect of Knitted Fabric Properties on Flame Resistance*. [Doctoral dissertation, İstanbul Technical University]
[3] Varga, K. Noisternig, M.F., Griesser, U.J., Aljaž, L., Koch, T. (2011). Thermal And Sorption Study of Flame–Resistant Fibers. Lenzinger Berichte, 89, 50 – 59.
[4] Şardağ, S. (2019, September 26-27). *Investigation of comfort and mechanical properties of flame resistant knitted fabrics made from cotton, meta-aramid and tencel yarns with different blend ratios,* Ulusal Çukurova Tekstil Kongresi, Adana, Türkiye.
[5] Erkut, D. (2020). *Investigation of yarn and fabric properties made from flame resistant fiber with different blend ratios.* [Master Thesis, Uludağ University Institute of Science and Technology]
[6] Kim, H.A., Kim, S.J. (2019). Flame retardant, anti-static and wear comfort properties of modacrylic/Excel®/anti-static PET blend yarns and their knitted fabrics, The Journal of The Textile Institute, 110 (9), 1318-1328.
[7] Stygiene, L., Krauledas, S., Abraitiene, A., Varnaite-Žuravliova, S., Dubinskaite, K. (2022). Flammability and thermoregulation properties of knitted fabrics as a potential candidate for protective undergarments, Materials, 15, 2647, 1-22.
[8] Jamshaid, H., Mishra, R., Khan, A., Chandan, V., Muller, M., Valasek, P. (2023). Flammability and comfort properties of blended knit fabrics made from inherently fire-resistant fibers to use for fire fighters, Heliyon, 9 (2), 1-15.
[9] Alaybeyoğlu, E., Duran, K., Körlü, A. (2022). Flammability behaviours of knitted fabrics containing pla, cotton, lyocell, chitosan fibers, Muğla Journal of Science and Technology, 8(2), 18.
[10] TS EN ISO 139: 2008 - Textiles-Standard atmospheres for conditioning and testing.
[11] TS EN 14970 - Textiles - Knitted fabrics - Determination of stitch length and yarn linear density in weft knitted fabrics
[12] TS EN 14971:2006 - Textile - Knitted fabrics - Determination of the number of knitting loops per unit length and unit area.
[13] TS 7128 EN ISO 5084:1998 - Determination of the thickness of textiles and textile products.
[14] TS EN 12127: 1999 - Textiles- Fabrics- Determination of mass per unit area using small samples
[15] ASTMD 6413-08 Standard Test Method for Flame Resistance of Textiles (Vertical Test)
[16] TS 393 ISO 13938-2 - Textiles- Bursting properties of fabrics- Part 2: Pneumatic method for determination of bursting strength and bursting distension
[17] TS 391 EN ISO 9237: 1999 - Textiles- Determination of the Permeability of Fabrics to Air
[18] TS EN ISO 6330 Textiles - Domestic washing and drying procedures for textile testing
[19] TS EN ISO 12945-2 - Textiles- Determination of fabric propensity to surface fuzzing and to pilling- Part 2: Modified Martindale method
[20] ISO105 E04 Textiles - Tests for colour fastness - Part E04: Colour fastness to perspiration
[21] ISO105 E01 Textiles - Tests for colour fastness - Part E01: Colour fastness to water
[22] ISO105 X12 Textiles - Tests for colour fastness - Part X12: Colour fastness to rubbing
[23] ISO105 C06 - Test for colour fastness- Part C06: Colour fastness to domestic and commercial laundering

SUSTAINABLE CARPET DESIGN WITH rPET/PAN PILE YARN

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ABSTRACT

The recycle of the textile products have very low ratio of approximately 15%. According to The Europe Union (EU) Green Deal requirement the reuse and recycle of products must be increased, the usage of first (virgin) material must be decreased. For this aim, the ratio of the second use materials in the textile products should be increased and new sustainable products should be designed. In this study, pile yarns with three different rPET/PAN blend ratio were produced and then the carpet samples were manufactured by using the pile yarns with same physical properties. The carpet samples were applied compression-recovery and abrasion resistance tests according to the related standards. It was revealed that in rPET fiber content enhance both resilience and abrasion resistance performances of the carpet.

Keyword: *rPET, PAN, Sustainable textile, Carpet, Compression-recovery, Abrasion resistance*

1. INTRODUCTION

Because of the European Green Deal agreement, the European Union (EU) declared the goal of reducing net greenhouse-gas emissions by 55% by 2030. So, the EU needs to reduce emissions both at home and beyond its borders. Cement, iron-steel, fertilizer, aluminum and energy industries are the most important industries in terms of carbon footprint effect. After previously mentioned five industries, the textile industry is one of the most important sectors because of its ecological effects. Türkiye is one of the textile biggest textile manufacturer in thhe world. On the hand, Gaziantep is one of the most important carpet manufacturer in world and Turkiye. However, the useage of recycle material in the carpet structure is very low. Especially in the production of the carpets with high pile density approximatel 1.5 kg pile yarns are used for 1 m^2 carpet. Since the carpets consist of multilayer mixtures of different polymers, it is very difficult and costly to separate and reprocess at the end of their useful lives. In order to recude the virgin fiber usage in the carpet production, recycled fibers must be incorporated to the structure.

In the previous studies, the carpets were recycled for the development of non-carpet products containing carpet waste. The carpet waste material was used in the production of load-bearing structural composites [1-4]. There is very limited study that reveals the performance of the carpet samples from recycled pile yarns and comparison of them to carpet samples produced from virgin pile yarns [5].

The presented study was conducted to investigate the effect of rPET fiber blend ratio in the pile yarn structure on carpet compression-recovery and abrasion resistance performance properties. The pile yarn samples were manufactured with three different rPET/PAN fiber blend ratios; 30/70%, 50/50% and 70/30%. The carpet samples were woven with the constant physical properties. After the performance tests were applied, the results were analysed.

2. EXPERIMENTAL STUDY

2.1 Material

Pile yarn samples with the three different rPET fiber blending ratios and 100% virgin acrylic (PAN) were produced. The virgin PAN fiber has 8 Denier linear density and 150 mm length and the rPET fiber has 6 Denier linear density and 128 mm length. Then, the cut-pile carpet samples were woven by using Van de Wiele RCI03 Wilton type face-to-face carpet weaving machine. The properties of pile yarn and carpet samples were given in Table 1 and 2 respectively. The carpet samples were produced under the same manufacturing conditions via the same weaving loom.

Table 1. Pile yarn properties.

	P1	P2	P3	P4
rPET/PAN (%)	0/100	30/70	50/50	70/30
Yarn Count (Nm)	23/3	23/3	23/3	23/3
Twist/meter	380	380	380	380
Ply Twist/meter	270	270	270	270

Table 2. Carpet sample properties.

Ground weave	Pile density (piles/m^2)	Weft sett (picks/10cm)	Weft yarn (Nm)	Pile yarn linear density (denier)	Warp sett (ends/10cm)	Stuffer warp yarn linear density (denier)	Chain warp yarn linear density (denier)	Pile height (mm)
1/2 V	720,000	160	1.8 Jute	1125	40	1680 PET	820 PET	85

2.2 Method

In order to determine the effect of rPET fiber ratio on carpet resilience, durability and fuzzing performances, the carpet samples were applied to compression-recovery and abrasion resistance tests according to BS 4098:1975 [6] and BS EN 1813:1998 [7] standards respectively. Carpet samples were conditioned at standard atmospheric conditions (65% ±4% relative humidity and 20°C ±2°C temperature) according to ISO 139:2005 [8] for 2 h before the tests were conducted.

The compression-recovery that is compressibility test determines the resistance of the carpet to loading and unloading affect due to foot traffic. The carpet specimens with 75 mm×75 mm size was taken from 5 different regions of the carpet sample. The compressibility test was performed by using SDL K94 Atlas Digital Thickness Gauge machine. Firstly, the carpet specimen was placed under pressure foot with 325 mm^2 area and the initial thickness of the carpet specimen was measured under 2 kPa load. In first stage of the test procedure, the load on the carpet specimen was increased from 5 kPa-200 kPa by adding weight set from A to G (A: 5kPa, B: 10kPa, C:20 kPa, D: 50kPa, E:100 kPa, F:150 kPa, G:200 kPa) without removing the pressure foot. After each weight was added, the thickness value of the sample was recorded at 30 s intervals. In the second stage of the test procedure, the load on the carpet specimen descended from 200 kPa to 2kPa by removing the weight set from G to A without removing the pressure foot. The carpet thickness was measured after each weight removing at 30 s intervals. All the thickness values of the carpet specimen during loading and unloading process creates a curve as given in Figure 1.

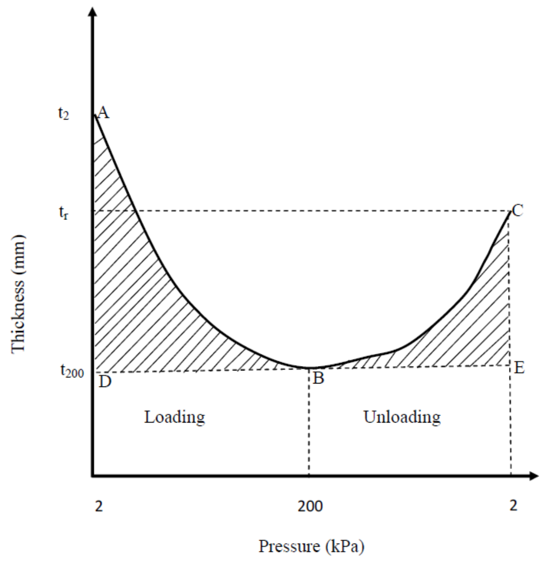

Figure 1. Thickness change of carpet under pressure.

The percentage compression recovery of the carpet sample after loading-unloading procedure is calculated using Eq.1.

$$Compression\ Recovery\ (\%) = \frac{t_r - t_{200}}{t_2 - t_{200}} \times 100 \qquad \text{Eq. 1}$$

Where t_r (point C) is the thickness at 2kPa pressure after unloading the weights, t_2 (point A) is the thickness under 2 kPa pressure at initial stage, t_{200} is the thickness at 200 kPa pressure (point B).

The area under loading and unloading curves give the work of compression and recovery in j/m^2 respectively. The percentage of work due to recovery of the pile yarns (area BCE) to work applied during compression (area ADB) is calculated by using Eq. 2.

$$Work\ Recovery\ (\%) = \frac{Area_{BCE}}{Area_{ADB}} \times 100 \qquad \text{Eq. 2}$$

It has been found that pile density and pile height have significant effect on carpet durability [9]. Abrasion resistance is one of the most important parameters in order to evaluate the carpet durability. In this study, the effect of rPET fiber blend ratio on the durability and fuzzing tendency was determined by abrasion resistance test. The circular carpet specimen with 38 mm diameter were taken from three different region of the carpet sample. The carpet specimen was applied rubbing effect against a standard abrading fabric. The abrasion resistance of carpets was evaluated as weight loss after 5,000 number of rotations.

3. RESULTS

The compressibility test results of the carpet samples were given in Figure 2 as the thickness change after loading and unloading applications. As seen from Figure 2, the initial thicknesses of the carpet samples are close to each other. On the other hand, the recovery thicknesses of the carpet samples are different from each other. The highest recovery thickness was obtained with P1 and P4 pile yarns that are the samples produced from 0/100 and 70/30 rPET/PAN pile yarns respectively. The lowest recovery thickness value was obtained with 50/50 rPET/PAN pile yarn (P3). The percentage of compression recovery values were given in Figure 3. The compression recovery percentages coincide with loading and unloading curves. The highest recovery percentage was obtained with 70/30 rPET/PAN (P4). As observed from Figure 3, there is no positive or negative linear relationship between rPET ratio and compression recovery performance. When the rPET fiber was incorporated into pile yarn structure with

30% and 50% ratios, the compression recovery performance was decreased from 57.5% to 46.56% and 39.02% respectively. However, this performance value increased to the highest value with 70% rPET content among four carpet samples. It can be said that the rPET content has enhancing effect above 50% blend ratio.

The percentage of work recovery can be explained as the ratio of released recovery work to the work of compression. As presented in Figure 4, the work recovery percentage values of carpet samples are close to each other. It can be observed from Figure 4, the work done by pile yarns during recovery is lower with respect to work applied on the pile yarns during compression. The percentage work recovery values are between 24.78% and 28.11%.

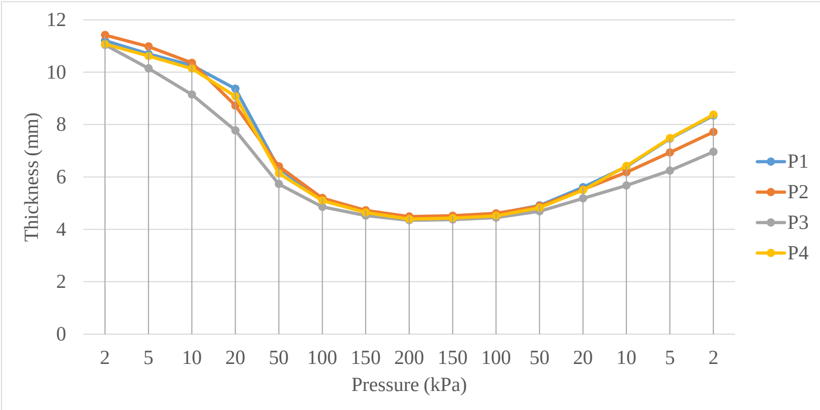

Figure 2. Thickness values of loading and unloading applications.

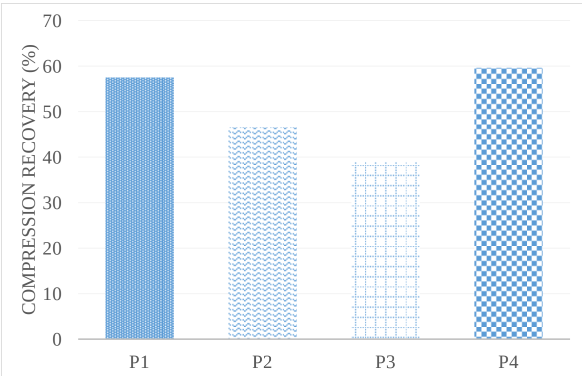

Figure 3. Percentage of compression recovery.

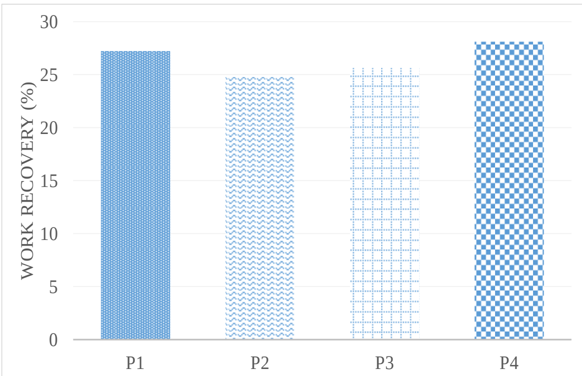

Figure 4. Percentage of work recovery.

The weight of fiber loss was calculated for unit meter square of the carpet samples. The amount of fiber loss due to abrasion rubbing was given in Figure 5. The acrylic (PAN) fiber has highest fiber loss after 5000 rubbing cycle. It was revealed that the virgin acrylic fiber has highest tendency to fuzzing and fiber loss due to walking traffic. It can be said that the rPET content has improving effect on the abrasion resistance performance. The fiber loss weight decreases as the rPET fiber ratio in the pile yarn increases. The lowest fiber loss was obtained with 70/30 rPET/PAN pile yarn. The fiber linear density, yarn packing density and fiber cohesion has significant effect on fiber loss and fuzzing tendency of the carpet surface. In previous studies, it was explained that the pile yarn with finer fibers has higher amount of fiber in the yarn cross section and so they provide higher cohesion against walking traffic rubbing effect [10-12]. Since the pile yarn number was kept constant, the pile yarn with higher rPET fiber ratio includes higher number of fibers in cross section and so it has higher fiber cohesion. The lower fiber loss with the increased rPET ratio can be explained with higher fiber cohesion.

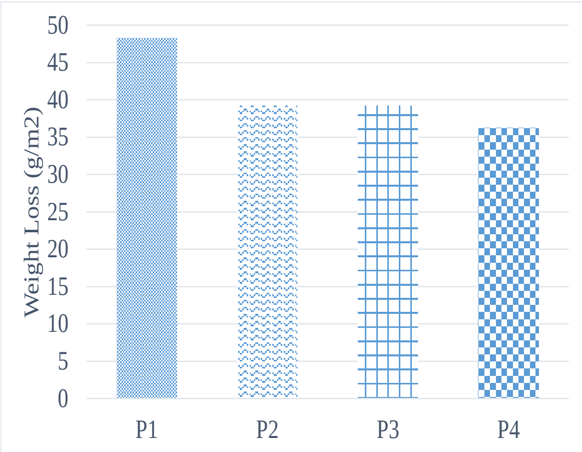

Figure 5. Weight loss after 5000 cycle abrasion.

4. CONCLUSION

In this study, ecological carpet design was achieved and the rPET fiber was incorporated in carpet pile yarn. The effect of rPET fiber ratio on carpet compression recovery and abrasion resistance performance was determined. It was found that the rPET fiber content with 30% and 50% ratio has diminishing effect on compression recovery performance. However, the rPET fiber ratio with 70% has improving effect on recovery performance. On the other hand, higher rPET fiber content provides higher abrasion resistance. The fuzzing tendency of the acrylic carpet can be decreased by adding rPET fiber. So, it can be revealed that the ecological pile yarn design with rPET fiber content provides both higher durability in terms of abrasion resistance and resilience performance.

As a result of this study, it can be concluded that the environmentally friendly carpets can be produced by using rPET fiber in the pile yarn and so the virgin fiber usage can be reduced. Recycled polyester yarn can be used with virgin acrylic in order to enhance the carpet performance. In the further study, the effect of rPET blend ratio on the thickness losses after static and dynamic loading performances may be investigated. The performance of rPET and virgin PET fibers may also be compared in the term of carpet pile yarn application.

REFERENCES

[1] Sotayo, A., Green, S., Turvey, G. (2015). Carpet recycling: A review of recycled carpets for structural composites. Environmental Technology & Innovation, 3, 97-107.

[2] Jain, A., Pandey, G., Singh, A. K., Rajagopalan, V. (2011). Fabrication of structural composites from waste carpet. Advances in Polymer Technology, 31, 4, 380-389.
[3] Mohammadhosseini, H., Abdul Awal, A.S.M. (2013). Physical and mechanical properties of concrete containing fibers from industrial carpet waste. IJRET: International Journal of Research in Engineering and Technology, 02, 12, 464-468.
[4] Mihut, C., Captain, D. K., Gadala-Maria, F., Amifudis, M. D. (2001). Review: Recycling of nylon from carpet waste. Polymer Engineering and Science, 41,9, 1457-1470.
[5] Watson, S. A., Warnock, M. M. (2003). Comparative analysis between recycled and newly manufactured carpets. Family and Consumer Sciences Research Journal, 31, 4, 425-44.
[6] BS 4098. Method for the determination of thickness, compression and recovery characteristics of textile floor coverings, 1975.
[7] BS EN 1813. Textile floor coverings – Determination of wool fiber integrity using an abrasion machine, 1998.
[8] TS EN ISO 139. Textiles - Standard atmospheres for conditioning and testing, 2008.
[9] Gupta, K. S., Goswami, K. K. (2015). Modeling of abrasion resistance performance of Persian handmade wool carpets using artificial neural network. Journal of The Institution of Engineers (India): Series E, 96, 175-180.
[10] Gokarneshan, N., Ghosh, A., Anbumani, N., Subramaniam, V. (2005). Investigation of inter fiber cohesion in yarns. I. Influence of certain spinning parameters on the cohesion in cotton yarns, Fibers and Polymers,6, 4, 336-338.
[11] Gokarneshan, N.; Subramaniam, V.; Anbumani, N.; Influence of material and process parameters on the inter-fibre cohesion in ring-spun yarns, Indian Journal of Fibre & Textile Research 2008, 33, 203-212.
[12] Çelik, H.İ. (2017). Effects of fiber linear density on acrylic carpet performance. Journal of Journal of Engineered Fibers and Fabrics,12,1,1-17.

AN ECOLOGICAL SOFTENER APPLICATION TO CHENILLE YARN

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ABSTRACT

Cationic softeners are commonly preferred for the dyeing process of chenille yarn to improve its feel better to the touch. The aim of this study was the comparison of the effects of softener type on properties of chenille yarn with environmentally friendly approach. For this purpose, softener solutions obtained with different concentrations were applied to recycle-containing chenille yarn and performance indicator results such as color fastness and rubbing fastness on rigid were examined. According to the results obtained, it has been observed that ecological softener produces results that can be considered equivalent to industrial softeners.

Key words: *Yarn dyeing, Softener, Ecological, Chenille yarn, Sustainable, Fastness, Durability*

1. INTRODUCTION

Chenille yarn was first introduced in eighteenth century and its popularity has grown in recent years. Chenille is a fancy yarn that can be made from different fibers variety. Chenille yarn are using a wide range which are home decor, car, curtain fabric, rug, carpet and clothing. For beautiful appearance and especially softness chenille yarn has become popular fabric of designers [1]. Chenille yarns are produced from two yarn components; one is used as chain and the other is used as pile. Polyester fibers, which are the most used synthetic fibers, are used commonly in Chenille yarns. Due to the fact that soft touch is one of the most required characteristics of upholstery and tricot fabrics, softeners are generally applied to dyed polyester chenille yarns to increase their softness after disperse dyeing [2].

In recent years, it is seen that environmental problems have increased and some balances have changed. Scientists attribute this to the fact that unsustainable situations are happening. As environmental problems started to threat both the environment and human health, some concepts such as sustainability and recycling have been expressed more frequently. Nowadays, both consumers and companies have become more aware of these issues [3].

Silicone-based softeners are softeners that are mostly produced as oil-in-water emulsions (O/W), which are used to give textile products not only better softness, brightness, and lubricity, but also flexibility, bulkiness (fullness), easy sewing, and tear strength [4]. It is a new generation industrial textile softener that is produced ecologically instead of classical softeners with fatty acid content used in textile finishing processes in the industrial textile sector, and obtained by utilizing new fatty acid (Ecological softener) and modified production processes.

Ecological softener is a product developed in line with the principle of "sustainability" for today's industrial textile sector and for the world in general. Sun-ecological softener, which is accepted as the main product in agricultural production and has high adaptability; Being able to be grown in dry and irrigated conditions and being suitable for mechanization from planting to harvest are among the outstanding features of its agriculture. Considering all these features, the use of sun-ecological softener oil as an alternative product and its contribution to agriculture is undeniably great.

Stearic acid, which is used in today's textile softeners and imported, is mainly obtained from the palm plant in the industrial sense and is an acid with a high saturated fat content. Millions of hectares of natural areas are destroyed annually in order to produce palm oil, and this destruction seriously damages nature and natural life. Therefore, palm oil production causes climate change, air pollution and soil erosion. On the other hand, the effect of palm oil on human health has recently become a subject of great debate. According to the researches of the World Health Organization (WHO), palm oil causes various heart diseases, premature death and respiratory diseases. On the other hand, Sun-ecological softener oil exhibits a more conventional and reliable attitude thanks to its nature-friendly identity.

In this study, ecological softener and silicone-based softener were applied to chenille yarn samples. The chenille yarn samples were also produced from recycle fibers in both chain and pile components. Thus, it was aimed that an ecological chenille yarn designed will be achieved and the softness of the chenille yarn will also be provided by an ecological softener material. The performance properties of the ecological softener were determined in terms of bending rigidity, washing fastness, rubbing fastness and durability of the softness after washing process. The performance of the ecological softener were compared with silicon-based softener.

2. EXPERIMENTAL STUDY

2.1. Material

In the content of this study, the knitted fabric samples were produced from chenille yarn. Properties of the chenille yarn were given in Table 1. The chenille yarn was produced from recycled materials in both chain and pile yarn components. The knitted fabric samples were then applied softener finishing. The softeners were applied to chenille yarns in hank form by exhaust method with 1:20 of liquor ratio at 40 °C. Softener type and softener concentrations were selected as independent variables. The knitted fabric sample properties were given in Table 2.

Table 1: Chenille yarn properties.

Yarn Properties	
Yarn Number (Nm)	4
Chain Yarn Count (Ne)	20/1
Chain Yarn Fiber Type	rPET
Pile Yarn Count (Ne)	20/1
Pile Yarn Fiber Type	80% PAN-20% rPAN
Pile Length (mm)	1.2

Table 2. Knitted fabric sample properties.

Sample Code	FABRIC PATTERN	FABRIC MASS, (G/M^2)	COURSE DENSITY (COURSE/CM)	WALE DENSITY (WALE/CM)	THICK NESS (MM)	SILICON FINISH
CS-1	Single jersey	484.67	6	5	4.30	1% Cationic Soft.
ES-1	Single jersey	507.33	6	5	4.47	1% Ecological Soft.
ES-3	Single jersey	499.33	6	5	4.54	3% Ecological Soft.
ES-5	Single jersey	487.00	6	5	4.34	5% Ecological Soft.

The yarns were dyed by exhaust method in a hank dyeing machine according to the recipe given in Table 3. The dyeing program was also given in Figure 1 and Figure 2.

Table 3: The cationic dyeing recipe.

Setacryl Golden Yellow	176
Schecocryl Red Gtln	18
Setacryl Blue Bg	49.2
Retarder (%owf)	1.5
Acetic Acid (g/L)	1

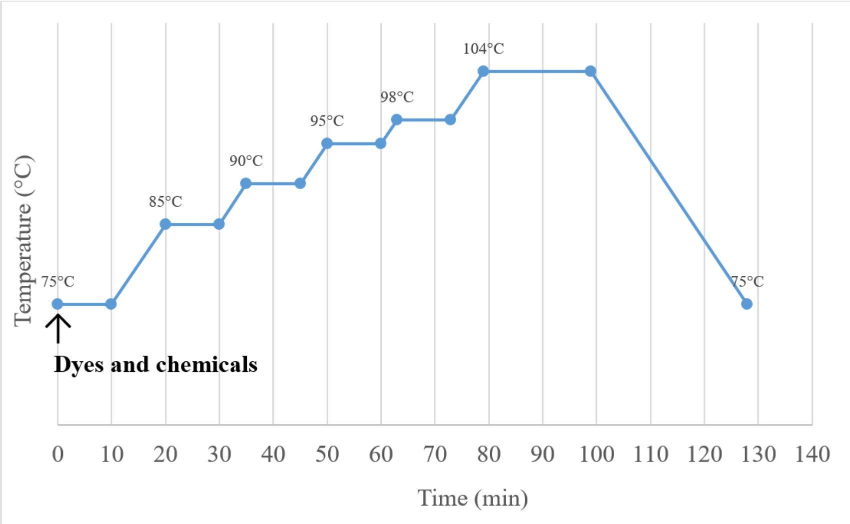

Figure 1: The dyeing programs.

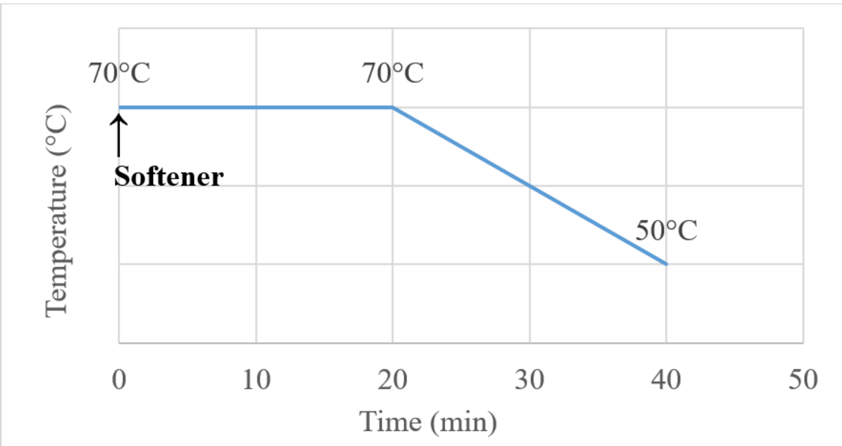

Figure 2: Diagram of softener applied after dyeing.

The fabric samples were subjected to fabric mass, thickness, courses and wale density tests according to ISO 3801:1977, ISO 5084:1996 and EN 14970:2006, respectively. All samples were conditioned for 2 hours under standard atmospheric conditions (65% relative humidity and 20 C° temperature) before the fastness tests.

Softener is applied on almost all cloths and home furnishing textiles, because most of the buyers and users consider the hand of fabric as one of the most important properties. The persons, who examine the textile, touch it in an automatic manner to assess the fabric hand [6]. Softeners add softness and smoothness to textile fabrics, increasing tear strength and color tone. They also guarantee gentle handling, moisture management and improved tear resistance. The main effects of softeners are on the surface of fabrics. In addition to allowing the fiber to breathe, small softener molecules penetrate the fiber to form a polymer through internal plasticization. Softening agents are lubricants that allow the fiber to glide within the fabric structure, allowing for easier wrinkling and deformation.

There are many fabric softeners depending on their chemical structure and specialized needs. Here are some of the common softeners used in the textile processing industry: Non-ionic Softeners, Cationic Softeners, Silicone-based Softeners. Stearic acid, which is used in today's textile softeners and imported, is mainly obtained from the palm plant (Palm Oil Acid) in industrial terms. Palm oil production causes climate change, air pollution and soil erosion. At the same time, millions of hectares of natural areas are destroyed annually in order to produce palm oil, and this destruction seriously damages nature and natural life. The main source of the ecological softener used in this study is Sunflower oil, which is one of the most produced fatty acids in nature. With the use of this softener, which has a hydrophilic character, it has properties that can be considered equivalent to the classical product.

2.2. Method

The knitted fabric samples were produced from chenille yarn samples. The fabric samples were applied bending rigidity, washing fastness and rubbing fastness tests according to related standards ASTM D1388-18, TS EN ISO 105-C06 and BS EN ISO 105-X12:2016 respectively. The durability of the softener application was also evaluated by determining the bending rigidity of the samples after cycled washing.

This instrument given in Figure 3 measures the bending length using the bending principle. The bending stiffness is calculated from the bending length under bending edge below 41.5°.

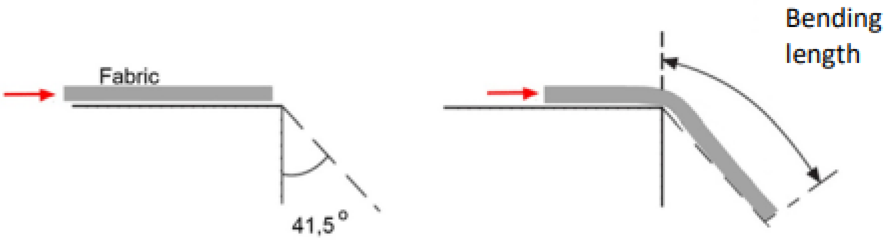

Figure 3. Bending rigidity measurement.

3. RESULTS

3.1. Bending test results

The measurement of fabric bending stiffness is one of the most widely used parameters to evaluation fabric handling and touch. Fabric stiffness is an important criterion factor for producers and end users. The degree of fabric touch in chenille yarn is related to the yarn fiber material, the filaments number of pile yarn and the softener used in dyeing finishing processes. In this test, the effects of ecological and cationic softener on it were investigated.

According to the bending test results in Table 6, it has been observed that there is no significant difference between ecological and cationic softeners used at the same concentration ratio. With the same result, it was revealed that when the concentration of the ecological softener was increased, it did not make a significant difference to the fabric stiffness. The same conclusion can be reached when the bending results after 5 washings are examined, which supports this result. When the durability of the softeners were evaluated, it can be said that the stiffness measurement results of the fabric samples are close to each other. A significant different between the samples were not determined. On the other hand, it was seen that the highest stiffness value was obtained with 1% ecological softener treatment and the lowest stiffness was obtained with 1% silicon softener. The stiffness of the fabric samples that were finished with ecological softener decrease with the higher concentration ratios.

Table 6: Fabric bending results.

Sample Code	**Original (unwashed)** Bending Length (cm)	**After 5 Laundering cycle** Bending Length (cm)
CS-1	8.10	5.95
ES-1	8.40	6.40
ES-3	8.00	6.25
ES-5	8.10	6.15

3.2. Colour fastness

Color fastness of textile materials is one of the most important features for both manufacturers and end users. Color fastness after laundering test results of fabrics treated with different types and concentrates of softeners were given in Table 7.

Table 7: Fabrics colour staining results.

Sample No	Sample Code	Laundering cycle	Grade (Color Staining on Multi Fiber)						Cross Staining
			Wool	Acrylic	Polyester	Nylon	Cotton	Acetate	
1	CS-1	1	4	4 - 5	4 - 5	4 - 5	4 - 5	4	4
2	ES-1		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
3	ES-3		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
4	ES-5		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
5	CS-1	5	4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
6	ES-1		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
7	ES-3		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4
8	ES-5		4	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4

According to the data in Table 7, it was observed that the softener types examined in this study showed similar color fastness results at the same concentration. The fastness tests performed after 5 washings, which supports this result, revealed the same results. It was observed that the concentration difference of the ecological softener did not affect the color fastness.

3.3. Rubbing Fastness Test Results

The rubbing fastness test results (dry and wet) of the sample fabrics produced with chenille yarns in which different types and concentrations were applied are given in Table 8. According to Table 8, it was observed that the difference of the softener type exhibited similar behavior in dry and wet rubbing results.

Table 8: The rubbing fastness test results.

Sample Code	Grade (Dry Rubbing)	Grade (Wet Rubbing)
CS-1	4	4 - 5
ES-1	4 - 5	4 - 5
ES-3	4	4 - 5
ES-5	4	4

4. CONCLUSION

Textile and garment industry is one of the most polluting industries in the world. The use of sustainable materials and recycling methods is of great importance for the solution of this increasing problem. While the textile products are in the design stage, the product life cycle designs should be made considering the effects on the environment. The product has more than one product lifecycle, and the use of cyclic material flow systems is environmentally valuable [5].

In this study, the results of ecological softener and classical softener applications used in the same proportions in chenille yarn produced with recycled polyester yarn in core yarn and recycled acrylic in pile yarn were examined. According to the bending rigidity test results applied to the fabric samples, it was observed that the fabric stiffness decreased after 5 washings. It was attributed to the deterioration of fabric because of mechanical effect of laundering. However, there was no significant difference between the samples. On the other hand, it was seen that the highest stiffness value was obtained with 1% ecological softener treatment and the lowest stiffness was obtained with 1% silicon softener. The stiffness of the fabric samples that were finished with ecological softener decrease with the higher concentration ratios.

According to fastness results, it was seen that the washing and rubbing fastness values of silicon and ecological softeners are close to each other. The silicon type and concentration of the ecological softener have not a significant effect on both washing and rubbing fastness property. Both washing and rubbing fastness values are high enough that is between 4 and 4/5 levels.

As a result of this study, It has been revealed that ecological softener with same concentration has the similar performance as compared to the classical softener. In this way, it has been concluded that ecological softeners can be used as a substitute for conventional softeners.

REFERENCES

[1] B. Esi, P. Duru Baykal. Tekstil ve Konfeksiyon. 2022, 32(1), 1-8

[2] N. Özdil, G.Ö. Kayseri, G.S. Mengüç. Abrasion Resistance of Materials. 2012, 119 146

[3] Investigation of tensile strength and elongation properties of chenille upholstery fabrics including recycling polyester yarns.

[4] SchindlerW.D, Hauser P. J., (2004). Chemical Finishing of Textile. Woodhead Publishing Ltd. Cambridge, England.

[5] Niinimäki K. Sustainable fashion: new approaches. Helsinki: Aalto University, 2013, pp. 12–29.

[6] Schindler, W. D., and Hauser P. J., 2004. Chemical Finishing of Textiles, England: Wood head Publishing Ltd.

COMPETITIVE ANALYSIS OF TURKISH COMPOSITE INDUSTRY BY USING FIVE FORCES MODEL: A CASE STUDY

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ABSTRACT

The aim of this research is to investigate the competitiveness and profitability potential of the Turkish Composite Industry. For this purpose, the Five Force Model Framework developed by Michael E. Porter was used. To collect data, a survey was developed and data from Turkish Composite Industry companies were tried to be obtained. According to results, The Turkish composite industry can be said to have low substitution threat, moderate bargaining power of buyers and medium to high bargaining power of suppliers. Due to the large number of companies large and small in the industry, competition among existing competitors can be considered high and barriers to entry are moderate to high.

Keyword: *Competitive Analysis, Composite Industry, Five Forces Model, Competitiveness*

1. INTRODUCTION

The theories that a firm will follow in order to reach high performance levels in the industry and markets in which it competes are called firm strategy [1]. or strategy refers to “a central, integrated, externally oriented concept of how the business will achieve its objectives” [2]. In the strategy development process, internal and external factors should be examined in detail. Porter (1985) developed the industry analysis model, known as the five forces model of competition, to examine external factors. (Threats from potential competitors (entrants) the bargaining power of suppliers, the bargaining power of buyers, threats from substitute products, and rivalry among current competitors) [3]. This model is based on what is known as industrial organization (I/O). In this model, a firm's market performance depends on the characteristics of its environment.

The global composites market size is projected to grow from USD 88.0 billion in 2021 to USD 126.3 billion by 2026, at a compound annual growth rate (CAGR) of 7.5%. The composites market is growing due to increasing demand from the wind energy, aerospace and defence, and automotive and transportation industries. However, due to COVID-19, sales of various industries have plummeted, resulting in reduced demand for composites [4].

A piece of wood, which is held together by a substance found in nature and called lignin, contains cellulose in its core, can be defined as a composite product. Composite materials, which are formed by the combination of two or more materials, as in a piece of wood, provide durability, permeability, flexibility, etc., thanks to the components with their own characteristics acquires different properties. The components that make up the composite material do not dissolve or mix with each other, giving the composite unique properties. Egyptians and Mesopotamians created a mixture of mud and straw to build stronger buildings and houses around 1500 BC. Due to the lightness and durability of composites during the World War II many developments took place in this industry and the production of Fiber Reinforced Composites (FRP) increased. Today, the composite industry continues its transformation by focusing on concepts such as renewable energy, resistance to heat and chemicals, replacement of synthetic fibers with natural fibers [5].

There are types of composites that contain different configurations of short fibers, particles, monofilaments, and long fibres. The matrix material can be polymeric, mechanical, or ceramic and makes up most of the composite. Reinforcement is usually provided with ceramic or carbon and glass fibers [6].

Composite materials, thanks to their corrosion resistance, light weight, strength, lower material costs, improved productivity, design flexibility, and durability properties have been used areas such as space, appliance, architecture, automotive, transportation, construction and infrastructure, corrosive environment, electrical, energy, marine, sports, recreation [6].

In the 2020-year, European Glass Reinforced Plastics (GRP) production volume is expected to fall by 12.7 %. As a result, the total volume of the European Glass Reinforced Plastics (GRP) market is 996,000 tonnes. The market is thus experiencing its sharpest decline since the crisis of 2008/2009 [7].

According to JEC Group, the European transportation industry will see the most significant share of total growth (44%) by volume size in the next 4 years. This is followed by the construction (14%), pipe & tank (13%), and wind energy (10%) industries [8].

The aim of this research is to determine the competitiveness level of the composite industry in Turkey and to generate data for the companies working in this industry to develop their competitive strategy. It is aimed to contribute to both composite industry and the literature about competition level of industries by using Porter's five forces model.

2. EXPERIMENTAL STUDY

2.1 Material and Method

A survey method was used as data collection method in the research. The questionnaire form used in the research consists of two parts. In the first part, it was tried to determine to what extent the participants agreed or disagreed with the statements about making the structural analysis of the industry. There are 27 statements in this section. Each statement of industry forces was measured by using the five-point Likert type scale from 1 (strongly disagree) to 5 (strongly agree). Survey was developed and adapted from the studies of Porter 2008 [9] Five Forces Model, Dess and Miller (1996) [10], Grant (2002) [11] Eren (2010) [12], Akçagün (2015) [13]. The second part includes statements about the characteristics of the firm and manager participating in the research.

The survey was sent by an email to 102 companies specified on the Turkish Composite Association web page. Some companies stated that they did not want to attend for the survey. 22 surveys were taken into consideration because they were filled in completely and are important for determining competitiveness level of the industry. 5 survey data were not taken into consideration because the required information fields were empty. Accordingly, the survey was evaluated by 22 companies. The number of survey participants was limited due to the small size of the industry. The data obtained in the survey were evaluated by using SPSS 21.0 package program. From the answers given by the company managers, it was tried to reveal the views on composite industry competitive structure. While evaluating the data on the program, frequency analysis, mean and standard deviation results were evaluated. The propositions in the survey regarding the competitiveness level of the composite industry in Turkey are sufficient to reveal the strategic capabilities of the companies in question. "Cronbach Alpha" internal consistency coefficients were calculated for reliability study of the scale. The internal consistency/reliability coefficient of the scale, which consists of 27 items in total is Cronbach alpha value $\alpha = 0.721$. The Cronbach Alpha reliability coefficient obtained for the expressions in the survey is statistically sufficient and shows that its scale is consistent and reliable. The research method chosen is suitable for the purpose and subject of the research and the solution of the questions.

2.2 Ethics Committee Approval

In this study, all the rules specified to be followed within the scope of "Scientific Research and Publication Ethics Directive of Higher Education Institutions" were complied with. Participants were informed about the research, it was stated that the data would be used for scientific research, and their written and verbal consents were obtained.

3. RESULTS

3.1 Respondents' and Composite Firm's Characteristics

Table 1 summarizes the demographic characteristics of the people who participated in the survey. It was observed that 90.91 % (20) of the respondents were working in a managerial position (general manager, marketing manager, logistic manager, buying manager and consultant) and another person who answered the survey was an employee in the R&D department 4.55 % (1) and logistics 4.55 (1). A total of 63.64 % (14) respondents has a master's degree or higher and 36.36% (8) respondents have bachelor's degree. The fact that all the participants are university graduates shows the importance that institutions give to education. A total of 22.73% (5) respondents have worked in their current position for less than five years, while 45.45 % (10) have worked 6-10 years, 18.18 % (4) have worked 11-20 years and 13.64 % (3) have worked in their current position for more than 20 years. In addition to respondents' current position working time also total working time of respondents' have been analysed. A total of 45.45 % (10) respondents have been working in this industry for 21-30 years, while 18.18% (4) respondents have been working for 16-20 years, 27.27% (6) respondents have been working for 11-15 years and 9.09% (2) have been working for less than 10 years. Participants are generally people who have experience and know-how in the composite industry.

Table 1. Respondents' and composite industry firms' characteristics.

Characteristics	f	%	Characteristics	f	%
Current position			Number of workers		
R&D and Logistic staff	2	9.09	1-100	8	36.36
Manager (Ceo, Marketing etc.)	20	90.91	101-200	7	31.82
			201-300	4	18.18
Education			301 and more	3	13.64
Bachelor's degree	8	63.64	Total Time in the Industry of the Firm		
Master's and higher	14	36.36	2-5 years	3	13.64
Total working time			6-10 years	4	18.18
1-10 years	2	9.09	11 years and more	15	68.18
11-15 yeas	6	27.27	The Company's Foreign Partnership Status		
16-20 years	4	18.18	Have	1	4.55
21-30 years	10	45.45	Don't Have	21	95.45
Year of current position			**Total**	**22**	**100**
1-5 year	5	22.73	Regions Your Company Exports Its Products		
6-10 year	10	45.45	Europe	17	
11-20 year	4	18.18	Asia	12	
21-30 year	3	13.64	US	6	
Total	**22**	**100**	Other	8	

The composite firms' characteristics are described in Table 1. A total of 13.64 % (3) company was hiring 301and more, 18.18 % (4) companies were hiring 201-300 workers, 31.82 % (7) were hiring 101-200 and 36.36% (8) were hiring 1-100 workers. Firms generally employ few people. Of the respondents, 68.18% (15) of the companies have been operating in the composite industry for more than 11 years, while 18.18% (4) have been working in the composite industry for 6-10 years and 13.64 % (3) for 2-5 years. 95.45% of the companies operating in the composite industry do not have foreign partners. Composite companies operating in the industry export more to countries (twelve companies each) located in the European and Asian Regions. While companies are exporting to several regions at the same time, six companies are exporting to America. The fact that all the companies participating in the survey export to many parts of the world can be described as promising in terms of the volume and potential of the industry. This situation highlights the importance of the composite industry for the development and growth of Turkey once again.

3.2 Impact of Industry Forces

In the next step all firms were asked to evaluate the strength of the five forces and sub forces which is listed in Table 2. Industry forces was measured by using the five-point Likert type scale from 1 (strongly disagree) to 5 (strongly agree). Accordingly, responses were calculated as 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree) and 5 (strongly agree).

Table 2. Five forces and sub forces result.

Forces and Sub-Forces	**n**	**Mean**	**Std. Dev.**
Threat of new entry			
Economies of scale	22	2.50	1.06
Capital demands	22	3.01	1.25
Access to distribution channels	22	3.00	1.02
Technical know-how necessity	22	4.55	0.67
Experience and product differentiation	22	3.96	0.72
Access to raw materials	22	2.91	1.11
Brand loyalty	22	3.41	1.10
Bargaining Power of Buyers			
Switching costs	22	2.64	1.00
Price information	22	3.55	0.80
Number of buyers	22	3.41	1.05
Threat of backward integration	22	2.91	1.23
Standard products	22	1.77	0.81
Order size for buying threat	22	2.96	1.00
Bargaining Power of Suppliers			
Number of suppliers	22	3.86	0.83
Contribution to products quality	22	4.46	0.60
Supplier procurement time threats	22	4.18	0.80
Switching costs	22	2.64	0.95
Forward integration threat of suppliers	22	2.82	1.18
Company importance for the suppliers	22	4.00	0.76
Threat of Substitutes			
Substitute products	22	2.90	0.97
Threat of technology	22	2.68	0.95
Rivalry among Existing Companies			
Equally balanced competing firms	22	3.46	1.37
Slow industry growth	22	2.55	1.37
Excess supply and production for industry	22	2.64	1.05
Low stock cost	22	1.86	0.94
Strategy differentiation	22	3.82	0.96
High exit barriers	22	2.86	0.77

3.2.1 The Power of Buyers

It can be said that the factors affecting the bargaining power of buyers are the number of buyers, information about product prices, replacement costs, backward integration capabilities, and profit rates. So, buyers are very powerful when the number is small, high know how about products, generate low margin, and threaten to backward integration.

When the answers given by the participants to the statements about the bargaining power of the buyers are evaluated which is shown in Table 2, it is seen that the number of buyers is low ($\bar{x} = 3.41, \text{Std. Dev.} = 1.05$) and the buyers have detailed information about the prices in the market ($\bar{x} = 3.55, \text{Std. Dev.} = 0.80$). This can be considered as a factor affecting the profitability of the composite industry. On the other hand, it is seen that the ability of the buyers to produce the products they buy from the firms has a low to moderate value ($\bar{x} = 2.91, \text{Std. Dev.} = 1.23$). Here, it can be said that buyers only buy instead of producing due to factors such as investment costs, lack of production know-how, difficulties in creating a market etc. Likewise, according to the answers of the participants, it is seen that it is not easy for the buyers to purchase alternatives of the products produced from other companies without incurring an additional cost ($\bar{x} = 2.64, \text{Std. Dev.} = 1.00$). In addition to this, the companies do not use the number of production orders as a bargaining factor ($\bar{x} = 2.96, \text{Std. Dev.} = 1.00$). Also, the companies do not sell standard products which can also decrease the bargaining power of buyers ($\bar{x} = 1.77, \text{Std. Dev.} = 0.81$) (Table 2).

When a general evaluation is made with the answers given by the participants to the statements measuring the bargaining power of the buyers, it can be said that the bargaining power of the buyers is moderate. Buyers in these markets may have some power to negotiate prices and terms of supply, but they may also be limited by the specialized nature of composite materials and the limited number of suppliers. Also, high switching costs of producer and lack of production know-how limits the bargaining power of buyers.

3.2.2 The Power of Suppliers

Factors that affect the bargaining power of suppliers can be listed as; dominated by few companies, no substitutes to the supplier's products, contribution to quality of customer product, switching costs of the customer, threat of forward integration and firms are not important customers for suppliers.

When the answers given to the questions about measuring the bargaining power of the suppliers are examined, it is seen that there are few companies from which the companies can supply products ($\bar{x} = 3.86, \text{Std. Dev.} = 0.83$). The quality of the supplied products directly affects the product quality of the company ($\bar{x} = 4.46, \text{Std. Dev.} = 0.60$). The product lead times directly affect the production workflow ($\bar{x} = 4.18, \text{Std. Dev.} = 0.80$), and they receive a high number of raw materials from their suppliers ($\bar{x} = 4.00, \text{Std. Dev.} = 0.76$). In addition, it is seen that the cost of switching suppliers is very difficult and costly ($\bar{x} = 2.64, \text{Std. Dev.} = 0.95$). On the other hand, it is stated that the efforts of suppliers to make forward integration are low ($\bar{x} = 2.82, \text{Std. Dev.} = 1.18$) (Table 2).

When all these factors are examined, it is seen that the bargaining power of the suppliers is moderate to high. And it can be quite effective on the profitability of the companies in the composite industry. The industry buys raw materials such as resins, fibers and additives from a limited number of suppliers. These suppliers can have significant power to negotiate prices and quality standards and, they may be able to limit supply in times to high demand.

3.2.3 Threat of New Entry

The threat posed by entry into an industry varies depending on the reaction the new entrant can expect from existing competitors and the existing barriers to entry. Factors such as economies of scale, capital requirement, access to distribution channels, learning and experience curve, and access to raw materials constitute barriers to entry.

When the answers given by the respondents to the questions about the threat of new entry into the industry are examined, it is seen that a new company that will enter the composite industry does not need to start with a large amount of production ($\bar{x} = 2.50, \text{Std. Dev} = 1.06$). According to the results, the capital requirement for establishing a new firm in the industry can be described as moderate ($\bar{x} = 3.01, \text{Std. Dev} = 1.25$) and it is not very hard for a new company to have access to distribution channels ($\overline{x} = 3.00, \text{Std. Dev} = 1.02$). On the other hand, it can be said that the access to raw materials is of moderate difficulty ($\overline{x} = 2.91$, Std. Dev.= 1.11). And also, it is seen that the loyalty of the customers to the company and their products is quite high ($\overline{x} = 3.41, \text{Std. Dev.} = 1.10$)and it is necessary to have a significant amount of technical knowledge and experience in the field ($\overline{x} = 4.55, \text{Std. Dev.} = 0.67$) (Table 2).

When a general evaluation is made, it can be said that the new entry threat is low to moderate for companies that produce and sell composites in Turkey, according to the responses to the threat of new entry. Here, the ability to start with a small amount of production in scale and the moderate capital requirement to establish a new company can be considered as factors that reduce the entry barrier for new companies but especially high technical knowledge and equipment requirement, experience and know-how requirement in production and loyalty of buyers can be considered as factors that increase the barrier to new entry.

3.2.4 Rivalry Among Existing Firms

The factors that determine the competition among current competitors can be listed as the presence of many equal companies, increased capacity, and high exit barriers, slow industry growth, lack of differentiation.

When the data obtained from the companies participating in the survey are evaluated, it is seen that there are many large and small enterprises in the composite industry ($\overline{x} = 3.46, \text{Std. Dev.} 1.37$). This factor increases the competition among existing firms. On the other hand, in the question asked to measure the growth rate of the composite industry: 'The growth rate of the industry is low.' Participants stated that they did not agree with the statement ($\overline{x} = 2.55, \text{Std. Dev.} 0.91$). From this, it is understood that the growth rate of the composite industry continues to increase. In addition, according to the answers of the respondents, it is seen that there is not too much excess supply in the composite industry yet ($\overline{x} = 2.64, \text{Std. Dev.} = 1.05$), and the exit barrier from the composite industry is low ($\overline{x} = 2.86, \text{Std. Dev.} = 0.77$). In addition, they stated that they did not agree with the statement that measures the inventory costs of the products and that the costs of waiting in stock for the products are quite high ($\overline{x} = 1.86, \text{Std. Dev.} = 0.94$) (Table 2).

In general, when the answers given to the statements measuring the rivalry among existing competitors are examined, it can be said that the competition between the companies is moderate to high.

There are many small and medium sized companies competing with established large companies in the Turkish composite industry. Established companies use brand recognition and have more bargaining power than smaller companies. However, the large and small number of companies in the industry may increase the competition in factors such as price, quality, and delivery times. In addition to this, the high growth rate of the industry creates a positive effect for the industry firms.

The current demand for the composite industry, the growth rate of the industry, the need and potential for innovative products keep the interest in this industry high.

3.2.5 Substitute Products

According to the answers given by the respondents to the questions measuring the threat of substitute products, it is seen that the substitution threat of the products produced by the companies is low. It can be said that companies partially agree to the question asked about finding substitutes for the products they produce($\overline{x} = 2.90, \text{Std. Dev.} = 0.97$). In addition, with the development of new technologies like 3D, industry 4.0 cannot be direct threats for the industry to create substitute products ($\overline{x} = 2.68, \text{Std. Dev.} = 0.94$) (Table 2).

Composite materials have many unique properties such as durability, resistance to corrosion and impacts, and high strength. These properties cannot be copied by other materials and provide unique advantages to composite materials. These reasons make composite materials a preferred choice in many industries.

4. CONCLUSION

This research focuses on external factors of Turkish Composite Industry that define firm profitability and industry competitiveness using Porter's Five Forces Framework. The number of companies currently operating in the industry is quite limited (102 companies) according to the information obtained from the Turkey Composite Association. This situation shows that the industry continues to grow. The survey created and shared with the companies by e-mail and filled by only 22 of them. It can be said that averagely 25% of the companies answered the survey. It was thought that the study would contribute to the industry by guiding the industry, and the obtained data were evaluated as sufficient.

As a result, the Turkish composites industry is a highly competitive industry with low threat of substitution and moderate bargaining power of buyers. Suppliers have moderate to high bargaining power due to the special nature of the raw materials used in composite manufacturing. Due to the large number of large and small companies in the industry, competition among existing competitors can be considered high and barriers to entry are moderate to high.

REFERENCES

[1] Jay B. Barney. (2007). *Gaining and Sustaining Competitive Advantage* (3rd ed.). Pearson Hall.

[2] Bharadwaj, N. (2018). Strategic decision making in an information-rich environment: A synthesis and an organizing framework for innovation research. In *Innovation and strategy* (pp. 3–30). Emerald Publishing Limited.

[3] Porter, M. E., & Advantage, C. (1985). Creating and Sustaining Superior Performance. *Competitive Advantage*, *167*.

[4] MarketsandMarkets INC. (2021). *Composites Market by Fiber Type, Manufacturing Process, End-use Industry and Region—Global Forecast to 2026*. https://www.marketsandmarkets.com/Market-Reports/composite-market-200051282.html

[5] Ngo, T.-D. (2020). Introduction to composite materials. *Composite and Nanocomposite Materials—From Knowledge to Industrial Applications*, 1–240. https://doi.org/10.5772/intechopen.91285

[6] Clyne, T. W., & Hull, D. (2019). *An introduction to composite materials*. Cambridge university press.

[7] Witten, E., & Mathes, V. (2020). *The Market for Glass Fibre Reinforced Plastics (GRP) in 2020 Market developments, trends, outlooks and challenges*. Industrievereinigung Verstärkte Kunststoffe.

[8] European Composites Resource Guide. (2020). *European Composites Resource Guide 2020 Edition*. https://www.trade.gov/european-composites-resource-guide20Brief%202020_508%20Compliant.pdf

[9] Porter, M. E. (2008). The Five Competitive Forces that Shape Strategy. *Harvard Business Review*, *86*(1), 25–40.

[10] Miller, A., & Dess, G. G. (1996). *Strategic management*. McGraw-Hill.

[11] Grant, R. M. (2002). *Contemporary strategy analysis: Concepts, techniques, applications* (Fourth Edition). Blackwell Publishing.

[12] Eren, E. (2010). *İşletmelerde Stratejik Yönetim ve İşletme Politikası*. Beta Basım.

[13] Akcagun, E., & Dal, V. (2013). The Analyses of Turkish Apparel Industry by the Five Forces Model. *Industria Textila*, *64*(2), 115–119.

THE EFFECT OF MASK STYLE AND FABRIC SELECTION ON THE COMFORT PROPERTIES OF FABRIC MASKS

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ABSTRACT

The purpose of fabric masks in the prevention of the spread of Covid-19 often requires that the masks must be worn for extended periods without removal. The management of the conditions in the microclimate inside the masks is important to enhance user compliance. In this study the effect of mask design and fabric type on the micro-climate was investigated, using thermocron iButtons to record the temperature and humidity inside the masks. It was found that mask style, and its effect on the amount of air incorporated in the micro-climate, had a significant influence on the factors that determine the temperature and humidity levels. Significant differences were also found in the temperatures recorded in the different time segments. The results of this study emphasize the importance of considering all the components of mask design, namely style, fibre type and fabric structure, in the development of masks to enhance user compliance.

Keywords: *Fabric masks, Covid-19, Mask style, Micro-climate, Temperature, Humidity*

1. INTRODUCTION

Reusable fabric face masks, designed to serve as "source control", were recognized in 2020 as probably the most effective means to mitigate the Covid-19 disease transmission (by preventing outward transmission of contaminated droplets by an infected person) [1–3], It's purpose is to stop the transmission of micro-droplets (≥ 5 μm) from an infected person to the environment [4]. Masks should be designed to cover the nose and mouth acceptably to minimise leakage of respiratory excretions. This implies that the components should be selected to enhance the thermo-physiological comfort experienced by the wearer to such an extent that the mask can be worn in the correct position for long periods when required.

Comfort in clothing is generally defined as a neutral state where the wearer is unaware of the textiles covering the skin [5]. In the case of masks, mild to severe deviations from the neutral state leads to frequent touching or displacement of a mask and temporary or permanent withdrawal from the face. This can compromise its effectiveness significantly. Apart from the failure as source control, this could lead to an increase in self-infection or the creation of a route for secondary infection [6]. Studies on the wearing of face masks by medical personnel show that non-compliance to recommended practices was mostly due to factors related to the development of a state of discomfort during wear [7,8]. The thermo-physiological comfort properties in a textile fabric are closely related to its ability to provide thermo-regulation and moisture transportation from the micro-climate (between the skin and the first layer of fabric) to the surrounding environment [9–11]. Masks that can transfer heat and moisture away from the face are considered to provide higher levels of comfort [12].

Heat loss through the facial area plays an important role in the thermoregulation of the body. Due to the high concentration of thermo-receptors, it accounts for 20% of the total heat loss drive (cooling action) from the skin. This process is impeded when a mask, covering the nose and mouth, is worn [6]. Changes in the micro-climate in a mask can lead to the development of heat stress [13] or a potential decrease in mental and physical performance [14]. Differences in measured heart rates, skin temperature and perceived humidity of participants were reported, which caused greater wearing discomfort and lower user compliance [6,7,15]. An increase in the skin temperature of less than 2°C was regarded as significant [6,16]. Skin temperature increased irrespective of workload [16]. As most of the studies mentioned focussed on medical masks, it is postulated that the effect would be accelerated in reusable fabric masks, where the total thickness and thermal resistance of the masks depend on the individual fabric properties. Several factors affect the micro-climate inside a mask. Fabric thickness is a key indicator of thermal resistance [17], with the effect being accelerated when multiple layers are involved. Heat loss through a fabric depends largely on the amount of air incorporated in the fabric structure (hence the thickness) [17–19]. Jung et al [20] confirmed the effect of the amount of dead air space created between the skin and mask by the mask's design. Body heat is conducted from the skin to the layer of air that surrounds it. The heat is then transferred further through the micro-climate and then through the air between textile layers and surrounding individual textile fibres and yarns, and lastly through the textile fibres, by a combination of conduction and convection. A higher airflow rate through the mask will increase the convective heat transfer from the skin to the environment [10,16].

Moisture management inside the micro-climate involves the transfer of moisture vapour through the air spaces between the fibres and yarns to keep the micro-climate dry enough to allow for the evaporation of sensible and insensible perspiration from the skin surface. The mask should also allow any liquid moisture to be absorbed and spread effectively throughout the fabric, offering a dry hand, and enabling moisture to be evaporated [9, 10]. If the moisture management properties of the fabric are inadequate it will cause an uncomfortable sensation of wetness and eventually cause clinging to the face [12].

This study aims to explore factors that affect the levels of comfort experienced during the wearing of fabric masks focusing on how well the micro-climate inside the mask is managed in terms of temperature (T_{mc}) and humidity (H_{mc}). Both T_{mc} and H_{mc} relates to the effect of all aspects of the mask's design, which include the physical design of the mask (in this study referred to as "mask style") as well as the performance properties of all the fabrics the mask is made of.

2. EXPERIMENTAL STUDY

In this study, the term "mask design" refers to the combination of mask style and fabric type. (Described in Table 1). Three mask styles and three fabrics/filter combinations were selected for evaluation, based on popular designs manufactured and worn regularly by the public. It should be noted that the study aimed to investigate factors that influence the micro-climate only in masks that conform to the general guidelines for face masks. Based on the results of a subjective pilot study, the masks for this study were all described as "acceptable" concerning wear comfort. The three mask styles are depicted in Figure 1(a) to (c). Style E is a two-layer mask, which is constructed like an envelope with pleats on the side (to enhance fit) and an opening at the top (for an optional filter). Style EF is a mask with the same design as E, but with a filter inserted between the two layers. Style S is a shaped mask consisting of 2 fabric layers with a thin but firm nonwoven layer permanently stitched in between (to keep its shape). In all the mask styles the inner and outer layers of the mask were made of the same fabric type. The two nonwoven filter layers used in style EF and style S masks were selected for optimum performance in the specific designs and differ in thickness and stiffness.

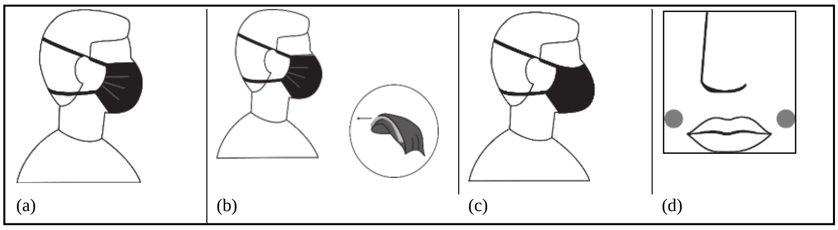

Figure 1. Illustration of mask styles: (a) envelope type mask; (b) envelope type mask with filter; (c) shaped mask with sewn-in filter and (d) illustration of the placement of iButtons on the face during the wear trials.

(a) (b) (c)

Figure 2. Microscope images of fabrics used as inner and outer layers in the mask design: (a) weft-knit polyester (eyelet design); (b) medium weight woven cotton and (c) lightweight woven polycotton.

The three fabrics (selected as inner and outer layers) and the filter fabrics are described in Table 1. The fabrics were analysed and tested in the laboratory and selected structural and performance properties that relate to thermo-physiological comfort are summarized in Tables 1 and 2. Where applicable, measurements are reported for single, double, and three-layer fabric assemblies. The filtration efficiency (FE) and air permeability (AP) of the selected fabrics were measured by Gericke, *et al* [21], using a method that utilizes upstream and downstream particle count measurements to calculate FE (%) and AP (%). Other measurements include fabric thickness (mm), fabric weight (g/m^2), horizontal wicking (cm^2) and Permetest measurements for relative moisture vapour permeability (WVP) and thermal resistance (R_{ct}) [22]. The masks were washed and conditioned for 24 hours before the wear trials.

Table 1. Referencing and description of structural and performance properties of fabric layers used the masks in this study.

Mask Reference[#]	Fabric Type	Filter Ref.	Mask Style	Weight (all layers) (g/m^2)	Thickness (all layers) (mm)	MVP (%)	R_{ct} (m^2.K.W^{-1})	FE (%)	AP (%)
KPE	KP	none	E	260	1	60,2	22,6	91,0	95,0
WCE	WC	none	E	350	0,8	46,7	9,2	68,0	34,0
WPCE	WPC	none	E	250	0,4	52,9	15,4	76,0	30,0
KPEF	KP	Nw1	EF	360	6	29,8	156,9	90,0	84,0
WCEF	WC	Nw1	EF	450	5,8	21,3	92,7	91,0	31,0
WPCEF	WPC	Nw1	EF	350	5,4	26,9	129,9	97,0	16,0
KPS	KP	Nw2	S	310	1,6	44,0	50,5	72	80
WCS	WC	Nw2	S	400	1,4	37,0	28,3	72	21
WPCS	WPC	Nw2	S	300	1,0	45,0	27,9	92	16

[#]Mask design is described in the Mask References and comprises combinations of three mask styles and three fabric types. It is referenced using the fabric reference, followed by the mask style (e.g., WCE = WC (woven cotton) +E (envelope style mask)). Other abbreviations used include K (knitted), W (woven), Nw (nonwoven), P (polyester), C (cotton) and PC (polycotton).

Table 2. Structural and performance properties of (single layer) fabrics and filters used in the masks described in Table 1.

Fabric Ref.	Fabric structural properties (single layer)				Fabric Performance Properties (single layer)				
	Fabric structure	Fibre content	Weight (g/m^2)	Thickness (mm)	MVP (%)	R_{ct} ($m^2.K.W^{-1}$)	Wicking (cm^2)	FE (%)	AP (%)
WC	Plain weave	Cotton	175	0,4	66,4	9,5	21,7	61	58
WPC	Plain weave	Polycotton	125	0,2	70,9	8,5	10,1	85	30
KP	Weft-knit	Polyester	130	0,5	76,7	10,3	24,0	69	97
Nw1	Fibre web	Polyester	100	5,0	30,3	117,0	-	75	92
Nw2	Fibre web	Polyester	50	0,6	67,8	24,1	-	68	90

Thermocron iButtons, commonly used in clinical trials, are small, standalone, calibrated data loggers that can be placed directly on the skin to log temperature and humidity at a user-defined rate. In this study, the iButtons were used to record and log T_{mc} and H_{mc} in the micro-climate between the skin and the mask digitally at sixty-second intervals over a minimum duration of thirty minutes, under conditions resembling wear in an office, laboratory, or general work environment. Before the start of each evaluation, the respondent was made comfortable and two iButtons were secured on the skin as shown in Figure 1(d). The positioning was selected to make sure the conditions in the micro-climate are recorded without being affected by warm or moist air expelled during breathing. The mask was then fitted securely on the face. The respondent was instructed to continue with sedentary work for at least 30 minutes while breathing normally through both the mouth and nose. The mask was not to be touched or adjusted unnecessarily. After every 10 minutes a short (mild) exercise routine, was followed. This involved moving or lifting the arms and legs in a controlled manner while making sure that the exercise did not lead to a change in breathing pattern. To minimize variances, three precautions were implemented. Firstly, only one respondent was used to reduce physiological variances, secondly, the wear trials were carried out under controlled conditions ($21 \pm 0,5\ ^{o}C$ and $55 \pm 5\%$ RH) to simulate office conditions, and thirdly, all the evaluation cycles were repeated five times.

Results were analysed using Tibco Statistica Software. The experimental design aimed to examine the effect of mask design versus that of mask components (fabrics) on the micro-climate between the skin and inner surface of the mask during wear. The dependent variables were T_{mc} and H_{mc}.

3. RESULTS

Temperature and humidity data were logged at a defined rate of 1 measurement every 60 seconds for 30 minutes, which was divided into three time-segments, namely the first, second and third 10 minutes of the trial (time segments are referred to respectively as TS1, TS2 and TS3. Initial statistical analyses showed significant differences between the measurements recorded within the different time segments.

An overview of all the results is depicted in the scatterplots for T_{mc} and H_{mc} in Figure 3. It shows that the highest temperatures were measured in style EF masks (which contained an inserted filter). Concerning the humidity inside the mask, fabric type was the strongest determinant, with the highest values measured in the masks made of woven cotton (WC).

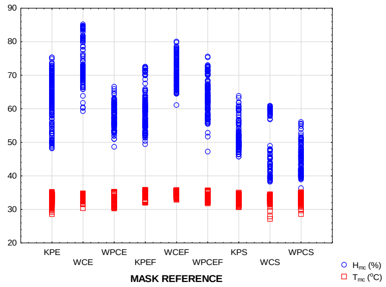

Figure 3. Scatterplot of multiple variates (T_{mc} and H_{mc}), depicted per mask design, to provide an overview of all the results.

3.1. Mask style

The effects of the factors mask style and time segment on T_{mc} and H_{mc} are shown in the two-way ANOVAs in Figures 4 to 7 (Vertical bars denote 95% confidence levels).

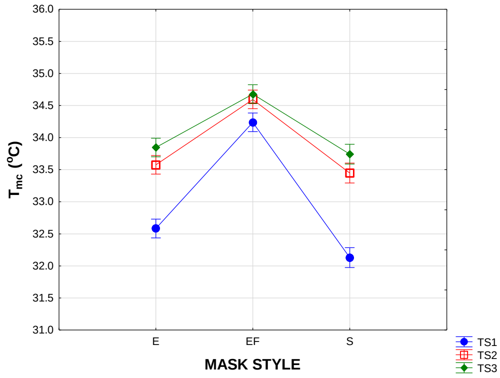

Figure 4. Two-way ANOVA of T_{mc} per mask style according to time segment.

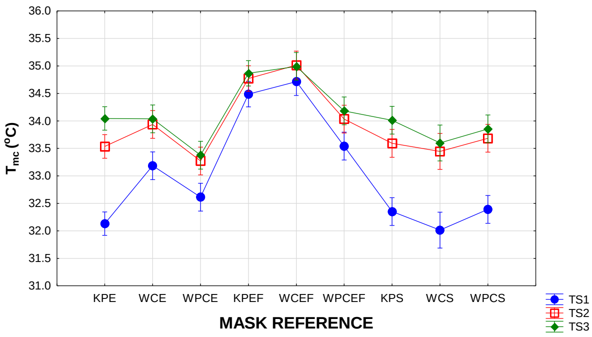

Figure 5. Two-way ANOVA of T_{mc} per time segment according to mask design (referenced as explained in Table 1).

The interaction graph in Figure 4 confirms a significantly higher T_{mc} in the beginning and throughout the wear trials in style EF masks. The results were further interpreted in the interaction graph in Figure 5 to investigate the effect of mask design (combinations of mask style and fabric type) and time segments. The T_{mc} measurements in all the style EF's were consistently the higher than in the other styles. This was expected, as the physical properties of the inserted filter increased the thickness of the masks in this style to more than three times that of the others, and the laboratory measurements for thermal resistance (R_{ct}) on the three layers were more than three times higher than that of the fabrics in the other mask styles (Table 1). The remaining two mask styles (S and E) performed similarly in the last two time segments, but the temperature inside the shaped masks (style S), took significantly longer to stabilise. Figure 5 indicates that in most cases, the T_{mc} measurements in TS1 were much lower than those measured in TS2 and TS3. In both styles E and style S masks, the temperatures increased significantly from TS1 to TS2 and TS3. The lowest initial T_{mc} measurements were recorded in the masks in style S (KPS, WCS and WPCS) as well as one of the style E masks (KPE), but this was followed by a significant rise in T_{mc} after 10 minutes. In most cases, the rise between TS2 and TS3 was not significant. In all cases, the highest T_{mc} were recorded in the last 10 minutes of the wear trial. It should be noted that in the style EF masks the T_{mc} was high from the beginning and the increase in T_{mc} between the time segments was not significant. It can be noted that individual temperature measurements inside some of the style EF masks (predominantly in the woven cotton masks with reference WCEF) reached values exceeding 36°C.

The difference in thermal behavior among the three mask styles is explained as follows: Initially, the ambient temperature in the laboratory (21°C) will determine the temperature inside the mask (T_{mc}). However, during wear, the conduction of heat from the skin (temperature ±35°C) will lead to an increase in the temperature of the immediate air layer surrounding the skin, which will then cause an increase in the temperature of the air in the micro-climate inside the mask. The increased temperature gradient will initiate the transfer of heat from the micro-climate to the environment through the fabric layers in the mask. The rate of transfer depends on the combined effect of the total amount of air involved and the thermal resistance of the fabrics in the masks. The combined effect of the air between the skin and the mask, as well as the air incorporated in the fabric structure and between the fabric layers, will contribute to the transfer of heat from the skin to the environment [11, 16]. Due to the design of the shaped style S masks, the larger micro-climate in the mask causes a slower increase in T_{mc} than in the other styles. The "buffer effect" caused by the prominent air layer against the skin, slows down the conduction of heat from the skin surface. After 10 minutes, the buffer effect in style S mask was overcome and the mask styles S and E performed similarly. The amount of air incorporated in the highly porous filter layer in mask style EF (without the effect of a "buffer air layer") caused the development of a significantly higher temperature inside the micro-climate. This accords with findings in research on medical masks [20]. The H_{mc} measured inside the shaped masks (style S) was significantly lower than in the other two styles (p<0,00). This is demonstrated in Figure 6, which also shows that the effect of the time segment was not significant in most of the masks in this style. It does appear, however, that, as with the T_{mc} results, the larger micro-climate in the shaped masks caused the H_{mc} levels to take longer to stabilise. Although the means for the style E and EF masks were very close, some of the individual measurements in the style E masks were very high (>80%). Further interpretation of the data confirmed the influence of fabric type on especially the properties of the style E masks (Figure 7).

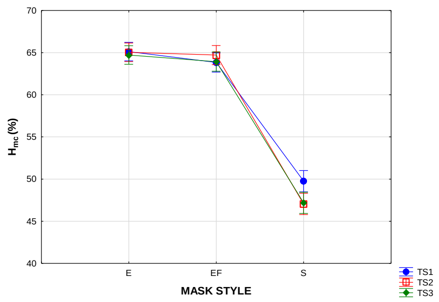

Figure 6. Two-way ANOVA of H_{mc} per mask style according to time segment.

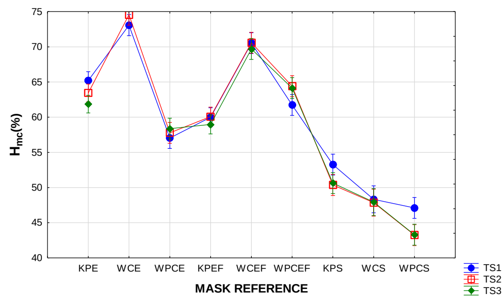

Figure 7. Two-way ANOVA of H_{mc} per time segment accor-ding to mask design (referenced as explained in Table 1).

3.2. Fabric type

To investigate the influence of fabric type on T_{mc} and H_{mc}, the results were interpreted separately for each mask style per fabric type and time segment. When a mask fits snugly around the face (as in style E masks), a thinner layer of air is expected in the micro-climate (compared to for example shaped masks) and the transfer of heat and moisture to the environment depends on the thermal and moisture management properties of the mask itself, which in turn depends on the collective performance properties of all the fabric layers in the mask. It is postulated that in this type of mask, the T_{mc} and H_{mc} will be directly dependent on the specific thermal resistance (R_{ct}) and moisture management properties of the fabrics in the mask. The heat and moisture transfer in masks made of each of the three fabric types used in this study (weft-knit polyester, woven cotton and woven polycotton) is explained by Gericke et al [22]. The main influencing factors are thickness and drape (implying incorporated still air) and fibre composition (affecting moisture management properties) for respectively T_{mc} and H_{mc}. In the style EF masks, T_{mc} was significantly higher than in those without filters (Figure 4). The incorporated filter layer adds to the thickness and stiffness of the mask (incorporating a substantial amount of still air) and has a highly significant effect on the mask's ability to dissipate heat from the micro-climate to the surrounding atmosphere, negating the effect of the individual fabric properties. The H_{mc} in the case of fabrics KP and WC (Figure 6) in the style EF masks could be attributed to the increased stiffness of the EF masks, which caused them to fit less snuggly, allowing water vapour to escape through the open sides. This was not the case with the WPC fabric, which is softer and allowed a better fit around the face contours, even with the filter. The stiffer nonwoven fabric used in between the two layers of fabric in the style S masks, causes the front part of the mask to stand away from the face, resulting in a substantially larger micro-climate between the skin and the mask and causing the effect of fabric type in the style S masks to be not significant ($p>0.05$) (Figure 7).

4. CONCLUSION

This study aimed to determine the effect of mask design and fabric type on the conditions inside the micro-climate between the skin and the mask. Mask style had a significant influence on the factors that determine mask performance: In the shaped masks, the design and fit caused a large air layer to form in the space between the skin and the mask. The impact of the air layer outweighed the effect of the fabric type on the Tmc and Hmc inside the mask. In the mask with the inserted filter, the increase in total mask thickness, together with the high porosity of the nonwoven filter, outweighed the effect of fabric composition on mask comfort. In the masks where the two fabric layers fit snugly around the face, the air layer between the face and the mask is minimized. This enhances the role that fabric performance properties play in the effective transfer of heat and moisture from inside these masks to the environment. Significant differences were found between temperatures recorded in masks within the three time segments. This variance within the time intervals highlights how important it is that comfort evaluations are conducted for a long enough time to prevent an initial false interpretation of the comfort factors. A mask may be perceived as comfortable if tested for a few minutes but may not perform as well in the long run. None of the fabric structures or structural properties could be singled out as having a more pronounced influence than the others.

5. REFERENCES

[1] Prather, K. A., Wang, C. C., & Schooley, R. T. (2020). Reducing transmission of SARS-CoV-2. *Science*, *368*(6498), 1422-1424.

[2] Milton, D. K., Fabian, M. P., Cowling, B. J., Grantham, M. L., & McDevitt, J. J. (2013). Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. *PLoS pathogens*, *9*(3), e1003205. doi: 10.1371/journal.ppat.1003205.

[3] Asadi, S., Gaaloul ben Hnia, N., Barre, R. S., Wexler, A. S., Ristenpart, W. D., & Bouvier, N. M. (2020). Influenza A virus is transmissible via aerosolized fomites. *Nature communications*, *11*(1), 4062. doi: 10.1038/s41467-020-17888-w.

[4] Lindsley, W. G., Beezhold, D. H., Coyle, J., Derk, R. C., Blachere, F. M., Boots, T., ... & Noti, J. D. (2021). Efficacy of universal masking for source control and personal protection from simulated cough and exhaled aerosols in a room. *Journal of occupational and environmental hygiene*, *18*(8), 409-422. doi: 10.1080/15459624.2021.1939879.

[5] Li, Y. (2001). The science of clothing comfort. *Textile progress*, *31*(1-2), 1-135. doi: 10.1080/00405160108688951.

[6] Scarano, A., Inchingolo, F., & Lorusso, F. (2020). Facial skin temperature and discomfort when wearing protective face masks: thermal infrared imaging evaluation and hands moving the mask. *International journal of environmental research and public health*, *17*(13), 4624. doi: 10.3390/ijerph17134624.

[7] Cao, W., & Cloud, R. M. (2011). Balancing comfort and function in textiles worn by medical personnel. In *Improving comfort in clothing* (pp. 370-384). Woodhead Publishing.

[8] Braswell, M. L., & Spruce, L. (2012). Implementing AORN recommended practices for surgical attire. *AORN journal*, *95*(1), 122-140. 2012, doi: 10.1016/j.aorn.2011.10.017.

[9] Das, B., Das, A., Kothari, V. K., Fanguiero, R., & Araújo, M. (2007). Moisture transmission through textiles. Part I: Processes involved in moisture transmission and the factors at play. *AUTEX Research Journal*, *7*(2), 100-110.

[10] Bhatia, D., & Malhotra, U. (2016). Thermophysiological wear comfort of clothing: an overview. *J. Text. Sci. Eng, 6*(2), 1-8. doi: 10.4172/2165-8064.1000250.

[11] Fan, J., & Hunter, L. (2009). *Engineering apparel fabrics and garments*. Cambridge: Woodhead Publishing Ltd.

[12] Lee, K. P., Yip, J., Kan, C. W., Chiou, J. C., & Yung, K. F. (2020). Reusable face masks as alternative for disposable medical masks: factors that affect their wear-comfort. *International Journal of Environmental Research and Public Health*, *17*(18), 6623. doi: 10.3390/ijerph17186623.

[13] Hayashi, C., & Tokura, H. (2004). The effects of two kinds of mask (with or without exhaust valve) on clothing microclimates inside the mask in participants wearing protective clothing for spraying pesticides. *International archives of occupational and environmental health*, *77,* 73-78. doi: 10.1007/s00420-003-0472-3.

[14] Romney, M. G. (2001). Surgical face masks in the operating theatre: re-examining the evidence. *Journal of hospital infection*, *47*(4), 251-256.doi: https://doi.org/10.1053/jhin.2000.0912.

[15] Li, Y., Tokura, H., Guo, Y. P., Wong, A. S. W., Wong, T., Chung, J., & Newton, E. (2005). Effects of wearing N95 and surgical facemasks on heart rate, thermal stress and subjective sensations. *International archives of occupational and environmental health*, *78,* 501-509. doi: 10.1007/s00420-004-0584-4.

[16] NIELSEN, R., BERGLUND, L. G., GWOSDOW, A. R., & DUBOIS, A. B. (1987). Thermal sensation of the body as influenced by the thermal microclimate in a face mask. *Ergonomics*, *30*(12), 1689-1703. doi: 10.1080/00140138708966058.

[17] Gericke, A., Militky, J., Venkataraman, M., Steyn, H. J., & Vermaas, J. (2022). Investigation of thermal comfort properties of fabrics containing mohair. *The Journal of The Textile Institute*, *113*(4), 616-627. doi: 10.1080/00405000.2021.1896158.

[18] Afzal, A., Ahmad, S., Rasheed, A., Ahmad, F., Iftikhar, F., & Nawab, Y. (2017). Influence of fabric parameters on thermal comfort performance of double layer knitted interlock fabrics. *Autex Research Journal*, *17*(1), 20-26. doi: 10.1515/aut-2015-0037.

[19] Jhanji, Y., Gupta, D., & Kothari, V. K. (2015). Thermo-physiological properties of polyester–cotton plated fabrics in relation to fibre linear density and yarn type. *Fashion and Textiles*, *2*(1), 1-14. doi: 10.1186/s40691-015-0041-x.

[20] Jung, J. Y., Kang, C., Seong, Y., Jang, S. H., & Lee, J. Y. (2020). Effects of wearing COVID-19 protective face masks on respiratory, cardiovascular responses and wear comfort during rest and exercise. *Fashion & textile research Journal*, *22*(6), 862-872. doi: 10.5805/sfti.2020.22.6.862.

[21] Gericke, A., Venkataraman, M., Militky, J., Steyn, H., & Vermaas, J. (2021). Unmasking the mask: investigating the role of physical properties in the efficacy of fabric masks to prevent the spread of the COVID-19 virus. *Materials*, *14*(24), 7756. doi: 10.3390/ma14247756.

[22] Gericke, A., Militký, J., Venkataraman, M., Steyn, H., & Vermaas, J. (2022). The effect of mask style and fabric selection on the comfort properties of fabric masks. *Materials*, *15*(7), 2559. doi: 10.3390/ma15072559.

A NOVEL YARN FOR PROTECTION IN KNITTED SPORTSWEAR

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ABSTRACT

In the textile and clothing sector, a wide range of auxetic textiles have been made and shown great application potential in many areas. Creating auxetic effect at the yarn stage is relatively a simple approach since helical auxetic yarns (HAY) can be made only by winding or twisting different conventional filaments together with existing spinning machinery. Employing sports safety equipment is a cost-effective solution for avoiding injury and increasing the safety and protection. In the area of materials development for sports safety equipment, an important candidate is auxetic materials. In this study, polyester filament/elastane based helical auxetic yarns (HAY) and knitted fabrics from the yarns were developed that will offer dampening effect against injuries during sports activities. Effects of count of the elastane component and the presence of a third component in the HAY structure on the auxetic behaviour of the knitted fabrics were also studied.

Keyword: *Helical auxetic yarn, HAY, Knitted fabric, Safety, Sports*

1. INTRODUCTION

Auxetic materials are a relatively new class of functional materials which exhibit negative Poisson's ratio [1]. Auxetic behaviour opens up a number of possible technological benefits and applications for auxetic textiles like shockwave protection fabrics, medical bandages, compression hosiery and support garments, etc. [2]. One of the methods to fabricate auxetic textiles is to use conventional fibers and yarns to create auxetic effect by knitting or weaving them in a special configuration. Another approach is to use auxetic fibers or yarns to fabricate auxetic textiles by using simple weaving or knitting constructions. Creating auxetic effect at the yarn stage is a novel and interesting approach and a helical auxetic yarn (HAY) can be made simply by winding or twisting different conventional filaments together using existing spinning machinery [3]. In the structure of the helical auxetic yarn (HAY), which consists of a thick low-stiffness elastic core and a thin stiffer yarn, the thin stifer component is wrapped around the thick soft one. When the HAY is stretched in the longitudinal direction, the stiffer wrapping yarn becomes straight, forces the low-stiffness core yarn to wrap around the stiffer yarn. Although the original elastic core becomes thinner with the stretching effect, it still extends in the sideways, leading to the overall expanding of the auxetic yarn diameter [4,5]. Several studies (and numerous others cited within) have concentrated on the structure, production, properties and modelling of HAYs [6-9]. In these studies, a third component has not been included into the helical auxetic yarn structure in order to augment the auxetic behaviour of the yarns. Also, there is limited research reported regarding the performance of HAYs in conventional knitted structures [10]. Therefore, the current work aims at comparatively studying the performance of HAYs with a roving component in a knitted structure. Effects of the core count were also included.

2. EXPERIMENTAL STUDY

A hollow spindle machine was used to produce the auxetic yarns with/without roving component having different core yarn count and twist amount. Count of the core elastane was 1280 den for producing single elastic core and (1280+1280) den for producing double elastic core wrap yarns. 150 denier PET filament was used as the wrap yarn whereas Nm 11, 8 and 5 acrylic rovings were employed as the third component. The yarns were tested for determining their tenacity/elongation properties according to TS EN ISO 2062. A laboratory type circular knitting machine was used for the production of single jersey knitted samples. Two 1x1 rib fabric samples were also produced for comparative purposes. Thickness of the fabrics was measured using R&B Cloth Thickness Tester according to ASTM D1777-96 under pressures of 5, 30, 40, 50 cN/cm^2 for determining the auxetic tendency of the knitted samples, BS EN ISO 20932-1 standard method was adopted. Accordingly, the fabrics were subjected to tensile loading and the resulting changes in the dimensions of their unit area (2 cm x 2 cm) was measured while applying the load. Elongation of the samples in lengthwise direction was also recorded after application of 10N load was released.

2.1 Properties of the yarn and fabric samples

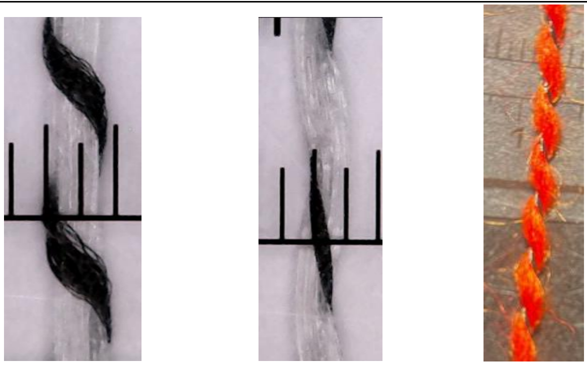
Yarn count, tenacity and extension properties of the yarns are presented in Table 1.

Table 1. Tested properties of the yarn samples.

	COUNT (NM)	TENACITY (CN/TEX)	EXTENSION (%)
1280 R_0-300	7,1	3,39	51,19
1280 R_{11}-300	4,2	6,88	43,73
1280 R_8-300	3,7	6,37	41,89
1280 R5-300	2,9	7,67	34,84
1280+1280 R_0-300	3,7	2,12	64,70
1280+1280 R_{11}-300	2,8	4,73	51,57
1280+1280 R_8-300	2,6	4,99	55,29
1280+1280 R_5-300	2,0	5,28	43,71

In the Table, 1280 stands for the core elastane count, R_0 means there is no roving and the others indicate the presence of rovings their counts of which are given as the indices.

Examples for the bare and roving including HAY samples are given in Figure 1.



(a) (b) (c)

Figure 1. Bare HAY without roving (a) without tension (b) under 45% extension. (c) HAY with roving under 45% extension.

In Table 2, the final dimensions of the 2 cm x 2 cm square after cyclic application of 10 N as well as the elongation of 100 mm length of the specimens after releasing the load (10 N) are presented. Change in the thickness values refer to the change when the applied pressure is increased 10 times as much, namely increased from 5 to 50 N. In the table, SJ and R stand for the single jersey and R rib fabric, respectively.

Table 2. Properties of the fabric samples.

	A_W	A_L	L_{10N} (MM)	WEIGHT (G/M^2)	THICKNESS (MM-50N)	FABRIC DENSITY (KG/M^2)	CHANGE IN THE THICKNESS (%)
1280 R_0-300-SJ	1,1	2,5	66,2	488	1,08	451,9	33
1280 R_{11}-300-SJ	1,6	2,7	36,9	800	1,88	425,5	14
1280 R_8-300-SJ	1,8	2,5	32,1	802	2,08	385,6	14
1280 R_5-300-SJ	2,0	2,4	13,5	881	1,97	447,2	22
1280+1280 R_0-300-SJ	2,0	3,1	10,3	987	1,30	759,2	28
1280+1280 R_{11}-300-SJ	2,0	2,9	10,5	1115	1,88	593,1	19
1280+1280 R_8-300-SJ	1,9	2,5	9,8	1145	2,15	532,6	12
1280+1280 R_5-300-SJ	1,9	2,1	5,1	1173	2,28	514,5	15
1280 R_0-300-R	2	2	9,7	1027	1,44	713,2	13
1280 R_{11}-300-R	2	2	10,2	1076	1,5	717,3	19

In the table, and also in Figure 2, A_W and A_L represent the width and length of the initial "2 cm x 2 cm square" drawn onto the sample under 10 N load. l_{10N} is the elongation of initial 100 mm distance on the samples determined by placing reference marks and immediately measured after removing the specimen and laying it on a flat surface.

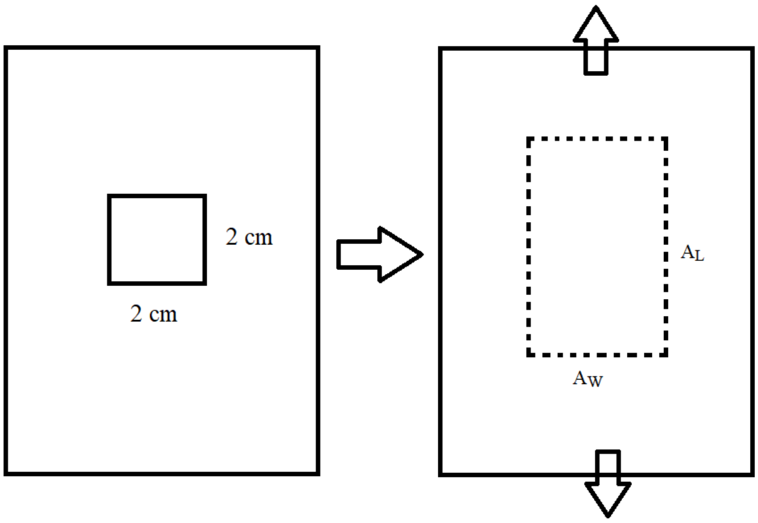


Figure 2. Schematic representation of the change in 2 cm x 2 cm square.

3. RESULTS

The tested yarn results presented in Table 1 shows that the presence of roving in the wrap yarn structure as the third component resulted in a decrease in the elongation of the yarns while increasing their tenacity. Accommodation of the coarser rovings in the structure seems to contribute more to the observed tendency. Doubling the core component thickness appears to increase the elongation potential of the yarn at the expense of yarn tenacity.

As was expected, the weight and thickness of the samples tended to increase and fabric density tended to decrease as the wrap yarn count increased (Table 2).

Determination of the change in the dimensions of a 2 cm x 2 cm square under a tensile load was used as an approach to observe the auxetic behaviour tendency of the knitted samples from HAYs. For conventional structures, when under a tensile load, the square width is expected to narrow while its length is expected to increase. We supposed that no or a small change in the width of the samples could be an indication of an auxetic tendency that can be further improved.

According to the results presented in Table 2, for the fabrics from single elastic core helical auxetic yarns, it was observed that the higher the roving count, the lower the change in width of the square on the fabric. The change in the lengthwise direction, which did not perform a certain tendency, was within the range of 20 to 35%.

For the knitted samples from double elastic core HAYs, on the other hand, no change in the width was observed while increase in the length of the square decreased from 55% to 5% consistently as the roving became coarser. This might be due to the fact that use of coarser rovings resulted in stiffer structure which resist transverse dimensional change under tensile loading.

Independent of the elastic core thickness, incorporating roving into the helical yarn structure seemed to contribute to the auxetic tendency of the samples.

The results also show that using roving in either single or double elastic core HAY structure resulted in a lower change in the thickness of the samples. Comparatively higher thickness change of fabrics in the presence of coarser rovings could be due to the fluffy structure of such yarns.

After releasing the load applied, the knitted samples from the single elastic cores with the coarser rovings tended to keep lower elongation values on themselves. This is parallel to the behaviour of corresponding yarn elongations observed. The residual elongation on the fabric samples from the double elastic core wrap yarns were lower than those of the ones from single core wrap yarns. For both single and double elastic core yarns, it was the sample knitted from the coarsest yarn that had the lowest residual elongation. Finally, for comparative purposes two rib fabrics were produced from 1280 R_0 and 1280 R_{11} yarns. These structures seemed to be more stable than the single jersey ones.

4. CONCLUSION

This work aimed to serve the studies that will be conducted to improve the auxetic properties of knitted fabrics from helically auxetic yarns (HAYs). With this intention fabrics knitted from helical auxetic yarns were developed. The results obtained seem to be promising since some of the developed structures tended to keep their width dimensions under an axial load applied and Utilizing such yarn structures in simple knit structures help the development of auxetic fabrics. In the later stages of the study, the effect of wrapping twist amount change will be studied in detail.

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REFERENCES

[1] Alderson A., Rasburn, Ameer-Beg S., Mullarkey P.G., Perrie W., & Evans K.E. (2000) An Auxetic Filter: A Tuneable Filter Displaying Enhanced Size Selectivity or Defouling Properties, Ind. Eng. Chem. Res. 2000, 39, 3, 654–665 https://doi.org/10.1021/ie990572w.

[2] Wright J.R, Burns M.K., James E., Sloan M.R. & Evans K.E. (2012). On the design and characterisation of low-stiffness auxetic yarns and fabrics, Textile Research Journal, May, 82(7) 645–654 DOI: 10.1177/0040517512436824

[3] Ng W.S. & Hu H., Tensile and Deformation Behavior of Auxetic Plied Yarns, Phys. Status Solidi B2017,2541600790 DOI: 10.1002/pssb.201600790

[4] Hu H, Zhang M. & Liu Y. (2019) Auxetic fibres and yarns in Auxetic Textiles, A volume in The Textile Institute Book Series Book.

[5] Sloan M.R., Wright JR. & Evans K.E. (2011). The helical auxetic yarn – A novel structure for composites and textiles; geometry, manufacture and mechanical properties, / Mechanics of Materials 43 476–486.

[6] Mushtaq B., Ahmad A., Ali Z., Qadir M.B., Khaliq Z., Muhammad Irfan, et.al. (2022) Core Spun Based Helical Auxetic Yarn: A Novel Structure for Wearable Protective Textiles, Journal of Natural Fibers, 19:16, 15058-15070, DOI: 10.1080/15440478.2022.2070322

[7] Liu, S., Gao, Y., Chen, X. et al. (2019) A Theoretical Study on the Effect of Structural Parameter on Tensile Properties of Helical Auxetic Yarns. Fibers Polym 20, 1742–1748. https://doi.org/10.1007/s12221-019-9019-4

[8] Ullah T., Ahmad S. & Nawab Y. (2022). Development of helical auxetic yarn with negative Poisson's ratio by combinations of different materials and wrapping angle, Vol. 51(2S) 2181S–2196S, DOI: 10.1177/1528083720941116

[9] Sibal A. & Rawa A. (2015). Design strategy for auxetic dual helix yarn systems, Materials Letters Volume 161, 740-742, https://doi.org/10.1016/j.matlet.2015.09.060

[10] Khalid R., Jamshaid H., Mishra R., Ma P.&Zhu G. (2022). Performance analysis of socks produced by auxetic yarns for protective applications. Journal of Industrial Textiles.;51(4_suppl):6838S-6863S. doi:10.1177/15280837221082544

EFFECT OF UV TREATMENT ON HYDROPHILICITY AND WHITENESS PROPERTIES OF HEMP FABRICS

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ABSTRACT

Hemp fibres have come to the forefront with their environmentally friendly features and superior usage performance when ecological concerns have increased. Textile products that can be used in different fields, which are in demand in the world markets and has a high added value, are obtained from hemp. However, finishing these environmentally friendly hemp-containing textile products with environmentally friendly technologies is important in sustainable production. The effect of lignin, hemicellulose, cellulose and pectin molecules on the physical properties of hemp is known. This study aims to improve the hydrophilicity and whiteness degree of hemp fabric via innovative process combination. For this purpose, hemp fabrics were impregnated with different amount of H_2O_2 concentrations (40, 60 ml/l) in cold environment and then kept under UV light irradiation for 60 minutes. According to the results obtained, UV application increased the hydrophilicity and whiteness degree of hemp fabrics.

Keyword: *Hemp, UV, Hydrophilization, Whiteness, Sustainability*

1. INTRODUCTION

Sustainable and biodegradable hemp fibre has come to the forefront with its eco-friendly properties and a range of remarkable properties such as antimicrobial properties, quick absorption of humidity accompanied by quick drying, effective thermal and electrical properties, prominent tenacity (50–90 cN/tex), antiallergenic effects, biodegradability and UV radiation protection [1]. It is an alternative to cotton and petroleum-based synthetic fibres for textile raw material sourcing. The importance of hemp textiles, which are in demand in the world markets with high added value, is increasing day by day.

The European Union has given significant support to hemp fibres, the production and the use of these fibres in final products, with the project called HEMP-SYS within the framework of the program called "Quality of Life and Management of Living Resources" [2]. Hemp is a bast fibre and its colour properties are generally not suitable for textile applications in its raw (griege) form [3]. For this reason, pre-treatment processes are important in order to obtain healthy results from the finishing processes such as dyeing, printing and finishing processes of the raw hemp fibre. What is more, it is more resistant to chemical effects than cotton due to its higher crystalline structure [4]. The main constituents of hemp fibres are cellulose, hemicellulose, lignin, and pectin. Cellulose, hemicellulose, and lignin are basic components that define the physical properties of fibres [5]. Lignin is located in the middle lamellae and secondary wall and it provides rigidity to the cell wall. Both pectins and lignins can be associated with cellulose microfibrils. Hemicelluloses are deposited as the amorphous and unoriented cell-wall constituent, which occupy spaces between the fibrils in both primary and secondary walls. They are insoluble in hot water and hydrogen-bonded to cellulose. The content and amount of cellulose, hemicellulose, lignin, pectin, some fats and waxes can be variable in hemp fibres. Therefore, the approximate values can be given in Table 1 [3]. Some of these components which are in its structure, make hemp fiber hydrophobic. Preparation of these fibers for further processing, removal of non-cellulosic components improves absorption and other fiber properties [6].

Table 1. The raw hemp fiber contents.

RAW HEMP FIBER CONTENT (%)			
Cellulose	**Hemicellulose**	**Lignin**	**Pectin, Fats and Waxes**
67–78	5.5–16.1	3.7–8	0.9–4.3

Pejic et al. [1] investigated the effects of hemicelluloses and lignin removal on the water uptake behaviour of hemp fibres by chemical treatment with sodium hydroxide (NaOH) and sodium chloride ($NaClO_2$). It has been observed that the capillary properties of hemp fibres are improved when the hemicellulose or lignin content is gradually reduced by chemical treatment. Qu et al. [7] bleached hemp in a bath containing alkali-hydrogen peroxide. In this one-bath process, alkali and hydrogen peroxide have been reported to have joint effects in effectively removing most of the non-cellulosic components. Thanks to the use of excipients, the degradation of cellulose are prevented and the yield of peroxide is increased. With this alkali-peroxide single-bath process, the gum and lignin found in raw hemp were significantly removed.

Many innovative technologies use in textile applications for energy and water saving, minimising or without chemical consumption. UV treatment is one of the methods that is used for different textile applications such as; bleaching, decolourisation, surface modification ext. Pretreatment process can be performed in a shorter time with UV. Hydrogen peroxide can be activated by the ultraviolet (UV) effect and hydroxyl radicals are formed (H_2O_2+ hv → 2OH.) [8-11] in bleaching cotton at room temperature and via the photocatalytic process. Successful results have been reported without activators [12].

This study's aim is to improve hydrophilicity and whiteness with environmentally friendly UV+H2O2 treatment instead of applying a conventional process.

2. EXPERIMENTAL STUDY

In the study, 100% hemp plain (160 g/m^2) fabrics, Merck brand H_2O_2 and a custom-made (254 nm) UV cabin were used. The hemp fabrics impregnated with the solution at different H_2O_2 concentrations (40, 60 ml/l) in cold environment were treated by hanging them in the UV cabinet for 60 minutes. Other part of samples were treated by hanging them for 60 minutes in without the UV cabinet for seeing the effect of UV. After the treatment, the activity of H_2O_2 with catalase was stopped and it was dried by washing with non-ionic (Rudolf) detergent. The hydrophilicity values of the samples obtained were measured according to the AATCC 79-2007 standard [13].
Whiteness of the samples were measured via Konica Minolta CM3600D spectrophotometer. Stensby values of the hemp samples were determined as whiteness formula. Each sample was measured twice on each side of the fabric for consistency, and the average value was calculated.

3. RESULTS

The hydrophilicity values of the hemp fabric samples obtained as a result of H_2O_2 treatment in UV environment are given in Table 2. When the hydrophilicity values of the fabrics are examined in Table 2.; it is seen that the hydrophilicity values of the fabrics without UV application are lower. In cellulosic fibers; Thanks to containing chromophoric groups, lignin is responsibility for UV absorption in cellulosic fiber. For this reason, lignin absorbs 85–90% of the light [14]. Thanks to increase the in UV light absorption, hemicellulose is removed therefore the moisture absorption reduces. Hemicelluloses and lignin allow and/or favour moisture sorption. Some methods (like UV treatment) are able to increase the hydrophob/hydrophil balance [15]. UV radiation also increases crystallinity and causes cracks on the surface. This leads to more effective results by increasing the penetration of the chemicals used [16]. Lignin acts as an absorbent material that helps absorption through carboxyl and both aliphatic and dephenolic hydroxyl groups [6]. Studies show that the presence of lignin and hemicellulose in the fabric increases the hydrophilicity values of the fabrics. When the raw fabric is treated in UV environment without being impregnated with H_2O_2, it is seen that its hydrophilicity decreases. With the removal of lignin and hemicellulose, it is seen that the hydrophilicity values decrease approximately 2 times compared to the raw fabric hydrophilicity values.

Hydrophilic properties of fabrics impregnated with H_2O_2 but not treated in UV environment have improved. However, as can be seen in Figure 1, there was no improvement in the whiteness values of the fabrics. The hydrophilicity values and the whiteness values of the fabrics impregnated with H_2O_2 and kept in the UV cabin improved. These results have shown that UV increases the crystallinity and causes cracks on the surface, thus increasing the penetration of the used chemical (H_2O_2), resulting in more effective results.

Table 2. The hydrophilicity values of the hemp fabric samples.

Sample Name		**Hydrophilicity (sec)**
Raw		74
Raw UV Treated		135
H_2O_2 Concentration without UV Treated (ml/l)	40	8
	60	9
H_2O_2 Concentration with UV Treated (ml/l)	40	28
	60	26

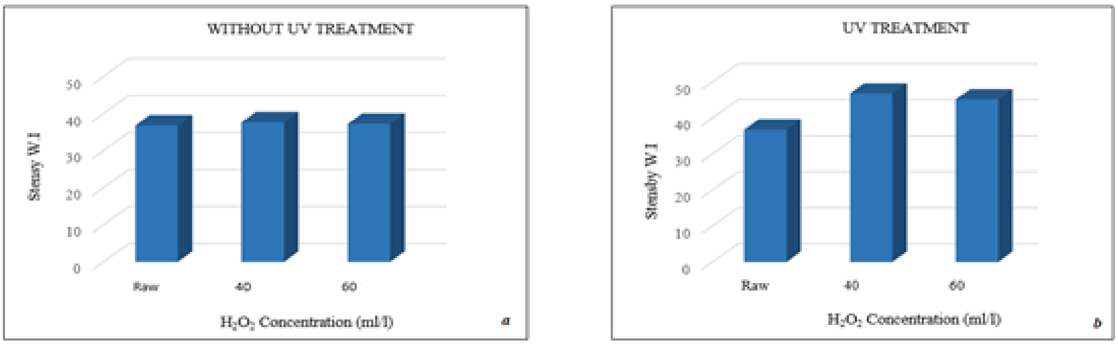

Figure 1. Whiteness degrees of hemp fabrics a) Without UV treatment for 60 minutes at different H_2O_2 concentrations b) UV treatment for 60 minutes at different H_2O_2 concentrations.

When the hydrophilicity values of the hemp samples were examined after H_2O_2 treatment in the UV environment, it was observed that the values improved significantly compared to the raw (greige) fabric. As the peroxide concentration increased, the water absorbency of the hemp fabrics increased. Nevertheless, the data obtained show that it is not necessary to work at very high peroxide concentrations to improve the hydrophilicity of hemp fibre and that a treatment performed at only 40 ml/l H_2O_2 concentration significantly improves the hydrophilicity of hemp. The improvement in the hydrophilicity levels of the hemp fabrics after the UV light irradiation for 60 minutes following the impregnation of different amount of H_2O_2 shows the success of this innovative finishing combination process. Contrary to conventional processes, the UV treatment, which is made by saving the use of chemicals in cold environments, has provided to increase the hydrophilicity of hemp fabrics.

Pejic et al. 2008, reported that the progressive removal of lignin or hemicellulose influenced the accessibility and sorption properties of hemp fibres differently [1].

4. CONCLUSION

Textile treatments are intense processes that display huge water and chemical consumption. Therefore, the waste load after aqueous treatments is very high. The scientific world has been working on innovative methods for less water and chemical consumption. It is one of these innovative technologies in the processes performed in the UV environment. It was observed that the hydrophilicity and whiteness degree of hemp fabrics have improved with the treatment with different concentrations of H_2O_2 in the UV media. This study shows that the presence of lignin and hemicellulose in the fabric increases the hydrophilicity values of the fabrics and UV has affected the lignin and hemicellulose in cellulosic fibre therefore the lignin and hemicellulose are removed from the fabrics by UV. Removal of lignin and hemicellulose decrease the hydrophilicity of fabric. These studies are in laboratory scale and these pre-processes are promising and enlighten the scientific world in this regard.

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REFERENCES

[1] Pejic, B. M., Kostic, M. M., Skundric, P. D., & Praskalo, J. Z. (2008). The effects of hemicelluloses and lignin removal on water uptake behavior of hemp fibers. Bioresource technology, 99(15), 7152-7159.
[2] Amaducci, S. 2003. “HEMP-SYS: Design, Development and Up-Scaling of a Sustainable Production System for HEMP Textiles– An Integrated Quality SYStems Approach”, Hemp-SYS - Journal of Industrial Hemp, 8(2), 79-83.
[3] Wang, H. M., & Postle, R. (2004). Improving the color features of hemp fibers after chemical preparation for textile applications. Textile research journal, 74(9), 781-786.
[4] Carr, C.M. 1995. Chemistry of Textiles Industry. Cambridge: Springer Netherlands.Pejic vd., 2008
[5] Shahzad, A. (2012). Hemp fiber and its composites–a review. Journal of composite materials, 46(8), 973-986**.**
[6] Manich, A. M., Lis Arias, M. J., Pérez-Rentero, S., Riba-Moliner, M., Mijas, G., Martí, M., & Cayuela, D. (2022). Influence of alkaline delignification time on the moisture uptake behaviour of hemp. The Journal of The Textile Institute, 113(10), 2263-2273.
[7] Qu, L. J., Zhu, S. F., Liu, M. J., Wang, S. Y. 2005. “The mechanism and technology parameters optimization of alkali H2O2 one bath cooking and bleaching of hemp”, Journal of applied polymer science, 97(6), 2279-2285.
[8] Costa, F. A., Reis, E. M., Azevedo, J. C. Nozaki, J. 2004. “Bleaching and photodegradation of textile dyes by H2O2 and solar or ultraviolet radiation”, Solar Energy, 77(1), 29-35.
[9] Daneshvar, N., Rabbani, M., Modirshahla, N., Behnajady, M. A. 2005. “Photooxidative degradation of Acid Red 27 in a tubular continuous-flow photoreactor: influence of operational parameters and mineralization products”, Journal of hazardous materials, 118(1-3),155-160.
[10] Radovic, M. D., Mitrovic J. Z., Bojic, D. V., Antonijevic, M. D., Kostic, M., Baosic, R.M. Bojic, A.L. 2014. “Effects of system parameters and inorganic salts on the photodecolourisation of textile dye Reactive Blue 19 by UV/H2O2 process”, Water South African, 40(3), 571-578.
[11] Perincek, S. D., Duran, K., KÖRLÜ, A. E., & Bahtiyari, M. I. (2007). Ultraviolet technology. Textile and Apparel, 17(4), 219-223.

[12] Eren, S. 2019. "Photocatalytic Clearing of Disperse Dyed Polyester". AATCC Journal of Research, 6(5), 10-15.

[13] Test Method for Absorbency of Textiles.

[14] Han, H., Gong, X., Zhou, M., & Wu, Y. (2020). A study about water/alkali treatments of hemp fiber on ultraviolet ageing of the reinforced polypropylene composites. Journal of Polymers and the Environment, 28, 2572-2583.

[15] Tanasă, F., Zănoagă, M., Teacă, C. A., Nechifor, M., & Shahzad, A. (2020). Modified hemp fibers intended for fiber-reinforced polymer composites used in structural applications—A review. I. Methods of modification. Polymer Composites, 41(1), 5-31.

[16] Mijas, G., Manich, A., Lis, M. J., Riba-Moliner, M., Algaba, I., & Cayuela, D. (2021). Analysis of lignin content in alkaline treated hemp fibers: thermogravimetric studies and determination of kinetics of different decomposition steps. Journal of Wood Chemistry and Technology, 41(5), 210-219.

PRODUCTION AND CHARACTERIZATION OF BASALT FIBER/PET COMPOSITES

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ABSTRACT

The use of fiber-reinforced thermoplastic composite materials is increasing day by day due to their high strength and recyclability. In addition to these superior advantages, high melt viscosity is among the disadvantages of these materials because it makes reinforcement absorption difficult. This problem can be solved by using hybrid yarns in which reinforcement and thermoplastic fibers are homogeneously mixed together for the production of thermoplastic composites. In this study, it was aimed to prepare basalt fiber/PET hybrid yarns containing basalt fiber in different volume ratios by air-jet mixing method and to prepare thermoplastic composite materials by pressing from fabrics woven from hybrid yarns. By determining the mechanical properties of basalt fiber/PET thermoplastic composites prepared to contain basalt fiber in different proportions by volume, the effects of basalt fiber amount in hybrid yarn blends on the mechanical properties of the composite material were examined and the most appropriate basalt fiber amount was determined.

Keyword: *Basalt fiber, Hybrid yarn, PET, Thermoplastic composites*

1. INTRODUCTION

Polymer-based composites are divided into two as thermoplastic and thermoset composites. Thermoplastic composites have begun to be used instead of thermosets due to the limited shelf life, long production times and no recycling of thermoset-based composites [1]. Thermoplastic composites can be recycled and reshaped by heating, but the use of thermoplastics introduces the problem of insufficient resin penetration for the fiber. Thermoplastic melts, in contrast to thermoset resins, have a significantly higher viscosity. Injecting the resin into a tightly woven textile structure is very difficult due to the high viscosity. This problem increases the void content in the composite material, which must be overcome by using higher injection pressure and heavier molds. The formation of voids in the composite product and the misalignment of the reinforcing fibers during consolidation are other problems caused by high matrix viscosity. Reducing the mass transfer distance by using hybrid yarns is one of the solutions to this problem [2].

Thermoplastic polymers such as polypropylene (PP) and polyethylene (PE) as matrix materials and glass fibers as reinforcement elements have been widely used in studies for the production of thermoplastic composites [3-5]. Basalt fiber has better tensile strength compared to e-glass fibers, excellent thermal stability and chemical stability properties make the use of basalt fiber widespread. In addition, many studies have been carried out on the mechanical properties of polymer matrix composites containing basalt fibers. Zhang et al. [6] used polyimide resin and basalt fiber for composite production, the obtained composites showed excellent wear properties. Ronkay and Czigány [7] produced basalt/polyethylene terephthalate (PET) and glass/PET composites and compared their tensile, bending and impact strengths. The test results of basalt/PET composite were better than E-glass/PET composite. Liu et al. [8], [9] investigated the mechanical strength of basalt fiber reinforced composite materials. Epoxy resin was used as matrix material, basalt fibers and E-glass fibers were used as reinforcement materials, and although their mechanical strengths were similar, basalt/epoxy composites retained their resistance to water absorption.

In this study, it was aimed to produce basalt fiber/PET hybrid yarns containing basalt fiber in different volume ratios (45%, 50%, 55%, 60%) and to examine the mechanical properties of thermoplastic composite samples formed by using the produced hybrid yarns.

2. EXPERIMENTAL STUDY

The materials and methods were explained in detail below.

2.1 Materials

In this study, to produce of hybrid yarn, continuous basalt fiber that is compatible with polyethylene terephthalate (PET) from Kamenny Vek and ecru PET yarn from KORTEKS Mensucat Sanayi ve Ticaret A.Ş. were supplied and the properties of these materials are shown in Table 1.

Table 1. Properties of basalt fiber and PET yarn.

	BASALT FIBER	PET YARN
YARN COUNT (TEX)	150	33
DENSITY (G/CM^3)	2,67	1,38

2.2 Method

Basalt fiber/PET (BF/PET) hybrid yarns containing 45%, 50%, 55% and 60% basalt fiber by volume were prepared using the air-jet mixing method. In the air-jet mixing method, BF reinforcement and PET matrix fibers were dispersed with the help of compressed air in the air jet and the fibers were mixed with each other. The basalt fiber/PET hybrid yarns with different volume ratios were woven in 2/2 fabric construction and converted into thermoplastic composite materials under hot press. An example of the composite materials obtained is shown in Figure 1. In order to examine the mechanical properties of these samples, ISO 527-4 Tensile, ISO 14125 3-point bending and ISO 6603-2 impact tests were carried out.

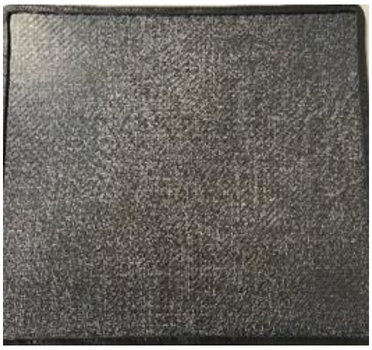

Figure 1. Termoplastic composite plate.

3. RESULTS

To see the mechanical properties of 45% Basalt fiber/PET (BF45/PET), 50% Basalt fiber/PET (BF50/PET), 55% Basalt fiber/PET (BF55/PET), and 60% Basalt fiber/PET (BF60/PET) thermoplastic composite materials obtained by using basalt fiber/PET hybrid yarns containing basalt fiber in different proportions by volume (45%, 50%, 55% and 60%), test specimens were prepared in accordance with ISO 527-4 tensile, ISO 14125 3-point bending and ISO 6603-2 impact test standards and tests were carried out. Test results are shown in Table 2, Table 3 and Table 4.

Table 2. Tensile test results.

	FMAX (N)	TENSILE STRENGTH (MPA)	ELONGATION AT BREAK (%)
BF45/PET	14740	287,1	1,8
BF50/PET	14724	321,6	1,7
BF55/PET	10754	293,8	2,4
BF60/PET	8540	238,4	1,9

As seen in Table 2, according to ISO 527-4 tensile test results, the most durable sample was the BF50/PET thermoplastic composite sample. As the basalt volume ratio increased, the tensile strength initially increased, but decreased after the basalt volume ratio in the material exceeded 50.

Table 3. 3-Point bending test results.

	FMAX (N)	BENDING TENSION (MPA)	MODUL (MPA)
BF45/PET	493	414	17566
BF50/PET	397	420	20424
BF55/PET	215	348	21522
BF60/PET	176	314	21987

As seen in Table 3, according to ISO14125 3-point bending test results, the most durable sample was the BF50/PET thermoplastic composite sample. As the basalt volume ratio increased, the bending tension initially increased, but decreased after the basalt volume ratio in the material exceeded 50.

Table 4. Impact test results.

	FMAX (N)	ENERGY AT HOLE (J)
BF45/PET	11330	81,6
BF50/PET	11174	78,2
BF55/PET	7929	52,1
BF60/PET	7199	53,0

As seen in Table 4, according to ISO 6603-2 impact test results, BF45/PET sample showed the best resistance. As the basalt volume ratio increased, the impact resistance of the material decreased.

4. CONCLUSION

In this study, basalt fiber/PET hybrid yarns containing basalt fiber in different volume ratios (45%, 50%, 55% and 60%), fabrics woven from hybrid yarns and thermoplastic composite samples were successfully produced. ISO 527-4 tensile, ISO 14125 3-point bending and ISO 6603-2 impact tests were performed to see the mechanical properties of the produced thermoplastic composite samples. According to tensile and 3-point bending tests BF50/PET sample showed the best mechanical strength property with values of 321,6 MPa and 420 MPa, respectively. According to impact test, BF45/PET sample showed the best resistance with a value of 81,6 J. The detailed examination of the mechanical effects of BF/PET thermoplastic composites prepared by using fabrics woven from basalt fiber/PET hybrid yarns containing basalt fiber in different volume ratios obtained within the scope of the study contributed to the literature as it is a comprehensive study that has not been done before.

REFERENCES

[1] Alagirusamy, R., Fangueiro, R., Ogale, V., & Padaki, N. (2010). Hybrid yarns and textile preforming for thermoplastic composites. Textile Progress, 38(4), 1-71.
[2] Alagirusamy, R. (2005). Development and characterization of GF/PET, GF/Nylon, and GF/PP commingled yarns for thermoplastic composites. Journal of Thermoplastic Composite Materials, 18(4), 269-285.
[3] Gude, M., Böhm, R., & Zscheyge, M. (2011). The effect of temperature on mechanical properties and failure behaviour of hybrid yarn textile-reinforced thermoplastics. Material Design, 32, 4278-4288.
[4] Long, A.C., Wilks, C.E., & Rudd, C.D. (2001). Experimental characterisation of the consolidation of a commingled glass/polypropylene composite. Composite Science and Technology, 61, 1591-1603.
[5] Abounaim, M., Diestel, O., Offmann, G., & Cherif, C. (2011). High performance thermoplastic composite from flat knitted multi-layer textile preform using hybrid yarn. Composite Science and Technology, 71, 511-519.
[6] Zhang, X., Pei, X., & Wang, Q. (2009). Friction and wear properties of polyimide matrix composites reinforced with short basalt fibers. Journal of Applied Polymer Science, 111(6), 2980-2985.
[7] Ronkay, F., & Czigany, T. (2006). Development of composites with recycled PET matrix. Polymers for Advanced Technologies, 17(9-10), 830-834.
[8] Liu, Q., Shaw, M.T., Parnas, R.S., & McDonnell, A. (2006). Investigation of basalt fiber composite mechanical properties for applications in transportation. Polymer Composites, 27(1), 41-48.
[9] Liu, Q., Shaw, M.T., Parnas, R.S., & McDonnell, A. (2006). Investigation of basalt fiber composite aging behavior for applications in transportation. Polymer Composites, 27(5), 475-483.

REDUCING MICROFIBER POLLUTION: BIODEGRADABLE PET YARN

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ABSTRACT

Synthetic microfibers are short fibers that shed or break from clothings, carpets, fabrics and products made from synthetic materials such as polyester, nylon etc. Microfibers are the predominant form of secondary microplastic pollution in soil and most aquatic environments, and they can be detected in the air, soil, seawater, landfills, wastewater treatment plants, and even marine life and humans. Since synthetic microfibers are very small, they are very difficult to clean from the environment. As they are not naturally biodegradable like many plastics, they remain in nature. Due to the increasing environmental pollution problem, our future is great threat and a solution to this problem is needed. In this study, it was aimed to develop a biodegradable PET yarn for in order to reduce the permanence of synthetic microfiber contamination. Biodegradability tests were applied according to ASTM D5210-Standard Test Method for Determining the Anaerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewage Sludge, ASTM D5988-Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil, ASTM D6691-Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum and ASTM D 5511- Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions test standards, and it was seen that PET yarn gained biodegradability according to the test results. In addition, physical tests (dtex and tenacity) were carried out to see the effect of the biodegradable additive on the yarn and it was observed that the additive did not change the mechanical properties of the yarn.

Keyword: *Biodegradable, Microfiber, PET, Yarn*

1. INTRODUCTION

Biodegradation is the conversion of large or complex molecules into smaller or simpler molecules caused by the biochemical action of microorganisms. Basically, textiles consist of fibers produced from natural and synthetic polymers. Natural fibers are renewable due to their biological origin and exhibit biodegradability in their natural form because microorganisms are evolutionarily adapted to break biologically formed chemical bonds and alter the chemistry of these polymers [1]. Most synthetic fibers are resistant to biodegradation, contributing to the accumulation of plastic waste. The accumulation of plastic waste causes environmental pollution and threatens the so-called “microplastic problem” ecosystems. Microplastics were defined as plastic particles smaller than 5 mm in size, which can be formed from the generation of plastic waste in industrial processes and the degradation of larger plastic consumer products [2]. Fibers and fragments were found to be the most common type of microplastics. Fibers can be obtained from synthetic clothing and fabrics that release microfibers when worn and washed [3]. It is estimated that one equivalent of every 500 shirts produced is lost as microfiber in the manufacturing process [4]. One study calculated that between 1950 and 2016, 5.6 million tons of synthetic microfibers were emitted worldwide from washing clothes [5]. Today, microscopic pieces of plastic and fibers have been found in coastal surface sediments, offshore, fresh water, soil and etc. Polyethylene terephthalate (PET), a member of synthetic fibers, is chemically inert and highly resistant to biodegradation. The presence of the petrochemical-based terephthalic acid (TA) monomer creates barriers to biodegradability due to the aromatic hydrocarbon ring conferring polymer chain stiffness and hydrophobicity [6]. The biodegradability of PET has been studied in recent years, most of which have been associated with the enzymatic degradation of plastic, including hydrolysis, alcohollysis, glycolysis, ammonolysis, and depolymerization by aminolysis, and these studies generally used enzymes isolated from microorganisms. For example, Barth et al used polyester hydrolase from Thermobifida fusca to hydrolyze PET film [7], while Vertommen et al used an enzyme isolated from Fusarium solani [8]. Many studies have attempted to identify microorganisms that are effective in breaking down biodegradable polymer materials. For example, Kim et al evaluated the utility of Bacillus sp. bacteria [9]. Recently, Yoshida and colleagues isolated a new bacterium, Ideonella sakaiensis 201-F6, that can use PET as its main energy and carbon source and convert PET into two environmentally friendly monomers [10]. In the biodegradation of contamination, the application of enzymes as catalysts often involves a time-consuming and costly preparation process, and enzymes generally have low catalytic activity. For these reasons, additional developments are required to commercialize these studies.

Another strategy developed to break the biodegradation resistance of PET is the use of degradable additives. "Degradable additives" are typically incorporated into conventional plastics such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) during the conversion process from polymer pellets to final products. Addition rates vary with the type of degradable additive and planned use, but are typically less than 5% [11]. If these additives contain transition metals such as cobalt, manganese, iron, they are called oxo-degradable. The biggest problem with oxo-degradable materials is that they quickly break down into large amounts of microplastics when exposed to a combination of sunlight and oxygen.

In this study, it was aimed to produce PET yarn that reduces microfiber pollution and for this purpose, biodegradable additives that are not related to oxo-degradable materials and that do not change any mechanical, performance or recyclability properties of the final product were used. For the determination of biodegradability, biodegradable PET yarns were produced using biodegradable additives and these yarns were tested in ASTM D5210- Standard Test Method for Determining the Anaerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewage Sludge, ASTM D5988-Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil, ASTM D6691-Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum and ASTM D 5511- Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions test standards. In addition, to prove that the additive does not change the mechanical properties of the yarn, physical tests (dtex, tenacity) were performed on standard PET and PET yarn containing biodegradable additives and the results were compared.

2. EXPERIMENTAL STUDY

The materials and methods were explained in detail below.

2.1 Materials

In order to develop biodegradable PET yarn, a biodegradable additive and PET chips were used as material.

2.2 Method

During the melt spinning process, the biodegradable additive is added to the PET yarn and the biodegradable PET yarn is produced. (This biodegradable additive creates multiple biodegradable spots in the PET yarn matrix. These spots then allow naturally occurring microorganisms to break down and digest the PET fibers, providing biodegradability). Biodegradability tests according to ASTM D5210, ASTM D5988, ASTM D6691 and ASTM D5511 test standards are applied to see the biodegradability of PET yarn.

3. RESULTS

In order to see the biodegradability of PET yarn, biodegradability tests were performed on PET yarn with biodegradability additives and PET yarns without additives in different test standards (ASTM D5210, ASTM D5988, ASTM D6691 and ASTM D5511) and the results were shown in the Table 1. As a result, it was observed that PET yarn containing biodegradability additives showed a higher rate of biodegradability compared to PET yarn without biodegradability additives.

Table 1. Biodegradability test results

TEST STANDARD	TREATED YARN	UNTREATED YARN
ASTM D5210 (WASTEWATER TREATMENT PLANT SLUDGE)	88% biodegradation in 847 days	0% biodegradation in 847 days
ASTM D 5988 (SOIL)	88% biodegradation in 742 days	0% biodegradation in 742 days
ASTM D6691 (MARINE/OCEAN ENVIRONMENT)	92% biodegradation in 844 days	5% biodegradation in 844 days
ASTM D5511 (LANDFILL ENVIRONMENT)	91% biodegradation in 1278 days	6% biodegradation in 1278 days

In addition, the mechanical properties of standard PET yarn and PET yarn with biodegradable additives were also compared. For this purpose, 75/36R texturized standard PET yarn and 75/36R texturized PET yarn containing biodegradability additive were produced and their mechanical properties such as dtex, tenacity, were examined. The data obtained are shown in Table 2.

Table 2. Mechanical test results

TEST	BIODEGRADABLE PET YARN	STANDARD PET YARN
DTEX	91	91
TENACITY (CN/DTEX)	3,60	3,60

As can be seen from the results in Table 2, the biodegradability additive did not cause any change on the yarn mechanical properties when compared to standard PET.

4. CONCLUSION

In order to help reduce the permanence of microfiber pollution in the environment, it was aimed to develop biodegradable PET yarn, and in this direction, PET yarns that gained biodegradable properties by using biodegradable additives were successfully produced. In order to examine the biodegradability properties of the produced yarns, biodegradability tests were carried out according to ASTM D5210, ASTM D5988, ASTM D6691 and ASTM D5511 test standards on both PET yarns containing biodegradability additives and non-biodegradable additives. According to the results of the biodegradability test performed in wastewater treatment sludge environment according to ASTM D5210 test standard, while PET yarn containing biodegradability additives biodegraded 88% in 847 days, PET yarn without biodegradation additive did not show any biodegradability in 847 days. According to the results of the biodegradability test performed in soil environment according to ASTM D5988 test standard, while PET yarn containing biodegradability additives biodegraded 88% in 742 days, PET yarn without biodegradation additive did not show any biodegradability in 742 days. According to the results of the biodegradability test performed in marine/ocean environment according to ASTM D6691 test standard, while PET yarn containing biodegradability additive was 92% biodegradable in 844 days, PET yarn without biodegradability additive was biodegraded at a rate of 5% in 844 days. According to the results of the biodegradability test performed in landfill environment according to ASTM D5511 test standard, while PET yarn containing biodegradability additive was 91% biodegradable in 1278 days, PET yarn without biodegradability additive was biodegraded at a rate of 6% in 1278 days.

In addition, the mechanical properties of standard PET and biodegradable PET yarn were compared and it was proved that the additive did not change the mechanical properties of PET yarn.

This study has proven the biodegradability of PET yarns obtained by using additives that do not contain any harmful components, do not change the mechanical properties of the final product when used, and provide biodegradability to the product, and contribute to the literature.

REFERENCES

[1] McDonald, J.E., Houghton, J.N.I., Rooks, D.J., Allison, H.E., & Mccarthy, A.J. (2012). The microbial ecology of anaerobic cellulose degradation in municipal waste landfll sites: evidence of a role for fbrobacters. Environ Microbiol 14:1077–1087.

[2] Thompson, R.C., Moore, C.J., Saal, F.S.V., & Swan, S.H. (2009). Plastics, the environment and human health: Current consensus and future trends. Philos. Trans. R. Soc. Lond., 364, 2153–2166.

[3] Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011) Accumulation of microplastic on shorelines woldwide: Sources and sinks. Environ. Sci. Technol., 45, 9175–9179.

[4] Gately, H. (2021, June 8). Pre-Consumer Microfiber Emissions from Clothing Enter Oceans At Alarming Rate. Retrieved from https://www.nature.org/en-us/newsroom/ca-microfiber-emissions/.

[5] Gavigan, J., Kefela, T., Macadam-Somer, I., Suh, S., & Geyer, R. (2020). Synthetic microfiber emissions to land rival those to waterbodies and are growing. *PLoS ONE* 15(9): e0237839.

[6] Li, L., Frey, M., & Browning, K.J. (2010). Biodegradability study on cotton and polyester fabrics. J Eng Fiber Fabr 5:42–53.

[7] Barth, M., Oeser, T., Wei, R., Then, J., Schmidt, J., & Zimmermann, W. (2015). Effect of hydrolysis products on the enzymatic degradation of polyethylene terephthalate nanoparticles by a polyester hydrolase from Thermobifida fusca. Biochemical Engineering Journal, 93, 222-228.

[8] Vertommen, M.A.M.E., Nierstrasz, V.A., Van der Veer, M., & Warmoeskerken, M.M.C.G. (2005). Enzymatic surface modification of poly(ethylene terephthalate). Journal of Biotechnology, 120(4), 376-386.

[9] Kim, M.Y., Kim, C., Moon, J., Heo, J., Jump, S.P., & Kim, J.R. (2017). Polymer Film-Based Screening and Isolation of Polylactic Acid (PLA)-Degrading Microorganisms. Journal of Microbiology and Biotechnology, 27(2), 342-349.

[10] Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y., & Oda, K. (2016). A bacterium that degrades and assimilates poly (ethylene terephthalate). Science, 2016, 353, 759.

[11] Koutny, M., Jaques L., & Anne-Marie D. (2006). Biodegradation of Prooxidant films with Prooxidant Additives. Chemosphere, 64, 1243-1252.

EXAMINATION OF ACOUSTIC PROPERTIES OF POLYMER COATED NONWOVEN TEXTILE SAMPLES

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ABSTRACT

In this study, different types of polymeric layers were coated in different weights (g/m^2) on nonwoven fabrics by extrusion process and then, sound absorption and transmission loss properties of each sample were examined. Nonwoven fabrics were produced from polyester (PET) fiber, formed by carding process and bonded by needle punching process. These samples were tested between 50-6000 Hz frequency range to reveal the effect of polymer layer type and weight coated on nonwoven fabrics on the sound absorption and transmission loss performance at the low, medium and high frequency values. Polymer layers were coated with the weight of 400 gsm and 800 gsm. Nonwoven fabric samples coated with polyethylene or polypropylene layers and nonwoven fabric samples without polymeric coating were tested by using impedance tube and compared in terms of sound absorption and transmission loss performance. In the test system, two sides of the samples were tested separately. It was seen that sound absorption performance of the samples changed incase sound wave was firstly incident to polymeric layer or nonwoven layer.

Keyword: *acoustic performance, sound absorption, sound transmission loss, polymer coated nonwovens*

1. INTRODUCTION

In recent years, use of textile materials in the acoustic applications is quite remarkable. Especially nonwoven fabrics are more preferred these applications because of their high porosity and low cost features. While sound absorption performance of nonwoven fabrics is high in medium and high frequencies (>1000 Hz), it is pretty low in low frequencies [1-3]. Therefore, it is required to enhance acoustic properties of nonwoven fabrics for sound absorption in low frequencies. According to marketing research for automotive and construction sectors, the weigth of currently used fiber based nonwoven fabrics is more than 2000 gsm. Also, materials used as heavy layer have minimum 3000 gsm weight. In this study, for these two sectors, polymer coated nonwoven fabric samples, that are formed by coating of polymer layers via extrusion process on the PET based nonwoven fabric, were tested and their acoustic performance was evaluated. Sound absorption coefficient and transmission loss values of nonwoven fabric samples with polymeric coating in different types and weights were determined by using impedance tube.

2. EXPERIMENTAL STUDY

In the experimental study, sound absorption coefficient and transmission loss values for totally fives samples were determined by using impedance tube. The details of the test samples by which the type of polymer coating and the weight of polymer coating have been investigated are as follows;

Table 1. The details of test samples.

SAMPLE CODE	DETAIL
A	PET based nonwoven fabric
B	PET based nonwoven fabric with 400 gsm PE coating
C	PET based nonwoven fabric with 800 gsm PE coating
D	PET based nonwoven fabric with 400 gsm PP coating
E	PET based nonwoven fabric with 800 gsm PP coating

2.1 Sound Absorption Coefficient

Sound absorption tests were performed by using impedance tube according to ISO 10534-2 test standard. Experiments in large and small tubes were done and the data obtained were merged by the test software.

2.2 Transmission Loss

Transmission loss tests were performed by using impedance tube according to ASTM E2611-09 test standard. Experiments in large and small tubes were done and the data obtained were merged by the test software.

3. RESULTS

3.1 Sound Absorption Properties

Sound absorption behaviour of the samples was investigated in the frequency range of 50-6400 Hz. Fig. 1 illustrates sound absorption coefficient variation of the test samples A, B, C, D and E.

As seen in Fig. 1, the sample A has higher sound absorption coefficient (SAC) values in the higher frequencies.

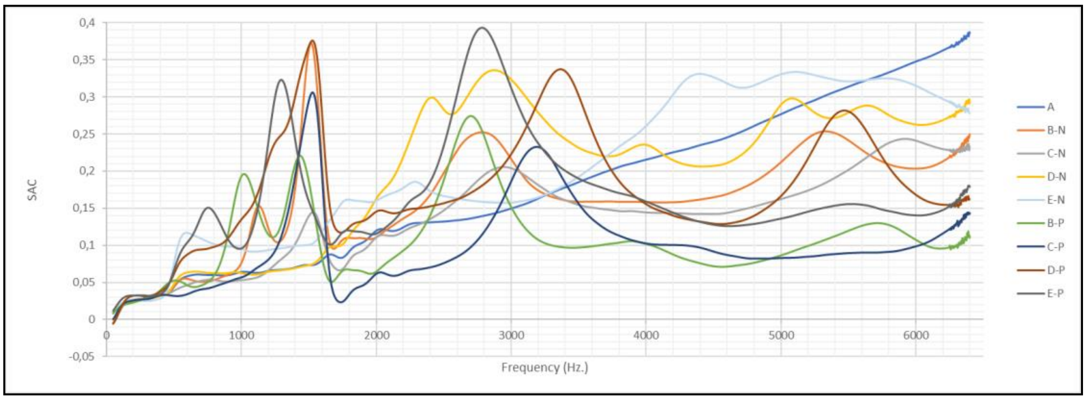

Figure 1. Sound absorption coefficient variation of the test samples in the case sound wave was firstly incident to the polymeric layer (B-P, C-P, D-P, E-P) or to the nonwoven layer (B-N, C-N, D-N, E-N).

3.1.1. Polyethylene Coated Samples (Sample B and Sample C)

According to Fig. 2, SAC data of B-P is almost the same as that of the sample A until 785 Hz. B-P has higher SAC values than that of the A in nearly 785-1605 Hz frequency range. From 1605 Hz to 2365 Hz approximately, the SAC values belong to B-P are lower than that of the A. In 2365-2988 Hz frequency range B-P has higher SAC values than that of the A and in 2988-6400 frequency range has lower SAC values than that of the A again. When the B-P reaches to 0,20 SAC value in 1021 Hz, the sample A has 0,06 SAC value. Moreover, SAC value of B-P is 0,22 and of A is 0,07 in 1435 Hz frequency. The highest SAC value of B-P is 0,27 at 2702 Hz, while A has 0,14 SAC values at the same frequency.

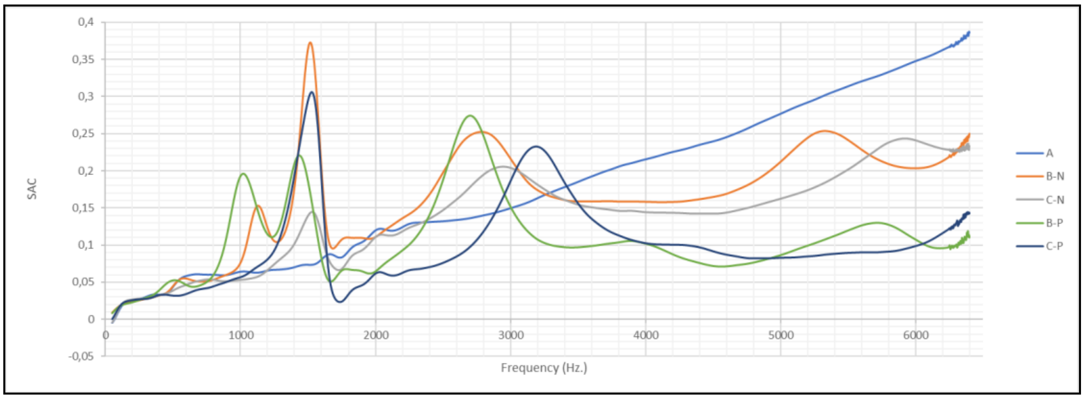

Figure 2 Sound absorption coefficient variation of the test samples A, B and C in the case sound wave was firstly incident to the polymeric layer (B-P, C-P) or to the nonwoven layer (B-N, C-N).

SAC data of the B-N is almost the same as that of the sample A until 943 Hz. The B-N has higher SAC values than that of the A in nearly 943-1674 Hz frequency range. In Fig. 2, there are peaks belonging to the B-N at 1131 Hz and 1517 Hz. At 1131 Hz, SAC value of the B-N is 0,15 while SAC value of the A is 0,06. Also, B-N has 0,37 SAC value at 1517 Hz while A has 0,07 at the same frequency. In 1696-2094 (approximately) Hz frequency range, SAC data of the B-N approximates to that of the A. There is a peak for B-N in the range 2094-3259 Hz (exactly at 2785 Hz) where B-N has the highest SAC value of 0,25 whereas A has 0,14 SAC value at 2785 Hz. However, B-N has lower SAC values than A above 3259 Hz.

In Fig. 2, C-P curve continues almost same as the curve A until 1078 Hz, after that it captures an increasing trend. In the 1078-1656 Hz frequency range there is a peak for the C-P curve at 1528 Hz where the SAC value is 0,31. At the same frequency (1528 Hz) SAC value of A is 0,07. The data of C-P is lower than that of the A in the frequency range of approximately 1656-2907 Hz. There is a small peak for the C-P at 3190 Hz where SAC value is 0,23. SAC value of the A is 0,16 at the same frequency (3190 Hz). The C-P curve proceeds below the curve A from 3420 Hz to 6400 Hz.

The curve C-N is almost the same as the curve A until approximately 1208 Hz, after that there is an increasing trend until approximately 1536 Hz. Then, it begins to decrease. In 1645-2383 Hz frequency range, the curve C-N is almost the same as the curve A again. There is a peak at 1536 Hz for the C-N where SAC is 0,14 whereas the SAC value of A is 0,07. There is an increasing trend for C-N from 2383 Hz to approximately 2933 Hz. At 2933 Hz, the SAC value of the C-N is 0,21 while that of the A is 0,15. Above 2933 Hz, the SAC value of the C-N decreases and from 3294 Hz to 6400 Hz the C-N curve becomes below the curve A.

3.1.2. Polypropylene Coated Samples (Sample D and Sample E)

In Fig. 3, the sample D-P has higher SAC values than that of the A in 355-3758 Hz frequency range. The D-P curve has totally three peaks. In the range of approximately 355-1537 Hz, there is an increase just after that there is a rapid decrease until 1728 Hz for the D-P curve. It follows a stabile trend in the range of 1728-2641 Hz which is similar to that of the curve A although all of the values for the D-P are higher than that of the A. Then, the SAC values of the sample D-P increase again until 3367 Hz and begins to decrease. From 3745 Hz on, the curve D-P becomes below the curve A. Here, it is observed that the SAC value is 0,37 for the D-P whereas that of the sample A is 0,07 SAC at 1537 Hz. The second peak is at the 3367 Hz where the SAC value is 0,33 for the D-P and 0,18 for the A. Above 3745 Hz, the SAC values for the D-P curve are lower than that of the sample A however, although the D-P curve approaches the curve A at around 5479 Hz frequency, then again gets further away from the curve A.

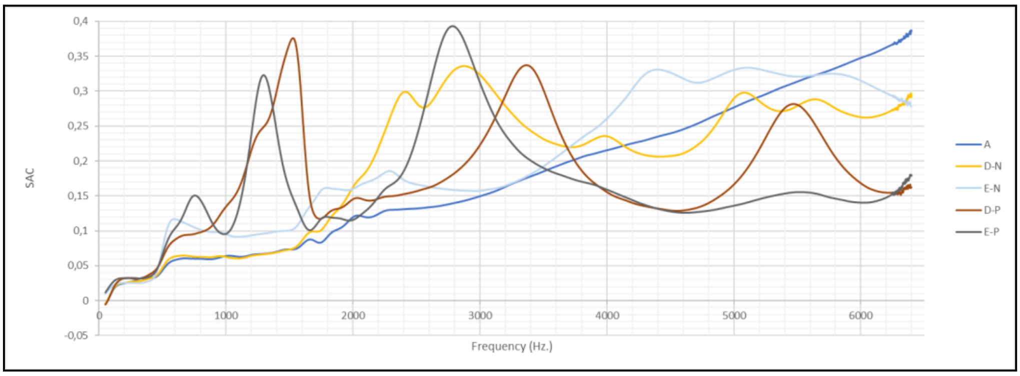

Figure 3 Sound absorption coefficient variation of the test samples A, D and E in the case sound wave was firstly incident to the polymeric layer (D-P, E-P) or to the nonwoven layer (D-N, E-N).

The D-N curve is almost the same as the curve A until 1500 Hz and then it captures an increasing trend until 2424 Hz. At the 2424 Hz frequency, 0,3 SAC value is reached by the sample D-N where SAC value of the sample A is 0,13. Just after there is a slight decline, then again there is a slight increase. It is seen that the SAC value reaches 0,34 at 2882 Hz. However, at the same frequency (2882 Hz), the sample A has 0,14 SAC value. From 2882 Hz to 3745 Hz, there is a decreasing trend for the D-N curve. Above 3745 Hz, the D-N curve is mostly just below the curve A and shows more wavy structure than the curve A.

The curve E-P has better SAC values than the curve A until 3540 Hz and then it remains under the curve A. The curve E-P has three prominent peaks until 3540 Hz whereas there is none after 3540 Hz. According to Fig. 3, the sample E-P reaches maximum 0,39 SAC at 2800 Hz.

The sample E-N has generally higher SAC values than the sample A with a maximum of 0,33 SAC at 4365 Hz. The curve E-N does not have prominent peaks.

3.2 Transmission Loss Properties

Sound transmission loss properties of the samples were investigated in the frequency range of 50-6400 Hz. Fig. 4 illustrates the transmission loss (TL) variation of the test samples A, B, C, D and E.

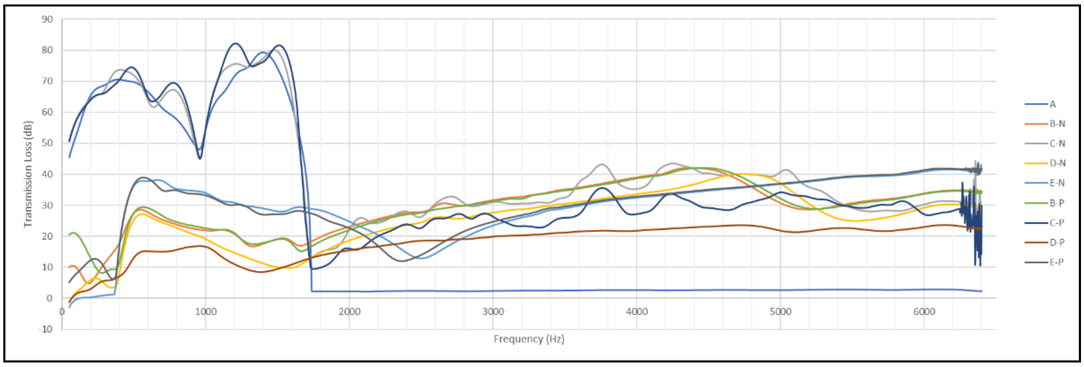

Figure 4. Transmission loss variation of the test samples in the case sound wave was firstly incident to the polymeric layer (B-P, C-P, D-P, E-P) or to the nonwoven layer (B-N, C-N, D-N, E-N).

As seen in Fig. 4, while the sample A has higher transmission loss values at low frequencies (approximately 50-1745 Hz.), there is a sudden decline at 1745 Hz and it continues to have low transmission loss values constantly up to 6400 Hz.

Also, it is observed that mostly, there is not pretty much change in the transmission loss values in the case sound wave is firstly incident to the polymeric layer or to the nonwoven layer.

3.2.1. Polyethylene Coated Samples (Sample B and Sample C)

According to Fig. 5, the sample B (B-N and B-P) has transmission loss values generally between 5-42 db. Below 1745 Hz, the sample B (B-N and B-P) has lower transmission loss than that of the sample A. In that range, the sample B (B-N and B-P) has maximum 30 dB transmission loss value while the sample A has nearly as much as 80 dB. In 1745 Hz, the sample B (B-N and B-P) doesn't have sudden decline like the sample A. Above 1745 Hz, the sample B (B-N and B-P) continues with slight peaks. It is seen in 4443 Hz that the sample B has 42 dB transmission loss, while the sample A has 2,7 dB transmission loss.

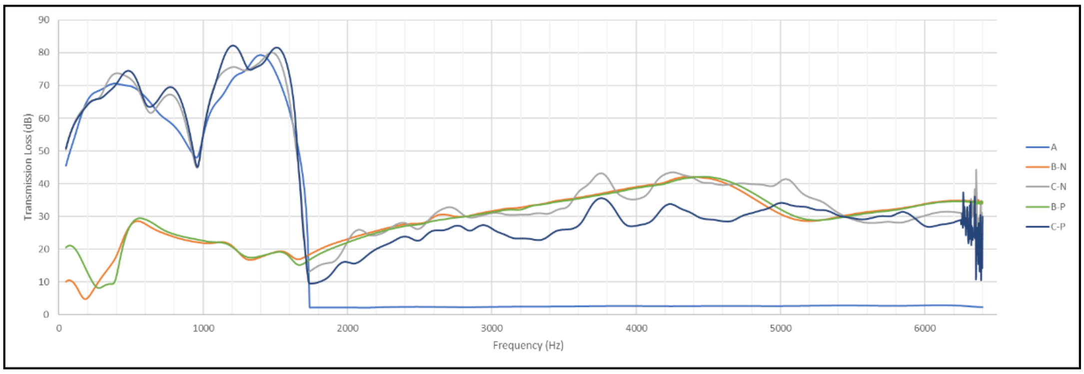

Figure 5. Transmission loss variation of the test samples A, B and C in the case sound wave was firstly incident to the polymeric layer (B-P and C-P) or to the nonwoven layer (B-N and C-N).

The sample C (C-N and C-P) has similar variations in the transmission loss to that of the sample A until 1745 Hz frequency. There is a sudden decline to 10 dB and 13 dB transmission loss for C-P and C-N, respectively at 1745 Hz after which the curve continues with the similar trend to that of the sample B. Above 1745 Hz, the sample C has greater transmission loss values than that of the sample A. The curve of the sample C is more wavier than that of the sample B.

3.2.2. Polypropylene Coated Samples (Sample D and Sample E)

As seen in Fig. 6, D-N mostly has higher transmission loss than that of the D-P over the entire frequency range. Below 1745 Hz, the D-N has transmission loss values between nearly 0-28 Hz. The transmission loss of the sample D-N declines to approximately 12 dB at 1745 Hz and then it rises slightly until it reaches nearly 40 dB at 4770 Hz. On the other hand, while the sample D (D-N and D-P) has lower transmission loss than that of the sample A below 1745 Hz, it has higher transmission loss than that of the sample A over 1745 Hz.

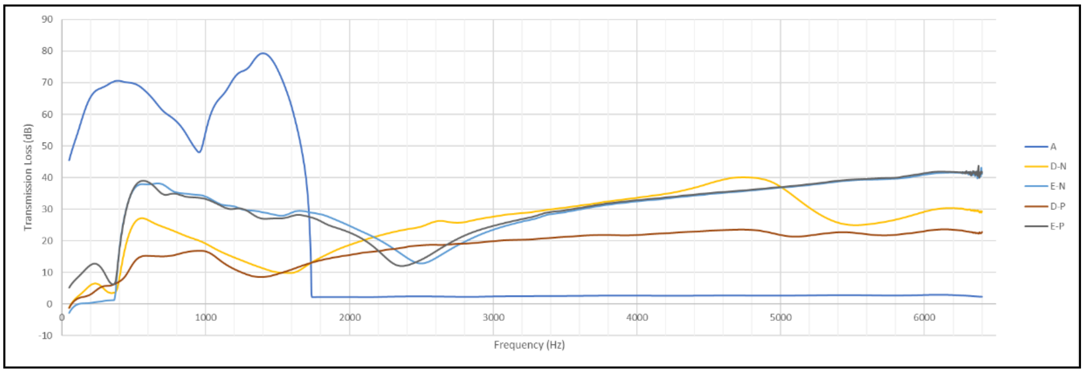

Figure 6. Transmission loss variation of the test samples A, D and E in the case sound wave was firstly incident to the polymeric layer (D-P and E-P) or to the nonwoven layer (D-N and E-N).

The sample E (E-N and E-P) has lower transmission loss values than that of the sample A however mostly higher than the sample D (D-N and D-P) below 1745 Hz. Above 1745 Hz, the curve E (E-N and E-P) firstly declines until 2500 Hz and then it increases slightly until 6400 Hz. At nearly 5500 Hz, the sample E (E-N and E-P) has 40 dB transmission loss while the sample A has 2,7 dB transmission loss. In this region from 1745 to 6400 Hz, the sample E has higher transmission loss than that of the sample A.

4. CONCLUSION

Nonwovens are known to be good sound absorbents at high frequencies. Hence, a development is required for nonwovens to be used as sound absorbents at low frequencies, too. However, there are limited number of studies in the scientific literature regarding examination of nonwoven samples' acoustic properties in terms of different parameters. Therefore, in this study, two polymers i.e. polyethylene and polypropylene are coated on the PET based nonwoven in two different weights as 400 gsm and 800 gsm. Test results show that polymer coating on a nonwoven sample affect the acoustic performance i.e. sound absorbency and sound transmission loss. Moreover, polymer type, polymer weight and the arrangement of the layers have been found to be some important factors that affect the acoustic properties. It has been observed that polymer coating on nonwoven sample may provide better sound absorbency properties especially at lower and medium frequencies, however the behaviour is so changeable and affected by frequency. If the sound absorbency property is evaluated in terms of polymer type, it can be said that polypropylene coating is superior than its polyethylene counterpart. Moreover, the weight of the polymeric layer affects sound absorbency coefficient. The effect is different according to frequency, polymer type and the surface where sound wave is firstly incident to. The curves belonging to the 400 gsm polyethylene coated sample (B-N and B-P) are similar in general terms. It is seen that B-N has better SAC values than that of the B-P. There is no significant difference between C-N and C-P and distribution of their data is similar. However, C-P has the greatest peak at 1578 Hz where SAC is 0,31. The sample A reaches the same SAC value above 5000 Hz. In 1888-3187 Hz range, the best SAC results belong to the D-N curve. Above 3743 Hz, the curves D-P and D-N are below the curve A. However, the curve D-N is closer to the curve A than the curve D-P. Results of the sample E shows that the sample E-P has good sound absorption property in narrow frequency ranges. In this study, it has also been observed that nonwoven sample does not have good transmission loss at high frequencies. However, polymeric coating significantly enhances the sound transmission loss of the nonwoven at high frequencies. Increasing the polymeric coating weight has different effects in different frequency ranges. It is seen that there is no significant difference in the distribution of transmission loss data for polyethylene and polypropylene over the entire frequency range. Moreover, it can be said that the arrangement of the layers just affects the sound absorbency coefficient. Because sound absorbency coefficient is the ratio of the absorbed energy to the incident energy. Since energy is actually absorbed by the layer sound wave is incident to, the arrangement of the layers has changed the sound absorbency coefficient as it is expected.

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REFERENCES

[1] Barron, R. (2003). Industrial Noise Control and Acoustics. New York: Marcel Dekker, Inc.
[2] Peters, R., Smith, B., & Hollins, M. (2013). Acoustics and Noise Control (3rd ed.). New York: Routledge.
[3] Nayak, R. & Padhye, R. (Eds.). (2016). Acoustic textiles. Singapore: Springer.

NATURAL ORGANIC DYE STANDARD (NODS)

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ABSTRACT

Environmental awareness has become more important among individuals and societies in recent years. The increasing awareness and sensitivity to the environment have made the reintroduction of natural dyes in the textile industries even more important. To date, natural dyes have been employed in the textile industries for years, and their use is now increasing rapidly. However, there is no standard or no criteria for textiles colored with natural dyes despite the fact that individual and institutional customers, textile brands, and other bodies have been advocating for such as standards. For this reason, NODS (Natural Organic Dye Standard) is required like GOTS (Global Organic Textile Standard), OECO-TEX (International Association for Research and Testing in the Field of Textile and Leather Ecology), and other certificates.

Keyword: *Standard, Natural dyes, Parameter, Prohibited, Restricted*

1. INTRODUCTION

In the past textile goods (such as a garment or home textiles), have been demanded on the market based on their price. The principal purpose of the textile companies producing fabrics and goods was to manufacture at low cost. Nowadays, when purchasing textile goods consumers demand not only specific designs, functionalities, and quality levels but also safety and consideration for ecology, with concern for the protection of the environment and producers in developing countries. Sustainability is becoming more of a marketing tool in the fashion supply chain, forcing textile producers to respect high environmental standards in their production methods [1]. Textile production is extremely complex and involves a multitude of mechanical, chemical, and physicochemical processes. These processes can include some harmful and toxic substances such as heavy metals, pesticides, etc. However, the processes are strictly controlled by ZDCH (Zero Discharge of Hazardous Chemicals), OEKO-TEX (International Association for Research and Testing in the Field of Textile and Leather Ecology), and GOTS (Global Organic Textile Standard), etc. standards. There are many academic studies on using natural dyes in the textile industry. The number of these studies has been increasing rapidly in recent years [2-5]. There are many methods and many different recipe studies in the dyeing of protein and cellulose-based fibers with natural dyes [6-10].

2. NODS

The NODS include lists of biological dye sources (dye plants, dye insects, dye mollusks, dye lichens, and dye fungi), main natural coloring compounds (dyestuffs), inorganic element content maximum limits in the natural dyed product, prohibited and restricted substances, maximum limits of residues in products, natural mordant substance in the product content, synthetic dyestuffs and binders contained in the product. Lists of the biological dye sources and coloring compounds were given at [11].

Table 1. Inorganic element content maximum limits in the natural dyed product.

Inorganic element content	CAS NO	Maximum limit (mg/kg)
Fe	7439-89-6	free
Ca	7440-70-2	free
Cu	7440-50-8	< 25.00
Cr	7440-47-3	< 1.00
Ni	7440-02-0	< 1.00
Ba	7440-39-3	< 1000.00
Si	7440-21-3	free
K	7440-09-7	free
Pb	7439-92-1	< 0.20
As	7440-38-2	< 0.20
Sn	7440-31-5	< 0.20
Cd	7440-43-9	< 0.10
Co	7440-44-0	< 1.00
Hg	7439-97-6	< 0.02
Se	7782-49-2	< 0.20
Mn	7439-96-5	< 90.00
Zn	7440-66-6	< 750.00
Sb	7440-36-0	< 0.20
Al	7429-90-5	free

Table 2. Maximum limits of residues in products.

Parameter	Criteria	Test Method
Alkyl phenol	< 20 mg/kg	GC/MS, HPLC/MS
AOX	< 5 mg/kg	ISO9562
Aryl amines	< 20 mg/kg	HPLC/GCMS
Formaldehyde	< 16 mg/kg	ISO 14184-1
Glyoxalin	< 20 mg/kg	ISO 17226-1 (HPLC)

Table 3. Natural mordant substance in the product content.

Substance group	Criteria
Aromatic and halogenated solvents	Prohibit
Flame retardants	Prohibited ones - Chlorinated flame retardants - Brominated flame retardants - Phosphorus flame retardants - Flame retardants containing antimony - Disodium octaborate
Chlorinated benzenes and toluene	Prohibit
Chlorophenols (salts and esters)	Prohibit
Complexing agents and surfactants	Prohibited ones • All AP and APEO • EDTA • DTPA • NTA • LAS • α -MES
Endocrine disruptors	Prohibit
Formaldehyde and other aldehydes	Prohibit
Glycol derivatives	Prohibit

Table 4. Prohibited and restricted substances.

Mordant substance	CAS NO	Maximum limit (mg/kg)
$KAl(SO_4)_2.12H_2O$	7784-24-9	free
$Al_2(SO_4)_3$	10043-01-*3*	free
$FeSO_4$	7782-63-0	free
$Fe_2(SO_4)_3$	10028-22-5	free
Ca compounds	all	free
Mg compounds	all	free
K compounds	all	free
Si compounds	all	free

Table 5. Synthetic dyestuffs and binders contained in the product.

Dyestuff	Group	Maximum limit (mg/kg)
Azoik dyestuffs	All	0.00
Direct dyestuffs	All	0.00
Vat Dyestuffs	All	0.00
Sulfur dyestuffs	All	0.00
Reactive dyestuffs	All	0.00
Reducing dyestuffs	All	0.00
Oxidation dyestuffs	All	0.00
Acid dyestuffs	All	0.00
Alkali dyestuffs	All	0.00
Mordant dyestuffs	All	0.00
Chrome dyestuffs	All	0.00
Disperse dyestuffs	All	0.00
Pigment dyestuffs	All	0.00
Synthetic binders	All	0.00

3. RESULTS

NODS was set as a standard after the needs of the textile industries and the demand of customers. Numerous published articles and books about natural dyes and natural coloring compounds have been published in the last thirty years. NODS includes natural dyes/coloring compounds found in textile goods. It rates the fastness of natural dyes lower than of synthetic dyes in cellulose-based fibers or fabrics. For this reason, it has been assumed that the fastness of natural dyes is moderate. However, the fastness values are sufficient for the textile companies using them for natural dyed textiles goods. Heavy metals and substances that are restricted, prohibited, and limited to use in textile products according to GOTS standards were also restricted, prohibited, and limited uses in NODS standards. Free mordant metals and some free elements were given in the NODS. All synthetic dyestuff groups and all synthetic binder groups contained in the textile product were prohibited in the NODS.

4. CONCLUSION

Quality, sustainability, eco-friendly, awareness, ZHCD, GOTS, and other criteria now outweigh price as the prime consideration for customers. Natural dye resources and natural coloring compounds (dyestuffs) are increasingly used in high-volume textile production industries (Karadag 2022, 2023). With both consumer and brand demand, it has become a necessity set a standard (NODS) in the dyed textile products for natural dyes as well as the other desirable standards for textile products. NODS criteria are also requested in the natural dyed productions. To respond to this demand, the articles have developed criteria for NODS based on previous research. When purchasing textiles that follow the NODS, the consumers can be sure that the goods are colored with natural dye and will be able to use them with confidence. Brands and textile industries that produce according to the NODS will be earning more while contributing to sustainability and eco-friendly dyeings.

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REFERENCES

[1] Caniato, F., M. Caridi, L. Crippa, and A. Moretto (2012). Environmental sustainability in fashion supply chains: An exploratory case based research. International Journal of Production Economics 135:659–70. doi:10.1016/j.ijpe.2011. 06.001.
[2] Alkan, R., E. Torgan, and R. Karadag (2017). The investigation of antifungal activity and durability of natural silk fabrics dyed with madder and gallnut. Journal of Natural Fibers 14 (6):769–80. doi:10.1080/15440478.2017.1279101.
[3] Baaka, N. (2020). Sustainable Dyeing of Wool Fabric Using Kermes Oak (Quercus Coccifera L) as Source of Natural Colorant. Journal of Natural Fibers 19:1–9. in press. doi:10.1080/15440478.2020.1726250.
[4] Guzel, T. E., and R. Karadag (2021). Sustainability of organic cotton fabric dyeing with a natural dye (Gallnut) and analysis by multitechnique approach. Journal of Natural Fibers 18 (8):1107–18. doi:10.1080/15440478.2019.1687064.
[5] Guzel, E. T., K. Karadag, and R. Alkan (2020). Durability, antimicrobial activity and HPLC analysis of dyed silk fabrics using madder and gall oak. Journal of Natural Fibers 17 (11):1654–67. doi:10.1080/15440478.2019.1588827
[6] Karadag, R. (2022). Sustainable and Mass Production of Cotton Dyeing with Natural Dye (Weld) in the Textile Industry. Journal of Natural Fibers 19 (15):10935–45. doi:10.1080/15440478.2021.2002781.
[7] Karadag, R. (2023). Cotton Dyeing with Cochineal by Just in Time Extraction, Mordanting, Dyeing, and Fixing Method in the Textile Industry. Journal of Natural Fibers 20 (1):1–11. doi:10.1080/15440478.2022.2108184.
[8] Karadag, R., B. Y. Buyukakinci, and E. T. Guzel. (2022). Extraction and natural cotton dyeing of Valonia Oak and Anatolian Buckthorn by microwave irradiation. Journal of Natural Fibers 19 (1):159–72. doi:10.1080/15440478.2020. 1731907. JOURNAL OF NATURAL FIBERS 21
[9] Karadag, R., and Y. Yildiz. (2022). Examination of Dyeing Properties of the Dyed Organic Cotton Knitting Fabrics Using Yarrow (Achillea Biebersteinii AFAN and Achillea Millefolium L. Journal of Natural Fibers 19 (14):7374–81. doi:10. 1080/15440478.2021.1946881.
[10] Ozdemir, M. B., and R. Karadag. (2023). Madder (Rubia tinctorum L.) as an Economic Factor Under Sustainability Goals in the Textile Dyeing. Journal of Natural Fibers 20 (1):138–47. doi:10.1080/15440478.2022.2128968.
[11] Karadag, R. (2023). Establishing a new international standard for natural dyed textile goods [natural organic dye standard (NODS)]. Journal of Natural Fibers, 20(1). https://doi.org/10.1080/15440478.2022.2162187

COLOR REMOVAL OF DISPERSE DYEING WASTE WATER BY OZONE IN AN EXAMPLE DYEHOUSE

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ABSTRACT

As a result of rapid population growth and industrialization, wastewater generated in various sectors poses a threat to the environment and living things.Textile industry wastewater comes first among these wastewater sources.These wastewaters contain dyestuffs and different chemicals. These waters, which contain many impurities, must be treated well, otherwise they may cause serious problems in the environments where they are discharged. Various physical, chemical and biological methods are used for color removal in wastewater. However, due to the cost and low efficiency of these methods, researches are carried out on innovative and more economical methods. Among the new technologies, advanced oxidation processes (AOPs) are highly efficient new methods being studied for the purification of certain impurities that cannot be removed by general techniques. AOP methods include photocatalytic reaction with UV, ultrasound, Fenton/Peroxide, ultrasound sound waves and similar reactions. One of these methods is ozonation method.

In this study, ozone decolorization of wastewater after disperse dyeing taken from Karesi Tekstil AŞ dyehouse was investigated. In the determined procedure, the removal of color by ozonation method, which is one of the advanced oxidation methods for wastewater recipes after dyeing, was investigated and the color absorbance and COD values of the samples were examined and the results were evaluated.

Keyword: *Ozone, Disperse dyeing wastewater, Decolorization*

1. INTRODUCTION

The most produced and consumed natural fiber in the world is cotton and synthetic fiber is polyester. While cotton fibers are dyed with reactive dyestuffs, polyester is dyed with disperse dyestuffs [1,2]. Dyeing processes are very water consuming processes and the water discharged as waste at the end of the process contains both colored dyestuff and many chemicals. Therefore, this dirty wastewater needs to be treated [3,4]. Today, wastewater treatment methods include solvent extraction, ion exchange, precipitation, evaporation, reverse osmosis, membrane bioreactor, and membrane separation. However, these existing methods are very costly and low-efficiency methods in wastewater treatment [5,6]. For this reason, ozone application, which has a high oxidation feature; It is an alternative method that has been studied recently in textile with its environmentally friendly and economical approaches.

Ozone decolorizes polluted waters by 99% [7-11]. Ozone (0_3) is three oxy-oxygen allotropes in its structure and has a high oxidation potential of 2.07 ev. It is a colorless gas with a characteristic odour. It is widely used as a disinfectant [12]. Ozonation is very useful and promising because it is both cheaper and very effective in decolorizing wastewater.

2. EXPERIMENTAL STUDY

In the experimental study, color removal study was carried out at 3 l/min ozone gas flow rates of Disperse dyeing wastewater. The recipe used in disperse dyeing is given in Table 1 and the staining diagram is given in Figure 1.

Table 1. Chemical materials and dyestuffs used in dyeing recipe.

No.	Material	Amount (g/l)
1	Dispersing agent	1
2	Acetic acid	1
3	Dispersing agent	0.07
3	Syncron yellow br cern	0.42
3	Syncron red tt	0.06
3	Syncron navy blue cern	0.47

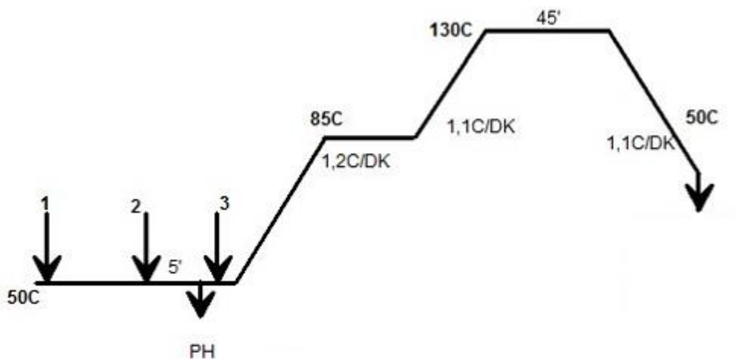


Figure 1. Coloring diagram.

Figure 2. Ozone generator.

The ozone generator shown in Figure 2 was used for the wastewater treatment process. For ozonation process, 400 ml wastewater sample was ozonated in a beaker with the help of a diffuser.

In order to test the color removal, the ADMI values of the samples were measured using the Spectroquant Pharo 300 brand spectrometer.

Spectrophotometric ready test tubes were used in the COD analyzes for wastewater samples and COD measurements were performed according to standard methods 5220.

3. RESULTS

In the study, the effect of reference (untreated dyeing wastewater) and ozonated samples on color absorbance and COD values at different ozonation times were investigated. Ozone treatment was done in 10, 20, 30 minutes. The initial state and ozonated samples of wastewater are shown in the Figure 3,4.

a. b.

Figure 3. Ozonation of sample wastewater: a. entrance colored wastewater b. Ozonation process.

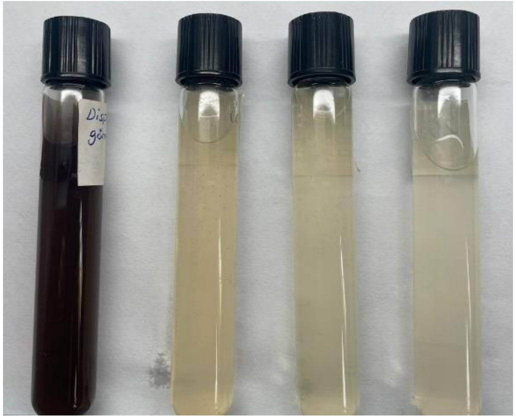
Absorbance measurement values and COD measurements of ozonated samples are given in Table 2 and Table 3, respectively.

Table 2. Absorbance measurement values of ozonated.

	Ozonation time (mn)	**Absorbance (based on 510nm)**
Initial	0	1.231
Ozonation	10	0.672
	20	0.642
	30	0.595

Table 3. COD measurement values of ozonated.

	COD values (%)
Entrance	3520
Ozonation	3100



a. b. c. d.

Figure 4. Ozonated samples: a. initial wastewater b. 10 min ozonated wastewater c. 20 min ozonated wastewater d. 30 min ozonated wastewater.

4. CONCLUSION

The color removal of disperse dyeing wastewater from Karesi textile dyehouse with ozone after dyeing was investigated, it was subjected to ozonation for certain periods and the results were interpreted. Color removal has been achieved successfully in disperse dyeing wastewater by ozonation.

As the ozonation time increased, both the color lightened and the COD value decreased. Ozone, which is one of the advanced oxidation methods, can be used successfully in the decomposition of aromatic hydrocarbons, pesticides, phenols and chlorinated hydrocarbons, dyeing watewater and COD. The absence of sludge formation and the absence of toxic metabolites are among the important advantages of ozonation. In the future reactive painting bath ozonation research is also planned.

REFERENCES

[1] Jaffe, M., Easts, A. J., Feng, X. (2020). Polyester fibers. *In Thermal Analysis of Textiles and Fibers*, 133-149. Woodhead Publishing.
[2] Öner, E. (2001). Boyama Teknolojisi I, *Ders Notu*, Marmara Üniversitesi, İstanbul.
[3] Bisschops, I., & Spanjers, H. (2003). Literature review on textile wastewater characterisation. *Environmental technology*, *24*(11), 1399-1411.
[4] Turan, F., & Ülkü, G. (2013). Gökpinar ve Çürüksu çaylarinin kirlilik parametre ve yüklerinin izlenmesi. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *19*(3), 133-144.
[5] Hutagalung, S. S., Muchlis, I., & Khotimah, K. (2020). Textile wastewater treatment using advanced oxidation process (AOP). In *IOP conference series: materials science and engineering* (Vol. 722, No. 1, p. 012032). IOP Publishing.

[6] Pourgholi, M., Masoomi Jahandizi, R., Miranzadeh, M., Beigi, O. H., & Dehghan, S. (2018). Removal of Dye and COD from textile wastewater using AOP (UV/O3, UV/H2O2, O3/H2O2 and UV/H2O2/O3). *Journal of Environmental Health and Sustainable Development*, 3(4), 630-636.
[7] Glaze, W.H., Kang, J.W., Chapin, D.H., (1987) The chemistry of water treatment processes involving ozone, hydrogen peroxide and ultraviolet irradiation. *Ozone Sci. Eng*., 9, 335–352.
[8] Staehelin, J., & Hoigne, J. (1985). Decomposition of ozone in water in the presence of organic solutes acting as promoters and inhibitors of radical chain reactions. *Environmental science & technology*, *19*(12), 1206-1213.
[9] Akçay, M. U. (2008). Ozon Ve Biyofiltrasyonla Doğal Organik Madde Giderimi Ve Dezenfeksiyon Yan Ürünleri Oluşum Potansiyellerinin Belirlenmesi (Master's Thesis, Anadolu Üniversitesi)
[10] Wang, C., Yediler, A., Lienert, D., Wang, Z., & Kettrup, A. (2003). Ozonation of an azo dye CI Remazol Black 5 and toxicological assessment of its oxidation products. *Chemosphere*, *52*(7), 1225-1232.
[11] Eren, H. A. (2006). Afterclearing by ozonation: a novel approach for disperse dyeing of polyester. *Coloration technology*, *122*(6), 329-333.
[12] Eren, H. A., Yiğit, İ., Eren, S., & Avinc, O. (2020). Ozone: an alternative oxidant for textile applications. *Sustainability in the Textile and Apparel Industries: Production Process Sustainability*, 81-98. Springer, Cham.

ELECTROCHEMICAL-MECHANICAL CHARACTERIZATION OF ELECTRICALLY CONDUCTIVE MULTI-COMPONENT FIBERS FOR TEXTILE DISPLAYS, SENSORS, ACTUATORS AND ENERGY STORAGES

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ABSTRACT

Smart textiles are textiles with an extended range of functions, namely the interaction of the textile with the environment, which includes the human user. Especially the application possibilities in the areas of sports, health, living, mobility or construction open up completely new markets and business models for consumer and technical products. Alongside other products based on flexible or wearable electronics, textile-based electronics promise greater user acceptance due to their flexibility, textile feel and superior aesthetics. The implementation of digital smart functions in textiles inevitably involves the incorporation of electrical circuits consisting of conductors, capacitors and power sources. Smart textiles currently available on the market use electrically conductive fiber surface coatings, metal strands incorporated into the textile surface and externally attached charge storage devices, e.g. batteries in foil form. However, these solutions represent interference points in the textile look and feel. Textile fiber systems with intrinsic electrical conductivity and capacity for charge storage and the construction of logic circuits, which do not have the disadvantages mentioned, are currently still under development.

The presentation will focus on the challenges of electrochemical-mechanical characterization of electrically conductive multi-component fibers, which proofed to be a promising approach for the development of textile displays, sensors, actuators and energy storages, enabling innovative technologies and new applications in the field of smart textiles. Due to the nature of fibers, e.g. structures in the micrometer regime and continuous production processes leading to radial fiber symmetries, the characterization of their electrical properties like conductivity, capacity and electrochemical-mechanical deformation is not trivial, although indispensable, and requires sophisticated methods and equipment as well as comparable characterization standards. The presentation highlights the uprising challenges in technical design, points out common misconceptions regarding the underlaying theory and introduces advanced measurement techniques as well as equipment for characterizing electrochemical-mechanical properties, based on the experience gained during several years of research of electrically conductive multi-component fibers. Furthermore, framework conditions for future characterization standards are defined.

Keyword: *Conduction Multi-Component-Fibers Characterization*

1. INTRODUCTION

Smart textiles are textiles with an extended range of functions, namely the interaction of the textile with the environment, which includes the human user. Especially the application possibilities in the areas of sports, health, living, mobility or construction open up completely new markets and business models for consumer and technical products. Alongside other products based on flexible or wearable electronics, textile-based electronics promise greater user acceptance due to their flexibility, textile feel and superior aesthetics. The implementation of digital smart functions in textiles inevitably involves the incorporation of electrical circuits consisting of conductors, capacitors and power sources. Smart textiles currently available on the market use electrically conductive fiber surface coatings, metal strands incorporated into the textile surface and externally attached charge storage devices, e.g. batteries in foil form. However, these solutions represent interference points in the textile look and feel. Textile fiber systems with intrinsic electrical conductivity and capacity for charge storage and the construction of logic circuits, which do not have the disadvantages mentioned, are currently still under development.

A frequently encountered approach in the relevant literature and in current research for the development of textile charge storage devices are multi-component fibres with capacitive properties. Here, the structure of a classical plate capacitor is transferred to the radially symmetrical form of a fibre. Such a fibre consists of an electrically conductive core component and a surrounding electrically conductive sheath component, which represent the electrodes of the capacitor (see figure 1). Between them is a layer of an electrically insulating dielectric. When an external voltage is applied to the electrodes, they become electrically charged and electrical energy is stored in the fibre. This can later be called up by an electrical appliance.

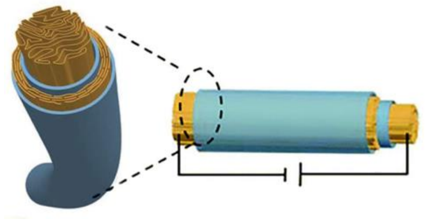

Figure 1. Schematic structure of a textile charge storage device made of a multi-component fibre [1].

By substituting the dielectric with an electrolyte, the capacity of the fibre capacitor can be increased. Depending on the sign of the charge, mobile ions in the electrolyte form an electrochemical double layer on the charged electrodes and shield its charge proportionally. This increases the effective charge of the electrodes and thus their capacity. In this case, one speaks of a supercapacitor.

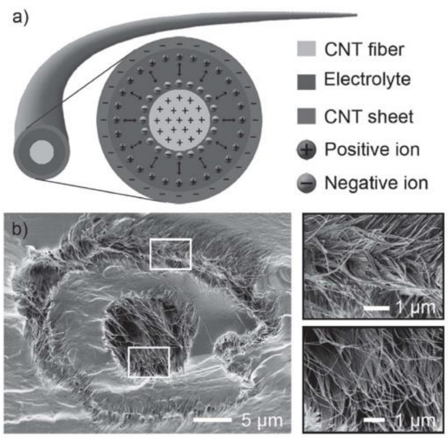

Figure 2. a) Schematic structure and b) electron microscopic images of a fibre based supercapacitor [2].

By replacing the electrolyte with a chemical redox system, which changes its morphology or absorption spectrum depending on the oxidation state, fibre actuators and imagers can be realised. If an external voltage is applied to the electrodes, the redox system can be oxidised or reduced depending on the sign of the electrode charge. If this changes its morphology, the multi-component fibre undergoes a change in length and the electrical energy is converted into mechanical energy. An abroption and thus colour change can be used for imaging. This way, fibre actuators, e.g. soft robotics and artificial mucle fibres, as well as fibre based displays are possible.

The development of such multi-component systems is not the only challenge on the way to an application in textile displays, sensors, actuators and energy storages, but also their electrochemical-machanical characterisation. The characterisation of the electrical properties is strongly influenced by the measurement setup. The contacting of multicomponent fibres is not trivial due to small structures in the micrometer range, the risk of short circuits and the low voltage and current numbers. From the resulting insufficient precision and reproducibility of the measurements, the need for the development of test equipment and test specifications is derived in addition to the actual material development.

2. EXPERIMENTAL STUDY

While also researching on the material systems itself as well as production processes for textile displays, sensors, actuators and energy storages, the necessity of testing equipment and standards arose for the aforementioned reasons.

2.1 Testing equipment

The design proposed here for a measuring stand for determining electrical conductivity and capacitance takes up the concept of commercially available measuring stands for microelectronics and develops it further to make it specifically suitable for multicomponent textile fibres. To keep costs as low as possible, existing equipment such as an optical microscope and an impedance spectrometer is used. Four micro-manipulators, electrode holders with connecting cables and needle-shaped tungsten electrodes are needed to realise a four-point electrode arrangement with high measurement accuracy.

The design and construction of the measuring stand is carried out in accordance with VDI 2221 and in modular design to enable easy integration of later extensions such as the temperature-dependent measurement of electrically conductive fibres or the conductivity measurement on textile surfaces.

To validate the functionality and precision, the measuring device was first calibrated with the associated measuring electrodes and cables under standard climate conditions according to DIN EN ISO 139 at 20 °C and 65 % relative humidity. Subsequently, test measurements were carried out on multi-component fibres in accordance with the DIN EN 16812 standard using the four-electrode measuring method.

2.2 Testing standards

The testing rig in development was supposed to operate in accordance to existing testing standards. However, extensive research revealed only two remotely relevant existing textile testing standards: DIN EN 16812 (Textiles and textile products - Electrically conductive textiles - Determination of linear electrical resistance of conductors) and ISO 13931 (Carbon fiber - Determination of volume resistivity).

These standards neither cover other electrical properties like capacity, multi-component fibers nor the electromechanical deformation of textile fibers. Therefore, new testing standards have to be defined for the upcoming new technologies.

3. RESULTS

As a result, a testing rig for the electrochemical-mechanical characterization of electrically conductive multi-component fibers was developed and built (see figure 3). The rig is capable of measuring electrical properties like Ohmic resistivity and impedance with a precision of 0.004 Ohm as well as capacity with a precision of 0.003 µF on multi-component fibers with a component diameter down to 1 µm. Optical detection of deformation is possible down to 0.1 µm. The implementation of force sensors for tensile corelated detection of deformation as well as heaters for temperature depended measurements are part of ongoing extensions of the rig. While a technical basis for the electrochemical-mechanical characterisation of electrically conductive multi-component fibres has been established, the definition of a suitable test standard is still pending. Requirements have already been worked out and a working group has been set up. This is open to other interested members.

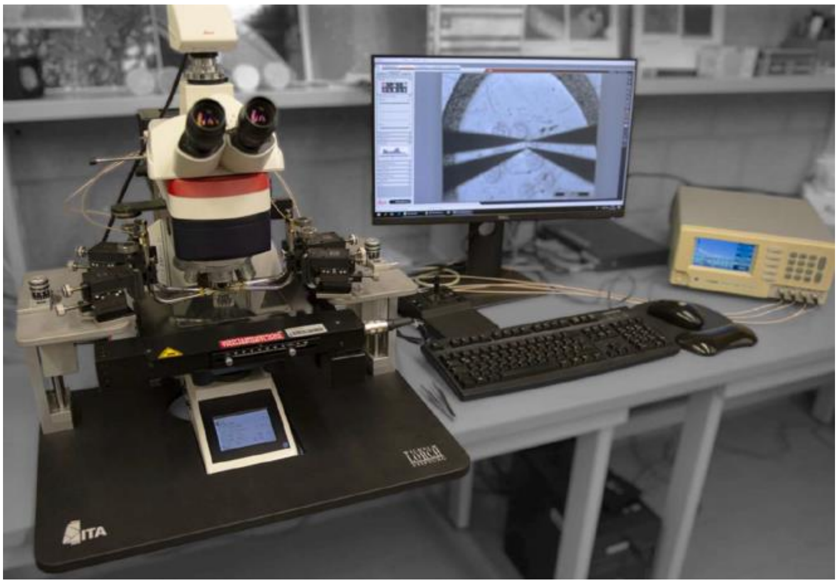

Figure 3. Testing rig for the electrochemical-mechanical characterization of electrically conductive multi-component fibers.

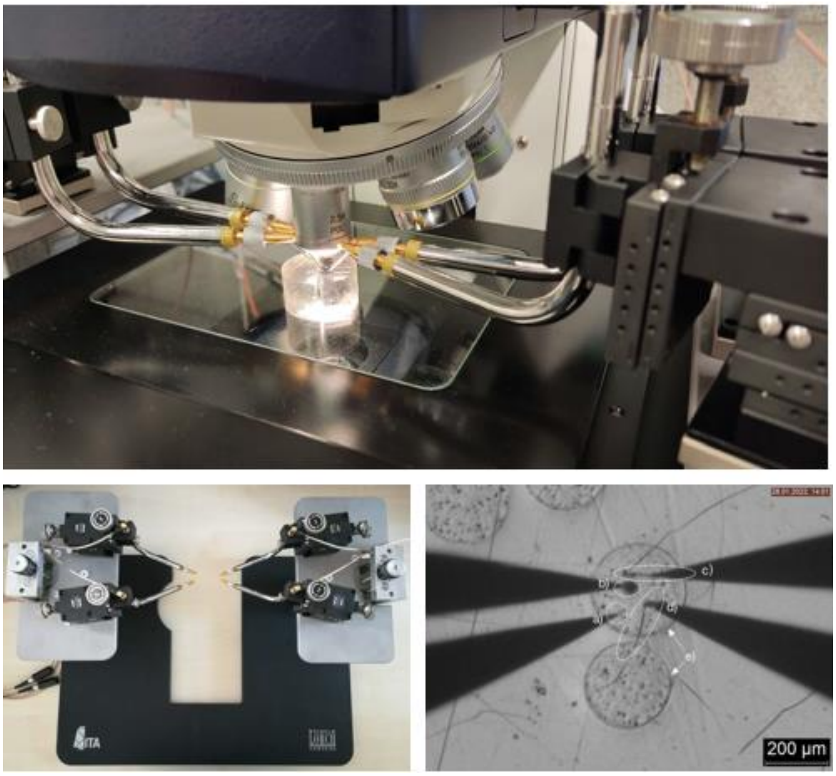

Figure 4. Contacting of electrically conductive multi-component fibers for the electrochemical-mechanical characterization.

4. CONCLUSION

While the development of electrically conductive multi-component fibres for textile displays, sensors, actuators and energy storages has made rapid progress in recent years, there is still a lack of standardised test methods and regulations for the characterisation of electrochemical-mechanical properties and the generation of comparable characteristic values. These are indispensable for the market maturity and commercialisation of the above-mentioned technology.

The present work introduces a modular, easy-to-adapt and highly precise, yet inexpensive concept for the characterisation of electrochemical-mechanical properties.

This not only promotes the development of textile displays, sensors, actuators and energy storages, but also offers companies the opportunity to expand their portfolio with companion technologies.

Institutes and companies have the opportunity to help shape the creation of corresponding norms and market standards to their (competitive) advantage.

ACKNOWLEDGMENT

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REFERENCES

[1] Chen, Xuli; Qiu, Longbin; Ren, Jing; Guan, Guozhen; Lin, Huijuan; Zhang, Zhitao; Chen, Peining; Wang, Yonggang; u. a.: *Novel Electric Double-Layer Capacitor with a Coaxial Fiber Structure.* Advanced Materials, Bd. 25 (2013), Nr. 44, S. 6436–6441.

[2] Zhao, Xiaoli; Zheng, Bingna; Huang, Tieqi; Gao, Chao: *Graphene-based single fiber supercapacitor with a coaxial structure.* Nanoscale, Bd. 7, The Royal Society of Chemistry (2015), Nr. 21, S. 9399–9404.

PHYSICAL PROPERTIES OF RING AND AIR VORTEX YARNS MADE OF SOYBEAN, RECYCLED POLYESTER, POLYESTER AND VISCOSE

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ABSTRACT

Vortex spinning technology is a modified form of air-jet spinning, which is preferred due to its advantages in production speed and yarn quality. The aim of this research is to compare yarns produced with Vortex and Ring spinning with different fibers. Soybean protein fiber, recycled polyester, polyester and viscose fibers were used in the study. Soybean fiber has superior comfort properties. The production of soybean protein fiber by Vortex spinning method will be analyzed and a contribution will be made to the literature. Produced Ne28 yarns from 6 different fiber blends using Vortex air-jet spinning and ring spinning methods were examined and the suitability of the spinning methods according to the fiber type was revealed. The results showed that the structural differences of both spinning methods according to the fiber blend give different strength, evenness and hairiness values. As a result of the yarn performance tests, it has been revealed that the strength values of 20% soybean, 80% polyester or 80% r PET blended yarns produced with Vortex spinning technology are lower than Ring spinning method. The hairiness value of yarns produced with Vortex is also lower than Ring. Low hairiness will positively affect pilling in the fabric.

Keyword: *Soybean fiber, yarn, recycle, Vortex, Ring, performance*

1. INTRODUCTION

In this study, the performance characteristics of the yarns produced were compared and the positive and negative aspects of Vortex were revealed. Vortex spinning technology is a preferred spinning technology due to its advantages in production speed and yarn quality. It is a different version of air jet spinning. Soybean protein fiber, recycled polyester, conventional polyester and viscose fibers were used in the study. While mostly synthetic fibers are produced with air jet, it is possible to produce yarn with Vortex from 100% natural and blended fibers [1,2]. The aim of this research is to compare Vortex and Ring yarns produced from different fibers. Soybean protein fibers are being from soybean plants [3]. Competitive SPF (soybean protein fiber) production is preferred for the textile industry [4]. Soybean fiber has superior comfort properties [1,2]. Soybean protein fiber production by Vortex spinning method will be analyzed and a contribution will be made to the literature. Nowadays, sustainable raw materials such as recycled polyester, soybean protein fiber are preferred. Problems with SPF(soybean protein fiber), fiber strength are nowadays developed using various methods. SPF benefits such as renewability and biodegradability, and soybean availability will be preferred in the future [5].

When the results of the performance tests applied to 12 yarns are examined, %CV, mass change coefficient, ring seems to be better than Vortex. When examined in terms of fiber type, it is seen that the mass change of soybean blended Vortex yarn is worse than other yarns, while soybean blended ring yarn is good. The oily structure of soybean fiber and the variability in fiber length caused the capacitive fluctuation to be high in the yarn produced in Vortex. Soybean protein fiber used in the study İS bleached, 1.5 D and lenght of fiber is 38 mm. Additional steps in ring production result in the elimination of fibers of different lengths. When compared in terms of yarn strength, the high % elongation at break, shows that the yarn is more flexible and more resistant to breaking. The % break elongation value of ring yarn was found better than Vortex. The hairiness value of Vortex yarn is better than Ring yarn. Low hairiness prevents pilling error when it becomes fabric. Low hairiness is preferred in the yarn. Vortex is advantageous in terms of hairiness.

2. EXPERIMENTAL STUDY

In this study, 6 different blend were used. Blend and ratios are shown in Table 1. Ne 28 yarns produced ring and Vortex spinning technology. Vortex machine setting values are shown in Table 2.

Table 1. Blends and ratio fibers.

	BLENDS & RATIO
1	%20 Soybean %80 rPET
2	%20 Soybean %80 PES
3	%20 PES %80 rPET
4	%100 PES
5	%20 Viscose %80 rPET
6	%20 Viscose %80 PES

Table 2. Vortex machine setting values.

	Machine Values
MDR	38
BDR	2,5
SLIVER AREA	0,150
SPINDLE	M
PRESURE	5
SPEED	450 m/minute

Each fiber blends were produced with two spinning technologies. A total of 12 different yarns were produced with 6 blends and 2 yarn spinning technologies. Yarns are produced with Vortex and ring spinning technologies.

2.1 Yarn Production

The advantages and disadvantages of the fiber type and production method were determined by comparing the yarns produced with the ring and Vortex spinning system and consisting of 6 different fiber mixtures. Vortex is a spinning technology with a high production speed. Ring is very old ang trustable method for production of yarn. Ring is very slower than Vortex. If suitable demands specification of yarns, Vortex prefer for fast production.

Soybean fiber is regenerated protein fiber. In production, the Vortex spinning machine speed of soybean fiber could be up to 350m/min due to its different fiber length and oily structure.

The image of soybean protein fibers and recycle polyester fibers produced in the Vortex machine is in Figure 1.

Figure 1. Soybean fiber and rPET fiber.

Spindle and draft rollers of the Vortex machine are in Figure 2.

Figure 2. Murata Vortex Machine.

2.1.1. Yarn Performance Test Results

Performance tests applied to 12 yarns are as follows: %CV-mass change coefficient, relative tensile strength, % elongation at break and hairiness in the yarn.

%CV- Coefficient of variation of yarns the capacitive fluctuation value in the yarn, shown in Table 3 and Figure 3. In the comparison based on the yarn production method, it is seen that ring is better than Vortex for all fiber blends. When examined in terms of fiber type, it is seen that the mass change of Soybean blended Vortex yarn is worse than other yarns, while Soybean blended ring yarns are good. The oily structure of soybean fiber and the variability in fiber length caused the capacitive fluctuation to be high in the yarn produced in Vortex. Additional steps in ring production reason in the elimination of fibers of different lengths.

Table 3. Coefficient of variation of yarn.

Number of Blends	Sample	Coefficient of variation of yarn (%CV) Vortex	Coefficient of variation of yarn (%CV) Ring
1	%20 Soybean %80 rPET	14,45	10,94
2	%20 Soybean %80 PES	13,99	10,69
3	%20 PES %80 rPET	13,37	10,59
4	%100 PES	12,68	10,17
5	%20 Viscose %80 rPET	12,37	12,10
6	%20 Viscose %80 PES	12,23	12,34

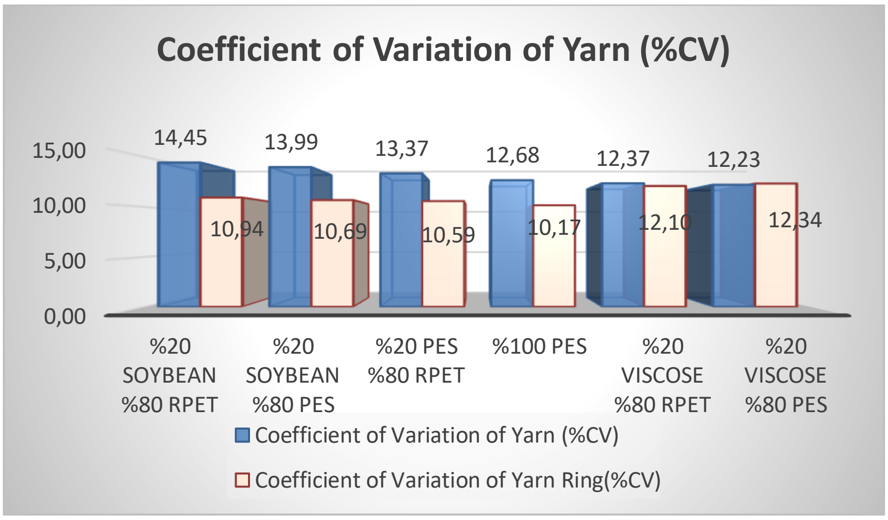

Figure 3. Graph of %CV.

Rkm is abbreviation of resistance per kilometer. It is calculated from the data of single yarn strength tests performed on manual or automatic single yarn testing installations. With Rkm - Resistance per kilometer can be measured. As a result of the resistance per kilometer tests, shown in Table 4 and Figure 4.

Table 4. Resistance per kilometer (Rkm) (Reisskilometer).

Number of Blends	Sample	Rkm Vortex	Rkm Ring
1	%20 Soybean %80 rPET	20,98	29,34
2	%20 Soybean %80 PES	22,08	29,82
3	%20 PES %80 rPET	23,65	24,17
4	%100 PES	24,79	24,23
5	%20 Viscose %80 rPET	19,86	18,78
6	%20 Viscose %80 PES	20,97	19,29

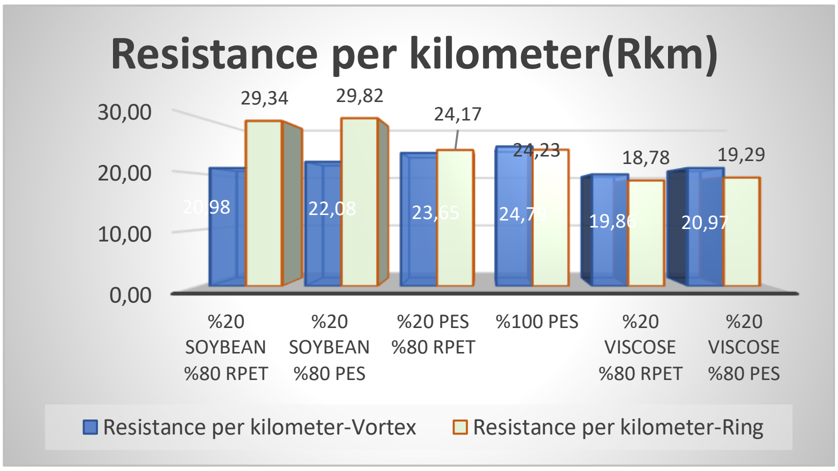

Figure 4. Graph of Rkm.

Compare of high % elongation at break shows that the yarn is more flexible and more resistant to breaking. The % break elongation value of ring yarn was found better than Vortex, shown in Table 5 and Figure 5.

Table 5. Elongation of break (%).

Number of Blends	Sample	(%) Vortex	(%) Ring
1	%20 Soybean %80 rPET	9,34	11,90
2	%20 Soybean %80 PES	9,13	12,21
3	%20 PES %80 rPET	9,06	12,22
4	%100 PES	9,08	12,11
5	%20 Viscose %80 rPET	8,80	11,80
6	%20 Viscose %80 PES	9,10	12,02

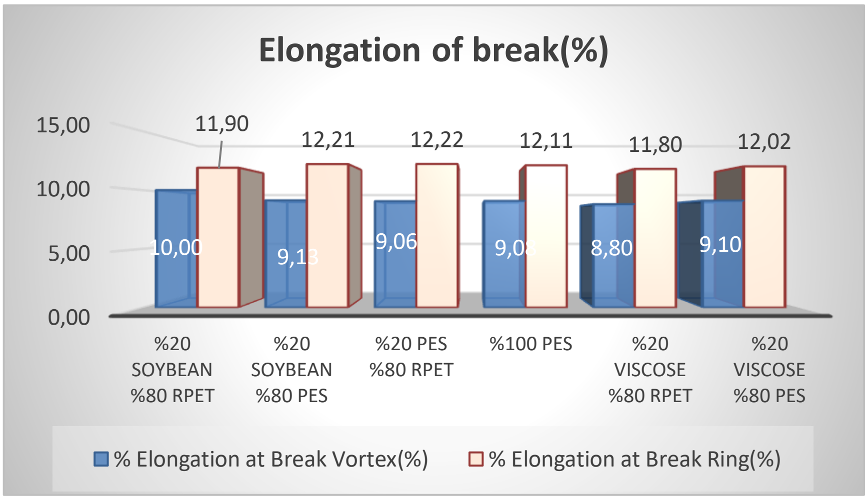

Figure 5. Graph of elongation break (%).

When the Hairiness Value is examined, the Hairiness value of Vortex yarn is better than ring yarn. Low hairiness prevents pilling when it becomes a fabric. Low hairiness in the yarn is preferred. Vortex is advantageous in terms of hairiness. The hairiness value of Vortex yarn is better than ring yarn. Low hairiness prevents pilling error when it becomes fabric. Test results shown in, Table 6 and Figure 6.

Table 6. Hairness index of yarns.

Number of Blends	Sample	Hairness Index (H) Vortex	Hairness Index (H) Ring
1	%20 Soybean %80 rPET	4,45	6,02
2	%20 Soybean %80 PES	4,78	5,60
3	%20 PES %80 rPET	4,60	6,03
4	%100 PES	4,32	5,75
5	%20 Viscose %80 rPET	4,69	6,02
6	%20 Viscose %80 PES	4,51	5,78

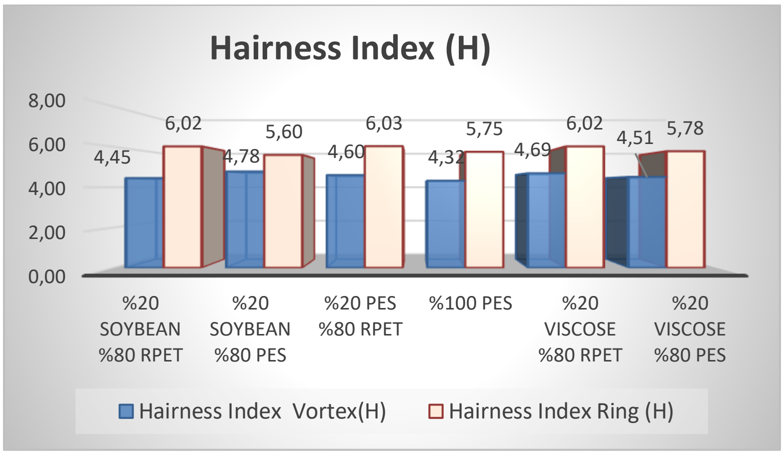

Figure 6. Graph of hairness index (H).

3. RESULTS

When the results of the performance tests applied to 12 yarns are examined. As a result of the yarn performance tests, it has been revealed that the strength values of the blended yarns of soybean protein fiber produced with Vortex spinning technology are lower than ring. The hairiness values of soybean blended yarns produced with Vortex are also lower than ring. Low hairiness positively affects pilling in the fabric.

Yarn performance test result, it has been revealed that the strength values of 20% soybean, 80% polyester with 20%soybean, 80% r PET blended yarns produced with Vortex spinning technology are lower than ring.

4. CONCLUSION

While there was no literature on the production of soybean protein fiber with Vortex before, this study contributed to the literature. It was understood that improvement studies should be carried out according to the strength tests carried out at the end of production.

ACKNOWLEDGMENT

We would like to thank ISKUR GROUP and Çukurova University Scientific Research Projects Unit for their contribution to the realization of the study. This study is supported by Çukurova University Scientific Research Projects Unit, under grant no ID FDK-2022-14473.

REFERENCES

[1] Tüksoy H.G. and all(2018). *A Comparative Analysis of Air-Jet Yarn Properties with The Properties of Ring Spun Yarns.* Industria Textila, 69, nr. 1.
[2] Erdumlu N. and all (2012). *Vortex spinning technology.* Taylor&Francis, ISSN: 0040-5167 (Print) 1754-2278.
[3] Rijavec T.,Zupin Z.(2011). *Soybean Protein Fibers*(SPF), ISBN :978-953-307-533-4, In Tech.
[4] Vynias D.(2018). Soyebean Fiber: *A Novel Fiber in the Textile Industry*, pp: 461-495, The University of Manchester. www.intechopen.com.
[5] Yıldırım F. and all(2014). *Soya Fasülyesi Protein Lifleri, Soya Fasülyesi Protein Liflerinin Genel Yapisi, Üretimi ve Çevresel Etkileri,* Uludağ Üniversitesi Mühendislik Fakültesi Dergisi, Cilt 19, Sayı 2, pp: 29-50.

QUANTITATIVE CHEMICAL ANALYSIS OF POPLAR AND POLYESTER BLENDED NONWOVENS

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ABSTRACT

Poplar fibers are short, lightweight, soft and hydrophobic fibers with large hollow lumen. They formed on the seeds of trees and reach a sufficient level of maturity in mid of April-May. In general, the fiber dissolution occurs upon breaking down the intermolecular forces due to sufficient penetration of the solvent. As part of the project, for the first time, poplar fibers will be dissolved with two different sulphuric acid concentrations (75 % and 50 %) at two different temperatures (40 °C and 60 °C). Although poplar fibers are also cellulose based fibers like cotton, there are substantial differences in their carbohydrate content, fiber diameter, and hollow lumen size which might influence the dissolution properties. Due to these substantial structural differences, poplar fiber should be dissolved at lower concentration (50 %) and at lower temperature (40 °C) compared to cotton fiber.

Keyword: *Fiber dissolution, Nonwoven, Poplar fiber, Populus*

1. INTRODUCTION

Poplar fibers are produced from the seed hairs. The fibers fall down from populus genus tree branches especially during the late spring [1]. They are short (average 0.95–1.59 cm), very light and soft, also hydrophobic and have large hollow lumen [2]. Additionally, they consist mainly of lignocellulose and have morphological structure like kapok and milkweed fibers [3]. They are environmentally friendly and for lab scale production, just required mechanical cleaning by steel tweezers [4]. Despite many advantages of using poplar fibers, every year tons of poplar fibers wasted because it cannot be used in any industrial application [4] due to their short lenght [5].

Poplar fiber, kapok-like substance, is lignocellulosic single cell fiber and more than 90 % of its content is carbohydrates [5]. Poplar fiber contains 41-44 % cellulose, 28-29 % lignin, 19-21 % hemicellulose and 4-9 % plant wax. It can be seen that poplar fiber slighlty differs from cotton fibers in chemical composition [1]. Therefore, it is not possible to dissolve poplar fibers like cotton, with % 75 sulphuric acid. Moreover, natural fine fiber size, hollow structure [6] and crystallinity have an effect on the kinetics of dissolution to provide information for efficient processing [7].

There are very few studies on the utilization of poplar fiber in the literature. To the best of our knowledge, this is the first report that identifies the dissolution process of poplar fiber. In this study, to evaluate the dissolution behavior and solubility of poplar fiber, considering the structure and chemical composition, were investigated and compared with the process applied for cotton fiber. The response and behavior to the chemical under different test conditions were evaluated. Its properties have also investigated by FT-IR analysis to determine the potential of poplar fiber for further studies.

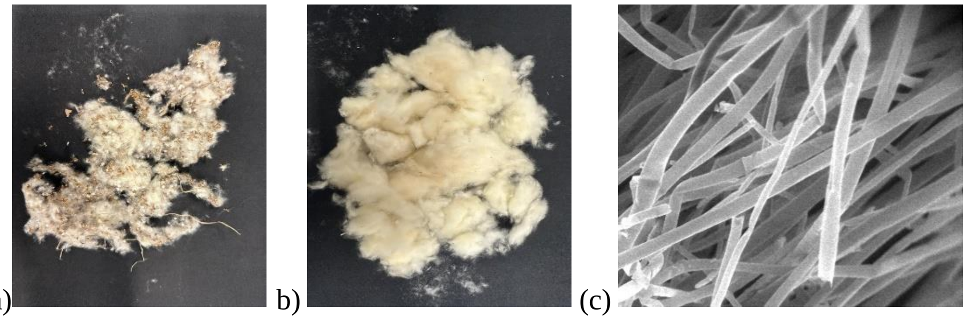
2. EXPERIMENTAL STUDY

2.1 Materials

2.1.1 Poplar fiber preparation

Poplar (Populus nigra italica) fibers were collected from trees in Istanbul, Turkey in May 2022. Fibers were freed from seeds and foreign materials by hand with the help of steel tweezers to use in experimental studies. After this process, aeration with nitrogen gas was performed to remove the remaining small impurities.

Photos of collected poplar fibers (a), cleaned from the seed manually (b) and longitudinal SEM images (c) are shown in Figure 1.



a) b) (c)

Figure 1. (a) Collected poplar fibers, (b) manually cleaned poplar fiber, (c) longitudinal SEM images of poplar fiber.

2.1.2 Preparation of poplar/ PET blended nonwoven samples

Webs were formed at carding machine and then bonded mechanically at needle punching machines. Laboratory type sample carding machine was used for making webs. Firstly, polyester fibers and poplar fibers were weighted according to blending ratios, as shown in Table 1. Polyester fibers were fed into the carding machine two times, first time for opening the fibers and second time for providing a smooth and even distribution. Polyester webs were produced at the end of the carding machine were wound on rotating drum. Then, the poplar fiber was laid into and sandwiched with these polyester webs and fed to the carding machine two times. After the polyester/ poplar blended webs are formed, bonding of webs was carried out in the industrial type needle punching machine which uses barbed felting needles.

Table 1. Nonwoven web properties.

SAMPLE NUMBER	SAMPLE NAME	POLYESTER FIBER (G)	POPLAR FIBER (G)
1	**PET-PO30**	100	30
2	**PET-PO60**	100	60

Nonwoven fabrics were bonded in the down-stroke and up-stroke needle punching machines at adjusted parameters, given in Table 2.

Table 2. Needle punching machine parameters.

FEEDING TOP	STROKES TOP	DELIVERY TOP	FEEDING BOTTOM	STROKES BOTTOM	DELIVERY BOTTOM
0.97	354	1.07	1.03	351	1.11

2.1.3 Chemicals

All the chemical reagents such as acetone, sulphuric acid (H_2SO_4, purity: 95-97 %) and nitrobenzene ($C_6H_5NO_2$, purity: >99 %) were supplied from Merck. While sulphuric acid was diluted with distilled water to the desired concentrations (75 % and 50 %) before use, nitrobenzene was used without dilution. Whatman filter paper No: 1 was used to study the dissolution process. To prepare 75 % (mass fraction) sulphuric acid, 700 ml of concentrated sulphuric acid is added carefully to 350 ml of distilled water. After the solution has cooled to room temperature, it is diluted to 1 L with water. Separately, 50 % concentration is prepared by adding 450 ml of acid to 550 ml of distilled water.

2.2 Methods

2.2.1 Fourier-transform infrared spectroscopy (FT-IR)

The chemical compositions of poplar/ polyester blended nonwoven fabrics which have different blending ratios were analyzed by Fourier transform infrared spectroscopy (Perkin Elmer UATR) at room temperature. Data were collected in the range of 4000–450 cm^{-1} with a resolution of 4 cm^{-1}. Constant pressure was applied on the samples that were placed on the diamond/ZnSe crystal and all data were obtained using Spectrum software.

2.2.2 Scanning electron microscopy (SEM)

In order to get information about the surface properties, the poplar fiber were examined under the scanning electron microscope. TESCAN VEGA3 at 10 kV accelerating voltage and working distance between 2.08- 6.92 mm were employed. To prepare samples for SEM analysis, samples were coated with Au/Pd under vacuum for 3 minutes using Quorum SC7620 Sputter Coater.

3. RESULTS

Our first attempts to dissolve poplar fiber was inspired from the test method (BS EN ISO 1833-11:2017) which is carried out to determine the ratio of cellulosic fiber in textiles made of mixtures of cellulose/ polyester fiber. According to this method, cellulosic fiber is dissolved out from a known dry mass of the mixture, with 75 wt. % sulphuric acid. Firstly, 0.1 g poplar was added into 20 ml 75 wt. % H_2SO_4 aqueous solution and the beaker is shaken carefully to wet out the specimen. Temperature is increased slowly to 60 °C. Interestingly, transparent solution was turned into black rapidly, indicating that fiber sample was damaged or even burned rather than dissolving the poplar fiber. This has encouraged us to study the dissolution of poplar fiber. Figure 2 shows the pictures of the dissolution process of poplar under different test conditions (in terms of H_2SO_4 concentration and temperature) in the laboratory.

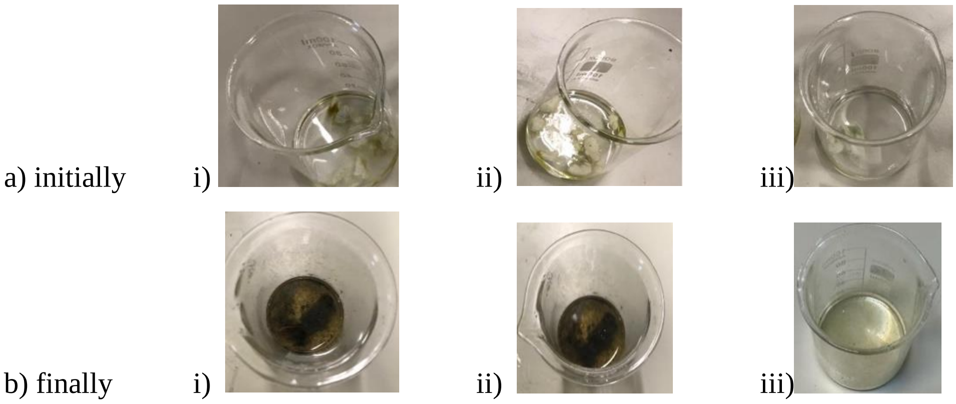


Figure 2. Pictures (a) at the beginning and (b) at the end of the dissolution process of poplar fiber in the 75 wt. % solvent at 60 °C (i), in the 75 wt. % solvent at 40 °C (ii), in the 50 wt. % solvent at 40 °C (iii) respectively.

As can be seen from the Figure 2, for poplar fiber, a complete dissolution of amount around 0.5 % (w/v) was observed in 50 wt. % H_2SO_4 at 40 °C. When the concentration of sulphuric acid was 75 wt. %, the poplar fibers completely damaged, which is evident from the discoloration that occurs initially upon contact with the solvent. Also, sulphuric acid aqueous solution at this concentration damaged fiber even at lower temperature. Therefore, sufficiently good dissolution of poplar fiber, required H_2SO_4 concentration was 50 wt. %. Higher temperature causes faster dissociation of fibers, so it was worth noting that all the poplar fibers disappeared in 50 wt. % sulphuric acid solution at 40 °C and no dark fibers and discoloration existed in the solution. Consequently, this acid concentration and temperature was used to prepare solutions in the quantitative chemical analysis of poplar/ polyester blended nonwoven fabrics.

In poplar/ polyester blended nonwoven fabric production, the fibers were blended in the specified proportions. However, it might be wrong to calculate the mixing ratio according to these amounts specified in the beginning, since the short poplar fibers fly away during the carding and needle-punching processes. Therefore, in order to determine the mixing ratios, quantitative chemical analysis had to be conducted.

Firstly, for both two fabrics, polyester dissolving process was performed due to the test method using nitrobenzene. 10 ml of nitrobenzene is put in the beaker and warmed up to its boiling temperature. After the solution boiled, 0.1 g fabric sample is added on it and waited for 2 minutes. The liquid was then filtered, liquor has drained under gravity through filter paper. Any residual fibers were transferred by washing out the residue with 10 ml acetone. The same washing process on the filter paper was repeated with 10 ml acetone once again. Finally, residue was collected, dried at 40 °C and weighed; its mass is expressed as a percentage of the dry mass of mixture. The polyester fiber ratio is found by the difference. In the case of PET-PO30 fabric, mass of residue (poplar fiber) was 0.024 g and was 0.040 g for PET-PO60 fabric. The results imply that the ratio of polyester fiber could be calculated as 76% for PET-PO30 and 60 % for PET-PO60 fabric.

The structure change of PET-PO60 blended nonwoven fabric after polyester dissolution was tested in order to reveal if the process results complete dissolution. Figure 3 shows the FT-IR spectra of fabrics before (a) and after dissolution (b) in nitrobenzene and pure poplar fiber (c).

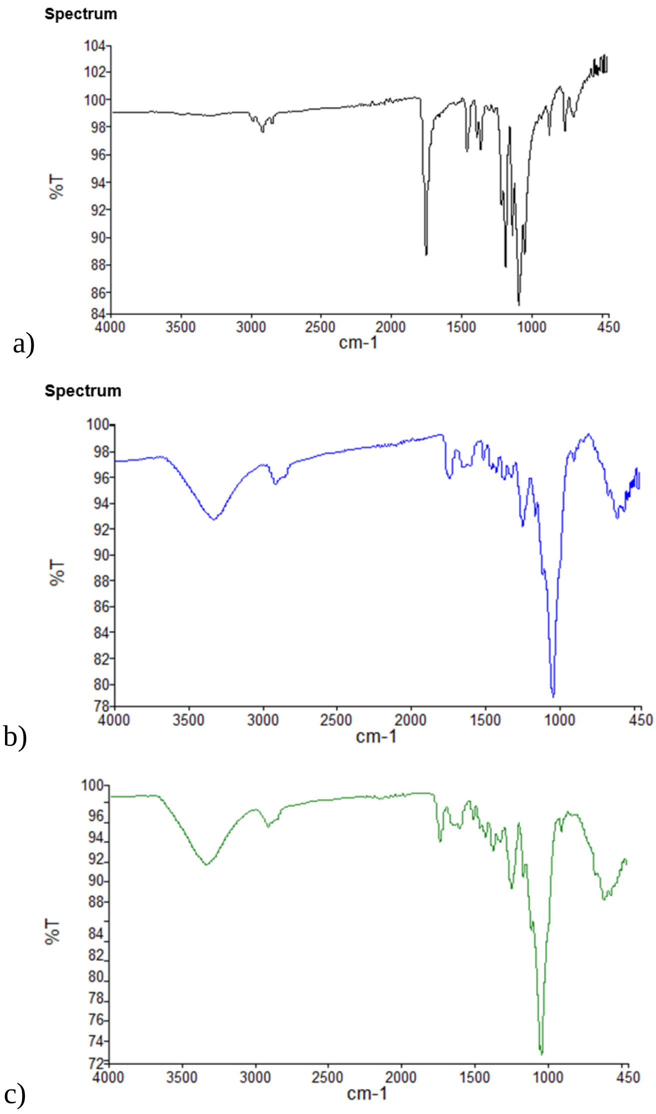


Figure 3. FT-IR of PET-PO60 fabric before (a) and after dissolution (b) in nitrobenzene and pure poplar fiber (c).

As shown in the FT-IR spectrum of poplar/ polyester blended nonwoven fabric before dissolution, the absorption bands were observed in two wave number regions of 1750 - 690 cm^{-1} and 2950 - 2850 cm^{-1} (Figure 3(a)). The presence of peaks on the spectra coming from poplar and polyester corresponds to characteristic bonds in these fibers. Besides, in Figure 3(b), visible differences were noted in the spectrum of sample after dissolution. Differences in appearance of old peaks in the spectrum indicated that polyester was completely disappeared. The FTIR spectra of the pure poplar fiber in Figure 3(c) was very similar to spectrum of dissolved sample (Figure 3(b)). This result implied the presence of poplar fiber in residue as only component what corresponds to complete removal of polyester fiber after dissolution.

Combined with these results, to ensure that the residue was poplar fiber, it was dissolved in sulphuric acid and checked to see whether completely dissolved or not. 10 ml of sulphuric acid at 50 wt. % was added to the residual specimen contained in the beaker. The beaker shaken carefully to wet out the specimen and kept at 40 °C. After applying mechanical stirring for 2 minutes, transparent solution was obtained shows all the residue was poplar fiber and dissolved completely, in accordance with the FT-IR results. The component content analysis results of fibers shows that the content of poplar fiber is about 24 % in PET-PO30 and 40 % in PET-PO60 nonwoven fabric.

4. CONCLUSION

The effect of concentration of H_2SO_4, with 75 % and 50 % concentration ratios, and temperature, at 40 °C and 60 °C on dissolution were examined. Aqueous solution of sulphuric acid with concentration of 50 wt. % was found to be a good and direct solvent for poplar fiber at low temperature (40 °C). Considering these results, this work suggested a convenient quantitative chemical analysis to determine the poplar fiber ratio in the poplar/ polyester blended nonwovens. The same procedure can be applied on the other textile products such as yarns, woven and knitted fabrics which might have poplar fibers.

ACKNOWLEDGMENT

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REFERENCES

[1] Gurarslan, A., & Narinc, M. E. (2019). Investigating the rose oil and toluene absorption of populus fiber. *Textile Research Journal*, *89*(10), 1952–1963.
[2] Chen, H. L., & Cluver, B. (2010). Assessment of poplar seed hair fibers as a potential bulk textile thermal insulation material. *Clothing and Textiles Research Journal*, *28*(4), 255-262.
[3] Likon, M., Remškar, M., Ducman, V., & Švegl, F. (2013). Populus seed fibers as a natural source for production of oil super absorbents. *Journal of Environmental Management*, *114*, 158-167.
[4] Narinc, M. E., & Gurarslan, A. (2018, December). AgNW coated on poplar fibers for flexible capacitors. In *IOP Conference Series: Materials Science and Engineering* (Vol. 460, No. 1, p. 012022). IOP Publishing.
[5] Zhang, X., Li, Z., Yu, Y., & Wang, H. (2018). Characterizations of poplar catkin fibers and their potential for enzymatic hydrolysis. *Journal of Wood Science*, *64*(4), 458-462.
[6] Jensen, E., & Ross, C. (1995). *Trees to know in Oregon*. Oregon State University Extension Service and Oregon Department of Forestry, Oregon,
[7] Ghasemi, M., Alexandridis, P., & Tsianou, M. (2018). Dissolution of Cellulosic Fibers: Impact of Crystallinity and Fiber Diameter. *Biomacromolecules*, *19*(2), 640-651.

INCREASING THE FASTNESS VALUES OF THE SULPHUR DYED WOVEN FABRICS USING CATIONIC POLYMER

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ABSTRACT

Sulphur dyestuffs are commonly being used for dyeing woven fabrics made of cotton. However, they offer limited color fastness performance. In this novel study we have researched a way to increase color fastness performance of Sulphur dyed woven fabrics. We have used gabardine woven fabric with poor color fastness values evaluated with the lightbox, and used a cationic polymer called SFX from Pulcra company and applied after the fabric was dyed. Test results shows that the color fastness rating of the gabardine woven fabric has risen.

Keyword: *Cationic Polymer, Sulphur Dye, After-Treatment, Color Fastness, Gabardine, Cotton Fabric*

1. INTRODUCTION

A colorant's ability to maintain its distinctive qualities in the presence of degradation factors including exposure to light and washing is known as color fastness. To determine whether the material is suitable for the intended finish application, product performance and analysis are performed. It's a designation for a substance [1]. Together with comfort features while being worn, the color of the denim fabric, which has a significant market share in the textile industry, is a crucial factor. While some consumers enjoy that the color of denim materials change as they are worn, others prefer that the colors of the fabrics remain stable.[2]

Sulphur dyes can be used to deposit insoluble pigments inside fibers more affordably, but their shade range is limited to black, mauves, olives, bordeaux, and reddish-browns. One of the first and best-known sulphur dyes is CI Sulphur Black 1, a well-liked black with good fastness properties that is still in use today [3].

Among all textile items, denim has the broadest public appeal and has had a significant cultural and societal impact on consumers [4]. One of the most often used dye groups for application on cellulosic fibers is sulfur. On these fibers, the dyes often produce moderate to good lightfastness, good wet fastness, but poor fastness to bleaching, medium to heavy depth hues at affordable prices [5].

The gradual fading of color and, in some situations, the staining of neighboring garments is caused by exposure to light, heat, harsh rubbing, or washing detergents. Because to the change in appearance and aesthetic value, this may render a garment useless [6].

In this novel study we have used a cationic polymer as after treatment to increase the fastness ratings for gabardine woven fabrics with poor color fastness ratings. A range of percantage (30g/L, 50g/L, 100g/L) of this Cationic Polymer called SFX has been applied and tested, the best result has been achived with 50g/L.

2. EXPERIMENTAL STUDY

Throughout the study, Sulphur dyed gabardine woven fabrics supplied by Pulcra Chemicals were used. Sulphur dyeing recipe is as follows: 10% (owf) Sulphur Dye, 1.5%(owf) Sodium Sulphate as reducing agent, 8g/L sodium chloride, 7g/L sodium carbonate. Gabardine woven fabric and all necessary chemicals including dyestuff were put in ATC-DYE HT PRC05F dyeing machine, and dyeing was carried at the temperature of 100°C, dyeing time of 90 minutes and the liquor ratio of 1:20. After completion of dyeing Sulphur dyed fabrics were rinsed and dried at room temperature.

2.1 Method

After testing the Sulphur dyed woven fabrics, a cationic polymer namely Stabifix SFX was applied at varying concentrations of 30g/L, 50g/L, 100g/L with a wet pick-up of 70%(Fig.1). Cationic polymer has been applied to the dyed fabric using pad-cure method and the curing carried at a temperature of 130°C for 3 minutes. (Fig.2)

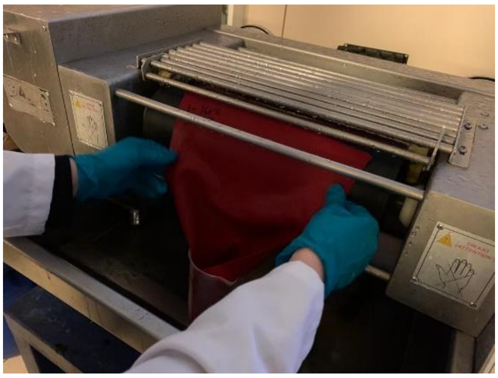


Figure 1. Padding machine.

Figure 2. Curing machine.

2.2 Testing

Prior to testing all samples were conditioned according to ISO-139. Sulphur dyed sample and the after-treated samples with various concentrations were tested for crocking fastness according to ISO-105X12, light fastness according to ISO-105B02, washing fastness according to ISO-105C06 option A1S, water fastness according to ISO-105E01, fabric stiffness according to ASTM D 4032-8.

3. RESULTS

Color fastness to crocking test results are presented in Table 1. As can be seen form Table 1, for all treated samples, both dry and wet crocking performances increased significantly.

Table 1. Color fastness to crocking test results.

	D	W
UNTREATED	2	1
30G/L	4	2
50G/L	4/5	2/3
100G/L	4	2/3

Color fastness to washing test results are presented in Table 2. As can be seen form Table 1, for all treated samples kept their color fastness to washing performance, with %50 SFX offering better performance among treated samples.

Table 2. Color fastness to washing test results.

	Cotton	Wool	Silk	Viscose	Polyamide	Polyester	Acrylic
Untreated	4/5	4/5	4/5	4/5	4/5	4/5	4/5
30g/L	4/5	4/5	4/5	4/5	4/5	4/5	4/5
50g/L	4	4/5	4/5	4/5	4/5	4/5	4/5
100g/L	4/5	4/5	4/5	4/5	4/5	4/5	4/5

Color fastness to water test results are presented in Table 3. As can be seen form Table 1, all treated samples kept their color fastness to water performance.

Table 3. Color fastness to water test results

	Cotton	Wool	Silk	Viscose	Polyamide	Polyester	Acrylic
Untreated	4/5	4/5	4/5	4	4	4	4/5
30g/L	4	4	4	4	3/4	4	4/5
50g/L	4/5	4/5	4/5	4	4/5	4/5	4/5
100g/L	4/5	4/5	4/5	3/4	4/5	4/5	4/5

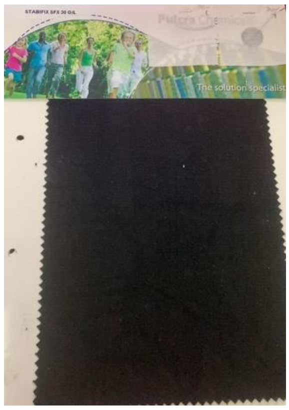
Rigidity and color fastness to light test results are presented in Table 4. As can be seen form Table 1, for all treated samples kept their color fastness to light performance, with acceptable increase in rigidity.

Table 4. Rigidity and color fastness to light test results

	Rigidity	Light Fastness
Untreated	0.903507	4/5
30g/L	1.677915	4/5
50g/L	1.498403	4/5
100g/L	2.157569	4/5

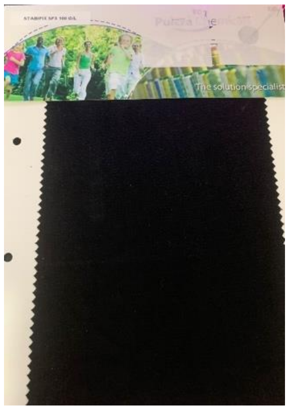
Images taken from untreated and treated samples are presented in Figure 2. It is apparent that a grey scale 4/5 level color change is observed on all treated samples compared to untreated one. This is acceptable, and rather expected as the surface of the fabric is altered with a surface treatment.

(A)



(B)

(C)



(D)

Figure 3. General appearance after treatment A) Without SFX B) 30g/L SFX C) 50g/L SFX D) 100g/L SFX.

As can be seen in the figures below and the result table the best choice for this process is the solution of 50g/L. This choice is also cost effective.

4. CONCLUSION

In this novel study we applied a cationic polymer to a gabardine woven fabric with poor color fastness performance and it increase the rating by 0,5-2 on the grey scale without sacrificing the fabric touch. Thanks to this after-treatment the fabric performance has enhanced which adds value to the final product. By expanding this research, the chemical recipe can be applied as an after treatment for other various fabrics and dyes.

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REFERENCES

[1] Ramesh Kumar, M., Sathish Kumar, T., Prakash, C., & Jayakumari, M. (2022). Investigation on fastness properties of plated interlock knitted fabrics. *Cleaner Engineering and Technology*, *8*, 100474. https://doi.org/10.1016/j.clet.2022.100474

[2] Sezgin Bozok, S., & Ogulata, R. T. (2021, January 4). Effect of silica based sols on the optical properties and color fastness of synthetic indigo dyed denim fabrics. *Coloration Technology*, *137*(3), 209–216. https://doi.org/10.1111/cote.12521

[3] Ingamells, W. (1993, January 1). *Colour for Textiles: A User's Handbook*. Woodhead Publishing Limited. https://doi.org/10.1604/9780901956569

[4] Paul, R. (2015). Denim and jeans: an overview. In Denim: manufacture, finishing and application, (pp. 1–11). Woodhead Publishing, Cambridge.

[5] Burkinshaw, S., & Gotsopoulos, A. (1996, December). The pre-treatment of cotton to enhance its dyeability—I. Sulphur dyes. *Dyes and Pigments*, *32*(4), 209–228. https://doi.org/10.1016/s0143-7208(96)00026-5

[6] Chakraborty, J. (2011). An overview of dye fastness testing. *Handbook of Textile and Industrial Dyeing*, 207–224. https://doi.org/10.1533/9780857093974.1.207

MORPHOLOGICAL AND MECHANICAL ASSESSMENT OF ELECTROSPUN PLGA VASCULAR SCAFFOLDS

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ABSTRACT

Cardiovascular disorders are the leading cause of global mortality and typically necessitate bypass surgery to replace the damaged blood vessel. Autologous vessels and commercial synthetic grafts are insufficient to replace small-diameter blood vessels due to the scarcity and harsh harvesting procedure of autologous vessels and the shortcomings in the clinical performance of synthetic grafts, which might result in intimal hyperplasia, thrombosis, and compliance mismatch. As a result, there is a critical need for tissue-engineered vascular grafts that can meet morphological, mechanical, and biological characteristics. While the scaffold is degrading over time and allowing the body for revascularization, it should preserve the mechanical properties until the regeneration of native tissue is complete. Vascular grafts with superior mechanical properties might be obtained by using appropriate synthetic biopolymers and utilizing fiber orientation. In this study, neat poly(lactic-co-glycolic acid) (PLGA) tubular scaffolds with randomly distributed or radially oriented fibers were produced by electrospinning, and the effect of fiber orientation on morphological and mechanical properties was investigated. The results show that fiber orientation has a great influence on both the morphology and mechanical characteristics of the PLGA scaffolds. The radial fiber orientation improved the tensile strength values in radial direction, and burst strength, whereas it was not favorable for the compliance.

Keyword: *Tissue engineering, Vascular grafts, Compliance mismatch, PLGA*

1. INTRODUCTION

Tissue engineering confronts a significant problem in replicating the particular architecture and mechanical properties of the arterial wall in order to meet the basic requirements of the native vessels with diameters smaller than 6 mm [1, 2]. An efficient vascular graft ought to possess a suitable topology, be biocompatible, antithrombogenic, bioactive, have good mechanical characteristics, and instantly adapt to the existing hemodynamic environment [3]. The mechanical characteristics of vascular prostheses influence biological activities such as the growth of smooth muscle and endothelial cells and accelerate extracellular matrix synthesis via enhanced macrophage activity. Thus, vascular grafts with inadequate mechanical characteristics create an unfavorable microenvironment for neotissue formation [4]. The design criteria that affect the properties of vascular grafts can be categorized under two topics: material selection and constructional components such as fiber diameters, pore sizes, fiber orientation, and wall thickness [5]. For instance, fiber alignment influences how cells grow, how they build their morphologies on scaffolds, and how they align through the vessel wall. Moreover, radial fiber orientation is known to have a beneficial impact on the values of modulus, tensile strength in the same direction, and burst strength, whereas it reduces compliance [6]. On the other hand, excessive wall thickness within the vascular scaffolds creates a disadvantageous situation in terms of cell activities and proliferation, as it restricts features such as porosity and compliance [7]. Also, the choice of biomaterials is critical in establishing the framework for mechanical qualities, cellular activities, biocompatibility, biodegradability, and anti-toxicity [8]. In this regard, PLGA is a synthetic biopolymer which supports the biological activities and has tunable mechanical strength and biodegradation rate [9]. Malik et al. (2021), produced tubular fibrous scaffolds with oriented fibers consisting of various biopolymers such as PLGA, polycaprolactone and poly (vinyl acetate). PLGA vascular grafts outperformed other polymers in terms of tensile strength (9.1 ± 0.6 MPa), suture retention strength, and burst pressure (350 ± 50 mmHg). These scaffolds have also been discovered to have appropriate porosity and elongation characteristics (87% and 183%, respectively), making them viable materials for vascular grafts. When the aligned scaffolds were compared with their counterparts, remarkable improvements in the mechanical properties such as tensile stress, burst strength, and tensile strain were observed in all the samples (2 MPa vs. 9.1 MPa, 350 mmHg vs. 680 mmHg, and 120% vs. 183%, respectively, for PLGA) [10]. In another study of Johnson et al. (2015) the effect of polymer selection and wall thickness on the mechanical features of the vascular prosthesis was investigated. First of all, the biomechanical characteristics of electrospun vascular grafts made of various biopolymers were examined. The bursting strength of the scaffold made of PLGA showed the highest value with 3.3 MPa, which is slightly higher than the burst pressure of commercially used Dacron graft with 3.2 MPa. However, compliance results revealed that PLGA grafts demonstrate a relatively low compliance value of 1.9%/mmHg [11].

Within the scope of this study, electrospun vascular prostheses consisting of randomly distributed and radially oriented PLGA fibers were fabricated for the purpose of assessing both the effect of fiber arrangement on the mechanical properties in terms of tensile strength and strain, burst strength, and compliance, as well as determining the suitability of PLGA scaffolds in regards to physical, morphological, and mechanical characteristics.

2. EXPERIMENTAL STUDY

2.1 Materials

PLGA (Mw: 50,000–75,000 g/mol, PLA/PGA:85/15) was used as a polymer, whereas chloroform (CH), acetic acid (AA), and ethanol (ETH) were utilized as the solvent system components. The chemicals were purchased from Sigma-Aldrich.

2.2 Methods

2.2.1. Fabrication of PLGA vascular grafts

PLGA was dissolved in CHL/ETH/AA (8/1/1 wt.) at a concentration of 18% wt. The tubular samples were manufactured by an electrospinning unit. The PLGA solutions were delivered by using a feeding rate of 2.25 ± 0.25 ml/h and subjected to 11 ± 2 kV voltage by using 20 cm needle to collector distance. Rotating rod collectors with different rotational speeds of 200 rpm and 10,000 rpm were used to achieve samples with randomly distributed (PLGA_R) and radially oriented fibers (PLGA_O). The spinning time for all samples was set at 40 minutes.

2.2.2 Morphological and physical characterization

SEM Analysis

The surface morphologies of electrospun surfaces were investigated by using a scanning electron microscope (SEM). The SEM images of tubular scaffolds were taken with magnifications of 1kx.

Fiber diameter and wall thickness measurement

The Image J Software System was used to calculate average fiber diameters from SEM images of at least 50 distinct fibers. The wall thickness of samples was measured with a Standard Gage Electronic External Micrometer (Hexagon Metrology, Turkey).

2.2.3 Mechanical assessment

Tensile strength and strain

Tensile testing was performed by using Zwick-Roell Z005 universal testing machine (ZwickRoell, Germany) for the assessment of the mechanical performance of the tubular grafts. The tubular samples were tested in axial (0°) and radial (90°) directions in both planar (_P) and tubular form (_T). The planar test samples were cut into 10mm x 15mm (width x length) dimensions from tubular scaffolds whereas tubular samples with 1.5 cm length were cut for testing in tubular manner. The cross-head speed was set at 10 mm/min while the distance between the gauges was 5 mm.

Burst pressure measurement

The burst pressure properties of the tubular graft structures were measured by custom design burst tester (Inovenso, Turkey). The balloon was placed into the tubular samples cut in 4 cm length. Then, the sample ends were fastened into the air nozzles with the help of sleeves, and pressurized air flow was provided. The burst pressure value was recorded when the sample fails as a result of supplied air pressure from the nozzles.

Compliance

The custom-designed device with provided air flow used to measure the compliance at a physiologically equivalent pressure of 80–120 mmHg. The compliance values were calculated by the formula given in Eq. 1.

$$\%compliance = \frac{\frac{R_{p_2}-R_{p_1}}{R_{p_1}}}{p_2-p_1} \times 10^4 \qquad \text{Eq. 1}$$

where R_{p2} is a pressurized radius at diastolic pressure (mm), R_{p1} is a pressurized radius at systolic pressure (mm), p_1 is a diastolic pressure (mmHg), and p_2 is a systolic pressure (mmHg).

3. RESULTS

3.1 SEM analysis

SEM images, which are represented in Figure 1, reveal that both scaffolds consist of smooth, homogenous, and bead-free fibers. On the other hand, the radial fiber orientation was achieved when the collector speed was set at 10,000 rpm. The high collector speed causes a higher linear velocity of the mandrel, which supports the fiber alignment in the circumferential direction [12].

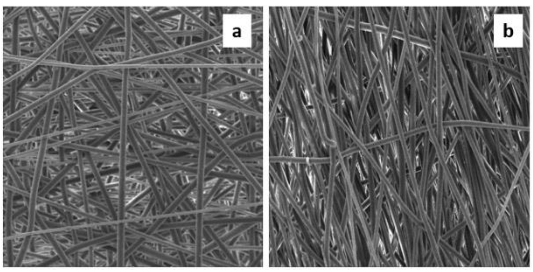

Figure 1. SEM images at 1kx magnification of neat PLGA samples produced on tubular collector with rotational speeds of 200 rpm and 10,000 rpm (a) PLGA_R and (b) PLGA_O.

3.2 Fiber diameter and wall thickness measurement

In Table 1, it can be seen from the fiber diameter values that the PLGA_O sample has thinner fibers than the PLGA_R sample. This situation can be explained by the stretching of the fibers because of the rotational movement and speed of the rotating collector [13, 14]. The wall thickness values measured in both grafts are sufficient and fall within the wall thickness range given for vascular grafts in the literature (200 µm-600 µm) [15]. It is also emphasized that the wall thickness of the vascular grafts should be as thin as possible if they can demonstrate enough mechanical endurance and biodegradation [16].

Table 1. Fiber diameters of PLGA vascular grafts.

Samples	Fiber diameter (µm)	Wall thickness (µm)
PLGA_R	2.579 ± 0.782	208 ± 33
PLGA_O	2.404 ± 0.464	245 ± 28

3.3 Tensile strength and elongation

When the tensile strength and strain values (Table 2) are investigated, it has been seen that the radial fiber orientation contributed to the strength values in the radial direction, whereas it caused a decrement in the tensile strength values in the longitudinal direction as the fibers were all aligned in the radial direction, which enabled them to resist the applied stress collectively [17]. On the other hand, the elongation values are improved in all directions with radial fiber orientation. In addition, the strain value of PLGA_O in the radial direction is much lower than that in the longitudinal direction because, as the oriented fibers are already under stress in their alignment direction and there are fewer junctions of fibers, they cannot be stretched too much in that direction [18].

Table 2. The tensile strength and strain values of the PLGA tubular samples with randomly distributed and radially oriented fibers.

	Test direction	Tensile Strength (MPa)	Strain (%)		Test direction	Tensile Strength (MPa)	Strain (%)
PLGA_R	0º_P	4.53 ± 0.80	60.41 ± 17.09	**PLGA_O**	0º_P	1.85 ± 0.42	851.01 ± 115.39
	90º_P	3.81 ± 0.07	48.34 ± 5.61		90º_P	6.23 ± 0.42	54.61 ± 20.84
	0º_T	5.89 ± 0.96	116.26 ± 55.85		0º_T	2.89 ± 0.23	1085.39 ± 83.10

3.4 Burst strength and compliance

The burst strength and compliance measurement results are given in Table 3. The values show that the fiber orientation resulted in improved burst strength, whereas it reduced the compliance levels. This situation is also supported by the study of Grasl et al. (2021), which showed that the burst strength of polylactic acid scaffolds increased from 570 ± 188 mmHg to 7641 ± 902 mmHg with radial fiber orientation, whereas compliance was reduced from 29.7%/100 mmHg to 4.1%/100 mmHg by fiber orientation in the radial direction because of the increased stiffness of the polyurethane scaffolds [19]. The results showed that the mechanical properties satisfy the minimum limits for the human saphenous vein (1599 mmHg and 0.6-1.5 %/100 mmHg) [20].

Table 3. The burst strength and compliance values of the PLGA tubular samples with randomly distributed and radially oriented fibers.

	PLGA_R	PLGA_O
Burst Strength (mmHg)	1873.50 ± 136.47	2889.00 ± 32.53
Compliance (%/100 mmHg)	1.416 ± 0.025	1.345 ± 0.822

4. CONCLUSION

Optimizing the design of the PLGA scaffolds by fiber orientation has proven to be a useful solution in regards to mechanical properties. Radial fiber orientation was successfully achieved in the produced fibrous vascular grafts, which also have sufficient wall thickness for mechanical tests. Alignment of the fibers along the periphery of the graft contributed to the tensile strength values in the radial direction and burst strength, resulting in a decrease in the compliance values. At the same time, the difference between the elongation values in the longitudinal and radial directions dramatically increased in the scaffolds with a radial orientation. The overall results showed that the manufactured scaffolds are promising for use in vascular grafts and can mimic the mechanical response of the native blood vessels if the stiffness problem in the radial direction can be eliminated by polymer blending or a multi-layered design approach for taking advantage of more ductile polymers.

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REFERENCES

[1] Nerem, R. M., & Seliktar, D. (2001). Vascular tissue engineering. In Annual Review of Biomedical Engineering (Vol. 3, pp. 225–243). https://doi.org/10.1146/annurev.bioeng.3.1.225

[2] Awad, N. K., Niu, H., Ali, U., Morsi, Y. S., & Lin, T. (2018). Electrospun fibrous scaffolds for small-diameter blood vessels: A review. In Membranes (Vol. 8, Issue 1). MDPI AG. https://doi.org/10.3390/membranes8010015

[3] Obiweluozor, F. O., Emechebe, G. A., Kim, D. W., Cho, H. J., Park, C. H., Kim, C. S., & Jeong, I. S. (2020). Considerations in the Development of Small-Diameter Vascular Graft as an Alternative for Bypass and Reconstructive Surgeries: A Review. In Cardiovascular Engineering and Technology (Vol. 11, Issue 5, pp. 495–521). Springer. https://doi.org/10.1007/s13239-020-00482-y

[4] Zhao, L., Li, X., Yang, L., Sun, L., Mu, S., Zong, H., Li, Q., Wang, F., Song, S., Yang, C., Zhao, C., Chen, H., Zhang, R., Wang, S., Dong, Y., & Zhang, Q. (2021). Evaluation of remodeling and regeneration of electrospun PCL/fibrin vascular grafts in vivo. Materials Science and Engineering C, 118(August 2020). https://doi.org/10.1016/j.msec.2020.111441

[5] Yalcin Enis, I., & Gok Sadikoglu, T. (2018). Design parameters for electrospun biodegradable vascular grafts. In Journal of Industrial Textiles (Vol. 47, Issue 8, pp. 2205–2227). SAGE Publications Ltd. https://doi.org/10.1177/1528083716654470

[6] Ozdemir, S., Yalcin-Enis, I., Yalcinkaya, B., & Yalcinkaya, F. (2022). An Investigation of the Constructional Design Components Affecting the Mechanical Response and Cellular Activity of Electrospun Vascular Grafts. Membranes, 12(10), 929. https://doi.org/10.3390/membranes12100929

[7] Meng, X., Wang, X., Jiang, Y., Zhang, B., Li, K., & Li, Q. (2019). Suture retention strength of P(LLA-CL) tissue-engineered vascular grafts. RSC Advances, 9(37), 21258–21264. https://doi.org/10.1039/c9ra04529e

[8] Yu, E., Mi, H. Y., Zhang, J., Thomson, J. A., & Turng, L. S. (2018). Development of biomimetic thermoplastic polyurethane/fibroin small-diameter vascular grafts via a novel electrospinning approach. Journal of Biomedical Materials Research - Part A, 106(4), 985–996. https://doi.org/10.1002/jbm.a.36297

[9] In Jeong, S., Kim, S. Y., Cho, S. K., Chong, M. S., Kim, K. S., Kim, H., Lee, S. B., & Lee, Y. M. (2007). Tissue-engineered vascular grafts composed of marine collagen and PLGA fibers using pulsatile perfusion bioreactors. Biomaterials, 28(6), 1115–1122. https://doi.org/10.1016/j.biomaterials.2006.10.025

[10] Gao, J., Chen, S., Tang, D., Jiang, L., Shi, J., & Wang, S. (2019). Mechanical Properties and Degradability of Electrospun PCL/PLGA Blended Scaffolds as Vascular Grafts. Transactions of Tianjin University, 25(2), 152–160. https://doi.org/10.1007/s12209-018-0152-8

[11] Johnson, J., Ohst, D., Groehl, T., Hetterscheidt, S., & Jones, M. (2015). Development of Novel, Bioresorbable, Small-Diameter Electrospun Vascular Grafts. Journal of Tissue Science & Engineering, 06(02). https://doi.org/10.4172/2157-7552.1000151

[12] Nitti, P., Gallo, N., Natta, L., Scalera, F., Palazzo, B., Sannino, A., & Gervaso, F. (2018). Influence of nanofiber orientation on morphological and mechanical properties of electrospun chitosan mats. Journal of Healthcare Engineering, 2018. https://doi.org/10.1155/2018/3651480

[13] Alfaro De Prá, M. A., Ribeiro-do-Valle, R. M., Maraschin, M., & Veleirinho, B. (2017). Effect of collector design on the morphological properties of polycaprolactone electrospun fibers. Materials Letters, 193, 154–157. https://doi.org/10.1016/j.matlet.2017.01.102

[14] Yuan, H., Zhou, Q., & Zhang, Y. (2017). Improving fiber alignment during electrospinning. In Electrospun Nanofibers (pp. 125–147). Elsevier Inc. https://doi.org/10.1016/B978-0-08-100907-9.00006-4

[15] Konig, G., McAllister, T. N., Dusserre, N., Garrido, S. A., Iyican, C., Marini, A., Fiorillo, A., Avila, H., Wystrychowski, W., Zagalski, K., Maruszewski, M., Jones, A. L., Cierpka, L., de la Fuente, L. M., & L'Heureux, N. (2009). Mechanical properties of completely autologous human tissue engineered blood vessels compared to human saphenous vein and mammary artery. Biomaterials, 30(8), 1542–1550. https://doi.org/10.1016/j.biomaterials.2008.11.011

[16] Jin, X., Geng, X., Jia, L., Xu, Z., Ye, L., Gu, Y., … Feng, Z. G. (2019). Preparation of Small-Diameter Tissue-Engineered Vascular Grafts Electrospun from Heparin End-Capped PCL and Evaluation in a Rabbit Carotid Artery Replacement Model. Macromolecular Bioscience, 19(8). https://doi.org/10.1002/mabi.201900114

[17] Yalcin Enis, I., Horakova, J., Gok Sadikoglu, T., Novak, O., & Lukas, D. (2017). Mechanical investigation of bilayer vascular grafts electrospun from aliphatic polyesters. Polymers for Advanced Technologies, 28(2), 201–213. https://doi.org/10.1002/pat.3875

[18] Nezarati, R. M., Eifert, M. B., Dempsey, D. K., & Cosgriff-Hernandez, E. (2015). Electrospun vascular grafts with improved compliance matching to native vessels. Journal of Biomedical Materials Research - Part B Applied Biomaterials, 103(2), 313–323. https://doi.org/10.1002/jbm.b.33201

[19] Grasl, C., Stoiber, M., Röhrich, M., Moscato, F., Bergmeister, H., & Schima, H. (2021). Electrospinning of small diameter vascular grafts with preferential fiber directions and comparison of their mechanical behavior with native rat aortas. Materials Science and Engineering C, 124. https://doi.org/10.1016/j.msec.2021.112085

[20] Ercolani, E., del Gaudio, C., & Bianco, A. (2015, August 1). Vascular tissue engineering of small-diameter blood vessels: Reviewing the electrospinning approach. Journal of Tissue Engineering and Regenerative Medicine, Vol. 9, pp. 861–888. John Wiley and Sons Ltd. https://doi.org/10.1002/term.1697

FABRICATION AND ANALYSIS OF PCL AND PLA BASED COAXIAL ELECTROSPUN FIBROUS SURFACES

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ABSTRACT

Tissue engineering is a promising biomedical approach for the restoration of damaged tissues and organs. The primary goal in this multidisciplinary practice is to develop scaffolds that are compatible with and can mimic the target tissue. These scaffolds should provide adequate mechanical support for tissues exposed to various loads as well as suitable physical and biological properties in the cell microenvironment. In tissue engineering applications, biomaterial selection and production method have an important role in providing the basic structure for mechanical properties, cell interactions, biocompatibility, biodegradability, anti-toxicity and cell growth. In this study, it is aimed to develop bicomponent fibrous electrospun surfaces for tissue engineering applications consisting of different combinations of biocompatible and biodegradable polycaprolactone (PCL) and polylactic acid (PLA) polymers. In addition, neat PCL, neat PLA and PLA and PCL blends are produced as control samples, and the morphological, chemical and mechanical properties of all surfaces are compared.

Keyword: *Bicomponent fibers, Coaxial electrospinning, Biopolymers, Tissue engineering*

1. INTRODUCTION

The difficulties brought by today's living conditions cause an increase in chronic and non-chronic diseases. Although the treatment of some of these diseases is possible with drugs, the number of diseases and damages that require tissue regeneration or change is too high to be ignored. Tissue engineering has emerged as a viable solution to meet this important medical need, and biocompatible and biodegradable scaffolds offered by tissue engineering for the treatment of damaged tissue provide hope for patients [1]. The extracellular matrix (ECM) is one of the most basic components that provides mechanical reinforcement to protect the tissue structure in the cell microenvironment and is an important factor affecting many cell behaviors such as cell viability, migration, proliferation and differentiation [2-3]. A tissue-engineered scaffold should mimic the regulatory role of the natural ECM, providing adequate mechanical support in the cell microenvironment, as well as appropriate survival conditions, optimal oxygen and nutritional levels, as well as efficient replenishment and waste movement [4-5]. On the other hand, the success of the scaffold relies on a number of parameters, including mechanical properties, structural features, biocompatibility and biodegradability. Material selection and production method play a major role in obtaining such crucial properties [6].

Synthetic biopolymers stand out with their characteristics such as high strength and regulated degradation rate, whereas natural biodegradable biopolymers dominate in biocompatibility and cell activities. In addition to the strengths of each biomaterial, there are also weaknesses that need to be improved, which brings up the necessity of using two or more polymers in blend or combined forms [7].

PCL and PLA are the biodegradable and biocompatible polymers that are widely used in tissue enginered scaffolds. PCL has a longer biodegradation time and superior ductility than PLA, while PLA has higher strength than PCL [8]. The combined use of these two biopolymers to serve different purposes is also highly common in the literature [9]. On the other hand, coaxial electrospinning is a technique that combines the characteristics of two different materials into a single fiber, and it provides special benefits including fiber formation and spinning with suitable materials for processing [10].

In this study, bicomponent fibrous electrospun surfaces composed of various combinations of biocompatible and biodegradable PCL and PLA polymers are intended to be developed for tissue engineering applications. Moreover, control samples of neat PCL, neat PLA, and PLA and PCL blend are produced, and the morphological, chemical, and mechanical characteristics of such surfaces are compared.

2. EXPERIMENTAL STUDY

2.1 Materials

PCL (Mn 80,000), PLA (Mn 230,000; %4,3 D-lactide content), and the components of solvent systems (chloroform, ethanol, acetic acid, and acetone) are supplied from Sigma Aldrich.

2.2 Methods

2.2.1 Surface Fabrication

Fibrous surfaces with core-shell fiber configurations of PLA/PCL (core part is PLA, shell part is PCL) and PCL/PLA (core part is PCL, shell part is PLA) are fabricated using coaxial electrospinning. The diameters of the inner and outer needles are 0.6 and 0.8 mm, respectively. To better examine the morphological, chemical and mechanical performance of the coaxial electrospun fibrous mats, neat PLA, neat PCL, and a 50:50 by weight blend of PLA and PCL, named as PLAPCL fibers via single-nozzle (0.8 mm dimeter) electrospinning are also fabricated using Nanospinner (Basic System, Inovenso). Polymers are dissolved in chloroform/ethanol/acetic acid (8/1/1) under stirring for 2h at room temperature. The voltage, feed rate, and tip-collector distances are kept constant at 11±1 kV, 3±1 ml/h, and 20±3 cm, respectively. After the fabrication, the fibrous surfaces on the aluminium foil are left to dry for 24h.

2.2.2 Scanning Electron Microscope Characterization

The surface morphology of the scaffolds is analyzed at 3kx magnification by the TESCAN VEGA3 scanning electron microscope (SEM) after coating with a thin gold-palladium alloy layer.

2.2.3 Fiber Diameter Analysis

SEM images of each scaffold surface are imported into the Image J software system to determine the fiber diameter. An average fiber diameter is calculated based on at least 50 randomly selected fibers.

2.2.4 Chemical Characterization

A Fourier-transform infrared spectroscopy (FTIR) (UATR Two, Perkin Elmer) is used to determine the chemical characteristics of the scaffolds.

2.2.5 Mechanical Characterization

For the purpose of assessing the mechanical performance of the fibrous samples, tensile testing is carried out utilizing the Zwick/Roell Z005 Tensile Tester. The samples are cut into 10mm x 15mm rectangular pieces. The gauges are set 5 mm apart, with the cross-head speed set at 10 mm/min.

3. RESULTS

3.1 Scanning Electron Microscope Characterization

SEM images of both single-nozzle and coaxial surfaces draw attention to the homogeneous and bead-free fiber distribution (Figure 1). It is seen that the fibers on polymeric surfaces with the same solution and production parameters do not have any effect on smooth fiber formation as pure polymer, blend or bicomponent. On the other hand, it is an indication of the inadequacy of solution viscosity at low concentrations necessary for the polymers to become entangled in molecular chains [11]. However, it is clearly seen that the polymer concentration and viscosity of all polymer solutions prepared within the scope of the study are at a sufficient level for fiber formation.

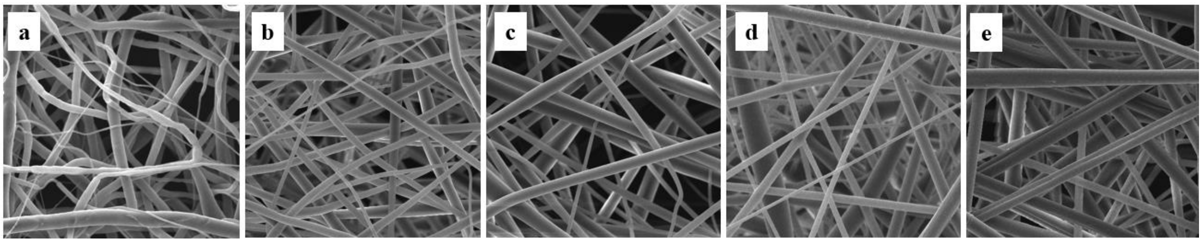

Figure 1. SEM images of PCL (a), PLA (b), and PLAPCL (c), PLA/PCL (d) and PCL/PLA (e) samples.

3.2 Fiber Diameter Analysis

The fiber diameters of the samples are given in Table 1. When these values are examined, it can be seen that the fiber diameters of the samples vary between 1.88-2.63 µm. It is observed that PLA fibers have a larger diameter than PCL fibers and the addition of PLA to the PCL structure increases the fiber diameters in the fibrous surface. Higher molecular weight polymers are known to result in larger fiber diameters [12]. The fact that PLA has a higher molecular weight than PCL explains this situation. On the other hand, compared to PCL-based fibers, bicomponent fibers have a higher fiber diameter. The larger fiber diameter of PLA are thought to be the reason of this situation.

Table 1. The fiber diameters of the samples.

Sample	Mean Diameter ± SD (µm)
PCL	1.88±0.37
PLA	2.56±0.70
PLAPCL	1.99±0.37
PLA/PCL	2.48±0.45
PCL/PLA	2.63±0.49

3.3 Chemical Characterization

When the FTIR spectra of the surfaces are examined, it is observed that the stretches and bendings of PCL and PLA [13] are present on both PLAPCL blend and bicomponent surfaces (PLA/PCL and PCL/PLA) (Figure 2). As can be seen in Figure 2, the spectra of PCL fibrous surface has three characteristic peaks, the bending vibration of C-H at 1365 cm^{-1}, stretching vibration of the carboxyl (C=O) at 1725 cm^{-1}, and stretching vibration of C-H at 2945 cm^{-1} [14]. On the other hand, these peaks are clearly visible on the PLAPCL blend, PLA/PCL, and PCL/PLA bicomponent surfaces although these peaks are specific to PCL.

Moreover, characteristic peaks exhibited on PLA, blend and bicomponent surfaces indicate the stretching vibration peak of C-H at 2995 cm^{-1} and the stretching vibration peak of carboxyl (C=O) at 1753 cm^{-1}, bending vibration peak of C-H at 1455 cm^{-1}, and C-O-C asymmetric stretching vibration at 1086 cm^{-1} and 1182 cm^{-1}, respectively [15]. In this case, it is concluded that both physically blended and coaxially produced fiber-containing surfaces include PCL and PLA polymers as components.

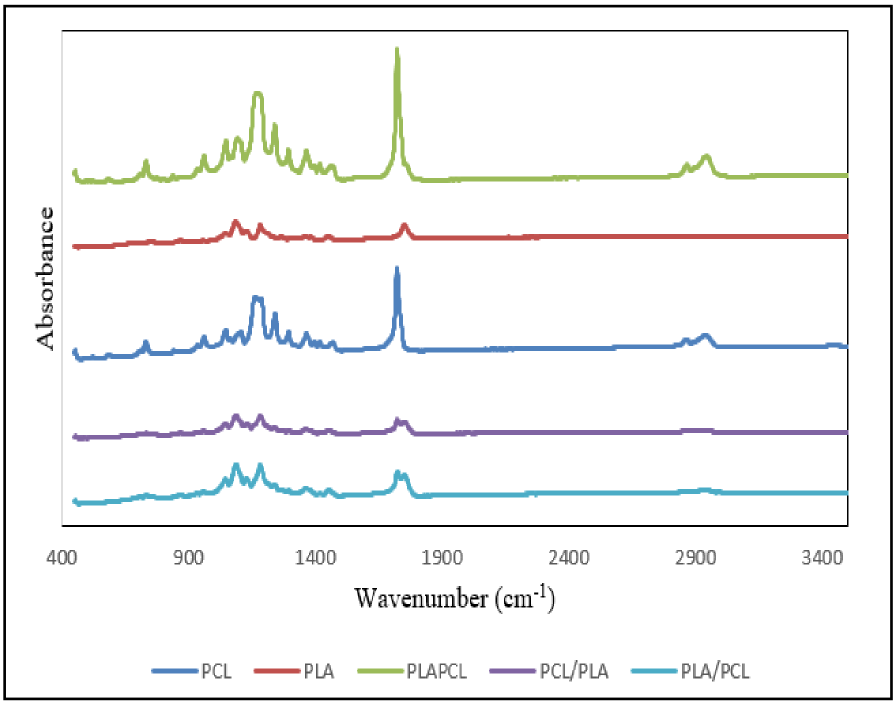

Figure 2. FTIR spectrums of surfaces produced with single nozzle and coaxial systems.

3.4 Mechanical Characterization

Table 2 shows the average tensile strength and elongation values of fibrous surfaces with different fiber compositions. Although the tensile strength of PLA is observed to be slightly higher than that of PCL, the main obvious difference can be seen from the elongation values of these two polymers. This difference in elongation values is due to the fact that PCL has a ductile characteristic while PLA has a stiff structure. This has also been observed in existing studies where PLA and PCL were studied together [16-18]. When the mechanical properties of the blend surface are investigated, it is clear that the elongation value is lower than both PLA and PCL, and there is no appreciable improvement in tensile strength, despite the expectation that the PLAPCL blend sample will address the weaknesses of both PLA and PCL. This can be explained by the immiscibility of PLAPCL blends and poor interfacial adhesion [15, 19].

Table 2. The average tensile strength and elongation values of the samples.

Sample	Average Tensile Strength (MPa) ± SD	Average Elongation (%) ± SD
PCL	2.56±0.32	390.20±76.05
PLA	2.73±0.22	62.80±3.82
PLAPCL	2.71±0.35	41.94±1.78
PCL/PLA	2.94±1.18	100,62±5,21
PLA/PCL	3.22±0.72	62,95±8,44

In recent years, the use of bicomponent fibers has become a preferred method to improve the properties of polymers used on fibrous surfaces and to eliminate their deficiencies. PCL/PLA and PLA/PCL samples prove this fact. It is seen that the average tensile strength is higher on both PCL/PLA and PLA/PCL compared to PLA, PCL, and PLAPCL. In a part of Kareem et al.'s (2019) study, the PCL-based surface and the surface with PCL core and PLA shell structured fibers are mechanically compared. As a result of the study, the ultimate tensile strength of the neat PCL fiber surface was recorded as 0.837 MPa, while that of the bicomponent fiber surface was recorded as 1.259 MPa [20]. In another study, Baudequin et al. (2017) produced surfaces with bicomponent fibers by positioning PLA and PCL both inner and outer of the bicomponent fiber and compared them with both neat PLA and neat PCL. The results of this investigation demonstrated that both bicomponent fibrous surfaces enhanced the ductility of the neat PLA-containing surface and approached PCL, which has a very flexible structure, in terms of elongation. Young modulus values of neat PCL, neat PLA, PLAouter, PCLouter samples were stated as 21.13, 24.41, 31.84, and 60.14 MPa, respectively. The results demonstrate that regardless of the relative positions of PCL and PLA in the core/shell structures under research, it can be assumed that the overall mechanical strength of the bicomponent fibers will provide a better behavior [21]. Therefore, in the both aforementioned studies [20, 21], it is noticed that samples with bicomponent fiber content at the same elongation withstand higher loads compared to neat PLA and neat PCL surfaces similar to our study.

4. CONCLUSION

In the context of this study, bicomponent fibrous surfaces are produced utilizing PLA and PCL polymers in different settling combinations. These surfaces are compared with neat PLA, neat PCL, and PLAPCL blend surfaces. Physical characterizations demonstrate that all surfaces form continuous, smooth fibers, and that the diameters of the fibers are comparable. FTIR analysis results prove the presence of PLA and PCL on both blended and bicomponent surfaces. While the tensile test results showed an incompatibility in the PLAPCL blend sample, which may be due to the immiscible nature of the physical blend, it was concluded that the mechanical properties of both polymers were better preserved in the bicomponent structure. Therefore, this study shows that bicomponent fibrous surfaces are more preferable in terms of mechanical properties in tissue engineering applications than blend surfaces. In future studies, it is aimed to determine the core/shell distribution by observing the structure of the bicomponent fibers by transmission electron microscopy and to examine the effect of this positioning on the surface properties.

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REFERENCES

[1] Chandra, P. K., Soker, S., & Atala, A. (2020). Tissue engineering: current status and future perspectives. In *Principles of Tissue Engineering*. INC. https://doi.org/10.1016/b978-0-12-818422-6.00004-6

[2] Barthes, J., Özçelik, H., Hindié, M., Ndreu-Halili, A., Hasan, A., & Vrana, N. E. (2014). Cell Microenvironment Engineering and Monitoring for Tissue Engineering and Regenerative Medicine: The Recent Advances. *BioMed Research International*, *2014*(i). https://doi.org/10.1155/2014/921905

[3] Yi, S., Ding, F., Gong, L., & Gu, X. (2017). Extracellular Matrix Scaffolds for Tissue Engineering and Regenerative Medicine. *Current Stem Cell Research & Therapy*, *12*(3), 233–246. https://doi.org/10.2174/1574888X11666160905092

[4] Dziki, J. L., Huleihel, L., Scarritt, M. E., & Badylak, S. F. (2017). Extracellular Matrix Bioscaffolds as Immunomodulatory Biomaterials. *Tissue Engineering - Part A*, *23*(19–20), 1152–1159. https://doi.org/10.1089/ten.tea.2016.0538

[5] Luo, Y. (2020). Three-dimensional scaffolds. In *Principles of Tissue Engineering* (pp. 343–360). INC. https://doi.org/10.1016/b978-0-12-818422-6.00020-4

[6] Oztemur, J. & Yalcin-Enis, I. (2020). *The Potential Use of Fibrous Webs Electrospun from Polylactic Acid/Polycaprolactone Blends in Tissue Engineering Applications* (C. Çivi & T. Yılmaz, eds.). Centinje, Montenegro: IVPE.

[7] Karkan, S. F., Davaran, S., Rahbarghazi, R., Salehi, R., & Akbarzadeh, A. (2019). Electrospun nanofibers for the fabrication of engineered vascular grafts. *Journal of Biological Engineering*, *13*(1), 1–13. https://doi.org/10.1186/s13036-019-0199-7

[8] Oztemur, J. & Yalcin Enis, I. (2020). The Role of Biopolymer Selection in the Design of Electrospun Small Caliber Vascular Grafts to Replace the Native Arterial Structure. In A. Hayaloğlu (Ed.), *Theory and Research in Engineering* (First, pp. 167–192). Gece Kitaplığı.

[9] Zhu, R. T., Tan, M. H., Zhang, P., Zhang, L., Chen, X. M., & Yang, F. (2014). Morphological structure and thermal property of PLA/PCL nanofiber by electrospinning. *Advanced Materials Research*, *1048*(C), 418–422. https://doi.org/10.4028/www.scientific.net/AMR.1048.418

[10] Han, D., & Steckl, A. J. (2019). Coaxial Electrospinning Formation of Complex Polymer Fibers and their Applications. *ChemPlusChem*, *84*(10), 1453–1497. https://doi.org/10.1002/cplu.201900281

[11] Hossain, M. F., Gong, R. H., & Rigout, M. (2016). Effect of polymer concentration on electrospinning of hydroxypropyl-β-cyclodextrins/PEO nanofibres. *Journal of the Textile Institute*, *107*(12), 1511–1518. https://doi.org/10.1080/00405000.2015.1128714

[12] Oztemur, J., Ozdemir, S., & Yalcin-Enis, I. (2022). Effect of blending ratio on morphological , chemical , and thermal characteristics of PLA/PCL and PLLA/PCL electrospun fibrous webs. *International Journal of Polymeric Materials and Polymeric Biomaterials*, *0*(0), 1–11. https://doi.org/10.1080/00914037.2022.2090356

[13] Oztemur, J., & Yalcin-Enis, I. (2021). Development of biodegradable webs of PLA/PCL blends prepared via electrospinning: Morphological, chemical, and thermal characterization. *Journal of Biomedical Materials Research - Part B Applied Biomaterials*, *109*(11), 1844–1856. https://doi.org/10.1002/jbm.b.34846

[14] Behtaj, S., Karamali, F., Masaeli, E., G. Anissimov, Y., & Rybachuk, M. (2021). Electrospun PGS/PCL, PLLA/PCL, PLGA/PCL and pure PCL scaffolds for retinal progenitor cell cultivation. *Biochemical Engineering Journal*, *166*(May 2020), 107846. https://doi.org/10.1016/j.bej.2020.107846

[15] Vilay, V., Mariatti, M., Ahmad, Z., Pasomsouk, K., & Todo, M. (2010). Improvement of microstructures and properties of biodegradable PLLA and PCL blends compatibilized with a triblock copolymer. *Materials Science and Engineering A*, *527*(26), 6930–6937. https://doi.org/10.1016/j.msea.2010.07.079

[16] Matta, A. K., Rao, R. U., Suman, K. N. S., & Rambabu, V. (2014). Preparation and Characterization of Biodegradable PLA/PCL Polymeric Blends. *Procedia Materials Science*, *6*(Icmpc), 1266–1270. https://doi.org/10.1016/j.mspro.2014.07.201

[17] Mittal, V., Akhtar, T., & Matsko, N. (2015). Mechanical, thermal, rheological and morphological properties of binary and ternary blends of PLA, TPS and PCL. *Macromolecular Materials and Engineering*, *300*(4), 423–435. https://doi.org/10.1002/mame.201400332

[18] Wachirahuttapong, S., Thongpin, C., & Sombatsompop, N. (2016). Effect of PCL and Compatibility Contents on the Morphology, Crystallization and Mechanical Properties of PLA/PCL Blends. *Energy Procedia*, *89*, 198–206. https://doi.org/10.1016/j.egypro.2016.05.026

[19] Finotti, P. F. M., Costa, L. C., Capote, T. S. O., Scarel-Caminaga, R. M., & Chinelatto, M. A. (2017). Immiscible poly(lactic acid)/poly(ε-caprolactone) for temporary implants: Compatibility and cytotoxicity. *Journal of the Mechanical Behavior of Biomedical Materials*, *68* (October 2016), 155–162. https://doi.org/10.1016/j.jmbbm.2017.01.050

[20] Kareem, M. M., Hodgkinson, T., Sanchez, M. S., Dalby, M. J., & Tanner, K. E. (2019). Hybrid core-shell scaffolds for bone tissue engineering. *Biomedical Materials (Bristol)*, *14*(2), 25008. https://doi.org/10.1088/1748-605X/aafbf1

[21] Baudequin, T., Gaut, L., Mueller, M., Huepkes, A., Glasmache, B., Duprez, D., … Legallais, C. (2017). The osteogenic and tenogenic differentiation potential of C3H10T1/2 (mesenchymal stem cell model) cultured on PCL/PLA electrospun scaffolds in the absence of specific differentiation medium. *Materials*, *10*(12), 1–19. https://doi.org/10.3390/ma10121387

EFFECTS OF ALKALINE CONDITIONS ON NATURAL DYESTUFF EXTRACTION FROM BLACK CARROT AND FABRIC PERFORMANCE

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ABSTRACT

Natural products are very valuable for both environment and human beings. Because natural alternatives are not harmful to health and they do not produce chemical load and hazardous wastes. Especially, dyestuff can be really problematic for being carcinogenic and allergic for both workers in production lines and for customers that wear garments that are dyed by using synthetic dyestuffs. In this study, a natural dyestuff is produced from black carrot by using soxhlet method. Dyestuff extraction solvent includes only water and sodium carbonate to observe the alkaline effect of dyestuff extraction solvent. Extracted dyestuff is used to dye cotton woven fabrics and tannic acid is used as mordant. Testing stage is conducted for spectrophotometric color analysis and washing fastness. According to results, alkaline conditions are better to yield darker colors and tannic acid helps both yielding darker colors and better washing fastness results.

Keyword: *Natural dyestuff extraction, Soxhlet, Black Carrot, Fastness*

1. INTRODUCTION

Every sector is responsible for providing greener processes and waste management to be environmentally friendly and respectful to Earth. Textile sector has great importance in this case because it has many processes that have high chemical content especially wet processes. Also, synthetic chemicals and dyestuffs are harmful for worker in case of respiration and direct skin contact and even remaining off on garments can be irrigative for many people especially for baby skin. Therefore, natural dyestuff usage preference increases [1].

Minerals, plants, and their wastes can be alternative sources and these sources can produce different dyestuffs such as Carotenoids, Flavonoids, Betalains, and Chlorophyll thanks to their different active materials. Flavonoids can be yielded from red or purple fruits and vegetables by extracting the phenylbenzopyran molecules as Anthocyanin. The most significant properties of anthocyanin are being water soluble and capable of bonding easily [2,3].

Different extraction methods as ultrasonic, supercritical liquid, microwave, soxhlet, enzyme, etc. can be used but it is important to select an extraction method that can reach the needed molecules in the plant and provide suitable solubility conditions for the needed molecule as water, oil, alkaline, acidic, etc. [4].

In this study, alkaline conditions are provided for soxhlet extraction of anthocyanin from black carrot. Sodium carbonate is combined with distilled water and cotton fabrics are dyed by using the extracted anthocyanin. The effects of alkaline conditions on dyeability and mordant interaction are evaluated.

2. EXPERIMENTAL STUDY

2.1 Materials

Black carrots, distilled water, sodium carbonate, tannic acid, and cotton woven fabrics are used as materials for this study.

2.2 Methods

Natural dyestuff extraction was done by using black carrot via soxhlet method in this work. Flavonoid dyestuff was selected thus black carrot which is very rich in anthocyanin was used. Its most important property for this study was resistivity to pH because it was desired to be observed the extraction conditions under alkaline conditions. The Soxhlet method is an environmentally friendly method if the solvents are not toxic, and in this study water and water with sodium-carbonate solutions were used as solvents. The balloon flask of the soxhlet system was filled with the solvents respectively as distilled water and distilled water with 5% sodium carbonate. Black carrots were grated and placed into a filter paper pocket and it was inserted into the soxhlet and the soxhlet head was closed with the condenser [5]. The soxhlet system which was shown in Figure 1 was placed onto the mantle heater and extraction was started. Evaporation of solvent was observed due to temperature increase and evaporated solvent collected on substrates in soxhlet. The solvent got colored and turned back to the balloon when evaporated solvent filled the soxhlet until the neck of it and a cycle was finished. Three cycles were completed for this study. The colored solvent was poured into petri dishes to evaporate the solvent on a heater. The resultant dyestuffs were placed into sample boxes. A dyeing procedure was followed by using 1g of dyestuff for 5g cotton fabric at 60°C at Gyrowash lab-type dyeing machine and a tannic acid post-treatment was applied onto some samples.

Figure 1. Soxhlet system.

3. RESULTS

Spectrophotometric color analysis and washing fastness tests were performed for the samples.

3.1. Spectrophotometric Color Analysis

Table 1 shows the spectrophotometric color analysis of the fabrics. According to the results, maximum color difference was yielded with Sodium carbonate solution and tannic acid post-treatment. Minimum lightness was observed at carbonate and tannic acid applied sample thus it is the darkest among all samples. Also, sodium carbonate addition provides better color with tannic acid treatment compared to water solvent and tannic acid post-treatment. All samples have positive a values which means including red tones while all samples except 5SDT include negative b values which means including blue tones. As a result, all samples have purplish brown. Alkaline application moves b values to the negative which means it gives blueish tone to the color compared to the samples that are dyed with only water extracts. Tannic acid application moves b values to the positive side which means it gives yellowish tone to the color.

Table 1. Spectrophotometric colour analysis of the fabrics.

Sample Name	L*	A*	B*	C*	H	ΔE	REF.
Scoured and bleached cotton fabric	98,51	4,84	-18,13	18,698	285,532	-	-
WD	85	5,36	-9,6	11,184	298,975	13,5	[6]
WDT	84,1	4,1	-0,4	11,887	291,462	20,79	[6]
5SD	83,15	5,3	-16,2	-1,61	286,122	12,96	-
5SDT	81,68	1,25	5,42	-13,1	305,072	22,43	-

3.2. Washing Fastness

Samples were tested for washing fastness according to ISO 105-C06. Gray scale evaluation in spectrophotometer was used for the study.

Firstly, color staining of multifiber was evaluated for all fibers in multifiber and 4-5 was observed for almost all fibers.

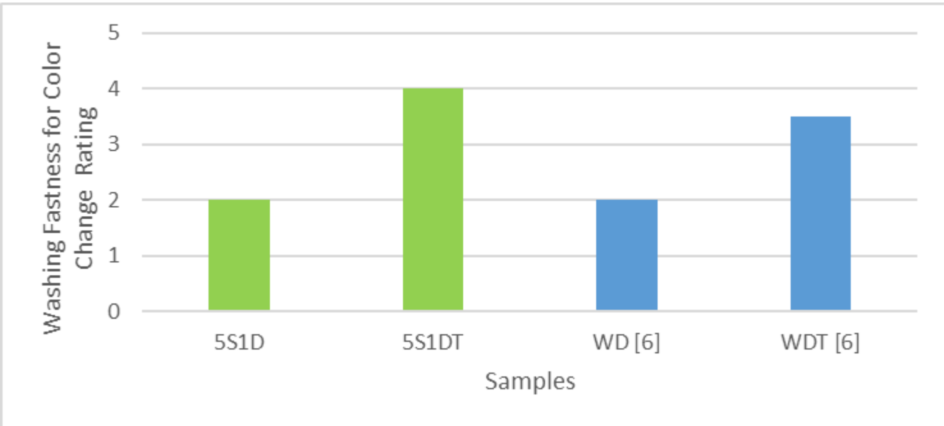

Figure 2. Washing fastness results for color change.

Secondly, color change of samples was tested and results are given at Figure 2. Alkaline dyestuff extraction has 2 as washing fastness for color change and it was almost same with previous dyestuff extraction studies of the authors [6]. Also, tannic acid treatment had a positive effect on washing fastness and fastness value reached to 4 which is higher than the previous study that use water as dyestuff extraction solvent [6].

4. CONCLUSION

Environment and human needs natural alternatives as natural dyestuffs and chemicals. There are many natural sources as plants and many methods for yielding them. Soxhlet method is used in this study via alkaline conditions that are provided by additions of sodium carbonate. After that cotton fabrics are dyed and tested for spectrophotometric color analysis and washing fastness. As a result, alkaline conditions provide darker colors with more purplish tones. Washing fastness are almost same for natural and alkaline conditions but tannic acid applications increase the washing fastness. Furthermore, alkaline conditions increase the effects of tannic acid a little bit more.

ACKNOWLEDGMENT

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REFERENCES

[1] Shukla, D., & Vankar, P. S. (2017). Innovative dye extraction methods. In *Natural Dyes for Textiles: Sources, Chemistry and Applications* (pp. 191–203). https://doi.org/10.1016/B978-0-08-101274-1.00005-7

[2] Leong, H. Y., Show, P. L., Lim, M. H., Ooi, C. W., & Ling, T. C. (2018). Natural red pigments from plants and their health benefits: A review. *Food Reviews International*, *34*(5), 463–482. https://doi.org/10.1080/87559129.2017.1326935

[3] Patra, S., Makhal, P. N., Jaryal, S., More, N., Rao Kaki, V., & History, A. (2022). Anthocyanins: Plant-based flavonoid pigments with diverse biological activities. *Int. J. Plant Bas. Pharm*, *2*(1), 118–127. Retrieved from https://ijpbp.com

[4] Mansour, R. (2018). Natural dyes and pigments: Extraction and applications. *Handbook of Renewable Materials for Coloration and Finishing*, 75–102. https://doi.org/10.1002/9781119407850.CH5

[5] Yusuf, M., Shabbir, M., & Mohammad, F. (2017). Natural Colorants: Historical, Processing and Sustainable Prospects. *Natural Products and Bioprospecting*, *7*(1), 123–145. https://doi.org/10.1007/s13659-017-0119-9

[6] Emekdar, E., Şahin, U. K., Ötev, B., Özdem, B. Ş., & Masır, Y. (2022). Natural Dyestuff Extraction From Black Carrot And Its Textile Application. In *3rd International Congress of Innovative Textiles* (pp. 201–208)

DESIGN OF NOVEL WATER REPELLENT FINISH WITH LOW ENVIRONMENTAL IMPACT

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ABSTRACT

Functional properties of textiles gain importance with the development of industry and technology. In this context, water repellency is often sought in textile products and there are many finishing and coating methods used. As an alternative to fluorocarbons, studies have been carried out on green chemicals with an environmentally friendly and human health-sensitive approach. In the first part, analysis was performed on the Hydrophobic Deep Eutectic Solvents (HDES) were synthesized. While it was determined that they were not volatile at room conditions, it was observed that the chemicals used for HDES formed bonds according to the FTIR analysis. In the second part, the prepared fabrics were analyzed in terms of water absorption time with contact angle device. As a result of these data, it is analyzed that the fabric treated with HDES repels water compared to the untreated fabric. This study is a pioneering study that can be used as an alternative to the toxic and environmentally harmful water-repellent finishes used today.

Keyword: *HDES, Water Repellency, Finishing Methods, Environmentally Friendly*

1. INTRODUCTION

In recent years, the importance of chemical finishing processes has increased with the increase in the performance properties expected from textiles. In this context, while features such as easy care and breathability are provided in textile products, it is aimed to provide textiles with various properties by using different chemicals in chemical finishing processes. However, by preventing pollution or using pollution-control technology, textiles should be environmentally friendly. Thus, some components, chemicals, and compounds that are prohibited or forbidden in textile industry due to a rule or law are included in the RSL published by the American Apparel and Footwear Association [1]. One of the most popular textile finishes nowadays is hydrophobicity. For apparel, household, and technical fabrics alike, finishes that deflect water, oil, and dry dirt are crucial [2]. By using acrylate repellents, zirconium and aluminum compounds, stearic acid-melamine repellents, and fluorocarbon-based repellents [3], one can achieve hydrophobicity and oleophobicity. But, The Environmental Protection Agency in the USA prohibited the use of perfluorooctanoic acid (PFOA) in 2015. Even though C8 fluorocarbon-based chemical has great oil and water repellency, it does emit PFOA and perfluorooctane sulfonate (PFOS), which are hazardous substances. Therefore, given their impacts on the environment and probable toxicity to people, it is inevitable to draw the conclusion that these fluorine-containing compounds are to blame for serious problems [4,5].

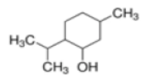
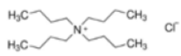
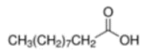
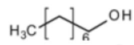
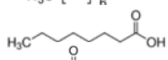
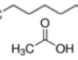
The subject of the this project is to research and develop the possibilities of applying hydrophobic deep eutectic solvents (HDES), known as green solvents, as water repellent finishing on raw cotton fabric. Based on the literature with the supplied chemicals, HDESs were prepared and their characterizations were carried out. Alternative application methods to be carried out in the study were determined based on the methods used in the water-repellent finishing application before. After the application, contact angle measurement and spray test were made on the fabrics, then the effect of the application was analyzed by looking at the yarn strength of the finished fabric. Finally, the results of the analyzes were commented.

2. EXPERIMENTAL STUDY

2.1 Materials

Menthol, decanoic acid (DecA), octanoic acid (OctA), 1-octanol (Oct), and N44Cl (tetrabutyl ammonium chloride) were purchased from Sigma-Aldrich. Acetic acid and the necessary equipment and devices for DSC, FTIR and yarn strength analysis to carry out the experiments were acquired from the laboratory at the faculty of Textile Technologies and Design of Istanbul Technical University. All chemicals were of an analytical standard and were used as received. Ne 28/1 raw cotton single jersey fabric was procured from Eren Retail & Textile Inc. Contact angle device (Biolin Scientific) and stenter machine (ATAC) were used from Pulcra Chemicals.

Table 1. Chemicals used in experiment.

FULL NAME	ABBREVIATION	PURITY	STRUCTURE
MENTHOL	-	99%	
TETRABUTYLAMMONIUM CHLORIDE	N44Cl	≥97%	
DECANOIC ACID	DecA	≥99%	
1-OCTANOL	Oct	≥99%	
OCTANOIC ACID	OctA	≥99%	
ACETIC ACID	AceA	≥99%	

2.2 Preparation of HDESs

The hydrophobicity of the initial components, in essence, determines how hydrophobic the dissolving solvents are. New low-viscosity hydrophobic eutectic solvents were also created at the same time, utilizing menthol and a naturally occurring acid. Also, FTIR spectroscopy has revealed that menthol and acids form intermolecular hydrogen bonds, and research is still ongoing. HDESs were used as a basis for obtaining a hydrophobic chemical. There are many possible combinations of HDES, and in this experimental study, long chain fatty acid materials were prepared, and the diversity of these combinations was analyzed (Table 2).

Table 2. Properties of HDES Samples.

Sample No	Hydrogen Bond Acceptor (HBA)	Hydrogen Bond Donor (HBD)	Molar Ratio	pH	Volume (mL)
1	Menthol	DecA	1:1	5	15.5
2	Menthol	DecA	2:1	5	15.5
3	Menthol	OctA	1:1	5	14.5
4	Menthol	OctA	1.5:5	5	16.0
5	N44Cl	DecA	1:2	3	5.0
6	N44Cl	OctA	1:2	4	5.0
6-2	N44Cl	OctA	1:2	4	17.0
7	N44Cl	OctA	1:1	4	6.0
8	N44Cl	Oct	1:1	5	4.5
9	N44Cl	Oct	1:2	5	4.5
10	N44Cl	DecA	1:1	2	13.5
11	N44Cl	DecA	1:2	3	18.0
12	Menthol	DecA	1:1	5	17.0
13	Menthol	DecA	2:1	5	17.0
14	Menthol	OctA	1:1	5	12.5
15	Menthol	OctA	1.5:1	5	7.5
16	N44Cl	AceA	1:1	5	8.0
17	Menthol	AceA	1:1	5	8.0
18	N44Cl	AceA	1:2	5	5.0
19	DecA	OctA	1:1	5	18.0

The HBAs and HBDs are mixed continuously at a certain temperature until a clear, homogeneous liquid is formed in the determined molar ratio. After the desired homogeneous mixture is obtained, this liquid is kept in room conditions for about 5 minutes. The process of obtaining HDEs was applied in the same way in all different combinations. As a result, a total of 20 HDES samples were obtained in Fig.1.

Figure 1. Images of All HDESS Samples.

2.3 Application of HDESs on Fabric

Then, these liquids in these different combinations were examined in FTIR in order to analyze them before they were applied to the fabric. The HDESs analyzed in FTIR were then applied to the same knitted fabrics containing 100% cotton, measuring 10 cm x 8 cm. This fabric was washed and dried before application. As the application method, 100% concentration was dripped onto the fabric in line with the determined volumes (80% wet pick up) and it was distributed equally on the entire fabric. Then, the fabrics were dried for 3 minutes at 120 degrees in a drying oven.

The drying fabrics were fixed at 140 degrees for 1 minute in a stenter machine. Then, they were left to rest at room conditions for 15 minutes. As a result, fabrics finished with HDES were made ready. The numbers given to all fabrics that have been treated with HDES are the same as the numbers of the prepared HDES samples. The washed and dried raw fabric to be used later in the contact angle test was named 0.

3. RESULTS

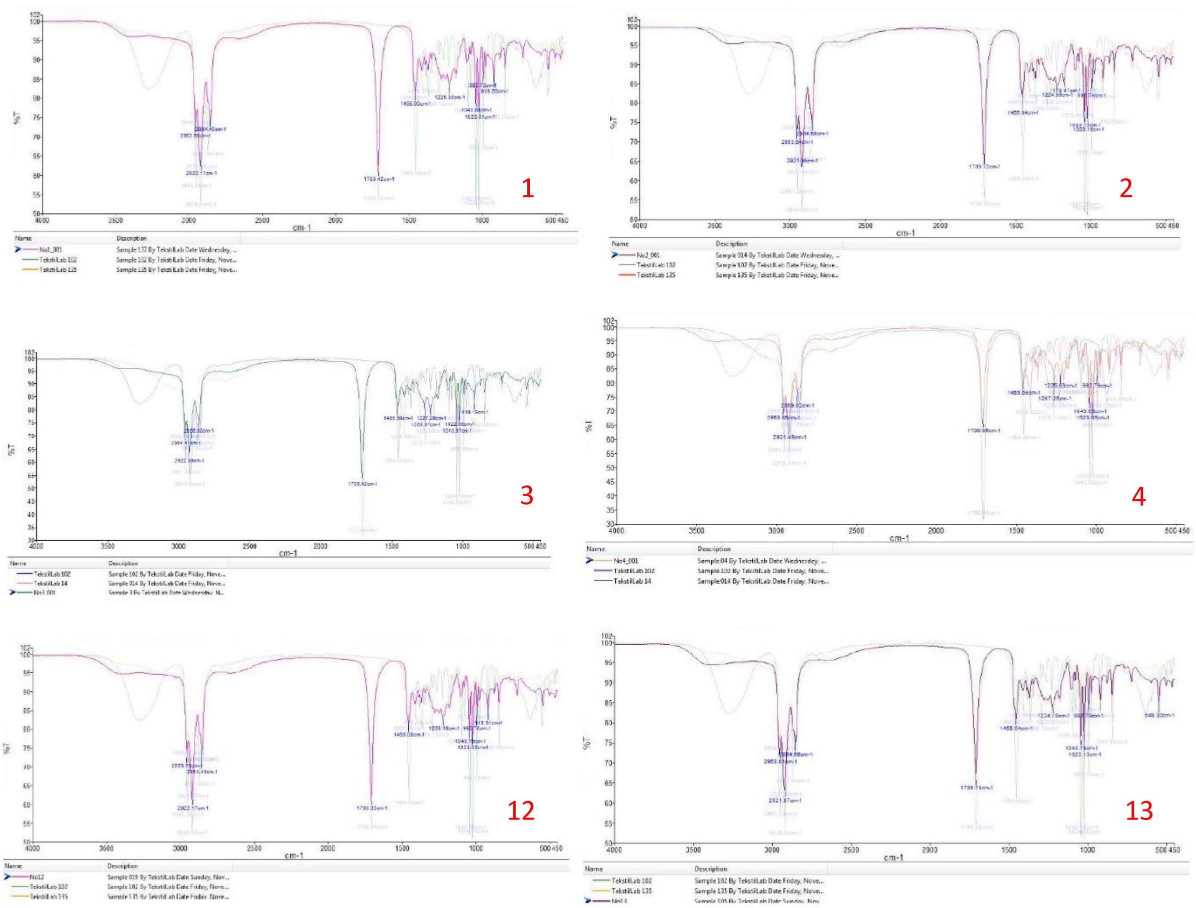
3.1 Analysis of Volatility and pH Measurement

In order to analyze the volatility of the prepared samples from 1 to 10, they were kept in room conditions for 24 hours after preparation. As a result of this application, no change was observed to their volumes.

Since the amount of HDES samples obtained was insufficient, analysis could not be performed on the pH meter device. However, the pH measurement was made with the litmus paper and the analysis results were added to the Table 2.

3.2 Analysis of FTIR

First of all, FTIR analysis of the materials used were made. Then, FTIR analysis of the obtained HDESs was performed. Below are the FTIR graphs of the generated HDES.



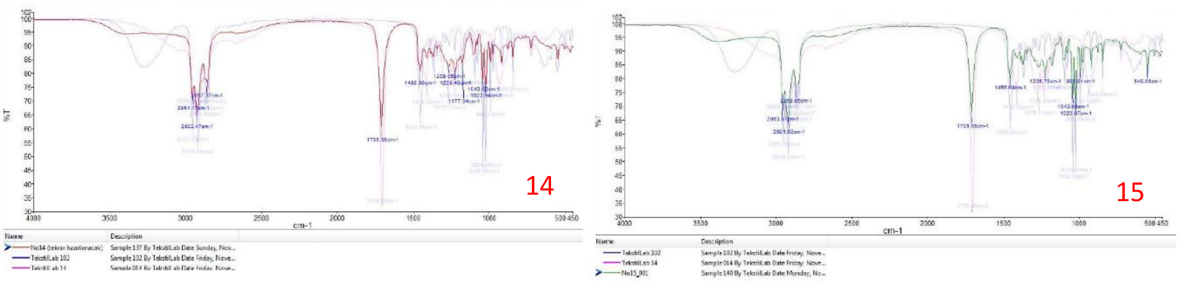
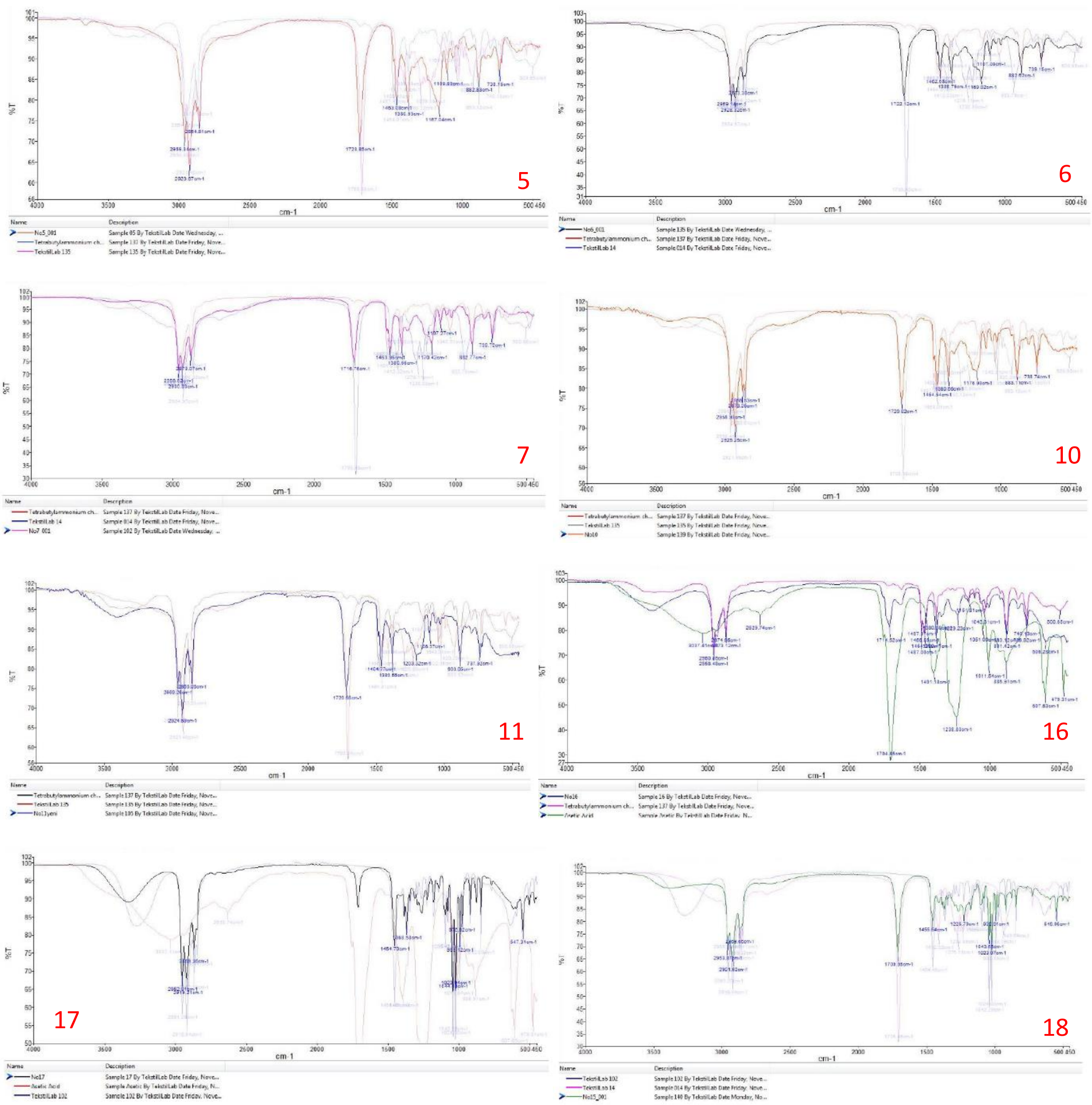


Figure 2. FTIR results of HDESs samples (No. 1, 2, 3, 4, 12, 13, 14, 15).



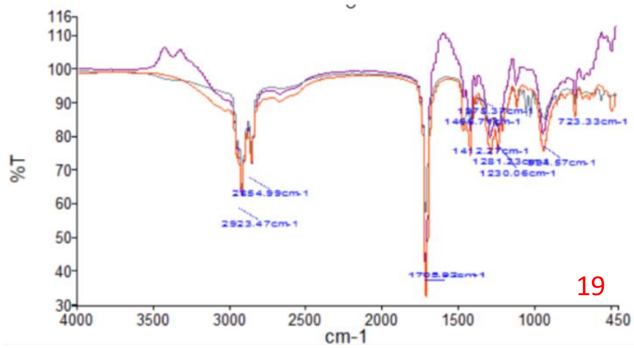


Figure 3. FTIR results of HDESs samples (No. 5, 6, 7, 10, 11, 16, 17, 18, 19).

When the FTIR graphs were examined, it was observed that HDES samples numbered 1, 2, 3, 4, 12, 13, 14, 15, created with chemicals with OH group, made a bond. Likewise, when the graphics of HDES samples 5, 6, 7, 10, 11, 16, 17, 18, 19 prepared with N44Cl without OH group were examined, it was observed that a CO bond was formed. However, it has been analyzed that HDES samples 8 and 9 have weaker bond formation.

3.3 Analysis of Water Absorption Times

After the analysis of the generated HDESs, the contact angle measurement of the samples prepared as applied to the fabrics was made.

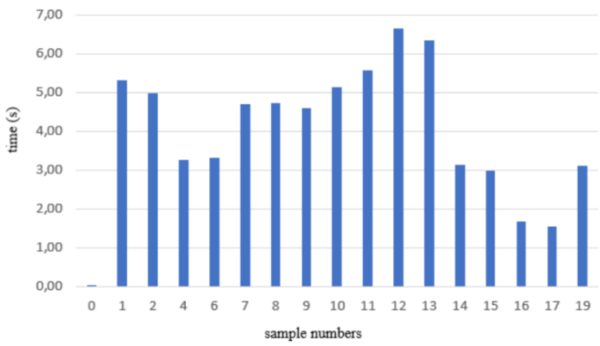


Figure 4. Water absorption times of fabrics on which HDESs with different contents are applied.

In this measurement, the prepared fabrics were analyzed in terms of water absorption time. While the water absorption rate of the raw fabric is very short, the water absorption rate of HDES finished fabrics is 5 times higher on average per second. Although the absorption rate of each sample is different, the results are close to each other. HDES, which repels water in the fabric for the longest time, was observed as variant 12. As a result of these data, it is analyzed that the fabric treated with HDES repels water compared to the untreated fabric.

4. CONCLUSION

In conclusion, when all these experimental applications and data were examined, it was observed that HDES had the potential as a water-repellent finish. These results were evaluated for the possibility of being used as a water-repellent finish, not as having the percent efficiency as the water-repellent finishes such as fluorocarbons used today and gave positive results.

ACKNOWLEDGMENT

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REFERENCES

[1] Choudhury, A. K. R. (2017). Sustainable chemical technologies for textile production. In Sustainable Fibres and textiles (pp. 267-322). Woodhead Publishing.

[2] Malik, T., Parmar, S. (2022, Jan 12). *Special Finishes to Garment-An Overview*. Retrieved from www.fiber2fashion.com

[3] Fahmy, H. M., Aly, A. A., Amr, A. A., Sayed, S. M., and Rabie, M. (2017). Effect of phenolic compounds and water repellents combination on performance properties of cotton/polyester blended fabric. Egyptian Journal of Chemistry, 60(1), 69-84.

[4] Zahid, M., Mazzon, G., Athanassiou, A., and Bayer, I. S. (2019). Environmentally benign non-wettable textile treatments: A review of recent state-of-the-art. Advances in colloid and interface science, 270, 216-250.

[5] Sunderland, E. M., Hu, X. C., Dassuncao, C., Tokranov, A. K., Wagner, C. C., & Allen, J. G. (2019). A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. Journal of exposure science & environmental epidemiology, 29(2), 131-147.

EFFECT OF ALKALINE HYDROLYSIS PROCESS ON THE PHYSICAL AND ELECTRICAL PROPERTIES OF REDUCED GRAPHENE OXIDE COATED POLYESTER KNITTED FABRIC

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ABSTRACT

In this study, the influence of surface modification of polyester weft knitted fabric via alkaline hydrolysis on graphene oxide coating and reduction process is analyzed. In this regard, polyester weft knitted fabric was first treated with sodium hydroxide solution to impart surface roughness to the fabric. Then, untreated and sodium hydroxide-treated fabrics were dip-coated with graphene oxide aqueous dispersion followed by a reduction process with L-ascorbic acid (Vitamin C) known as green reductant. The weight changes after each treatment were calculated. The physical properties of polyester knitted fabric were determined by means of abrasion resistance and bursting strength before and after alkaline hydrolysis, graphene oxide coating, and reducing processes. Scanning electron microscopy and Fourier transform infrared spectroscopy were employed to characterize the surface and chemical structure of fabric samples, respectively. The surface and volume resistivity of the fabric samples were tested using a setup consisting of a sourcemeter and resistivity test fixture.

Keywords: *Alkaline hydrolysis, Polyester fabric, Graphene oxide, Dip coating, Ascorbic acid reduction.*

1. INTRODUCTION

Textile materials have gained increasing attention in the field of technical end-use areas beyond traditional applications [1]. Textiles have various advantages such as good flexibility and mechanical properties, high surface area, and lightweight. These characteristics of textiles make them ideal supports for producing functional materials [2, 3]. Incorporation of functionality into textiles can be obtained by various approaches such as spinning, knitting, weaving, coating, and printing [4]. Among the several approaches that developed to produce functional textiles, the coating of textiles with nano-sized materials can be considered one of the most effective ones [5]. With the help of the hydrophilic groups on graphene oxide (GO) sheets, it can be easily dispersed in water. Therefore, graphene oxide can be deposited on textile materials by simple coating methods. Afterward, GO can be converted to reduced graphene oxide (RGO) which is the electrically conductive form, by chemical reduction method using a reducing agent [6]. Polyethylene terephthalate (PET) fiber finds applications in many areas including apparel, sports, activewear, protective clothing, medical textiles, and several technical applications [7]. Mechanical properties, durability, and abrasion resistance are major characteristics of polyester fibers

[8]. The low hydrophilicity of polyester fabrics causes problems in applications such as finishing, dyeing, and washing. To improve these properties, the surface of polyester fabric is modified [9]. Alkaline hydrolysis is an effective method for introducing roughness on the fiber surface by etching through chemical and morphological changes in polyester. As a result of the alkaline hydrolysis process, physical and chemical changes occur in the fiber surface with the formation of small craters and functional groups. Thus, the fabric has better wettability [10]. Sodium hydroxide (NaOH) is the most active and inexpensive material for surface modification of polyester [11]. In this regard, the aim of the study is the performing alkaline hydrolysis on polyester fabric and then evaluate the effects on physical and electrical properties of GO and RGO-coated polyester fabric.

2. EXPERIMENTAL STUDY

2.1 Materials

Polyester weft knitted fabric (1x1 rib, 8 wale/cm, 16 course/cm, 182 dtex f 35) with a basis weight of 300 g/m^2 was used as the substrate. All chemicals were of analytical reagent grade and used without further purification. Graphite flakes, L-ascorbic acid, and hexadecyltrimethylammonium bromide (CTAB) were purchased from Sigma Aldrich. Sulfuric acid (H_2SO_4, 95-98%), potassium permanganate ($KMnO_4$), and ethanol were purchased from Isolab. Hydrogen peroxide (H_2O_2 35%), phosphoric acid (H_3PO_4), hydrochloric acid (HCl, 37%), and sodium hydroxide (NaOH) were purchased from Merck. Distilled water was used throughout the experiments.

2.2 Synthesis of GO

Graphene oxide was synthesized from flake graphite by the improved Hummer's method. Briefly, a 9:1 mixture of concentrated H_2SO_4/H_3PO_4 (360:40 mL) was added to a mixture of graphite flakes (3 g) and $KMnO_4$ (18 g). The reaction was then heated to 50 °C and stirred for 12 h. The reaction was then cooled to room temperature and poured onto ice (400 mL) with 35% H_2O_2 (6 mL). The resulting suspension was washed by repeated centrifugation (each at 8000 rpm for 30 min), first with 400 ml of 1 M HCl and 200 mL of ethanol (2×), then with distilled water until a pH of 4-5 was achieved. The obtained solid product was dried overnight in an oven at 60°C.

2.3 Alkaline hydrolysis of polyester knitted fabric

The polyester weft knitted fabric was treated in a bath with liquor to goods ratio (L:G) = 15:1 containing nonionic washing agent (Perlavin OSV) for about 30 min at 60°C to remove impurities. The fabric was then washed with excess water and dried at room temperature. The alkaline hydrolysis treatment was applied by immersing the polyester knitted fabric in a NaOH solution (8% owf) with a liquor to goods ratio (L:G) of 20:1 at 70°C for 30 min. Then the fabric was neutralized by using 1%wt acetic acid solution followed by rinsing with excess distilled water. The treated fabric was dried in an oven at 95°C for 60 min.

2.4 Coating of polyester knitted fabric with GO

The synthesized GO nanosheet was dispersed in distilled water by bath sonication method to obtain 2 g/L GO aqueous dispersions. Polyester knitted fabric was then immersed in the GO dispersion for 30 min at 60°C. Then, the coated fabric was dried in an oven at 70°C for 60 min. The coating process was repeated 5 times in order to increase the GO adsorption on the fabric.

2.5 Reduction of GO coated on polyester knitted fabric

The GO-coated fabric was chemically reduced using aqueous solution of L-ascorbic acid. The reduction solution with concentration of 0.2 M was prepared by dissolving L-ascorbic acid in distilled water and liquor to goods ratio (L:G) was kept as 20:1. GO coated polyester fabrics were immersed in the L-ascorbic acid solution for 45 min at 95°C. The resulting fabrics were rinsed with distilled water to remove the remaining reducing agent. The fabrics were dried in an oven at 90°C.

2.6 Characterization

An attenuated total reflection Fourier transform infrared spectrometer (ATR-FTIR, Perkin Elmer Spectrum Two) was used at 400 - 4000 cm^{-1}. The weight loss of the fabrics due to alkaline hydrolysis and the weight increase due to GO coating were calculated using the following equations:

$$\text{Weight loss }(\%)=\left(\frac{W_0-W_1}{W_0}\right)\times 100 \quad \text{Eq. 1}$$

$$Weight\ increase\ (\%)=\left(\frac{W_f-W_i}{W_i}\right)\times 100 \quad \text{Eq. 2}$$

where W_0 is the weight of the polyester fabric before alkaline hydrolysis, W_1 is the weight of the polyester fabric after alkaline hydrolysis treatment; W_f is the final weight of polyester fabric after the GO coating process, W_i is the initial weight of polyester fabric before the GO coating process. The mechanical property of the untreated and alkali-treated polyester knitted fabric, GO and RGO coated polyester knitted fabrics was tested by means of bursting strength and distension using m229 AutoBurst (SDL ATLAS) according to the TS 393 EN ISO 13938-1 standard at 10 cm^2 test area. Each sample was tested three times and the average value was used after the diaphragm correction. The surface and volume resistivity of the fabrics were tested based on the ASTM D257-07 standard, using a setup consisting of a sourcemeter (Keithley 2450 Sourcemeter) and a resistivity test fixture (Keithley 8009). Surface resistivity is measured by applying a voltage potential across the surface of the specimen, whereas volume resistivity is measured by applying a voltage across the sample. The following equations were used to calculate the surface and volume resistivities of the samples:

$$\rho_s=\frac{53.4\times V}{I}\ ohm\ (\Omega) \quad \text{Eq. 3}$$

$$\rho_v=\frac{22.9\times V}{t\times I}\ ohm.cm\ (\Omega.\text{cm}) \quad \text{Eq. 4}$$

where ρ_s and ρ_v are the surface and volume resistivity of the specimen, respectively, V is the voltage and I is the current, and t is the average thickness of the specimen in cm. The abrasion resistance test was applied by using a Martindale pilling and abrasion instrument according to TS EN ISO 12947-2 standard. In this test, a standard wool woven fabric was used as an abrasive element, and 9 kPa pressure was applied to samples. The test is terminated when the breakdown of the fabric occurred.

3. RESULTS

The FTIR has been made to confirm the alkali surface modification of polyester fabric and the coating and reduction of graphene oxide nanosheets on the fabric surface. Figure 1(a) shows the FTIR analysis of untreated and alkali-treated polyester knitted fabric. The peaks at 722 cm^{-1}, 871 cm^{-1}, and 1408 cm^{-1} are attributed to C–H bond in the aromatic group, the peaks at 1713 cm^{-1} and 1238 cm^{-1} were assigned to C=O and C=O stretching vibrations of aromatic ester and ester, respectively [12, 13]. The peaks at 1015 cm^{-1} and 969 cm^{-1} are corresponding to the C–O stretching of glycol and benzene in-plane vibrations, respectively. The peak at 1091 cm^{-1} represents the ester C=O stretching vibration [3]. After the alkaline hydrolysis process, the intensity of the peaks at 1713 cm^{-1}, 1238 cm^{-1}, 1091 cm^{-1}, and 722 cm^{-1} increased. In Figure 1b, a broad peak between 3600-2800 cm^{-1} shows O–H stretching vibrations of carboxylic acid caused by the presence of absorbed water molecules and alcohol groups in GO. In Figure 1c, after the reduction of GO, the broad peak between 3600-2800 cm^{-1} disappeared and the intensity of the sharp peaks decreased.

The process parameters of polyester knitted fabric are given in Table 1. The weight loss after alkali treatment and the weight increase after the GO coating process of polyester knitted fabric can be found in Table 1. The weight loss of polyester fabric after alkali treatment is obtained as 4.48%. The weight increases of the GO-coated alkali-treated polyester fabric likewise the weight loss after the reduction of GO is obtained higher than that of the untreated polyester fabric. The weight increases of alkali-treated GO-coated polyester fabric can be explained by the formation of new active sides which mostly consist of carboxylic acid groups on the polyester filaments by the alkaline hydrolysis process. The surface roughness of the polyester filaments was obtained due to the chemical etching process applied by alkaline treatment. Therefore, a higher amount of GO nanosheets was coated on the alkali-treated polyester fabric.

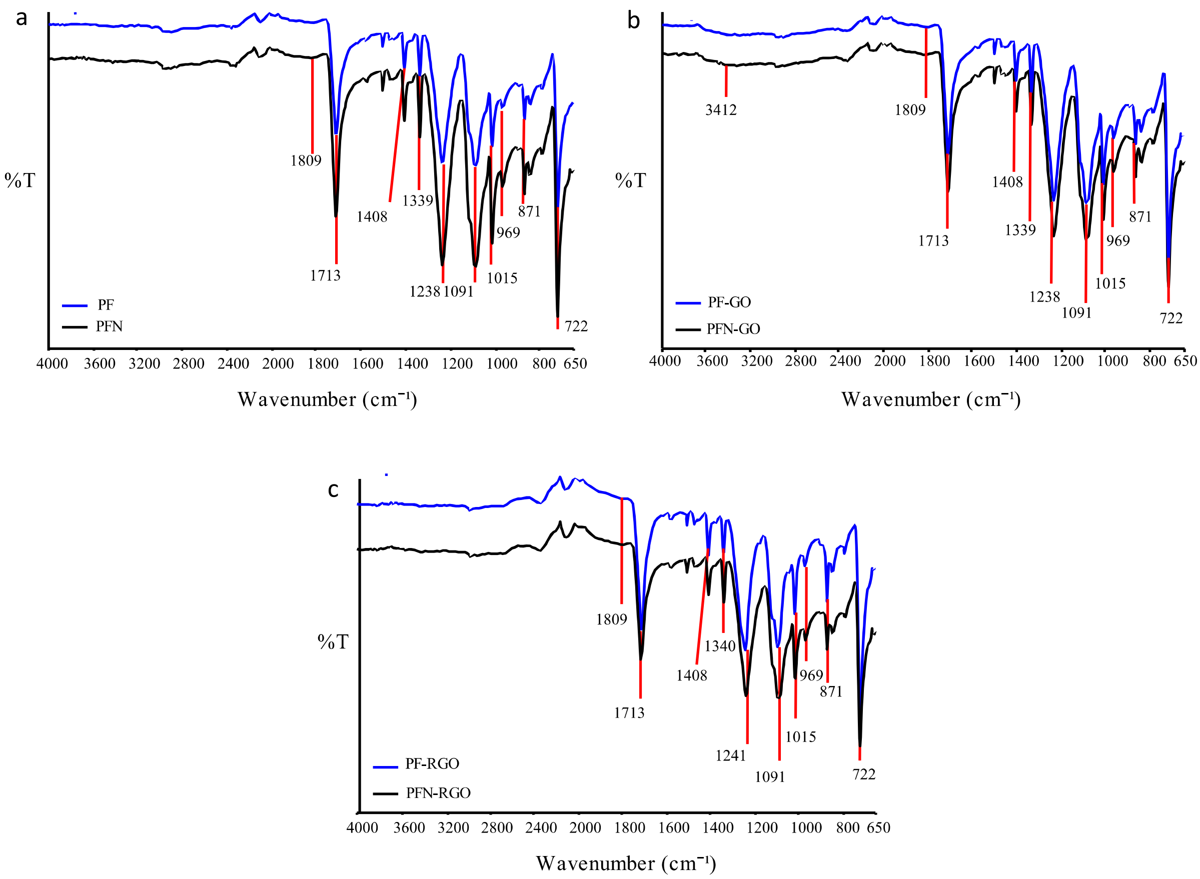

Figure 1. FTIR spectra of untreated and NaOH-treated polyester fabrics (a), GO-coated (b), and RGO-coated samples (c).

Table 1. The process parameters of polyester knitted fabric and corresponding sample codes.

Sample Codes	*NaOH (%) (owf)*	*Weight loss[1] (%)*	*Sample Codes*	*GO[a] (g/L)*	*Weight increase[2] (%)*	*Sample Codes*	*L-ascorbic acid[b] (M)*	*Weight loss[3] (%)*
PF	-	-	**PF-GO**	2	1.59	**PF-RGO**	0.2	0.66
PFN	8	4.48	**PFN-GO**	2	2.90	**PFN-RGO**	0.2	1.22

The surface and volume electrical resistivities of untreated and alkali-treated polyester fabric before and after GO coating and GO reduction process are given in Figure 2. In Figure 2a, it can be understood the untreated and alkali-treated polyester knitted fabric samples have high surface and volume resistivity values, which means that they do not conduct electricity. Besides, it is also known that GO is an electrical insulator due to the oxygen-containing functional groups attached to the surface and edge of the sheets. Therefore, the electrical surface and volume resistivities of GO-coated untreated and alkali-treated polyester fabric samples were obtained in the range of 10^9 Ω/sq and Ωcm and 10^8 Ω/sq and Ωcm, respectively (Figure 2b). With the reduction process using L-ascorbic acid, the electrical surface and volume resistivities of samples have shown a remarkable decrease. The electrical surface and volume resistivities of alkali-treated RGO-coated polyester fabric were obtained as the lowest with values of 6.86×10^4 Ω/sq and 1.51×10^5 Ωcm, respectively. This result can be attributed to the higher RGO nanosheet amount coated on the alkali-treated polyester fabric surface.

Bursting strength and bursting distension of untreated and alkali-treated GO and RGO-coated polyester knitted fabrics were given in Figure 3. The bursting strength of the alkali-treated polyester knitted fabric samples was obtained lower than the untreated samples. However, the bursting strength of alkali-treated polyester fabric increased after GO coating while the bursting strength of the untreated polyester fabric decreased after GO coating. The decrease in mechanical properties after the alkaline hydrolysis process is expected as a result of the chemical etching and formation of damages on the surface filaments. Figure 3b shows that the alkaline hydrolysis process did not affect the bursting distension of polyester knitted fabric samples.

The abrasion resistance of untreated and alkali-treated polyester fabrics, GO and RGO coated untreated and alkali-treated samples is given in Figure 4. The abrasion resistance of the untreated polyester fabric sample increased with GO coating and further increased with the reduction of GO. This result can be explained by the molecular lamellar arrangement of the GO nanosheets acts as a self-lubricant [14]. The alkaline hydrolysis process increased the abrasion resistance of the polyester fabric and GO-coated polyester fabric. The alkaline hydrolysis process causes the polyester filament surface more resistant to abrasion damage. The formation of microscopic damage on the surface of the polyester filaments causes less friction between them during the test, thus increasing the abrasion resistance [15].

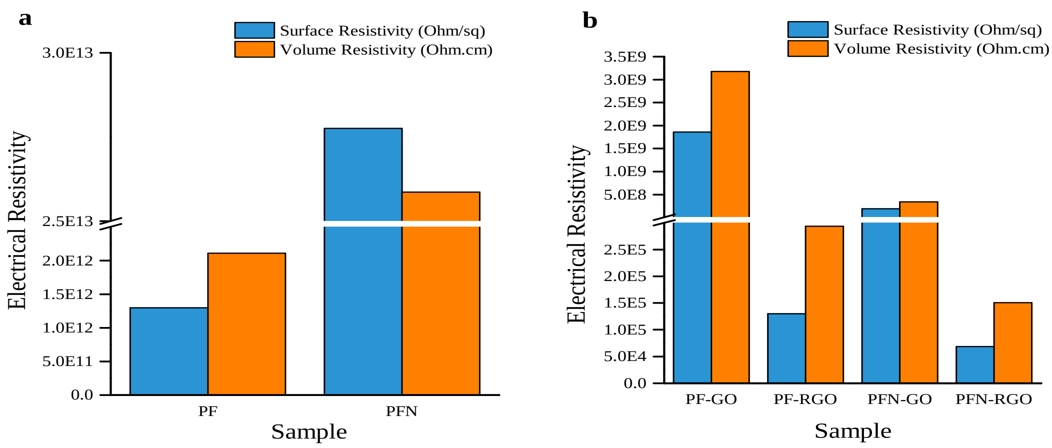

Figure 2. Surface and volume resistivities of untreated and NaOH-treated polyester fabrics (a) and GO and RGO coated untreated and NaOH-treated samples (b).

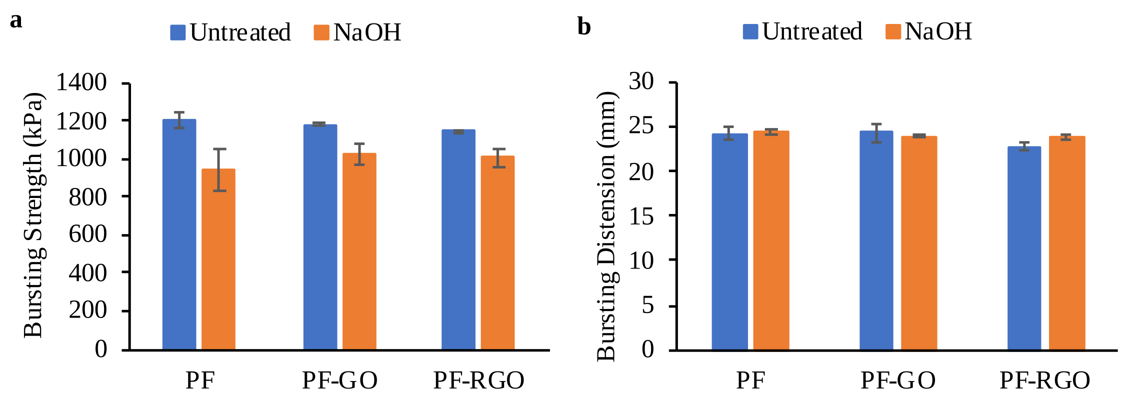

Figure 3. Bursting strength (a) and bursting distension (b) of untreated and NaOH-treated samples.

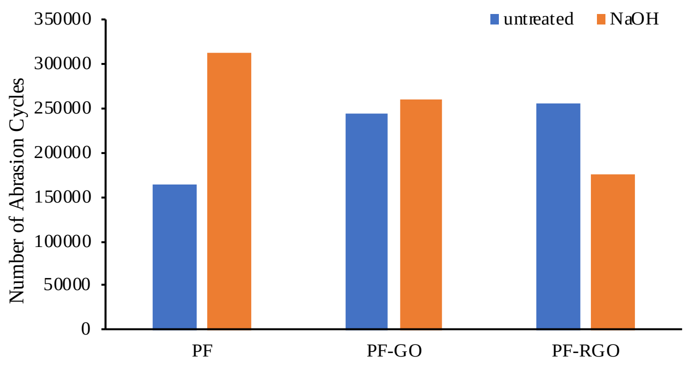

Figure 4. Abrasion resistance of untreated and NaOH-treated polyester fabrics, GO and RGO coated untreated and NaOH-treated samples.

4. CONCLUSION

In this study, the influence of surface modification of polyester weft knitted fabric via alkaline hydrolysis on graphene oxide coating and reduction process is analyzed. The weight loss of polyester fabric was obtained after the alkaline hydrolysis. Moreover, the percentage of weight increase of GO-coated polyester fabric was found higher than GO-coated untreated polyester fabric. The alkaline hydrolysis process has decreased the electrical resistivity of RGO-coated polyester fabric. The mechanical property of polyester knitted fabric decreased by the alkaline hydrolysis treatment. However, the alkaline hydrolysis treatment did not affect the bursting distension of polyester fabric samples.

REFERENCES

[1] Rosace, G., V. Trovato, C. Colleoni, et al. (2017). Structural and morphological characterizations of MWCNTs hybrid coating onto cotton fabric as potential humidity and temperature wearable sensor. Sensors and Actuators B: Chemical. 252, 428-439.

[2] Molina, J., J. Fernández, A. I. del Río, et al. (2013). Chemical and electrochemical study of fabrics coated with reduced graphene oxide. Applied Surface Science. 279, 46-54.

[3] Ouadil, B., O. Cherkaoui, M. Safi, et al. (2017). Surface modification of knit polyester fabric for mechanical, electrical and UV protection properties by coating with graphene oxide, graphene and graphene/silver nanocomposites. Applied Surface Science. 414, 292-302.

[4] Gültekin, B. C. (2022). Electrically conductive, hydrophobic, UV protective and lightweight cotton spunlace nonwoven fabric coated with reduced graphene oxide. Turkish Journal of Chemistry. 46(4), 968-986.

[5] Chatterjee, A., M. Nivas Kumar and S. Maity. (2017). Influence of graphene oxide concentration and dipping cycles on electrical conductivity of coated cotton textiles. The Journal of The Textile Institute. 108(11), 1910-1916.

[6] Hasani, M. and M. Montazer. (2017). Cationization of cellulose/polyamide on UV protection, bio-activity, and electro-conductivity of graphene oxide-treated fabric. Journal of Applied Polymer Science. 134(44).

[7] Musale, R. M. and S. R. Shukla. (2016). Weight reduction of polyester fabric using sodium hydroxide solutions with additives cetyltrimethylammonium bromide and [BMIM]Cl. The Journal of The Textile Institute. 108(4), 467-471.

[8] Kongahge, D., J. Foroughi, S. Gambhir, et al. (2016). Fabrication of a graphene coated nonwoven textile for industrial applications. RSC Advances. 6(77), 73203-73209.

[9] Corak, I., A. Tarbuk, D. Dordevic, et al. (2022). Sustainable Alkaline Hydrolysis of Polyester Fabric at Low Temperature. Materials (Basel). 15(4).

[10] Lee, S. (2022). Superhydrophobicity and conductivity of polyester-conductive fabrics using alkaline hydrolysis. RSC Adv. 12(35), 22911-22921.

[11] Al-Balakocy, N. G., T. Hassan, S. Khalil, et al. (2021). Simultaneous chemical modification and functional finishing of polyester textiles. Research Journal of Textile and Apparel. 25 (3), 257-273.

[12] Shao, F., S. W. Bian, Q. Zhu, et al. (2016). Fabrication of Polyaniline/Graphene/Polyester Textile Electrode Materials for Flexible Supercapacitors with High Capacitance and Cycling Stability. Chemistry- An Asian Journal. 11(13), 1906-12.

[13] Rathinamoorthy, R. and S. Raja Balasaraswathi. (2022). Effect of surface modification of polyester fabric on microfiber shedding from household laundry. International Journal of Clothing Science and Technology. ahead-of-print(ahead-of-print).

[14] Bhattacharjee, S., R. Joshi, A. A. Chughtai, et al. (2019). Graphene Modified Multifunctional Personal Protective Clothing. Advanced Materials Interfaces. 6(21), 1900622.

[15] Textor, T., L. Derksen, T. Bahners, et al. (2019). Abrasion resistance of textiles: Gaining insight into the damaging mechanisms of different test procedures. Journal of Engineered Fibers and Fabrics. 14, 1558925019829481.

THEORETICAL AND PRACTICAL ASPECTS FOR FLAT-KNITTED BAND-STOP FREQUENCY SELECTIVE SURFACE

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ABSTRACT

This article presents the design, fabrication, and analysis of a textile-based band-stop frequency selective surface (FSS), in GSM, Wi-Fi, LTE, and WiMAX bands where the electromagnetic (EM) pollution is intense. In this study, textile-based FSSs were designed using a flatbed knitting machines. The unit cell of the proposed FSS has been designed and simulated via a full-wave EM solver; CST Microwave Studio at the frequency of interest. The main purpose lies in the discussion of the contradictory results between model and manufactured samples derived from the research depending upon the theoretical knowledge and practical aspects within. The results of this study showed that the flat knitting loop density and types has a dramatic effect on the electromagnetic behaviour of the FSS.

Keyword: *EM filter, FSS, Flat-bed knitting, Textile*

1. INTRODUCTION

Recent scientific studies on electronics show that people are using more wireless gadgets, multimedia devices, and other electronic equipment that generate EM waves on a regular basis. These apps transmit electromagnetic waves (EM waves) at different frequencies including 2G, 3G, and LTE, WiFi, Wimax, and Bluetooth. Due to the rapid speed, large area, and mobility of these frequencies, EM pollution is the result. The strong EM wave interference poses a threat to the occupants' health, particularly in dense residential settings. Studies in this area are becoming more common as EM-wave interference affects human health. Within the context of cancer research, the World Health Organization (WHO) concurred that EM waves may have a proclivity to cause cancer [1]. Thus, shielding of EM waves gains more importance.

Electromagnetic waves are typically shielded using metallic casing or shielding enclosures. Conventional metals and their alloys can make effective electromagnetic shielding materials, but their uses in EMI shielding are limited by their large weight, high price, and poor corrosion resistance. And also due to their rigidity, metallic shieldings are unable to provide a flexible pass or stop frequency range. For these reasons, the trend moves towards plastic encasings for electrical equipment and plastic materials have become more popular in the last 20 years due to their low weight, flexibility, and aesthetic properties. Since light and integrated electromagnetic-shielding materials are gaining interest, the research nowadays interferes with the field of textile engineering. For this reason, the focal point of innovative research is to employ fundamental textile manufacturing techniques to the implementation of FSS. In case textile-based FSSs are designed using a flat-bed knitting technique, there would be many theoretical and practical aspects to discuss for the the design, fabrication, and analysis of a textile-based band-stop frequency selective surface (FSS) in GSM, Wi-Fi, LTE, and WiMAX bands where the electromagnetic (EM) pollution is intense. Thus, this study intends to present these theoretical versus practical points for the implementation of knitted FSS.

Frequency selective surfaces (FSS) are generally designed as two-dimensional periodic structures with planar metallic array elements (patches or apertures) on a dielectric substrate that exhibit transmission and reflection at a relevant resonant frequency. The subject of FSS is studied intensely for the electromagnetic (EM) pollution reduction [2]. In the past, FSSs have been widely employed for semi-optical microwave devices, resonance beam splitters, antennas and radomes, diplexers, and reflector antennas. Fundamental FSS research has lasted for more than 60 years. However, today the main aim seems to have shifted to the employment of FSSs for radio frequency identification, lens antennas, and electromagnetic shielding (RFID) rather than the empirical research for the fabrication of FSS. In the aerospace and military sectors, antenna radomes and radar cross-section reduction (RCS) are particularly hot topics. The knowledge in this sector has been continuously updated and has reached the current level as a result of rigorous studies in both theory and practice.

Conventional FSSs refer to simple FSS geometries such as loop, dipole, cross, and patch type FSSs. In the figure 1, group 1 (N-poles or center-connected such as dipoles, tripoles, square spirals and Jerusalem crosses), group 2 (looped types such as circular, square and hexagonal loops), group 3 (solid interior or patch types in various shapes) and group 4 (combinations of any of the above). Also, 4 types of FSSs are employed according to filtering characteristic such as band-stop, band-pass, high pass, low pass. Depending on its filtering features, an FSS behaves like a series or parallel RLC circuit. Fig. 1 depicts the analogous circuits and related filter responses for various filters. The FSS patches will produce R and L, while the gaps between the FSS cause C. The electrostatic knowledge may be utilized including capacitance of a parallel plate capacitor and inductance of two parallel wires for explaining the physical sense of these C and L values of various FSS [3].

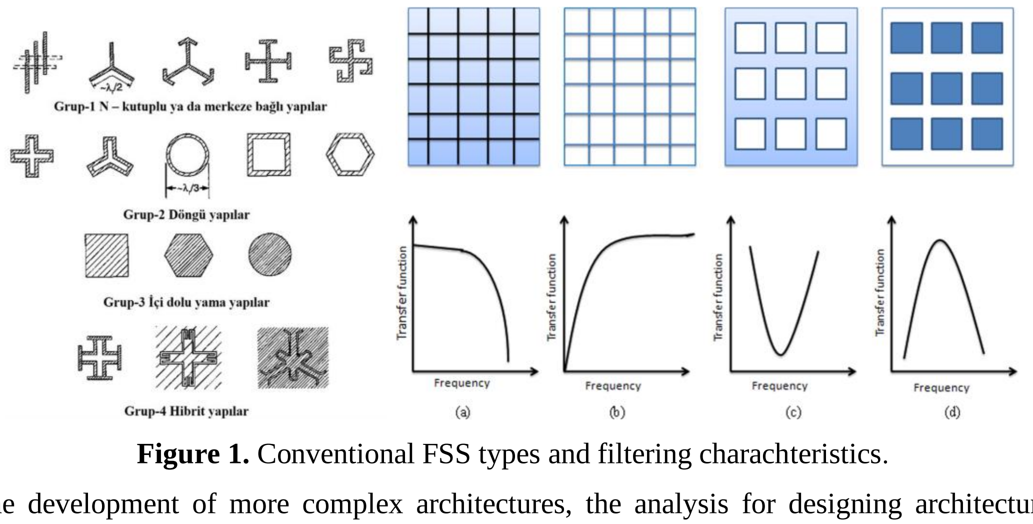

Figure 1. Conventional FSS types and filtering charachteristics.

With the development of more complex architectures, the analysis for designing architectures has become even easier as the state-of-the-art numerical techniques based on the periodic boundary conditions (PBC) have been developed. Some of the numerical analysis techniques already implemented for the synthesis of planar FSS structures include finite element method analysis (FEM), method of moments (MoM), finite difference time domain method (FDTD), and integral equation [3].

As a result of studies on both patch and dielectric layer, microwave absorbers, active-passive structures, and information security [4] diverted the trend towards wearable FSSs, and textile FSS applications. Despite the vast number of scientific studies describing the function of conventional FSSs, there are relatively few that demonstrate flexible, lightweight, and wearable textile FSSs.

In textile FSS investigations, square loop architectures in woven FSSs are typically used to build high-pass filters [5-7]. The printing technique is also promising for FSSs since silk screen printing produces the appropriate shape with a little margin of error [8-10]. With a CAD modeling and patterning technology, massive pattern surfaces may be produced for the embroidery process [11-14].

The main purpose of this research is to implement a widely used unit cell for the design of band-stop FSS, namely Jerusalem cross (JC). The specific dimensions of JC unit cell were numerically calculated for 3.5 GHz. In this study, band-stop FSS design at 3.5 GHz was made with CST microwave studio software. This main model (M1) was re-modeled for 3 types of loop sizes (in different course sizes M2). These models were followed by the fabrication of JC unit cell with industrial flat-bed knitting machines (14 gauge). The main purpose lies in the discussion of the contradictory results between models and manufactured samples derived from the research depending upon the theoretical knowledge and the practical aspects within.

2. EXPERIMENTAL STUDY

Two types of yarn are used to perform knitting by flat-bed knitting technique. While dielectric yarn is used for the substrate part in FSS, silver coated conductive yarn is employed for the conductive patch. Using computer simulation technology (CST), the band-stop characteristic FSS is modelled and simulated at a 3.5 GHz frequency. Modelling two different aproach in this study, the first model is donated as a copper tape model (M1) which does not include textile parameters (Fig. 2) and the second is knitting texture model (M2) (Fig.3) with three types of course widths.

2.1 FSS modelling and simulation

The unit-cell was designed since the waveguide method was used in the study. Based on the unit-cell structure of the Jerusalem cross, the numerical study and optimization process for the band-stop characteristic at 3.5 GHz was carried out by CST Microwave Studio, and the geometric dimensions of the unit-cell were indicated in figure 2. The scattering parameters were created by considering the dielectric coefficients of the fabrics used in the study.

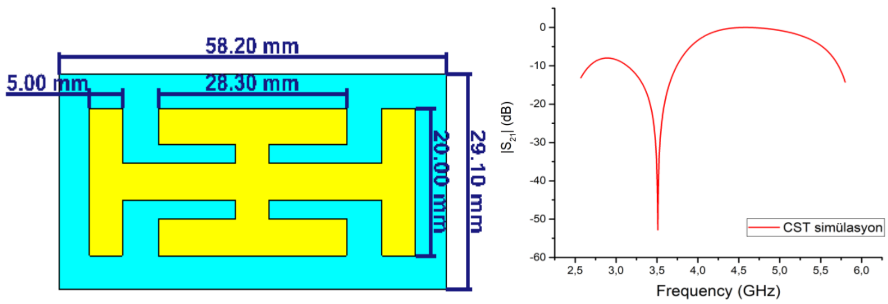

Figure 2. Jarusalem cross unitcell and transmission coefficient (M1).

According to Figure 2, it is seen that the Jerusalem cross unit-cell was fitted at a frequency of 3.5 GHz and a band-stopping characteristic was observed. In the design, the dimensions of the substrate were determined according to the WR 229 waveguide which have a frequency range of 3.3 GHz to 4.9 GHz and 58.17x29.08 mm dimension.

In our previous study, it has been calculated that the shiedex statex 117/17 2 ply conductive yarn has approximately 1µm conductive layer. The knitted unit cell modeling phase is shown in figure 2 step by step.

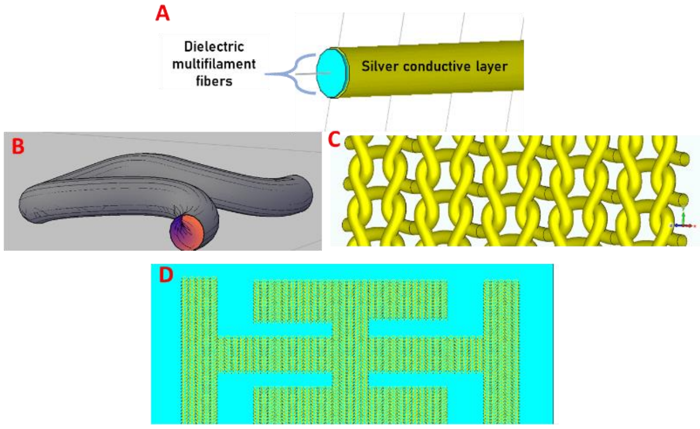

Figure 3. The composition of knitting texture FSS modelling (M2), conductive yarn model (A), loop model (B), loops composition (C), knitting model unitcell of FSS (D).

As per the detailed description given in figure 3, three different sizes of loop are modeled 1mm, 2.5 mm and 5mm respectively and their effects on EM wave filtering are shown with the help of scattering parameters (Figure 4).

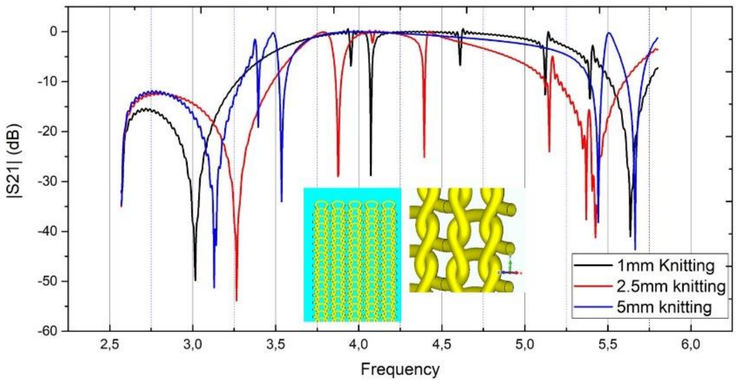

Figure 4. Loop size effects on transmission coefficient.

When the transmission coefficients of the knitting model in figure 4 are compared with the coefficient of the copper tape model in figure 2, the shifting is seen in the targeted resonance frequencies depending on the loop sizes. Therefore, it can be said that the resonance frequencies of knitted FSSs occur at lower frequencies than expected.

2.2 FSS manufacturing

The most common knitting technique is weft knitting in which horizontal rows of loops (called courses) are interconnected. With the consecutive addition of courses the knitted fabric grows in vertical direction. With the less common warp knitting method, however, loops are added to a vertical column of stitches which makes the fabric grow in horizontal direction. With modern flatbed knitting machines it is possible to integrate warp knitted vertical structures of (functionalized) yarns into a weft knitted base structure using special intarsia needles. Intersia fabrics have the advantage that, unlike the jacquard method, different-colored yarns do not create a complicated appearance on the fabric's reverse. Because of this, the color that shows on the front of an intersia fabric also appears on the back. The intersia knitting technique is favored for the manufacturing of knitted FSSs because of this characteristic.

Figure 5. Intersia knitting FSSs.

2.3 Theoretical vs practical points

Free space measurements are conducted by using two identical antennas with the same polarization. The sample size for that measurement setup has limitations in terms of array size and the far-field distance of the antennas. In order to satisfy far-field limitations the distance between the antenna and the sample has to be larger than $2D^2/\lambda$ where D denotes the maximum dimension of the antenna and λ is the wavelength. Due to these space limitations and cost-effective preferences, this study focuses on a waveguide measurement setup that will reduce the measurement cost by reducing the sample size to a unit cell instead of an n *x* m array size. In this study, the designs are considered as having the substrate dimensions of a 200 mm-long WR229 waveguide size which is 29.083mm in width and 58.166mm in height. After defining those the most critical design parameters are noted below and the experimental results of the study are analyzed by considering the notes stated below ;

- Design the unit cell properly to fit exactly inside the waveguide.
- Stick on the dimensions of the resonator that is designed to have filtering properties (Since the frequency is a function of inductance and capacitance values satisfying the relation f_r =1)
- The conductor part should satisfy a certain level of conductivity for satisfying requirements as can be seen in the full-conductor structure.
- The continuity should be satisfied especially for the conductor part
- Permittivity value for the yarn evaluated precisely and considered as the measured value during the simulations
- Loss factor should be counted in to account for higher frequency values

2.4 Results and Discussions

There are studies in the literature suggesting more textile detailed 3D modeling and EM simulations. However, the authors fail to acknowledge the significance of the conductive yarn structure's effect on EM filtering. The conductive yarn should be modeled as a multifilament yarn instead of a monofilament wire.

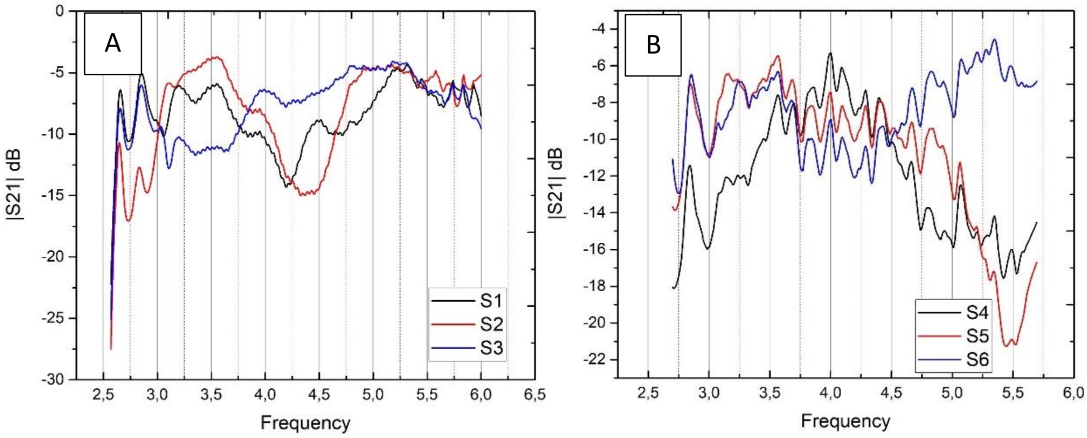

Figure 6. Transmission coefficient of knitting FSSs.

In Figure 6, the transmission coefficients of the S1 and S2 samples showed similar characteristics and resonated at around 4.25 GHz under -10 dB. In the graph of S3, resonance occurred at 3.5 GHz under -10 dB. Resonance was observed around -15 dB at 3 GHz in the S4 graph and over -10 dB in the graph of S5 and S6. Resonance below -10 dB at the relevant frequency is required for the study to detect a band-stop filter effect. As a result, the causes of the lack of resonance at the pertinent frequency or the excessive frequency shift were investigated.

Due to the excessive stretching of the fabrics, the dimensions of the knitted unit cell change during the fixing of the unit cell produced in precise dimensions into the waveguide. As explained before, this shows a different resonance behavior as it affects the inductance and capacitance functions. The conductivity of the conductor is an important factor for filtering at the targeted resonance. The level of conductivity was tested by measuring the EM wave shielding performance of the knitting fabric independent of the unit cell.

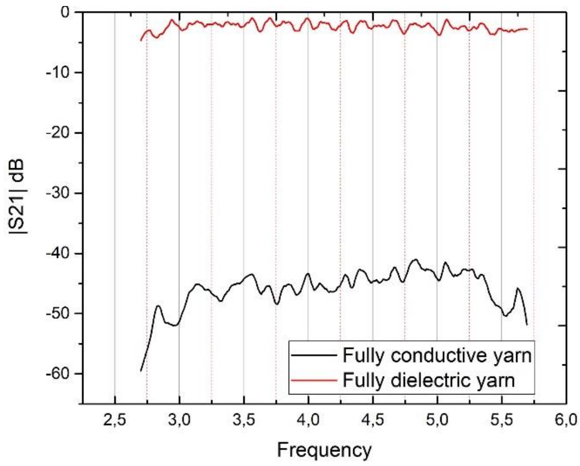

Figure 7. Fully conductive and dielectric fabric EM filtering behavior.

According to figure 5, resonances below -10 dB indicate adequate shielding of the EM wave of corresponding frequencies. While the fully conductive fabric resonated around -45 dB at approximately 2.5-5.7 GHz, the resonance was around -5 dB in the non-conductive fabric.

3. CONCLUSION

This study provide an understanding of how knitted constructions behave under electromagnetic waves, what are the effects of knitting density and furthermore what is the transmission coefficient of knitted textile FSSs and the measurements about the knitted FSSs are presented at the congress. Further analysis showed that knitting precision and structural stability have a significant effect on the resonance properties. In addition, the effects of knitting parameters on scattering parameters are examined and the best production conditions are revealed in modelling and simulation phases. Especially, there is a significant correlation between loop size and resonance frequency at knitting FSSs.

REFERENCES

[1] Tunakova, V., Tunak, M., Tesinova, P., Seidlova, M., & Prochazka, J. (2020). Fashion clothing with electromagnetic radiation protection: Aesthetic properties and performance. *Textile Research Journal*, *90*(21-22), 2504-2521. doi: 0040517520923047.

[2] Munk, B.A. (2000). Frequency Selective Surfaces: Theory and Design. Hoboken, NJ, USA: John Wiley & Sons, Inc. *Epub ahead of print 12 April 2000*. doi: 10.1002/0471723770.

[3] Kapoor, A., Mishra, R., & Kumar, P. (2022). Frequency selective surfaces as spatial filters: Fundamentals, analysis and applications. *Alexandria Engineering Journal*, *61*(6), 4263-4293.
[4] Noor, D., Yadav, S. K., Yadav, S., Garg, M., & Garg, S. (2017, May). A triple BandStop frequency selective surface for escalation in the security of WiMax and WLAN application. In *2017 International Conference on Computing, Communication and Automation (ICCCA)* (pp. 524-528). IEEE.
[5] Guan, F., Li, Z., Yang, Z., Zhang, C., & Qiu, Y. (2018). Design and Characterization of Periodically Conductive Woven Fabric. *Autex Research Journal*; *0. Epub ahead of print*. doi: 10.1515/aut-2018-0049.
[6] Huppé, C., Cochrane, C., Burgnies, L., Rault, F., Ducournau, G., Lheurette, E., ... & Lippens, D. (2017, October). Woven metamaterials with an electromagnetic phase-advance for selective shielding. In *IOP Conference Series: Materials Science and Engineering* (Vol. 254, No. 3, p. 032004). IOP Publishing.
[7] Seager, R. D., Chauraya, A., Bowman, J., Broughton, M., & Nimkulrat, N. (2014, April). Fabrication of fabric based frequency selective surfaces (FSS). In *The 8th European Conference on Antennas and Propagation (EuCAP 2014)* (pp. 1978-1980). IEEE.
[8] Guan, F., Xiao, H., Shi, M., & Wang, F. (2016). The novel frequency selective fabric and application research. *Journal of Industrial Textiles*, *46*(1), 143-159.
[9] Lee, D., & Lim, S. (2016, October). Wearable metamaterial absorber using screen printed chanel logo. In *2016 International Symposium on Antennas and Propagation (ISAP)* (pp. 928-929). IEEE.
[10] Whittow, W. G., Li, Y., Torah, R., Yang, K., Beeby, S., & Tudor, J. (2014). Printed frequency selective surfaces on textiles. *Electronics Letters*, *50*(13), 916-917.
[11] Almirall, O., Fernández-García, R., & Gil, I. (2022). Wearable metamaterial for electromagnetic radiation shielding. *The Journal of The Textile Institute*, 1–9.
[12] Guan, F., Xiao, H., Shi, M., Yu, W., & Wang, F. (2017). Realization of planar frequency selective fabrics and analysis of transmission characteristics. *Textile Research Journal*, *87*(11), 1360-1366.
[13] Kursun Bahadir, S., Mitilineos, S. A., Symeonidis, S., Şahin, U. K., Vassiliadis, S., Kalaoglu, F., ... & Savvaidis, S. P. (2020). Electromagnetic shielding and reflection loss of conductive yarn incorporated woven fabrics at the S and X radar bands. *Journal of Electronic Materials*, *49*, 1579-1587.
[14] Tahseen, M. M., & Kishk, A. A. (2017). Flexible and portable textile-reflectarray backed by frequency selective surface. *IEEE Antennas and Wireless Propagation Letters*, *17*(1), 46-49.

SEPARATION AND IDENTIFICATION OF MICROFIBERS IN THE WASTEWATERS OF TEXTILE FINISHING PROCESS

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ABSTRACT

Microplastic pollution is a major global issue, with the textile industry responsible for 35% of the microplastics (MPs) released as microfibers (MFs). Due to their small size, MPs can interact with a wide range of organisms and lead to chromosomal mutations that cause obstruction, inflammation, and organ accumulation. This study aims to detect and separate MFs released from the textile finishing machinery, which is used to give a soft touch to fabrics. Before being transferred to the effluent water, the wastewater samples taken from the section were pretreated with 15% H_2O_2 at 25 °C for 5 days, and then MFs were captured by a filter. Filters with accumulated MFs were observed using a light microscope, and a micro-FTIR was used to detect MFs chemically. The main results showed that acrylic and cotton MFs were detected in wastewater, and wastewater samples from different dates contained 0.058 g/L and 0.251 g/L MFs which reveals the seriousness of the MP problem we are facing.

Keyword: *Microplastic pollution, Microfibers, Textile wastewater, Filtration, Micro-FTIR*

1. INTRODUCTION

The most common type of marine litter, comprising 60% to 80% of all, is plastic particles [1]. The use of plastic for diverse purposes began in the 1930s, and when industrial plastic manufacturing rose in the 1940s, a large amount of plastic waste entered marine and freshwater habitats [1, 2]. Global production of plastics derived from petrochemicals with high molecular masses and plasticity reached 368 million metric tons in 2019 [3,4]. The worldwide output of thermoplastics is predicted to reach 445,250 million metric tons in 2025. Over the next few decades, annual production is expected to keep going up, reaching about 590 million metric tons by 2050 [5].

There are numerous industries that use plastic, with the textile industry being among the most prevalent. Worldwide textile fiber production reached 108 million metric tons in 2020, with synthetic fibers accounting for about 62% of the total [6]. While 60% of the synthetic fibers produced are buried or disposed of as waste after use, it can take up to 100 years for these fibers to decompose and disappear in nature [7, 8].

From the extraction of fossil fuels to consumer use and disposal, plastics represent a risk to human health at every stage of their existence [9]. Microplastics (MPs) are among these dangers that are most crucial. They are particles smaller than 1 mm according to ISO/TR 21960 and particles up to 5 mm in size according to scientific literature [10-12]. According to Gies et al., in Vancouver, Canada, 1.76 ± 0.31 trillion MPs enter the WWTP annually, whereas 0.03 ± 0.01 trillion MPs are discharged into the environment [13]. The majority of MPs end up in the environment as a result of human error, wastewater treatment facilities, or the textile sector [9]. Annually, between 200,000 and 500,000 tons of MPs are released from synthetic fibers, the vast majority of which end up in the ocean [7, 14]. Although 85-99% of MFs can be removed during the wastewater treatment process, the amount of MFs released into the environment by textile wastewater is substantially higher than that of municipal wastewater treatment facilities [15]. Although it is known that almost all machinery in the textile production process cause MF release, some of them result in more MFs in line with their working principles and usage purposes. Biancalani is a textile finishing machine which contains a raising procedure that involves removing a fiber layer from the fabric's surface to give it a hairy surface or generate a pile [16]. This finishing procedure gives the fabrics a warm, velvety texture. However, the fibers emerging from this finishing machine mix with the wastewater and lead to the formation of a high concentration of MFs in the wastewater.

MPs released into nature can accumulate in marine species and be transported to higher trophic levels, like humans, through the food chain. Due to the widespread presence of MPs in human foods and environments such as honey, milk, beer, seafood, table salt, drinking water, and the air, the potential health risks posed by microplastics have received considerable attention in recent years [17].

The aim of this study is to determine and separate the MFs released from the textile finishing machine used to give a soft touch to the fabric in a textile factory. Within the scope of the study, wastewater samples from the factory were pretreated with 15% H_2O_2 at 25 °C for 5 days, and then the treated wastewater was filtered. MFs captured on the filter were analyzed both by microscope and micro-FTIR, and their amounts were determined.

2. EXPERIMENTAL STUDY

2.1 Materials

The wastewater examined in the study was obtained from the exit of a finishing machine (Biancalani) belonging to a Turkish textile company. The wastewater sample was taken over two different time intervals (February and March in 2022) at the exit of the finishing process for cotton and acrylic fabric treatments before mixing with the effluent. Totally, 1 L of wastewater was collected in both months. In order to prevent contamination, the bottles and all other equipment used were sterilized with distilled water and ethanol, and the samples provided were kept in the refrigerator.

2.2 Methods

2.2.1. Pretreatment and filtration of wastewater

The 15% hydrogen peroxide (Sigma-Aldrich) was used to pretreat the 1 L samples for 5 days at 25 °C. After pretreatment, the filtration process was done with a 0.7 µm pore-size glass fiber (GF, Whatman, Ø 47 mm, 0.092 g) filter, then dried overnight at 40 °C.

Figure 1. Filtration process for separation of MFs.

2.2.2 Analysis of Microfibers

After filtration and drying, each filter was weighed with a precision balance (Precisa, PB-220A, ± 0.001 g). An ORTHOLUX II POL-MK optical microscope was used to examine the GF filters. The microfibers were characterized using a Shimadzu AIM-9000 Micro-FTIR at 700–4000 cm^{-1} and the library of spectra used was Shimadzu-T-Polymer2.

3. RESULTS

Macro- and micro-images of the MFs can be seen in Figure 2. The resulting images prove that the finishing process releases a large number of MFs. The reason for this can be explained by the fact that a fiber layer is cut away from the surface of the fabric during the finishing process applied by the Biancalani textile finishing machine, as mentioned before. Due to a large number of fibers, MFs' analysis could not be performed by counting but rather by weight measurement.

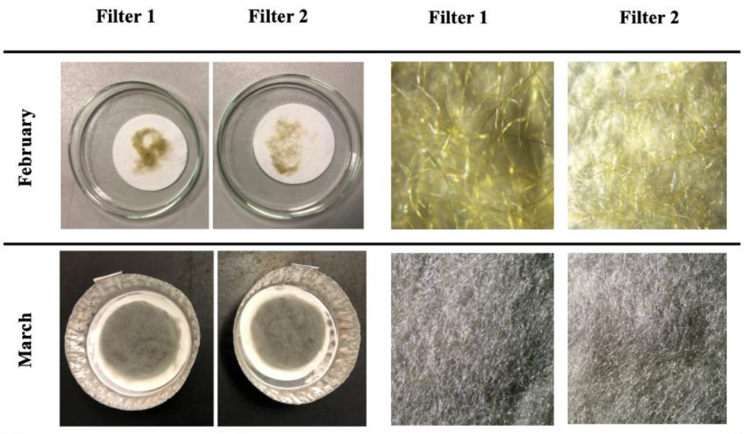

Figure 2. Macro and micro images of filters.

When the MFs filtered from the February and March wastewater samples were weighed, it was discovered that the samples contained 0.058 g/L and 0.251 g/L MF, respectively.

According to the Micro-FTIR results (Figure 3), the characteristic peaks of acrylic (C-H stretching at 2924–2853 cm^{-1}, CN stretching at 2242 cm^{-1}, C=O stretching at 1734 cm^{-1}, and C–C stretching in-ring at 1452 cm^{-1}) and cotton fibers (O-H stretching at 3300 cm^{-1}, C-H stretching at 2896 cm^{-1}, C=O stretching at 1730 cm^{-1}, C-H bending at 1428 cm^{-1}, C–C, C–O, and C–O–C stretching at 1030 cm^{-1}) were clearly detected in the spectra. This demonstrated that MFs in the wastewater were released from acrylic and cotton fabrics used in the Biancalani process, as expected.

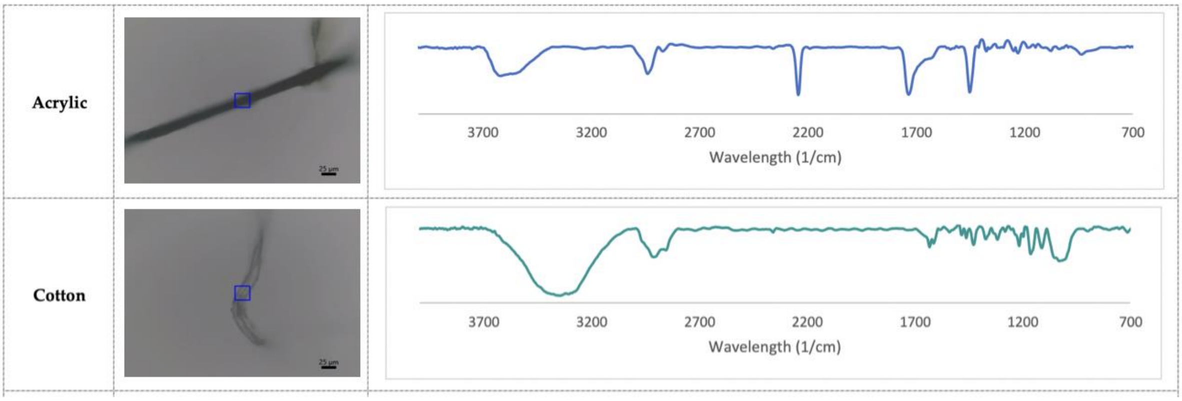

Figure 3. Micro-FTIR analysis.

4. CONCLUSION

This study aims to separate and identify MFs in wastewater resulting from a finishing process applied in the textile industry to give the fabric a soft feel. Within the scope of the investigation, wastewater samples from the factory were processed with 15% H_2O_2 at 25 °C for 5 days, and then the treated wastewater was filtered. MFs accumulated on the filter were examined both by microscope and micro-FTIR and their weights were determined. Examining the 1 L wastewater samples collected on various days reveals how much MFs (0.058 - 0.251 g/L) get into the wastewater from even just one finishing machine. This preliminary study on MF identification and separation will provide guidance to plan and improve the process of separating MFs from the wastewater of textile companies in the future.

REFERENCES

[1] Bergeron, C. (December, 2016). Fact Sheet: A Summary of the Literature on the Chemical Toxicity of Plastics Pollution on Aquatic Life and Aquatic-Dependent Wildlife. EPA.
[2] Westphalen, H., & Abdelrasoul, A. (2018). Challenges and treatment of microplastics in water. Water Challenges of an Urbanizing World. https://doi.org/10.5772/intechopen.71494
[3] Ian Tiseo, (2021, September 10). Global plastic PRODUCTION 1950-2020. *Statista.*
[4] Laskar, N., & Kumar, U. (2019). Plastics and microplastics: A threat to the environment. *Environmental Technology & Innovation, 14, 100352*. https://doi.org/10.1016/j.eti.2019.100352
[5] Tiseo, I., and 21, M. (2022, March 21) Global plastics production forecast 2025-2050. *Statista*.
[6] Lucía Fernández, (2021, September 6). Chemical and textile fibers production worldwide 2020. *Statista.*
[7] Plastic in textiles: Towards a circular economy for synthetic textiles in Europe. European Environment Agency. (2021, September 17). Retrieved from https://www.eea.europa.eu/themes/waste/resource-efficiency/plastic-in-textiles-towards-a.
[8] Patti, A., Cicala, G., & Acierno, D. (2020). Eco-sustainability of the textile production: Waste recovery and current recycling in the composites world. *Polymers, 13(1), 134.* https://doi.org/10.3390/polym13010134
[9] Issac, M. N., & Kandasubramanian, B. (2021). Effect of microplastics in water and Aquatic Systems. *Environmental Science and Pollution Research, 28(16),* 19544–19562. https://doi.org/10.1007/s11356-021-13184-2
[10] ISO TR 21960 Plastics. Environmental aspects. State of knowledge and methodologies. 52 pp.
[11] Crawford, C. B.; Quinn, B. *Microplastic pollutants*; Elsevier Limited, 2016.
[12] De Lucia, Giuseppe Andrea, et al. “Water | Free Full-Text | Sea Water Contamination in the Vicinity of the Italian Minor Islands Caused by Microplastic Pollution.” *MDPI*, 20 Aug. 2018, doi.org/10.3390/w10081108.

[13] Gies, E. A., LeNoble, J. L., Noël, M., Etemadifar, A., Bishay, F., Hall, E. R., & Ross, P. S. (2018). Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada. *Marine Pollution Bulletin*, *133*, 553–561. https://doi.org/10.1016/j.marpolbul.2018.06.006

[14] Manshoven, S., Smeets , A., Arnold, M., & Mortensen, L. F. (2021). Plastic in textiles: Potentials for circularity and reduced environmental and climate impacts. Eionet Portal.

[15] Zhou, H., Zhou, L., & Ma, K. (2020). Microfiber from textile dyeing and printing Wastewater of a typical industrial Park in china: Occurrence, removal and release. *Science of The Total Environment,* 739, 140329. doi:10.1016/j.scitotenv.2020.140329

[16] Senthil Kumar, R., & Sundaresan, S. (2013). Mechanical finishing techniques for technical textiles. *Advances in the Dyeing and Finishing of Technical Textiles*, 135–153. https://doi.org/10.1533/9780857097613.2.135

[17] Zhang, Q., Xu, E. G., Li, J., Chen, Q., Ma, L., Zeng, E. Y., & Shi, H. (2020). A Review of Microplastics in Table Salt, Drinking Water, and Air: Direct Human Exposure. Environmental Science & Technology, 54(7), 3740–3751.doi:10.1021/acs.est.9b04535

THE EFFECT OF EMBROIDERY AND SCREEN PRINTING TECHNIQUES ON THE FABRICATION OF BAND-STOP FSS

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ABSTRACT

This article describes the design, construction, and analysis of a textile-based band-stop frequency selective surface (FSS) for use in the highly EM-polluted GSM, Wi-Fi, LTE, and WiMAX bands. A full-wave EM solver called CST Microwave Studio was used to develop and simulate the unit cell of the proposed FSS at the relevant frequency. In this study, embroidered and screen printed textile-based FSSs were designed. The results of this study showed that both embroidered and screen printing methods are useful for textile based FSSs.

Keyword: *EM filter, FSS, Embroidery, Screen printing*

1. INTRODUCTION

It has been concluded that individuals are utilizing wireless devices, multimedia equipment, and other electronic appliances that regularly produce EM radiation. The intensity of electromagnetic waves (EM waves) of various frequencies such as WiFi, Wimax, Bluetooth, 2G, 3G, and LTE is known as EM pollution. The EM-pollution or sometimes partially the range, the magnitude, the interference, or the mobility of these frequencies are proved to cause health risk for the residents especially in crowded residential areas. Despite these health problems, it appears that electromagnetic shielding, lens antennas, and radio frequency identification devices (RFID) are still widely used.

The impact of EM-wave interference on human health is the latest focal point for many scientific researches. Thus, frequency selective surfaces (FSS) are designed and used more than six decades for for the reduction of electromagnetic (EM) pollution. FSSs are two-dimensional periodic structures with planar metallic array elements (patches or apertures) on a dielectric substrate that exhibit transmission and reflection at a relevant resonant frequency [1]. Antennas and radomes, diplexers, reflector antennas, resonance beam splitters, semi-optical microwave devices, and other devices have all made extensive use of FSSs in the past.

Few studies have been done to show how flexible, lightweight, and wearable textile FSSs outperform traditional FSSs, although many have been done to characterize the function of traditional FSSs. Textile based FSSs can be classified into the partially-textile employed the metallic conductive patches over textile substrates and fully-textile FSS where both the patch and substrate were employed as a textiles.

For example, Guan et. al. studied embroidered cross shaped textile based fss at X band freaquency. In their study, it was observed that there was small resonance differences between experimental and simulation. Also, Uner et. al. studied embroidered FSS for GSM, Wifi and WIMAX. Square loop designs in woven FSSs are frequently employed to construct high-pass filters in textile FSS research [2–4]. Since silk screen printing delivers the right form with a small margin of error, the printing process is also promising for FSSs [5–7]. Massive pattern surfaces for embroidery may be created using CAD modeling and patterning technologies [8–11].

In this study, band-stopping FSS design at 3.5 GHz was made with CST microwave studio software. Embroidery and silkscreen printing methods were used for the production of optimized textile based FSS. In the study, embroidery and screenprintig FSSs were compared in terms of transmission coefficient.

2. EXPERIMENTAL STUDY

2.1 Materials

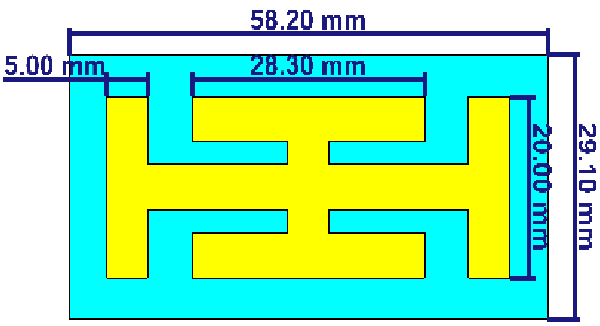
Embroidery and silk screen printing method was employed in this study. The plain weave cotton fabric was selected as the substrate for all samples: the fabric counts for warp and weft directions were 170 and 170 per 10 cm, respectively; the areal density of the fabric was 300 g/m^2; the equivalent thickness was 0.56 mm. The dielectric coefficient of fabric was determined as 1.83 in the aforementioned study [12]. The embroidery density applied in the study included 90 punch/cm^2 in complex fill and vertical onto horizontal embroidery direction was applied. Also, 80T mesh polyester silk was used for printing and silver conductive inks was carried out.

The band-stop characteristic FSS was modelled and simulated using computer simulation technology (CST) at a 3.5 GHz frequency. Also, copper tape FSS was designed to verify the simulation data.

2.2 FSS design and simulations

The unit-cell was developed in accordance with the waveguide boundary condition since the waveguide technique was employed in the study. The numerical analysis and optimization procedure for the band-stop characteristic at 3.5 GHz was carried out by CST Microwave Studio using the Jerusalem cross unit-cell, and the geometric dimensions of the unit-cell are shown in figure 1.

The scattering parameters were calculated by considering the dielectric coefficients of the fabric used in the study.



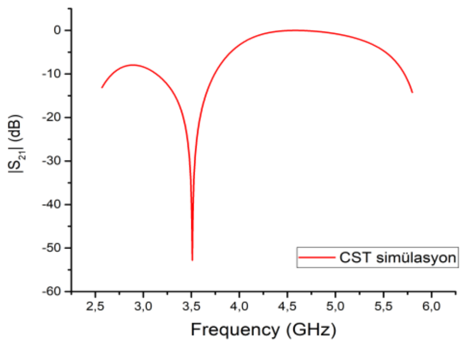


Figure 1. Jarusalem cross unitcell and transmission coefficient.

According to figure 1, it is seen that the Jerusalem cross unit-cell was fitted at a frequency of 3.5 GHz and a band-stopping characteristic was observed. In the design, the dimensions of the substrate were determined according to the WR 229 waveguide which have a frequency range of 3.3 GHz to 4.9 GHz and 58.17x29.08 mm dimension.

2.3 Textile based FSS Fabrication

Band-stop filters at the relevant frequencies are produced by textile production methods. In this process, Pfaff Creative 1.5 computerized embroidery machine was employed for embroidery process (Figure 2). While shieldex statex 117 / f 17-2 layers of silver coated nylon thread is used as upper yarn, conventional polyester yarn is prefered as a bottom yarn. In the study, two-stage embroidery design is applied in the fabrication of the embroidered FSSs. The sticth direction is utilized in the vertical direction in the 1st stage and in the horizontal direction in the 2nd stage to allow the surface current generated in the patch to move in both directions. Novacentrix silver conductive ink is preferred for screen printing. Screen printing process including lacquer drawing, exposure and printing steps is performed, and then pre-drying at 120 ^{o}C for 20 minutes and sintering at 200 ^{o}C for 1 minute (Figure 2).

Figure 2. Embroidered and screen printed textile FSS.

2.4 Testing Method

Waveguides were used in both simulation and measurement setups to analyze unit cell responses. For this purpose, the Pasternack WR-229 waveguide (2.29 Inch [58,166 mm] x 1.145 Inch [29,083 mm]) with a frequency range of 3.3 GHz to 4.9 GHz was employed. Since the unit cell was designed according to the waveguide boundary conditions, the side lengths of the unit cell were defined as having the length value and the width value of waveguide. The textile substrate with thickness value 0,56 mm was considered as substrate with permeability value 1.83 and the resonator model was proposed.

Pasternack WR-229 waveguide was connected to Rohde & Schwarz ZVL13 Vector Network Analyzer, which is capable of measuring a frequency interval of 9 kHz - 13.6 GHz, and the cross-section of the waveguide was shown in Figure 3.

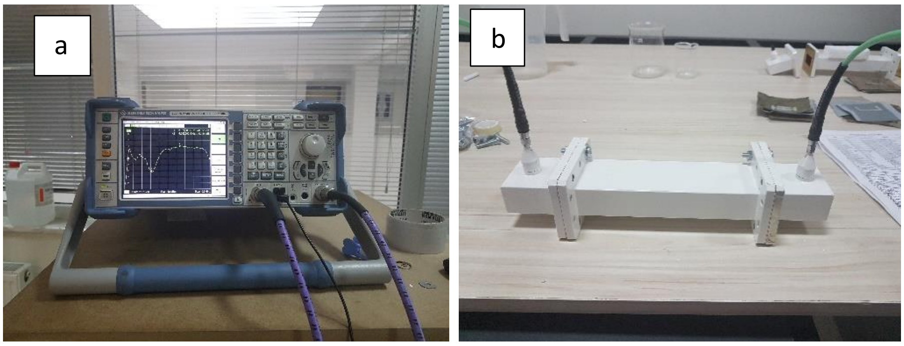


Figure 3. Measurement setup, network analyzer (a), WR 229 waveguide (b).

2.5 Result and Discussion

Studies in the literature show inconsistencies between the experimental measurements of textile-based FSSs and the simulations. In particular, the conductivity and geometry differences between the copper tape model and the textile experiments are decisive in this regard.

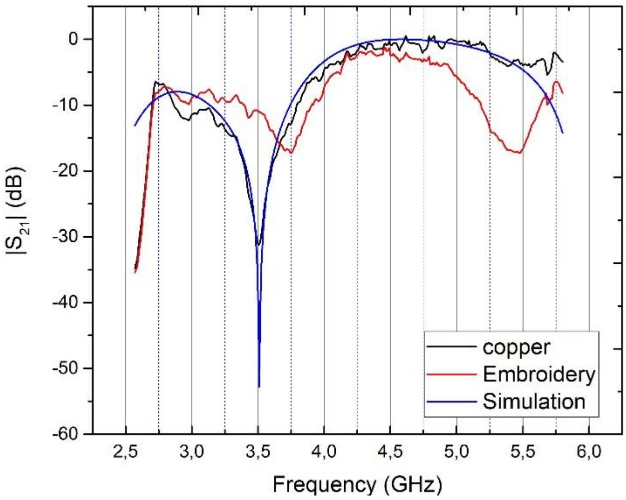


Figure 4. S-parametres of embroidered FSS.

According to figure 4, as expected from the literature, there is resonance in embroidery and copper tape FSS at 3.5 GHz. The resonance is observed at around -30dB at 3.5GHz at copper tape and -18 dB at embridered FSS. Also, resonance shifting occurs as expected from study [9]. When the embroidered FSS patch surface is examined in detail, it is seen that the stitch directions and density are important parameters. The gaps between the embroidery paths in both directions are analyzed with the help of image processing software and measurement data is given in the Table 1.

Table 1. Measurements of stitch gaps.

Count No	Vertical Stitch Gap (mm)	Horizontal Stitch Gap (mm)
1	1.161	0.388
2	0.581	0.504
3	0.677	0.659
4	0.645	0.233
5	0.645	0.349
6	0.516	0.426
7	0.613	0.426
8	0.419	0.233
9	0.452	0.388
10	0.613	0.388
11	0.871	0.388
12	0.516	0.388
13	0.452	0.388
14	0.677	0.504
15	0.742	0.426
16	0.581	0.31
17	0.581	0.31
18	0.548	0.426
19	0.387	0.388
20	0.935	0.504
Mean	0.631	0.401
SD	0.186	0.097
Min	0.387	0.233
Max	1.161	0.659

According to Table, both vertical and horizontal directions have approximately 0.5 mm stitch gaps. It is possible to say that the gaps between the stitch paths disrupt the structural integrity of the unit cell. These design and manufacturing limitations cause differences between simulation and embroidered FSS resonance frequencies.

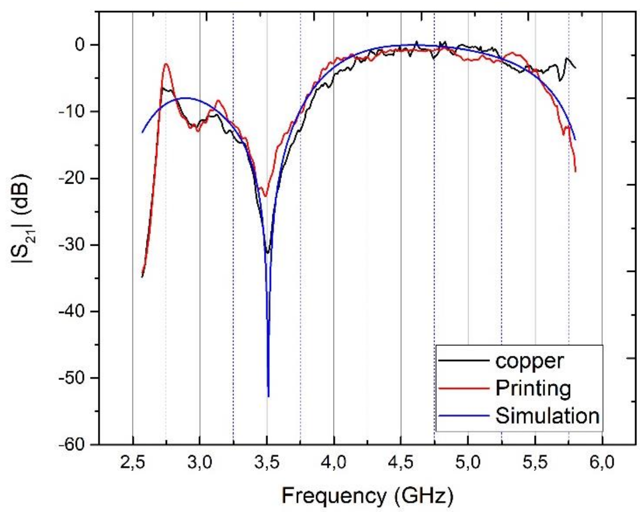


Figure 5. S- parametres of screen printing FSS.

As can be seen in figure 5, there is resonance in screen printing and copper tape FSS at 3.5 GHz. The resonance is observed at around -30dB at 3.5GHz at copper tape and -23 dB at screen printed FSS. There is no resonance shifting between simulation, copper tape, and screen printing FSS. The unit cell pattern fabricated by the screen printing method structurally has the same structural integrity as the copper tape. therefore, it performs a filtering characteristic quite compatible with the copper tape and simulation.

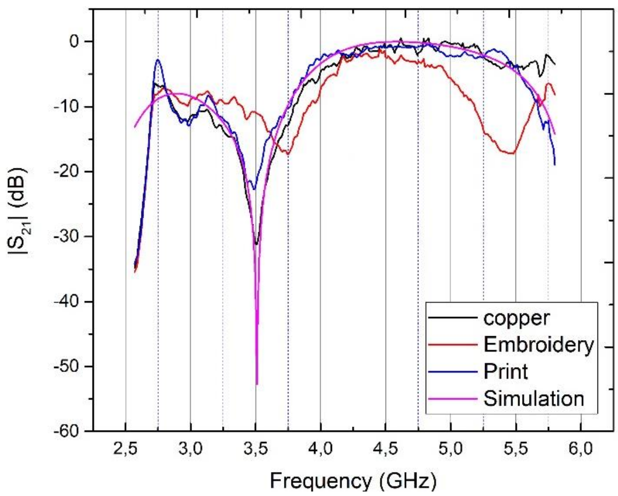


Figure 6. Transmission coefficient of textile based FSSs.

Among all the methods, the screen printing method exhibits the best result in terms of resonance frequency sensitivity. In contrast to screen printing, resonance frequency shift occurred in embroidered FSS. It can be said that the properties of the silver-coated conductive yarn used in embroidery FSS have an effect on the scattering parameters.

3. CONCLUSION

Embroidery and screen printing techniques have been used to fabricate the conductive patches in textile-based FSSs. While silver-coated conductive thread is used in the embroidery technique, conductive ink with silver nanoparticles is used in screen printing. In this study, horizontal onto vertical stitch direction and 90 punch/cm^2 stitch density are applied in embroidery process. The transmission coefficient of embroidered FSS is around 3.75 GHz and approximately 0.25 GHz resonance shifting is occurred. In embroidered FSS, the attachment of the conductive yarn to the fabric by needle prick movements and the presence of small gaps between the parallel penetrating paths can be considered as structural defects on the patch surface. As a matter of fact, in 3D CST modelling, the patch surface is modelled with perfect roughness. therefore, resonance frequencies in copper tape and silkscreen printed FSSs are identical to simulation. As a result of the study, the usability of the textile mass production method in the design of textile-based FSSs has been proven. Also, 3D modelling and simulations of embroidery parameters are appropriate for a better understanding of stitch direction and density.

REFERENCES

[1] Munk, BA. (2000). Frequency Selective Surfaces: Theory and Design. *Hoboken*, NJ, USA: John Wiley & Sons, Inc. Epub ahead of print 12 April 2000. doi: 10.1002/0471723770.

[2] Guan F., Li Z., Yang Z., et al. (2018). Design and Characterization of Periodically Conductive Woven Fabric. *Autex Research Journal*; 0. Epub ahead of print 1 December 2018. doi: 10.1515/aut-2018-0049.

[3] Huppé, C., Cochrane, C., Burgnies, L., Rault, F., Ducournau, G., Lheurette, E., ... & Lippens, D. (2017, October). Woven metamaterials with an electromagnetic phase-advance for selective shielding.

In *IOP Conference Series: Materials Science and Engineering* (Vol. 254, No. 3, p. 032004). IOP Publishing.
[4] Seager, R. D., Chauraya, A., Bowman, J., Broughton, M., & Nimkulrat, N. (2014, April). Fabrication of fabric based frequency selective surfaces (FSS). In *The 8th European Conference on Antennas and Propagation (EuCAP 2014)* (pp. 1978-1980). IEEE.
[5] Guan, F., Xiao, H., Shi, M., & Wang, F. (2016). The novel frequency selective fabric and application research. *Journal of Industrial Textiles*, *46*(1), 143-159.
[6] Lee, D., & Lim, S. (2016, October). Wearable metamaterial absorber using screen printed chanel logo. In *2016 International Symposium on Antennas and Propagation (ISAP)* (pp. 928-929). IEEE.
[7] Whittow W g., Li Y, Torah R, et al. Printed frequency selective surfaces on textiles. *Electronics Letters* 2014; 50: 916–917.
[8] Almirall, O., Fernández-García, R., & Gil, I. (2022). Wearable metamaterial for electromagnetic radiation shielding. *The Journal of The Textile Institute*, *113*(8), 1586-1594.
[9] Guan, F., Xiao, H., Shi, M., Yu, W., & Wang, F. (2017). Realization of planar frequency selective fabrics and analysis of transmission characteristics. *Textile Research Journal*, *87*(11), 1360-1366.
[10] Kursun Bahadir, S., Mitilineos, S. A., Symeonidis, S., Şahin, U. K., Vassiliadis, S., Kalaoglu, F., ... & Savvaidis, S. P. (2020). Electromagnetic shielding and reflection loss of conductive yarn incorporated woven fabrics at the S and X radar bands. *Journal of Electronic Materials*, *49*, 1579-1587.
[11] Tahseen, M. M., & Kishk, A. A. (2017). Flexible and portable textile-reflectarray backed by frequency selective surface. *IEEE Antennas and Wireless Propagation Letters*, *17*(1), 46-49.
[12] İbrahim, Ü. N. E. R., Sultan, C. A. N., GÜRCÜM, B. H., YILMAZ, A. E., & AKSOY, E. Design and Implementation of a Textile-Based Embroidered Frequency Selective Surface. *Textile and Apparel*, *32*(4), 297-303.

EFFECTS OF CREASE RECOVERY FINISHES ON BURSTING STRENGTH OF KNITTED FABRICS

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ABSTRACT

Fabrics tend to crease during use and care. A range of chemicals are applied as finishes on fabrics in order to prevent their wrinkled appearance. In this study, a low formaldehyde finis was applied on knitted fabrics, and its effect on bursting strength as well as fabric rigidity were investigated. It was shown that very high wrinkle recovery performance with limited strength loss and slight increase in rigidity were achieved.

Keyword: *Wrinkle recovery, Easy care finishing, Bursting strength, Fabric rigidity, Reactive dyeing*

1. INTRODUCTION

Fabrics tend to crease due to combined effect of heat, moisture and pressure occurred by daily usages [1]. Natural fibers especially cotton have higher tendency to crease and to eliminate this property different finishing types and recipes applied on to fabrics. These finishing applications increase the crease recovery angles of fabrics and provide longer crease proof characteristics until the finishes are removed from fabrics by washing and daily usages. Meanwhile applied finishes provide different physical properties to the fabrics that are applied. Thus, physical properties must be checked within the checking crease properties of fabrics.

Generally, formaldehyde including finishes are applied but they are harmful for human health. For this reason, low formaldehyde releasing resins that can provide comparable performance must be applied [2]. Modified ethylene urea resin, $MgCl_2$ and $AlCl_3$ catalyst and wetting agent were used by using pad-dry-cure method in this study to increase crease recovery property.

2. EXPERIMENTAL STUDY

Greige fabric sample is fabric after knitting operation from undyed yarns.

Dyed sample is sample that is dyed after knitting and there is not any finishing application. The fabrics were dyed in an ATAC brand lab-type dyeing machine which works at high liquor ratio with, C.I. Reactive Blue 19. The dyebath was based on 4% reactive dyestuff and 50 g/L sodium chloride dissolved in distilled water at room temperature. The dyeing process commenced as soon as the fabric was added to the dyebath using 60:1 liquor-to-fabric weight ratio. After 10 min, the temperature was raised to 60°C at a rate of 1.5 °C⁄min, and the 5 g⁄L sodium carbonate was added. The dyeing process was carried at this temperature for further 60 min. At the end of the process the fabrics were rinsed with warm and cold water, and neutralized with 1g/L acetic acid (30%). In order to remove the residual unfixed dyes and reactants the fabrics were soap-washed at 80°C for 20 min in a bath (bath-to fabric weight ratio 60:1) using 2 g⁄L of non-ionic detergent. The dyeing stage was completed with rinsing with tap water followed by drying at room temperature.

Finished sample is dyed knitted fabric that has a crease recovery finish on itself. Dyed samples are treated with a common durable press finish (DMDHEU). 1L of pad bath composed of 250g/L modified ethylene urea resin, 62.5g/L catalyst, 1g/L wetting agent and 686.5mL deionized water. 1g/L non-ionic softener was used in order to limit increase in rigidity. Fabric samples were padded to 80-90% wet pick up. Samples were dried for 5 minutes and cured for 2 minutes at 105^{o} C and 177^{o} C, respectively.

2.1 Testing

Bursting strength test (ISO 13938-1), crease recovery angle test (ISO 9867) and fabric stiffness test (ASTM D4032-8) were performed for the samples.

3. RESULTS

Table 1 shows the bursting strength and bursting time of the sample fabrics. According to results greige and dyed samples has almost same bursting strength and after finishing application bursting strength decreased 12% which is acceptable as crosslinking due to finishing decreases the shifting ability of cellulose chains over one another and thus decreases elongation which in turn results in lower bursting strength performance.

Table 1. Bursting strength values for kg and bursting time of samples.

	BURSTING STRENGTH (KG)					BURSTING TIME(S)				
Sample Name	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Greige	11,95	11,60	11,85	11,65	11,75	15	16	16	14	15
Dyed	11,75	10,65	11,05	11,50	11,70	17	16	15	16	15
Finished	9,40	9,80	10,5	10,35	9,95	12	12	13	13	14

Wrinkle recovery angle and rigidity test results can be seen at the Table 2. As can be seen from the results when the fabric is finished the product is in easy iron phase and because of the finish the surface of the fabric is straightened and more rigid. Thanks to use of softener, increase in rigidity after finishing was limited to as low as 27%.

Table 2. Wrinkle recovery angle and rigidity test results.

	WRINKLE RECOVERY ANGLE			RIGIDITY	
	C	W	T	C	W
Greige	87	91	178	0,451	0,482
Dyed	93	98	191	0,56	0,612
Finished	134	140	274	0,71	0,775

4. CONCLUSION

In this study, a low formaldehyde resin was applied on cotton fabric in order to increase its crease recovery performance, and its effect on bursting strength performance was investigated. Bursting strength values are rather similar, the wrinkle recovery angle values are better for finished fabrics which will be easy-iron phase. Rigidity has a risen a little because it has disposed of unevenness and other materials. The increase of the rigidity has been limited with the use of softener.

ACKNOWLEDGMENT

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REFERENCES

[1] Yemni, T., & Boyd, R. H. (1979). Dielectric relaxation in the odd-numbered polyamides: Nylon 7-7 and nylon 11. *Journal of Polymer Science: Polymer Physics Edition*, *17*(5), 741-751.
[2] Mitchell, J. A., Thomson, M., & Coyne, R. P. (2017). A guide to citation, London, England: My Publisher.

COMPARISON OF PHYSICAL PERFORMANCES OF PIMA VS LOCAL COTTON FIBER FABRICS

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ABSTRACT

Sustainability practices offer that raw materials should be provided from local sources. Thus, studies on utilization of local fibers are gaining attention. In this study, cotton fibers from two different origins were used to produce Ne30/1 yarns. Using these yarns, single jersey and interlock fabrics were produced, mercerized and dyed. The effects of fiber origin and knitted yarn construction on bursting strength, dimensional stability and spirallity were investigated. It was shown that local cotton fiber offers comparable performance with pima cotton.

Keyword: *Wrinkle recovery, Easy care finishing, Bursting strength, Fabric rigidity, Reactive dyeing*

1. INTRODUCTION

Cotton products are widely used and continue to account for approximately 25% of global fiber production. Despite having weak to medium dimensional stability, cotton is a popular natural fiber and its products offer superior breathability, flexibility, absorbency, soft handling and various comfort properties [1]. Mezarcıöz et al. investigated the performance of denim fabrics produced from recycled, conventional, organic and BCI cotton and discovered that fiber types have a significant effect on the strength properties of the products, although color measurements gave similar results [2].

Atalie and Rotich investigated the effect of raw material properties on the sensory comfort of woven fabrics using four cotton types (Pima, Upland and two Ethiopian cotton fibers) and investigated cotton fiber parameters and some comfort-related properties (surface roughness, breaking strength, elongation at break) including the surface. discovered an important relationship between They showed that short fiber content and fiber strength have a significant effect on the bending stiffness of woven fabrics. In summary, better sensory comfort properties were obtained when using medium length cotton fibers [3].

Dye uptake and fastness properties of knitted cotton fabrics produced from pima and local cotton were investigated and reported elsewhere [4]. It has been shown that dyed fabrics produced from pima cotton can reach the same color values with less dye intake compared to local cotton, and their color fastness tests give better results. In this study, knitted fabrics made of Pima and Local (Azerbaijani) cotton fibers are manufactured, and their bursting strength, spirality and dimensional stability performances compared.

2. EXPERIMENTAL STUDY

In order to reduce yarn hairiness, two different Ne30/1 yarns were produced by using pima and local (Azerbaijan) cotton in a compact spinning machine. For this study, an experimental design was created by considering two fiber types and two different constructions, namely single jersey and interlock fabrics obtained from Pima and Region cotton yarns were produced on 28 gauge 30” haze and 24 gauge 30” haze circular knitting machines, respectively. Mercerized fabrics are dyed black.

2.1 Testing

Bursting strength (ISO 13938-1), dimensional stability (ISO 5077) and spirality (AATCC 179) tests were performed for the samples.

3. RESULTS

Table 1 and Table 2 show the dimensional stability (in width direction and in length direction respectively) performances of knitted fabrics manufactured from Pima and Local fibers. Results show that dimensional stability values are satisfying and close to each other.

Table 1. Dimensional stability – width (%).

Sample Name – Measurement Taken	PIMA	LOCAL
1 – 1	-3	-3,5
1 – 2	-3,25	-3,5
1 - 3	-3,5	-3,25
2 – 1	-2,5	-3,75
2 – 2	-2,75	-3,5
2 – 3	-2,75	-3,5
3 – 1	3,25	-3,5
3 – 2	3	-3,5
3 - 3	3	-3,5
Average	**-3**	**-3,5**

Table 2. Dimensional stability – length (%).

Sample Name	PIMA	LOCAL
1 – 1	-2	-3
1 – 2	-2,25	-3
1 - 3	-2	-3,25
2 – 1	-2	-2,75
2 – 2	-1,75	-3
2 – 3	-2	-3
3 – 1	2,25	-3
3 – 2	-1,75	-3
3 - 3	-2	-3
Average	**-2**	**-3**

Table 3 shows the spirality performances of knitted fabrics manufactured from Pima and Local fibers. Results show that fabrics made of Pima cotton keep their shape and do not skew, while fabrics made of Local cotton has an acceptable spirality.

Table 3. Spirality (%).

Sample Name	PIMA	LOCAL
Average Spirality (%)	0	2,5

Table 4 shows bursting strength performances of knitted fabrics manufactured from Pima and Local fibers. Results show that both fabrics present similar strength performance which is enough for use.

Table 4. Bursting strength.

Sample Name	PIMA	LOCAL
Average Bursting strength (kPa)	234	241

4. CONCLUSION

In this study, knitted fabrics made of Pima and Local (Azerbaijani) cotton fibers are manufactured, and their bursting strength, spirality and dimensional stability performances compared. According to test results, Pima and Local fiber fabric samples has almost same physical performance properties and can be used instead of one another.

ACKNOWLEDGMENT

This study is supported by SANKO R&D Center under the project number 22-BSP-002 entitled "Developing Sustainable Products from Recycled and Innovative Complementary Materials (Geri Dönüştürülmüş ve Yenilikçi Muadil Malzemelerden Sürdürülebilir Ürünler Geliştirilmesi)".

REFERENCES

[1] Elmogahzy, Y., & Farag, R. (2018). Tensile Properties of Cotton Fibers. Elsevier. doi:10.1016/B978-0-08-101272-7.00007-9

[2] Mezarcıöz, S., Toksöz, M., & Sarker, M. E. (2021). Effect of Sustainable Cotton Fibers on Denim Fabric Selected Properties. *Journal of Natural Fibers,* 1–11. doi:10.1080/15440478.2021.1993502

[3] Atalie, D., & Rotich, G. K. (2020). Impact of cotton parameters on sensorial comfort of woven fabrics. *Research Journal of Textile and Apparel*, *24*(3), 281-302. https://doi.org/10.1108/RJTA-01-2020-0004.

[4] Acikgoz-Tufan, H; Emekdar, E.; Sahin, U.K.; Kursun-Bahadir, S.; Batcik-Genc, C.; Baykan, T.K.; Erici, E.; Catak, E.; Senturk, C.D. Pima ve Yöre Pamuğundan Üretilmiş Süprem ve İnterlok Örme Kumaşların Boya Alımı ve Haslık Özelliklerine Etkisinin İncelenmesi. Ulusal Çukurova Tekstil Kongresi-UÇTEK'2022. 2022, 29-30 Eylül 2022, Adana, Turkiye.

USE OF ORGANIC DYESTUFFS IN LUXURIOUS FIBER FABRIC PRINTING

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ABSTRACT

Organic dyestuffs are being commonly used in dyeing however their use in printing is limited. In this study, luxurious fiber fabrics made of silk, cotton/silk and wool fabrics were printed in acidic conditions using ecological thickening agents. Our results showed that high color yield can be achieved without haloing.

Keyword: *Ecological Printing, Ecological thickening agents, organic colorants, luxurious fiber fabrics, wool, silk*

1. INTRODUCTION

Use of organic dyestuffs in coloration of textile fabrics is gaining attraction due to increasing environmental concerns and awareness of the public [1]. Most studies on coloration of natural fiber fabrics focus on dyeing [2,3], and such studies on printing are rather limited [4]. For this reason, in this study we aimed to offer high color yield with acceptable fastness on silk, wool, and cotton/silk fiber fabrics ecologically printed using organic dyestuffs and ecological thickening agent.

2. EXPERIMENTAL STUDY

2.1 Material

100% silk, 54% cotton/46% silk, and 100% wool twill woven fabrics with unit weight of around 50 g/m^2 were used throughout the study. Organic dyestuffs namely Sun Yellow extracted from marigold (flowers of Tagetes Patula plant), Eco Saffron extracted from flowers of Bixa Orellana plant, Eco Beige extracted from walnut shells, and Olive Green extracted from flowering plants of mulberry from the Moraceae family were used throughout the study. Guar gum was used as thickening agent.

2.2 Method

Printing was carried out using screen printing technique. After printing, washing off was carried out using distilled water without surfactant.

2.3 Testing

Prior to testing all samples were conditioned according to ISO-139. Printed fabric samples were tested for color fastness according to ISO 105-C06-A2S - Color fastness to water, ISO-105-E01 Color fastness to washing, ISO-105-E04 Color fastness to acidic and alkaline perspiration, ISO-105-X12 Color fastness to rubbing, ISO-105-C09 Color fastness to oxidative washing.

3. RESULTS

Ecologically printed wool and silk fabrics are presented in Figure 1. It is apparent from Figure 1 that high color yield without haloing was achieved.

Figure 1. Ecological printed silk and wool fabrics.

Color fastness to washing results are presented in Table 1. As can be seen from the table all treated samples have very high color fastness to washing performance, with acceptable performance for cotton.

Table 1. Washing Fastness Results

	Cellulose Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool
Sun Yellow	5	3	5	5	5	5
Eco Saffron	5	3	5	5	5	5
Eco Beige	5	4/5	5	5	5	5
Olive Green	5	4/5	5	5	5	5
Multicolor	5	4	5	5	5	5

Color fastness to water test results are presented in Table 2. As can be seen from the table, color fastness to washing performance for natural printing is high, with an exception of the Sun Yellow and Eco Saffron, especially when tested against cotton.

Table 2. Water Fastness Results

	Cellulose Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool
Sun Yellow	3	2	3	3	3	3/4
Eco Saffron	4/5	3	3	4	5	5
Eco Beige	5	4/5	5	5	5	5
Olive Green	5	4/5	5	5	5	5
Multicolor	5	3/4	4	5	5	5

Perspiration fastness to acidic results are presented in Table 3. As can be seen from the table all treated samples kept their color fastness to acidic perspiration performance. Sun Yellow offered slightly lower performance when tested against cotton.

Table 3. Perspiration Fastness to Acidic Results

	Cellulose Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool
Sun Yellow	4/5	2	3/4	4	4	4
Eco Saffron	5	4	3/4	4/5	5	5
Eco Beige	5	4/5	5	5	5	5
Olive Green	5	4/5	5	5	5	5
Multicolor	5	3/4	4	5	5	5

Perspiration fastness to alkaline results are presented in Table 4. As can be seen from the table all treated samples kept their color fastness to alkaline perspiration performance. Sun Yellow and Eco Saffron offered slightly lower performance when tested against cotton.

Table 4. Perspiration Fastness to Alkaline Results

	Cellulose Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool
Sun Yellow	4	2	3/4	3/4	3/4	3/4
Eco Saffron	4/5	2	¾	4/5	5	5
Eco Beige	5	4/5	5	5	5	5
Olive Green	5	4/5	5	5	5	5
Multicolor	5	3	4/5	4/5	5	5

Color fastness to rubbing test results are presented in Table 5. As can be seen from the table all treated samples offered high wet and dry color fastness to rubbing performance.

Table 5. Rubbing Fastness Results

	Dry	Wet
Sun Yellow	5	5
Eco Saffron	4/5	4/5
Eco Beige	5	4/5
Olive Green	4	3/4
Multicolor	5	5

Color fastness to oxidative washing test results are presented in Table 6. As can be seen from the table all treated samples offered acceptable color fastness performance.

Table 6. Oxidative Washing Fastness Results

	Tone
Sun Yellow	2/3 On Tone
Eco Saffron	2 On Tone
Eco Beige	1 Off Tone
Olive Green	3 On Tone
Multicolor	2/3 On Tone

4. CONCLUSION

It is shown that luxurious fiber fabrics can be printed using organic dyestuffs in acidic conditions with ecological thickening agents. High color yield and fastness performance were achieved without haloing. All samples have shown high fastness values and even with the oxidative washing the color changes is nearly minimal, and it is in the acceptable range. By expanding this research more organic blend fabrics can be tested and the recipe can be altered.

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REFERENCES

[1] Gulrajani ML, (1999). Present Status of Natural Dyes, Colorage, 46 (7): 19-28.
[2] Davulcu A, Benli H, Şen Y, Bahtiyari MI, (2014). Dyeing of Cotton with Thyme and Pomegranate Peel, Cellulose, 21 (6): 4671–4680.
[3] Tutak M, Korkmaz NE., (2012). Environmentally Friendly Natural Dyeing of Organic Cotton, Journal of Natural Fibers, 9: 51–59.
[4] Pateland H, Chattopadhyay DP, (2009). Process Development for Printing on Cotton Fabric with Terminalia Chebula Dye, www.fibre2fashion.com.

A CASE STUDY FOR LIFE CYCLE ASSESSMENT OF TEXTILES

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ABSTRACT

Textile products are used extensively throughout the world, fulfilling basic human needs such as protection from atmospheric condition and contributing to our social position. The textile industry is known as the second most polluter industry after petroleum industry. The major environmental impacts of textile products arise from emissions of toxic substances, use of water and energy in the production and use phases of product's lifetime. This study aims to explore sustainability practices within the textile and clothing industry. The environmental management method, Life Cycle Assessment (LCA) is applied for 3 different T-shirts consisting of different fiber contents, namely, 100% organic cotton, 35%Viscose 65% PES, 100% PES. Results were analyzed in many impact factors such as on environment and human such as climate change, ozone depletion, etc.

Keyword: *Sustainability, life cycle assessment, textiles*

1. INTRODUCTION

The Global Textile and Clothing Market is one of the leading markets among the major industries in the world. One of the main reasons is, the necessity of clothing as they protect us from environmental conditions which is one of the basic needs for humankinds. Besides, enhancing life standards, fashion trends, population growth, various consumer needs have made a great impact on the textile and clothing demand which naturally increase the production of natural and man-made fibers as well as the number of apparel products. Types of the textile products are plenty and increasing day by day as a result of technological innovations. However, on the other hand, ecofriendly products, green production and an increased demand for sustainable products are growing as an alternative market recently. In 1987, the World Commission of Environment and Development defined sustainability as *d*evelopment that meets the needs of present without compromising the ability of future generations to meet their own needs [1]. Within this context, sustainable textile materials can be explained as being more ecologically friendly compared to the conventional peers by consuming less energy, chemical and waste throughout the entire processes. Therefore, they present more positive economic, social and environmental impacts throughout their life cycle.

Growing population and market demand at a global scale are likely to keep the textile and clothing (T&C) sector at a high level among the top industries for a considerable period of time. Behind the T&C supply chain, there is a great number of agricultural and manufacturing processes which use raw materials and midproducts for the end product. Growing of natural fibers involves significant water, land and chemical usage in cultivation, dyeing and finishing processes. However, their structure is bio-degradable and production energy requirement is less than synthetic fibers. On the other hand, synthetic fibers have petrochemical base such as polyester, polyamide and acrylic which are produced from non-renewable sources which requires significant energy input. Regenerated fibers can be petrochemical or cellulosic basis such as viscose, cuprammonium, acetate, rayon and bamboo. The production of man-made and regenerated fibers consumes more energy in manufacturing particularly in extruding fiber stage, spinning yarn. Because of the different advantages and demands of textile and apparel products, fibers have been used in wide spectrum in textile. Generally, fibers are commonly blended together in order to achieve more desirable qualities according to apparel requirements. However, natural and man-made fibers' combination makes effective recycling process difficult due to the complexity of separating and sorting each fiber from the blend which creates another environmental problem due to considerable amount of solid textile waste [2].

A model called Triple Bottom Line (TBL) sustainability model presented by John Elkington and the method has been used as one of the most influential business management models. Beside economy, TBL concept added the environmental and social responsibilities in business, which was a breakthrough in existing system [3]. The aim of this study is to explore ideas, materials, systems and products within the perspective of the Triple Bottom Line (TBL) sustainable business model. Under the study, retailers' practices have been monitored as well as governmental regulations for efficient outcomes. The new developments in the field of raw materials, pre-treatments, dyeing systems have also been analyzed in related sections. Life Cycle Assessment studies are useful for sustainability analysis of textiles [4-6]. In this thesis, Life Cycle Assessments (LCA) of three knitted T-shirts are determined from cradle-to-grave phases. The case study is evaluated based on ReCiPe 2016 method and their impacts on environment and human were measured accordingly by using SimaPro software programme.

2. EXPERIMENTAL STUDY

The environmental management method, Life Cycle Assessment (LCA) is used in this study. Three T-shirts consisting of different fiber contents, namely, 100% cotton, 35%Viscose 65% PES, 100% PES studied, and the related environmental hotspots were given. The LCA has been performed according to the ISO 14040 series standards. Inventory analysis is based on the values from literature and industrial practices. The chemical, energy and water consumptions of the fibers for cultivation and yarn production are used from literature. Primary data of the knitting, dyeing and fixation phases were given by confidential textile factory and the consumption values of the other phases which are cutting, sewing, ironing and packaging stages were supplied from a garment making company in Turkey. The ReCiPe 2016 Life Cycle Assessment (LCA) method was used to calculate the impacts of the materials by using the SimaPro software system, with the functional unit of "Wearing a T-shirt for 1 year" from cradle-to-grave. In order to carry out an LCIA, the following midpoint impact categories were investigated: climate change, ozone depletion, human toxicity, fresh water eutrophication, marine eutrophication, photochemical oxidant formation, terrestrial acidification, metal depletion, fossil depletion, particulate matter formation, ionizing radiation, water depletion, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation. Moreover, the damage on the human health, ecosystem and resources were determined as endpoint results.

2.1 Materials and Method

The T-shirts produced and assesses in this study had different fiber compositions. The specifications of them are given in Table 1.

Table 1. Specifications of the T-shirts**.**

LCIA Models	100% Organic Cotton	65%Polyester 35%Viscose	100% Polyester
Product	Short Sleeve T-shirt with turned up sleeves	Short Sleeve Tshirt	3/4 Sleeve V Neck tshirt with slits at sides
Composition	100%Organic Cotton (GOTS Certified)	65%Polyester 35%Viscose	100%Polyester
Fabric	30/1 Ne Single Jersey 150 g/m²	1x1 Rib 200 g/m²	Single Jersey 160 g/m²
Color	Pink	Light Pink	Light Green
Product weight (gross-net)	180-150 gr	182-150 gr	230- 191 gr

The impacts of the T-shirt products on environmental and human were calculated. Inventory analysis was made by analysis of processes of the t-shirt production in terms of chemical, water and energy usage in cultivation, fiber/yarn production, dyeing, finishing, cutting, sewing, quality control, packaging, transportation, usage, recycle/reuse options where the relevant inflows and outflows developed including emissions to air, water and soil from Cradle to Grave. Impact Assessment was made by measuring Midpoint and Endpoint impacts according to Recipe 2016 method via characterization factors of relevant inflows and outflows. Simapro software system has been used for calculations.

Goal and scope: The goal is to calculate the impacts of the T-shirt products on environmental and human. Functional unit is 1 year usage time and washing are considered once a week after 2 times wearing of the T-shirt which reaches 100 uses and 50 washes during whole lifetime of the product in this assessment. Washing degree is 40^{o}C and tumble dry is not included to the calculation as stated on the care labels of the products.

Inventory analysis**:** Processes of the t-shirt production are comprehensively analyzed in terms of chemical, water and energy usage in cultivation, fiber/yarn production, dyeing, finishing, cutting, sewing, quality control, packaging, transportation, usage, recycle/reuse options where the relevant inflows and outflows developed including emissions to air, water and soil from Cradle to Grave. Production Country is Turkey, shipment destination is Gothenburg.

Impact Assessment Method: Midpoint and Endpoint impacts are measured according to Recipe 2016 method via characterization factors of relevant inflows and outflows. Simapro software system has been used for calculations.

Assumptions: 20% wastage is added to cultivation and fiber/yarn production figures used from the literature, %20 wastage is included to the figures of inventory analysis in knitting, cutting and dyeing stages. %10 of the garments has been considered as stained during quality control and related chemicals and energy consumptions added accordingly. Sustainable dyestuffs and chemicals are used in dyeing progress. Half of the products are packed together in the big polybag as an assortment, small polybags have been used for the other half of each garment. One polybag weight is considered as 7 gr made out of recyclable material. 70 pieces garments are placed in one recyclable carton of which weight is 0.079 kg. Low carbon emission route is selected for transportation as below.

Gunesli- Yalova	Truck
Yalova- Trieste	Ferry
Trieste-Koln	Train
Koln- Kiel	Train
Kiel-Gothenburg	Ferry

In terms of climate change impacts for cotton, approximately 2 kg CO_2e/kg is derived from the results due to Cotton crop emits CO_2 in photosynthesis during cultivation. Turkey electricity mix used for cultivation and production; Sweden electricity mix is used for the usage phase consumption in Sweden. Washing machine load is considered as 70%. According to Eurostat report for the year 2016, 0,6% of municipal waste in Sweden goes to Landfill, while 50,5% goes to incineration thus we assume 28.9 % of municipal waste is recycled and 20% Re-use is also included to the calculations.

3. RESULTS

According to our study, following carbon footprint results have been found which affect global warming directly as seen in Table 2 and the global warming potentials were found as seen in Figure 1.

Table 2. Carbon footprint results of the products (CO_2 kg eq.).

Product Composition	Kg CO_2 eq. Emission for a T-shirt	Kg CO_2 eq. Emission for 1kg material (kg)
100% Organic Cotton	1.32	8.8
65% Polyester 35% Viscose	5.63	37.53
100% Polyester	4.92	25.89

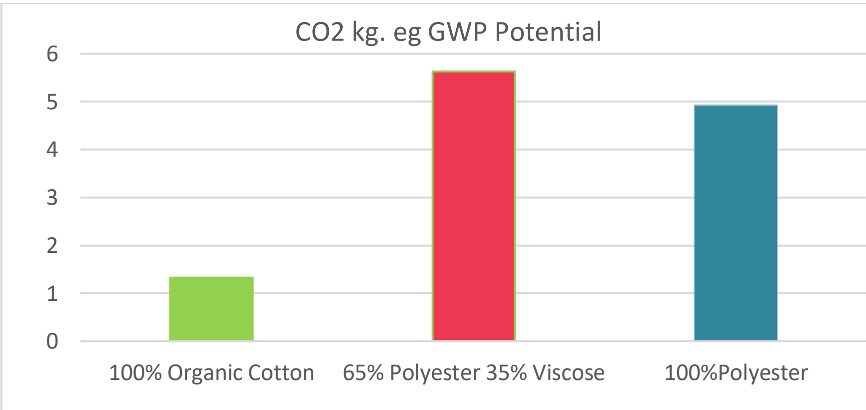

Figure 1. Global warming potentials of the T-shirts (CO_2 kg eq.).

The major reasons of the lower carbon emission result for the cotton can be explained as using organic cotton as base material which needs less energy requirement particulary in cultivation part, applying sustainable dyestuffs in dyeing,using organic chemicals as much as possible during the pre-treatment and dyeing processes, using HT jet machines in dyeing of which process time and water consumption is lower than standard machines, using lower carbon emission transportation, Excluding tumble dry from the LCA assessmment in the usage phase as stated on the care labels.

Beside of carbon footprint which has significant impact on climate change, other midpoint and enpoint factors have been analyzed according to Recipe characterisation metod. Ozone depletion, fresh water eutrophication, terrestrial acidification, terrestrial ecotoxicity, freshwater ecotoxicity, ionising radiation and agricultural land occpation as seen in Figure 2, 3, 4, 5, 6, 7 and 8.

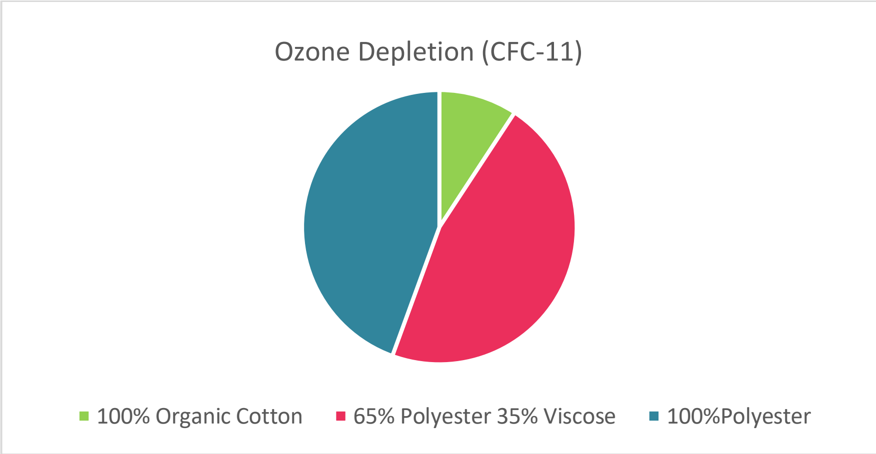

Figure 2. The impacts of the materials to ozone depletion.

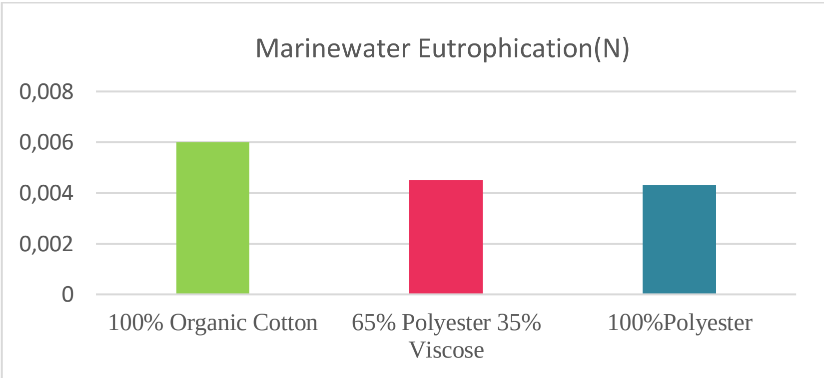

Figure 3. Marinewater eutrophication.

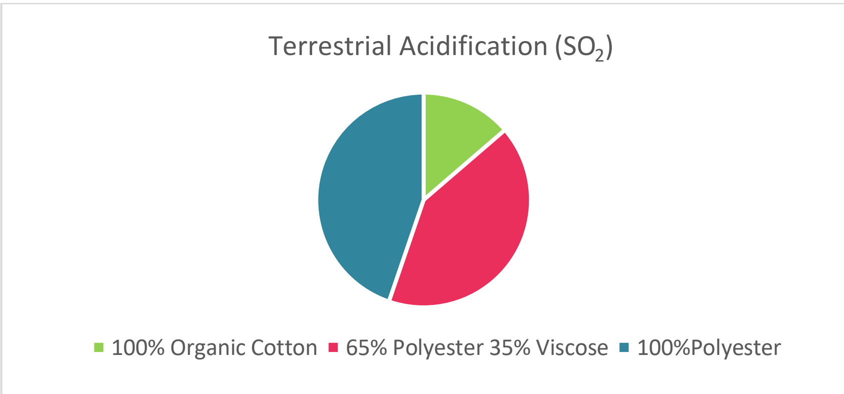

Figure 4. Terrestrial acidification.

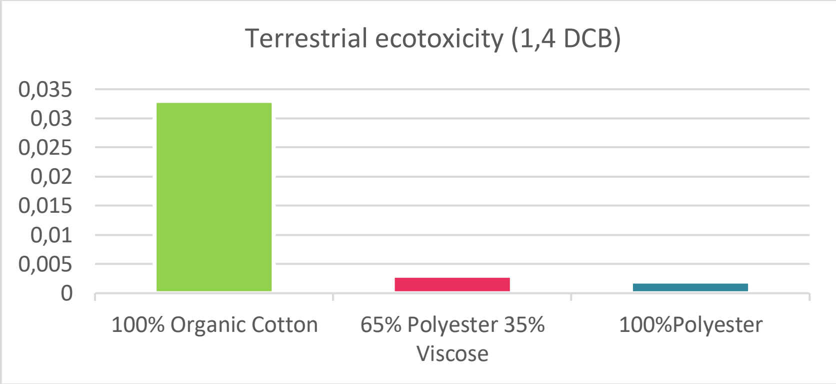

Figure 5. Terrestrial ecotoxicity.

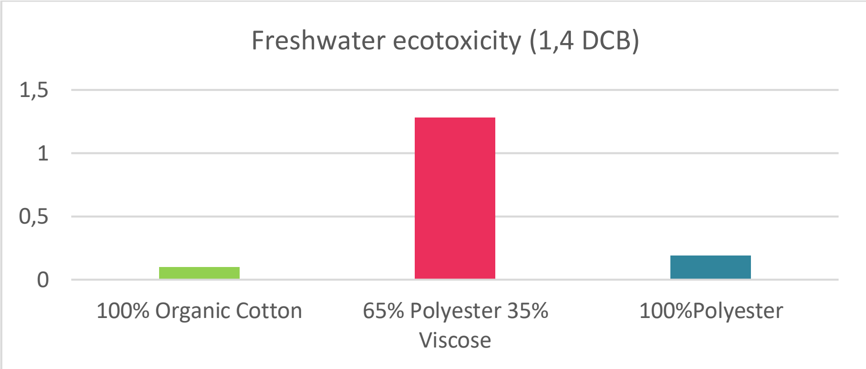

Figure 6. Freshwater ecotoxicity.

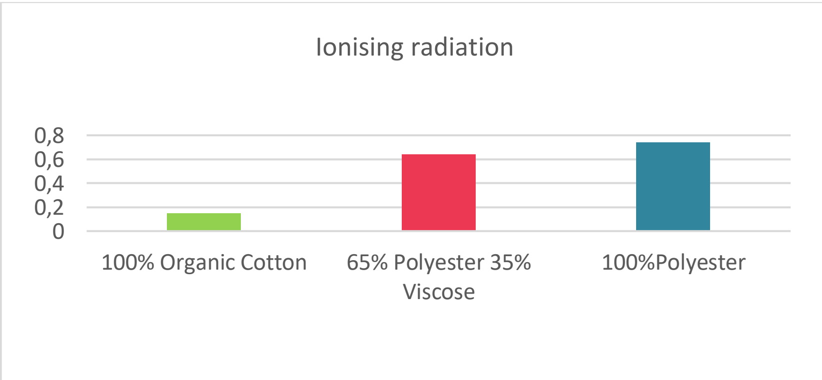

Figure 7. Ionising radiation.

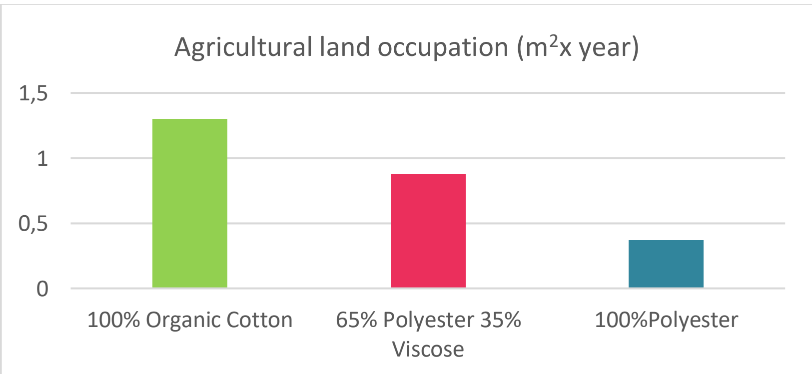

Figure 8. Agricultural land occupation.

As seen in the results, although Organic Cotton has remarkable advantages about sustainability in many impact categories, its water consumption and marine eutrophication effect are the higher . Marine eutrophication impact is directly related to the fertilizer usage which consists nitrogen during cultivation. On the other hand, 100% Polyester and 65% Polyester-35% Viscose blend have the higher values in other impact categories significantly, such as ozono depletion, fresh water eutrophication, human ecotoxicity, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity which are related to 1-4 DBC chemicals and terrestrial acidification which is directly affected by SO_2. Ionising radiation was the highest for 100%polyester blend .

4. CONCLUSION

This study presented an analysis of life cycle of t-shirt products and it suggested their contibution to global warming. Measuring sustainability of the textile product is not an easy process as it is involved to many processes with various different possibilities. In generel, a material can be more sustainable when less energy consumption, chemical and water usage are achieved. In the light of sustainable studies, energy consumption might be considered as one of the dominant and developable parameter which can be reduced with new technology such as renewable energy. On the other hand, chemical usage is also carrying out the significant importance on the environment and human.

REFERENCES

[1] *Report of the World Commission on Environment and Development , United Nations (*2023, January 25). Retrieved from https://digitallibrary.un.org/record/139811?ln=en#record-files-collapse-heade

[2] Payne, A. (2015). *Open and closed-loop Recycling of textile and apparel products. Handbook of Life Cycle Assesments of Textile and Clothing* (pp. 103-110). Brisbane : WoodHeadPublishing.

[3] Slaper, T.F., & Hall, T.J. (2011) The Triple bottom line: What is it and how does it work. Indiana Business Review, 86, 4-8.

[4] Peters, G., Swanström, M., Roos, M, Sandin, G., & Zamani, B. (2015). CArbon footprints in textile industry. Wodhead Publishing. *Handbook of Life Cycle Assesment(LCA) of Textiles and Clothing.* (pp. 3-17) Gothenburg : Elsevier Ltd.

[5] Sandra, R. (2016). *Advancing life cycle assesment of textile products to include textile chemicals.* [PhD thesis, Gothenburg : Chalmers University of Technology]

[6] Lisbeth, D. (2004). *Life Cycle Assesments (LCA) applied in the Textile Sector: The Usefulness, Limitations and Methodological Problems.* [Thesis, Goteborg : Chalmers University of Technology].

THE EFFECT OF HEMP WASTE REINFORCEMENT ON POLYURETHANE FOAM COMPOSITES

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ABSTRACT

In this study, hemp waste reinforced polyurethane (PU) rigid foam composites were prepared and characterized to determine morphology and mechanical properties. The effect of reinforcement types and amount were examined on both strength and cell size. Hemp shiv (HS) and short hemp fibre (HSF) that produced after combing were used as reinforcements. The composites were prepared with different reinforcement ratios (2, 5 and 10 wt. %). The neat (0%) PU rigid foam composite was also produced for comparison purpose. PU rigid foam composites were moulded by using a press with wooden moulds (300 x 400 x 20 mm). The increasing ratio of hemp waste reinforcement results in a decrease in the average cell size, but also increases the cell size distribution. The flexural strength decreased in higher hemp waste ratio. By using hemp waste as reinforcement in the composite will provide advantages such as production costs and reducing and reusing waste in terms of sustainability

Keyword: *Polyurethane foam, hemp waste, sustainability*

1. INTRODUCTION

Polyurethane foam created from the polymerization of polyols and polyisocyanates is a versatile material whose rigidness and flexibility could be customized by adjusting the ingredients of the reaction process [1]. Rigid polyurethane foam have gained increasing attention in the recent decades. Favorable properties such as being lightweight, as well as having high strength, preferable stiffness, and ideal impact resistance, has led to the utilization of RPUF composites in various engineering applications PU foams are generally used in building insulation, freezers and refrigerators, furniture and bedding, automotive.

Recent studies shows that organic or inorganic fillers can significantly improve the mechanical, thermal and acoustic properties of rigid polyurethane composites [2,3]. The use of wastes adds value to an underutilized by-product with excellent properties [4].

Hemp fiber has become extremely popular in natural fiber reinforced composites [5]. The hemp plant stem consists of the hemp fibers, the hemp shiv, the hemp short fibers and the dusts. Hemp stem contains approximately 20 wt%–40 wt% of hemp fibers and 60 wt%–80 wt% of the others [6,7]. Therefore, the use of hemp wastes in composites have an extremely important potential for sustainability. By using hemp waste as reinforcement in the composite will provide advantages such as production costs and reducing and reusing waste in terms of sustainability. Both ecological and economic benefits can be achieved with the development of hemp waste-reinforced composites.

2. EXPERIMENTAL STUDY

2.1 Materials

The hemp shiv (HS) and the short hemp fibre (HSF) used in this study were taken from Mayteks company (Manisa, Türkiye). The hemp shiv size was measured in the length range of 7 -44 mm and width in the range of 1 -4.5 mm. The short hemp fiber size was measured between 15 and 149 µm. At least 500 particles of each sample were measured. Polyurethane foams were prepared by using industrial raw materials; polyol (Plusol R-103-01, Pluskim, Turkey) and polyisocyanate (Plusnate-R-100-01, Pluskim, Turkey) was supplied by Pluskim chemicals.

2.2 Manufacturing of PU Rigid Foam Composites

PU rigid foam composites were reinforced with 2, 5, and 10% wt. hemp shiv and short hemp fibre wastes with respect to the total mass of polyol. The neat (0%) PU rigid foam composite was also produced for comparison purpose. The samples are coded as PU-X (reinforcement type)-Y (reinforcement amount). For example, PU-HS-2 means that 2% wt. hemp shiv reinforcement composite. PU rigid foam composites were manufactured by mixing polyol and isocyanate compounds in a 1/1.20 weight ratio. Hemp waste and polyol were mixed for 3 min until homogenization, then isocyanate was added to the mixture. The mixture was poured into the mould and placed at a hot press. Moulding was performed at room temperature by using 6 bars pressure for 60 min. After that, the material was removed from the mold and cut to sample sizes.

2.3 Density Measurement

The densities of PU rigid foam composites were measured according to ASTM D792-13 using a density meter (Precisa®, XP205) at room temperature. The averages of five specimens were calculated.

2.4 SEM Analysis

Scanning electron microscopy (SEM) images were obtained by using Tescan VEGA 3 microscope.

2.5 Micro-cellular Structure Analysis

Based on SEM images, cell sizes of PU rigid foam composites were measured using an image analysis software (BAB Bs200Doc, Turkey) and cell densities of composites were calculated by Equation (1).

$$N_f = \left(\frac{nM^2}{A}\right)^{3/2} \qquad \text{Eq. 1}$$

where N_f is cell density, n is cell number, A is SEM view area and M is magnification factor.

2.6 Flexural Test

Three-point flexural tests of PU rigid foam composites were carried out by a *SHIMADZU* Autograph, AG-IS testing device at 6 mm / min–1 constant displacement according to ASTM C393-16. The specimen dimensions were 200 × 40 mm. The flexural strength (Equation (2)) and strain (Equation (3)) of PU rigid foam composites were calculated by ASTM D790-90 formulations:

$$S = 3PL/2bd^2 \qquad \text{Eq. 2}$$

$$\varepsilon = 6Dd/L^2 \qquad \text{Eq. 3}$$

3. RESULTS

All the foams had almost hexagonal and oval cell structures, however, the addition of filler into rigid polyurethane foam matrix influenced greatly the cellular topology of the produced foams due to the fact that some factors such as viscosity of polyol, concentration, interaction and dispersion of filler affect directly the orderity of the cell structure [8].

Figure 1 shows the SEM views of neat and hemp shiv reinforced PU rigid foam composite samples. Figure 2 shows the SEM views of neat and hemp short fiber reinforced PU rigid foam composite samples. It was seen that the cells of neat foam were homogeneous and had a closed cell structure with uniform pentagonal/hexagonal shapes. The cells of reinforced hemp waste were inhomogeneous with non-uniform structures and shapes. It was observed that as the hemp waste rate increased, the cell structure and cell quality of the foam deteriorated. These observations are similar to those observed by researcher [8,9].

Table 1 offers the micro-cellular structure analysis results as cell size and cell density. The neat foam (PU0) had an average cell size of 418.81 µm and a cell density of 1.30×10^{12} cells cm^{-3}. PU-HS-5 showed the smallest average cell size with 131.210 µm and the highest cell density with 2.42×10^{13}cells cm^{-3}.

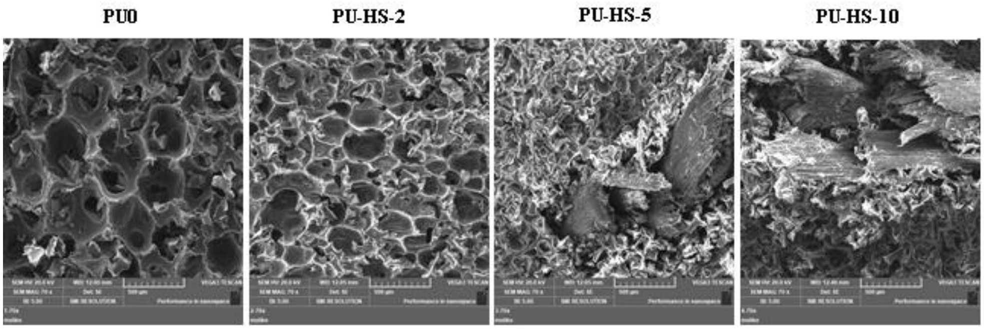

Figure 1. SEM views of neat and hemp shiv reinforced PU rigid foam composites.

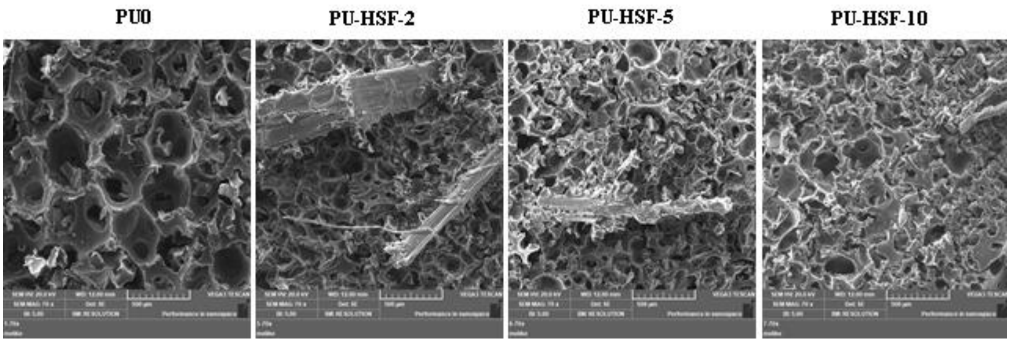

Figure 2. SEM views of neat and short hemp fibre reinforced PU rigid foam composites.

Table 1. Micro-cellular structure analysis results of PU rigid foam composites.

Label	Cell size (µm)	Cell density (cells cm−3)
Neat PU	418.81	1,30844E+12
PU-HS-2	261.83	3,70083E+12
PU-HS-5	131.21	2,42327E+13
PU-HS-10	180.77	6,79886E+12
PU-HSF-2	167.17	1,10868E+13
PU-HSF-5	162.20	1,04675E+13
PU-HSF-10	173.49	1,15907E+13

Table 2 shows the flexural strength and density values of PU rigid foam composites. As seen in the Tablo 2, the density of all the PU foams increased consistently with increasing in hemp waste percentage. Increases in the amount of hemp waste caused an increase in the densities of the polyurethane rigid foam composite due to the increase in mass per unit volume.

Table 2. Density and flexural test results of PU rigid foam composites.

Label	Density (kg/m^3)	Flexural strain (%)	Flexural strength (MPa)
Neat PU	96,10	2,83	1,41
PU-HS-2	98,20	5,18	1,57
PU-HS-5	100,10	5,56	1,28
PU-HS-10	111,20	4,53	1,22
PU-HSF-2	97,30	6,04	1,60
PU-HSF-5	102,80	5,29	1,30
PU-HSF-10	108. 90	5,99	1,20

Bending is the primary deformation mechanism of rigid foams because the struts at the cell edges deform under compression–tension loading [10]. In addition, flexural strengths of composite foams were related to other parameters such as volume fraction of cells, density and wall thickness [11]. Flexural stress–strain curves of hemp shiv PU rigid foam composites are shown in Figure 3. Flexural stress–strain curves of short hemp fiber PU rigid foam composites are shown in Figure 4. The flexural strength decreased in higher hemp waste ratio. The interaction between the polymer matrix and hemp waste reinforcement affected the mechanical properties of PU composites that reduced the flexural strength.

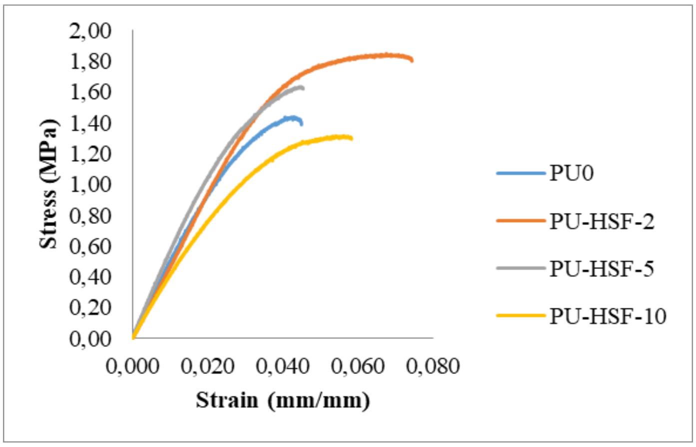

Figure 3. Flexural stress–strain curves of hemp shiv PU rigid foam composites.

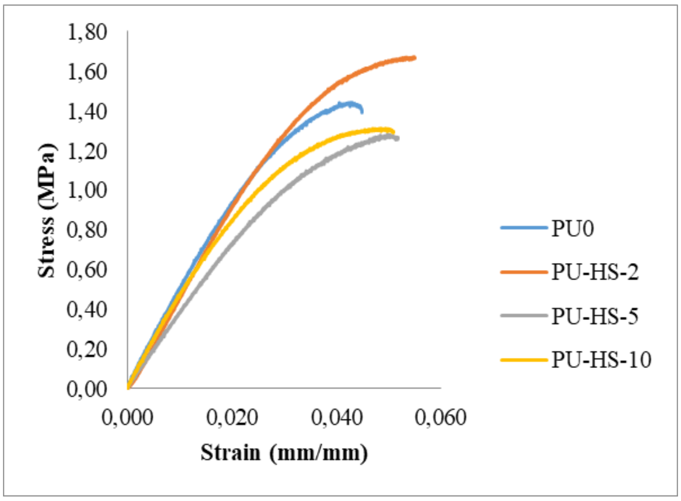

Figure 4. Flexural stress–strain curves of hemp short fiber reinforced PU rigid foam composites.

4. CONCLUSION

In this study, it was aimed to produce PU rigid foam composites reinforced with hemp shiv and short hemp fibre at various weight ratio to investigate the effect of morfology and mechanical properties. Results of the SEM analysis indicate the changes in cell structure of the examined materials related to the introduction of the hemp waste into the polyurethane foam. The cell size of foams decreased and cell density increased by the increase in hemp waste ratios. The flexural strength decreased in higher hemp waste ratio.The preparation of composite materials from hemp waste products can provide different properties for the rigid polyurethane foams as well as possibly solve the problem of their waste disposal. Hemp shiv and hemp short fiber waste reinforced polyurethane rigid foam composites will be used as a core material in the sandwich composites in future works.

REFERENCES

[1] Tao, Y., Li, P., Zhang, H., Shi, S. Q., Zhang, J., & Yin, Q. (2022). Compression and flexural properties of rigid polyurethane foam composites reinforced with 3D-printed polylactic acid lattice structures. Composite Structures, 279, 114866

[2] A. Oushabi, S. Sair, Y. Abboud, O. Tanane, A. El Bouari. (2017) "An experimental investigation on morphological, mechanical and thermal properties of date palm particles reinforced polyurethane composites as new ecological insulating materials in building", Case Stud. Constr. Mater., 7, 128–137.

[3] Khaleel, M., Soykan, U., & Çetin, S. (2021). Influences of turkey feather fiber loading on significant characteristics of rigid polyurethane foam: Thermal degradation, heat insulation, acoustic performance, air permeability and cellular structure. Construction and Building Materials, 308, 125014.

[4] Zanini, N. C., de Souza, A. G., Barbosa, R. F., Rosa, D. S., & Mulinari, D. R. (2022). Eco-friendly composites of polyurethane and sheath palm residues. Journal of Cellular Plastics, 58(1), 139-158.

[5] Siva Sankar, Pulleti & Singh, Shamsher. (2021). A Review of Natural Fiber Composites for Structural, Infrastructural and Ballistic Applications. 10.1007/978-981-16-1688-4_16.

[6] Stevulova, N., Cigasova, J., Estokova, A., Terpakova, E., Geffert, A., Kacik, F., ... & Holub, M. (2014). Properties characterization of chemically modified hemp hurds. Materials, 7(12), 8131-8150.

[7] Kaya, S., Öner, E. 2020. "Kenevir Liflerinin Eldesi, Karakteristik Özellikleri ve Tekstil Endüstrisindeki Uygulamaları", Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 11 (1), 108-123+

[8] Członka, S., Bertino, M. F., Strzelec, K., Strąkowska, A., & Masłowski, M. (2018). Rigid polyurethane foams reinforced with solid waste generated in leather industry. Polymer Testing, 69, 225-237.

[9] Chen, J., Yang, L., Chen, D., Mai, Q., Wang, M., Wu, L., & Kong, P. (2021). Cell structure and mechanical properties of microcellular PLA foams prepared via autoclave constrained foaming. Cellular Polymers, 40(3), 101-118.

[10] Özkan Buzğan, E. B., Kaya, G., Kertmen, M., & Türksoy, H. G. (2022). Properties of textile air conditioner waste dust-filled polyurethane rigid foam composites. Plastics, Rubber and Composites, 51(7), 352-362.

[11] Jiang, D., Wang, Y., Li, B., Sun, C., & Guo, Z. (2020). Environmentally friendly alternative to polyester polyol by corn straw on preparation of rigid polyurethane composite. Composites Communications, 17, 109-114.

EXAMINATION OF EQUESTRIAN BRANCHES AND CLOTHING

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ABSTRACT

Historically, horse and equestrian have played an important place in many countries. The horse was used as a vehicle in nomadic communities, in wars, entertainments and races. Turkish domesticated the horse and became the first society to ride horses. Until today, they have used the horse in many games (rahvan, javelin game, horse archery, horse wrestling). The organization of such games have decreased exponentially, yet, international equestrian practices have continued in the world and equestrian types (three-day competition, dressage, show jumping, equestrian endurance, equestrian gymnastics, equestrian riding, reining) have become important. Accordingly, equestrian clothes gained importance and besides the lack of a uniform riding clothing, the clothes varied according to the branches. In this context, the aim of this study is to make literature review on the history of riding, its branches, clothes and the materials used. In addition, the examination of the fabric and model formation of an existing equestrian clothing is also included in the aim of the study.

Keyword: *Equestrian history, Equestrian, Equestrian clothes*

1. INTRODUCTION

The societies, which discovered all the skills and abilities of the horses, historically used them as the fastest means of transportation, and benefited from their power and speed in agriculture, transportation and postal services [1].

The earliest communities known to use the horse in hunting and warfare are Assyrians, Babylonians and Hittites. The Scythians were also very skilled in riding and known to be the first community to use the saddle. The Equestrian art began to develop in Ancient Greece thanks to the Scythians. The importance given to equestrianism in Ancient Greece can be understood from the first written source, Xenophon's 'Hippike' (Equestrian) [2]. With the development of equestrian sport in time, the International Equestrian Federation (FEI) was established in 1921, headquarters located in Switzerland. The main aim of the federation is to gather and unify all the rules related to equestrian sport as well as to expand and develop equestrian sport in developing countries. The main principle of the Federation is to create equality and sports ethics without any discrimination among member countries. Also international equestrian sports branches are determined by the FEI. Jumping, dressage, eventing, endurance, voulting, driving and reining are international equestrian sports branches [3].

Equestrian sport is a movement based active sport and affected strongly by environmental factors and thus, has its own unique clothes. After the equestrian branches emerged at the beginning of the 20th century, the corresponding clothes emerged as well in this period and preserve the traditional equestrian image for a long time. Yet, it is not possible to say that the equestrian world is completely unaffected by design, technological developments and innovation. While preserving traditional clothes and forms, studies continue to make competition dresses more stylish, remarkable and functional [4]. In this context, the main purpose of this study is to examine the history of equestrianism, equestrian branches and equestrian clothing extensively. Various literature including research and review articles, books, master's and doctoral thesis on these subjects have been reviewed. In addition, to extend the knowledge on the subject, semi-structured interviews have been conducted with the experts from the Turkish Equestrian Federation (TBF) and Eskişehir Equestrian Club. Also, a written interview was held with Osmangazi University, Mahmudiye Equine Vocational School. The official website of the International Equestrian Federation (FEI) has been examined to access the regulations and detailed information about the branches. In the last part of the study, a riding trousers from Pikeur and a riding jacket produced by 'Fouganza' were examined in terms of fabric and pattern characteristics.

2. EQUESTRIAN BRANCHES

After the equestrian sport developed and became widespread, 5 branches were determined by the International Equestrian Federation (FEI) with certain rules.

2.1 Eventing

Eventing, as in other branches, is held by national and international federations in various categories according to their degrees. In this competition, the rider competes with the same horse in different branches for three consecutive days; dessage on the first day, overcoming the natural obstacles on the second day and show jumping on the last day. These competitions are held in accordance with national or international regulations related to corresponding branches [5].

2.1.1. Dressage

Dressage training is the basis of all equestrian branches. Thus, training is an indispensable element not only for dressage horses, but also for competition, hobby as well as the carriage horses. Horses trained for dressage are expected to move well, elegant, be strong, fluent and obedient . In order for a horse to be bred with these characteristics, it must have a certain appearance (Figure 1). A typical dressage horse should have elegant and harmonious lines. A lively neck, curved shoulder, sufficiently long back, and hind legs that are well angled are advantages for these type of horses. The musculature should be short and strong rather than long and flat. (Figure 2) [6].

Figure 1. Dressage horse and rider.

Figure 2. Dressage horse.

2.1.2. Show Jumping

Among the equestrian sports, show jumping is the most common one in the Olympics. In this branch, the goal is simply to pass the tracks without touching the obstacles. In a show jumping competition, the harmony of the rider and the horse are evaluated and the tracks prepared in different places are to be crossed (Figure 3). The aim of the competition is to reveal the skill of the rider, the attention of the horse to the obstacle, ability, power and obedience [7].

Show jumping is performed over artificial obstacles, instead of in natural areas. The competitions mostly take place in a grass field with all possible weather conditions. Show jumping is also an Olympic and popular independent sport administered by the FEI [8].

Figure 3. Show jumping horse.

2.1.3. Endurance

Equestrian endurance is known as a challenging and demanding sport. The distance chosen must be suitable for both horse and rider in this sport. The health of the horse is utmost important at all levels. Thus, horses go through veterinary control at every stage. Yet, such controls are not mandatory for riders. Equestrian endurance, like other equestrian sports, requires skill and good equestrianism, but unlike other disciplines, the time spent in the saddle takes hours rather than minutes (Figure 4). The rider is exposed to several different types of terrain and several weather conditions in a single ride. Thus, equipment that is not suitable for horse and rider creates stress and tension in horse as well as rider. [8].

Figure 4. Equestrian endurance horse and rider.

2.1.4. Voulting

Equestrian gymnastics is simply defined as gymnastics performed on horseback. It is an international sport administered by the FEI since 1982 and was developed from a teaching method used to accustom novice riders to the horse's movement, instilling a sense of balance and confidence. To train novice riders, cavalry schools provided jumping exercises to improve their balance, especially when the horse is in motion. To be a good athlete, it is necessary to have a good natural balance. In order for the horse to remain calm, strong, stable and balanced during the equestrian gymnastics sport, it is necessary for the athlete to be brave and stable to perform the exercise in a balanced way (Figure 5) [8].

Figure 5. Voulting.

3. EQUESTRIAN CLOTHES

The Smyrna Race Club races, which were initiated by the Levantines in the 1850s, were held according to the rules in England. Also, in accordance with those rules, the jockeys dressed the jerseys determined by the horse owners. The race rules in France were taken as a basis in the races of the Race Improvement Committee period, which started to be held in 1927. According to these rules, jockeys wore a long sleeved jacket and sweater made of one or more colors and silk fabric, with a single button on the front, a closed collar, white panties and yellow ankle boot and cap. While the cap may be the same color as the jacket sweater or in a different color, it should be made of 'a long visor and silk fabric'. Under the sweater, a plain and white neck tie and scarf would be used. It is not possible for jockeys to participate in the competitions, unless they do not wear proper outfit and do not pay attention to cleanliness and elegance (Figure 6) [9].

Figure 6. Equestrian Clothes.

4. EQUESTRIAN PANTS AND JACKET REVIEW

Within the scope of the study, a riding trousers belongs to Pikeur and a riding jacket produced by Fouganza were examined in terms of fabric and pattern properties. As a result of this examination, the following findings were obtained.

For the riding trousers;

- Suede leather is used for easy grip on the saddle.

- The form of the trousers does not restrict movement during boarding and ensures a full fit to the body.

- Velcro is used in the legs that can provide a comfortable use with boots (Figure 7).

Figure 7. Equestrian Pants.

For the riding jacket;

- Knitted fabric with a flexible and soft structure is preferred not to restrict the movements of the arm and shoulder of the rider during the harness.

- The pattern of the garment has a model that will not prevent the movements of horse harnesses during use, and close-fitting cuts have been used to fit the body perfectly.

- The fabric is cotton and has a thin but protective structure to prevent sweating during movement (Figure 8).

Figure 8. Equestrian Jacket.

5. RESULTS

Horses are suitable animals for running and competition due to their body structure and thus, have historically been used by human both for riding in daily life, wars and races. In addition to being used more as a means of transportation during the nomadic period, the horses connect best with people also emotionally. After the transportation vehicles and war equipment that emerged with the development of the industry, horses preferred to be used more for entertainment and games by people.

Horses are animals with special body forms and features. As they are exposed to different tracks and obstacles, especially the ones used for game purposes, should compete in fields suitable for their body structures,. In time, it has been seen that international equestrian branches were clearly determined and the games and the races were carried out within the framework of certain rules. After the determination of different branches, the horses were chosen for the branches suitable for them. In this context the riding harnesses and the materials used by the riders started to differentiate and gain importance. It is extremely important that the materials used on the horse are made of materials that will not harm the health of the horse.

The harmony between the horse and the rider on the tracks and obstacles is as important as the harnessed areas for the comfort of both parties. It is necessary for the rider to sit on the horse in a stable manner that does not disturb the horse. Horse harnesses have been an important factor that helps the rider in this respect. In addition to the harnesses, the clothes used by the rider should be comfortable and in a form that would not affect the movements during riding.

As a result of the literature review, it was concluded that the color, form, fabric and accessories of the riding clothes used for the competitions were defined in accordance with the regulations. Yet, it can be seen that the clothes used for different branches and free riding do not have a clear rule in design apart from the technical requirements. In addition, it was concluded that the traditional style continues in the riding clothes.

6. CONCLUSION

Many studies related to the history of equestrian and its branches have been included in the literature. On the other hand, concerning equestrian clothing there is more information in the regulations than in the literature. It is mostly stated in literature that the appearance of the clothes from the past to the present is largely preserved. Equestrian sport continues to develop and become widespread today as it was in the past. In addition, clothes are extremely important for equestrian sports, as it is one of the rare sports in which the entire human body is in motion. Thus, this research which examines the equestrian branches and the current clothes, provides valuable insight and will pave the path for future studies.

ACKNOWLEDGMENT

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REFERENCES

[1] Murathan, F., Koç, M., Kartal, M., Murathan, T. (2019). Equestrian in the Ottoman Empire. *Adıyaman University Journal of Social Sciences Instıtute,* 11(32), 669-807.
[2] Ksenophon, (2019). *Peri Hippikes.* (S. Sandalcı Çev.). Edirne: Ceren Publishing.
[3] Federation Equestre Internatıonale **(**2022, January 05). *The Fei headquarters flowchart* from https://inside.fei.org/fei/about-fei/structure/fei-headquarters
[4] Dashper, K. ve St John M. (2016). Clothes make rider? equestrian competition dress and sporting identity. *Annals of Leisure Research,* 19(2) 235-250.
[5] Ünver, A. (2006). *Equestrian sport from ancient world to Modern Olympics and Olympic development of Turkish Equestrianizm.* (Doctoral thesis). Science of Physical Education and Teaching of Sport. https://binicilik.org.tr/Dosya/EYayinlarPdf/6-2015/13-20131017_antik_cagdan_modern_olimpiyatlara_binicilik_sporu_ve_turk_biniciliginin_olimpik_gelisimi.pdf
[6] Radtke, S. M. (2010). *Dressur.* (I. Çakır Çev.). İstanbul: Bilge Kültür Sanat
[7] Ünver, A. (2006). *Equestrian sport from ancient world to Modern Olympics and Olympic development of Turkish Equestrianizm.* (Doctoral thesis). Science of Physical Education and Teaching of Sport. https://binicilik.org.tr/Dosya/EYayinlarPdf/6-2015/13-20131017_antik_cagdan_modern_olimpiyatlara_binicilik_sporu_ve_turk_biniciliginin_olimpik_gelisimi.pdf
[8] Muır, S. ve Sly, D. (2009). *Horse and rider.* London: Anness Publishing.
[9] Aydın, Ö. H. (2018). Horse racing industry and organized sales. *Z Journal,* 3, 374-379.

POLYURETHANE NANOCOMPOSITE FOAMS INCORPORATED WITH ORGANOCLAYS

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ABSTRACT

Organoclays exhibit pronounced improvements in the properties of nanocomposites compared with original polymer or conventional micro- and macro-composites, including increased elastic modulus and mechanical strength, improved thermal stability, heat and flame resistance, reduced gas permeability and increased biodegradability. These properties have led to the application of polymer clay nanocomposites in many industrial fields. The incorporation of organoclays into polyurethane matrices by in situ polymerization is a promising new approach for forming nanocomposites that would greatly expand the commercial opportunities for this technology.

In this study, we first reproduced organoclay (OC) by organic modification of montmorillonite (MMT) clay by a reaction with the sodium salt of octadecanoic acid, which is chemically stable, low cost and widely available; later we prepared polyurethane (PU) nanocomposite foam by using in situ polymerization technique in which 2 wt% organoclay was incorporated into polyurethane matrices. Random and uniform distribution of organically modified clay mineral in the host polymer was determined by SEM-EDS analysis. Thermogravimetric analysis and dynamic mechanic analysis results showed that the thermal and mechanical properties of nanocomposites considerably improved compared to ordinary PU foam.

Keyword: *Polyurethane, Organoclay, DMA, Nanocomposite*

1. INTRODUCTION

Polyurethane foams (PUF) belong to a family of segmented polymers with soft segments derived from polyols and hard segments from isocyanates and chain extenders, which have been extensively used in industrial applications as rigid or flexible lightweight polymers because it has excellent abrasion resistance, thermal insulation and displays properties of both elastomers and plastics. Recently a great deal of effort has been devoted to improve mechanical strength, thermal stability, impermeability, flame retarding properties of polyurethanes by dispersing nanosized clays or organically modified clays, organoclays, into the polyurethane matrix [1-4]. These acquired properties are the main components of polyurethane clay nanocomposites, mainly in automotive, aerospace, packaging, medical and technical textile industries.

In the present study, our aim is to investigate the morphology and thermo-mechanical properties of nanocomposites based on organoclay added polyurethane foams. We first modified Na-Montmorillonite

(MMT) by reacting it with the sodium salt of octadecanoic acid to produce organoclay OC as described in our previous study [5]; then we added 2.0 % by mass of OC into polyurethane nanocomposite foam by in situ polymerization technique. After that, PU nanocomposite foams were examined by thermogravimetric (TG) analyses and scanning electron microscopy (SEM) connected with energy dispersive spectroscopy (EDS). The thermo-mechanical properties of PU foams were tested with dynamic mechanical analysis (DMA).

2. EXPERIMENTAL STUDY

2.1 Materials

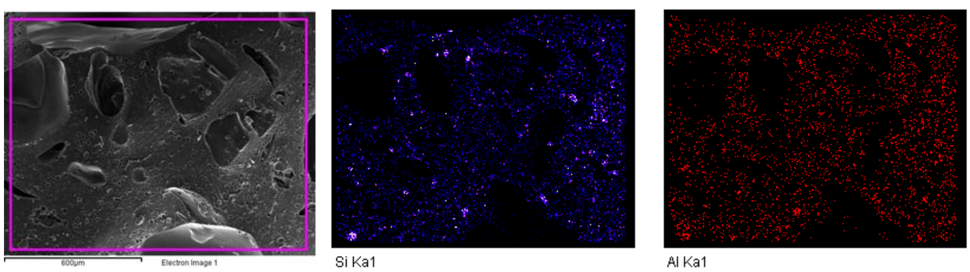
The Na-MMT, Nanocor®, was purchased from AMCOL International Corporation. The rest of the chemicals used in the experiments were technical grade and commercially purchased from Merck Co.

2.2 Methods

In the experimental study, Na-MMT clay was organically modified with sodium salt of the fatty acid, octadecanoic acid (common name: stearic acid) according to the procedure given in our previous study [5]. Then, to produce the PU nanocomposite foam, 420.5 mmol 1.3-propanediol was mixed with 2 wt % OC in a plastic container of 75 mL, at a speed of 1100 rpm, at 20°C for 45 min. While continuing mixing, 91.9 mmol TDI and 0.14 g of silicone oil were added to the polyol-clay mixture. Then, 0.012 g DABCO and 0.036 g stannus octoate were added as catalysts, and polymerization was continued for 10 minutes at a constant mixing rate. Finally, 0.2 g MDI, 1 mL of methylene chloride and a few drops of water were added to the polymer mixture to finish the reaction, and foam formation occurred by a rapid exothermic reaction. The production of polyurethane foam alone under the same reaction conditions was also carried out and was called PU (control). The foam samples were cured at room temperature for one week. Then PU nanocomposite foams were examined by TG analyses and SEM connected with EDS. The dynamic mechanical properties of PU foams were tested with Mettler Toledo DMA under the varying load between 1.0 N to 10.0 N and at 1 Hz frequency and 25 ^{0}C.

3. RESULTS

Figure 1 shows SEM image and related EDS mappings of Si and Al for PU-OC. EDS mapping of PU-OC supported efficient dispersion of the organically-modified clay in the host PU foam by in-situ polymerization, where the guest Si and Al atoms were randomly and evenly distributed throughout the body at comparable levels.



(Si: 4.3%) (Al: 0.6%)

Figure 1. SEM photograph and related EDS mappings of PU-OC.

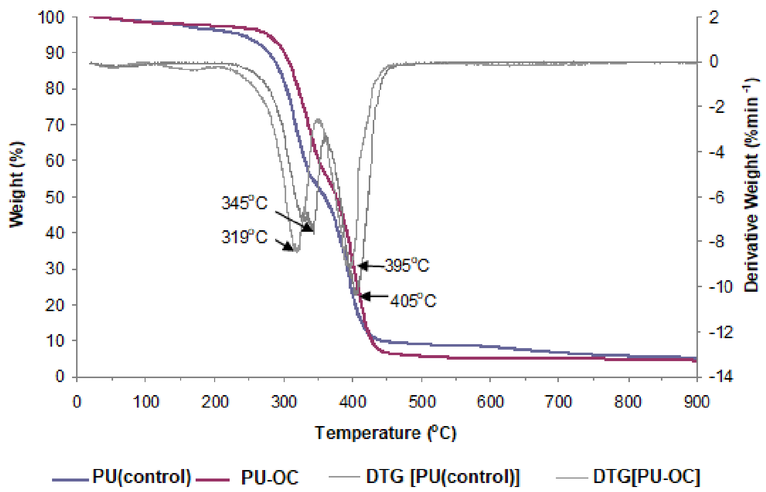


Figure 2. TG-DTG curves of PU(control) and PU-OC.

Table 1. Comparative TG results of PU(control) and PU-OC foams.

Sample	*T* (°C) at 5% mass loss	*T* (°C) at 10% mass loss	1st step		2nd step		Residual mass(%) at 410 °C
			T_{peak} (°C)	*Mass loss%*	T_{peak} (°C)	*Mass loss%*	
PU (control)	237	278	319	43	395	34	16
PU-OC	277	302	345	30	405	37	22

Figure 2 and Table 1 show the prominent differences in the TG-DTG curves and data of PU (control) and PU-OC. TG-DTG analyses show that both PU foams go through two main stages of degradation. While the thermal degradation of the PU (control) started at 200°C, the onset temperature at which the PU-OC started thermal decomposition was shifted to a much higher temperature, 238°C.

According to Table 1, the temperatures at which mass losses of 5% and 10% of PU-OC occurred correspond to temperatures as high as 40°C and 24°C compared to those of the PU (control) sample, which were measured as 277°C and 302°C, respectively. The maximum mass loss rates in the first and second stages of the DTG curve of PU-OC given in Figure 2 were reached at 345°C and 405°C, respectively, which were higher than those of the PU (control) sample. At the end of the first stage, the total mass loss of the PU-OC sample was 30%, while the PU (control) was 43%. The second stage of thermal decomposition of PU-OC ended at around 410°C, parallel to that of PU(control), and the nanocomposite residue was found to be 22% higher than the residue of PU (control) at this temperature, indicated the successful dispersion and binding of OC in the PU matrix. The results are supporting the data obtained from SEM-EDS mapping.

Table 2 summarizes the results of DMA compression tests for PU (control) and PU-OC samples of similar densities, with elastic modulus E' (MPa) and loss factor (tan δ). The results showed that at each level of the force applied in the range of 1.00 N – 10.00 N, the organoclay content of 2% in the composite structure significantly increased the elastic moduli of the samples; in turn, it has shown that it lowers tan δ values, emphasizing improvement from viscoelastic behavior to elastic behavior. The results are in good agreement with the previous studies [6]

Table 2. DMA Compression test data of PU (control) and PU-OC as a function of applied force at 25^{o}C.

	PU (control) (ρ=325 kg m^{-3})		PU-OC (1.synthesis) (ρ=335 kg m^{-3})		PU-OC(2.synthesis) (ρ=300 kg m^{-3})	
F [N]	E' [MPa]	tan δ	E' [MPa]	tan δ	E' [MPa]	tan δ
1.00	3.67	0.13	9.29	0.10	7.59	0.08
2.00	3.98	0.15	9.77	0.12	7.97	0.11
3.00	4.62	0.15	10.10	0.12	8.29	0.11
4.00	5.28	0.14	10.99	0.13	8.67	0.11
5.00	5.89	0.14	11.76	0.12	9.19	0.10
6.00	6.31	0.14	12.11	0.12	10.29	0.10
7.00	6.94	0.14	12.14	0.12	10.15	0.10
8.00	6.87	0.14	12.03	0.11	10.03	0.10
9.00	6.76	0.14	11.86	0.11	9.85	0.10
10.0	6.74	0.13	11.96	0.11	9.78	0.10

4. CONCLUSION

In this study, we first reproduced an organoclay OC by organic modification of montmorillonite (MMT) by a reaction with the sodium salt of octadecanoic acid, which is chemically stable, low cost and widely available. Afterwards, the polyurethane nanocomposite foam comprising 2 wt % of organoclay was successfully synthesized and the effect of organoclay on the thermal and mechanical performances of the polyurethane nanocomposite foams were investigated. Random and uniform distribution of organically modified clay mineral in the host polymer was determined by SEM-EDS analysis. The thermal stability of the produced polyurethane nanocomposite foam was significantly improved compared to the PU control. The dynamic mechanical analysis data showed that 2 wt% OC added to the polyurethane nanocomposite structure significantly increased the elastic modulus of the samples at a constant temperature of 25 OC; in addition, the decrease in tan δ values of PU nanocomposite foams emphasized the improvement from viscoelastic behavior to elastic behavior. The properties of PU-OC foams can be easily tailored by changing their composition, and therefore, PU-OC could be considered as promising materials usable in coating applications, such as top coating materials exposed to the damages of environmental conditions.

ACKNOWLEDGMENT

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REFERENCES

[1] Khan, T., Acar, V., Aydin, M. R., Hülagü, B., Akbulut, H., & Seydibeyoğlu, M. Ö. (2020). A review on recent advances in sandwich structures based on polyurethane foam cores. *Polymer Composites, 41*(6), 2355-2400.

[2] Sharma, A., Babar, M., Kakkar, P., Gahlout, P., & Verma, G. (2022). Correlating mechanical properties of polyurethane-organoclay nanocomposite coatings with processing. *Progress in Organic Coatings*, 169, 106895.
[3] Sachse, S., Poruri, M., Silva, F., Michalowski, S., Pielichowski, K., & Njuguna, J. (2014). Effect of nanofillers on low energy impact performance of sandwich structures with nanoreinforced polyurethane foam cores. *Journal of Sandwich Structures & Materials*, *16*(2), 173-194.
[4] Doğar, Ç., Gürses, A., Karaca, S., Köktepe, S., Mindivan, F., & Güneş, K. (2014). Investigation of thermal properties of PUF/clay nanocomposites. *Applied surface science*, 318, 59-64.
[5] Sarier, N., Onder, E., & Ersoy, S. (2010). The modification of Na-montmorillonite by salts of fatty acids: An easy intercalation process. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *371*(1-3), 40-49.
[6] Barick, A. K., & Tripathy, D. K. (2010). Thermal and dynamic mechanical characterization of thermoplastic polyurethane/organoclay nanocomposites prepared by melt compounding. *Materials Science and Engineering: A, 527*(3), 812-823.

YARN PULL-OUT AND DROP WEIGHT IMPACT PERFORMANCE OF SHEAR THICKENING FLUID IMPREGNATED BALLISTIC FABRICS

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ABSTRACT

Shear thickening fluid is used to enhance the performance of ballistic fabrics. This study aims to investigate the effect of impregnation of shear thickening fluid at different concentrations onto fabrics. To this aim, shear thickening fluids were prepared at two concentrations and applied onto three different types of para-aramid fabrics of different weights. Yarn pull-out test was established to check the effect of shear thickening fluid on the frictional force. Moreover, drop weight impact tests were applied to see the effect of shear thickening impregnation on the energy absorption behavior of the single-ply ballistic fabrics. The findings were interpreted according to concentration of shear thickening fluid solution as well as the fabric types.

Keyword: *Shear thickening fluid, Ballistic fabric, Yarn pull-out, Drop weight impact test*

1. INTRODUCTION

Various high-performance fibers like para-aramid based Kevlar®, Technora® and Twaron® are used for soft armor applications. Depending on low density combined with high strength, toughness, and thermal stability, Kevlar became the widely used para-aramid fiber preferred for the fabrics used in ballistic applications [1]. However, para-aramid fabrics should be used in multiple layers to provide adequate ballistic protection. In this respect, the impregnation of non-Newtonian fluids onto woven fabrics has drawn attention as it increases energy absorption induced by impact phenomena [1].

Acting as a non-Newtonian fluid, shear thickening fluid (STF) is a concentrated colloidal suspension and its viscosity increases drastically when the applied shear rate exceeds the critical value [2]. The performance of STF-impregnated Kevlar fabric to improve the impact resistance was explained with two factors, which are the increase in inter-yarn friction and the shear thickening mechanism respectively [2]. The influence of STF impregnation was measured by low and high-velocity ballistic tests or yarn pull-out test and drop weight impact tests.

Comparing the force values in the yarn pull-out test, Alikarami et al. indicated that the STF-treated samples have three times higher force than that of a neat sample [3]. Similar results were obtained by Bai et al. and Saraloglu Güler [4, 5]. Other researchers investigated the effect of process conditions on yarn pull-out test results. Gurgen and Kushan indicated that the fabrics treated with multi-phase STF having carbide particles in it showed higher performance in both yarn pull-out and ballistic tests [6]. Saraloglu Güler implied that the pulling rate triggers the shear thickening behavior [5]. Li et al. studied the yarn pull-out test at different speeds and temperatures to evaluate the contribution of the shear thickening effect [7]. Zhao et al. found that STF-impregnated samples had higher tensile force values and the force increased significantly with the increase of the drawing rate [8]. Applying drop weight impact test on single-ply and multi-ply fabrics, Saraloğlu Güler found that the impact resistance of STF-treated Kevlar improved [5]. Investigating the efficiency of STF-impregnated plain-weave fabric made of Kevlar under high and low-velocity impact conditions, Tria et al. applied a drop weight impact test on single and multi-ply fabric and confirmed the positive influence of STF impregnation on the energy absorption [1]. Majumdar et al. applied both dynamic impact and low-velocity impact tests on STF-applied Kevlar fabrics, whose results were similar to each other. Apart from these, the impact of process materials on the drop weight impact test results was investigated [9]. In this respect, Majumdar et al. found out that the positive impact of STF is dependent on the padding condition and so the STF concentration [9]. Preparing STF with silica particles of 500 nm and 100 nm diameter, Bajya et al. found that the absolute energy absorption by STF-100 and STF-500 impregnated fabrics of 20 to 24 plies of fabric were around 19% and 42% higher than neat fabric according to the results of dynamic impact test [2]. Srivastava et al. drew attention to the impact of the impregnation process parameters and revealed that high padding pressure reduces the STF add-on % and so the energy absorption during the impact tests [10].

The literature review revealed that STF impregnation onto fabric increased the frictional force between yarns and in this way, it improved the energy absorption of the ballistic fabrics. Most of the researchers applied STF onto fabrics, whose concentration was above 20%. [2-6, 8-10]. But Zhao implied that preparing STF solution at these concentrations was difficult under laboratory conditions. Moreover, the impregnation of STF has also been known to increase the weight of the fabric, which increases in the weight of the protective clothing. Even though, it depends on the dilution ratio, temperature, and process conditions, the impregnation of 25% STF onto fabric might increase the weight of the fabric by around 45% [11]. Therefore, it is important to know if the STF-impregnated fabrics also show high performance at lower concentrations of STF and so with lower add-on values. For this reason, in this study, the yarn pull-out tests and the drop weight impact tests were applied onto the fabrics impregnated with STF at two concentrations of 5% and 10% respectively.

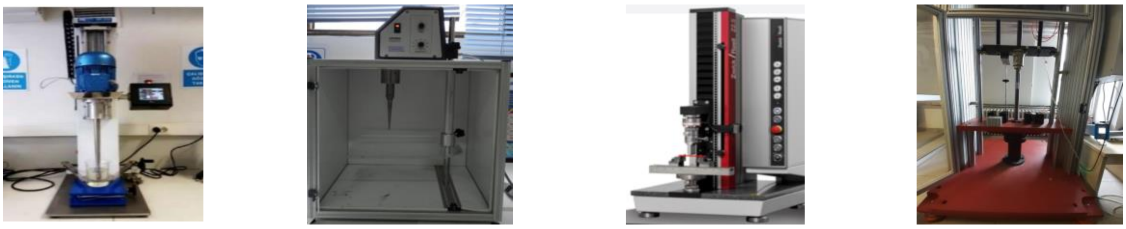
2. EXPERIMENTAL STUDY

Three types of fabrics were used for this study. The characteristics of fabrics were given in Table 1.

Table 1. Characteristics of fabrics.

Fabric Type	Yarn Count (tex)		Warp and Weft Density (unit/cm)		Thickness (mm)
	Warp	Weft	Warp Density	Weft Density	
Kevlar 200	92.66	93.51	9.5	9.5	1.24
Kevlar 410	322.19	319.59	6	6	1.58
Twaron	93.03	92.81	10.3	10.3	1.23

Fumed silica (Aerosil 200) having a specific surface area of 200 m^2 /g and Polyethylene glycol (PEG) with a molecular weight of 400 g/mol) was used to prepare STF. Ethanol was used to decrease the concentration of shear thickening fluid solution to be applied onto the fabric. STF solutions were prepared at the concentration of 5% and 10% fumed silica in PEG solution. Solutions were prepared by using the mechanical mixer (VBR-6000, YOKEŞ® Mak. San. ve Tic. Ltd. Şti) at 1500 rpm for 45 minutes at room temperature. An ultrasound mixer (Hielscher UP400S) was used for one hour to improve the homogeneity of solutions (Figure 1). The solutions were kept at room temperature for 24 hours to remove air bubbles [7, 11, 12].



(a) Mechanical Mixer (b) Ultrasound Mixer (c) Zwick Roell tensile tester (d) Drop weight impact tester

Figure 1. Mixing and testing instruments.

The solutions were diluted with ethanol at a 1:1 ratio and impregnated onto fabrics. The fabrics were immersed in the diluted solution for one hour. The excess fluid was padded manually with a roller and the impregnated fabrics were dried in the oven at 65°C for 30 minutes. Drying for some samples was continued until the weight of the samples stabilizes.

Yarn pull-out test was applied on neat and impregnated fabrics. The yarn pull-out tests were applied in Zwick Roell tensile tester, as seen in Figure 1, at two-speed values (20 mm/minute ve 100 mm/minute). Using a 100 N load cell, the maximum force load was recorded for each sample. The energy absorption behavoir of STF-impregnated fabrics was tested by using a drop weight impact tester (Besmak BMT-DW) as seen in Figure 1. Samples were subjected to low-velocity impact loading at the kinetic energy of 200J.

3. RESULTS

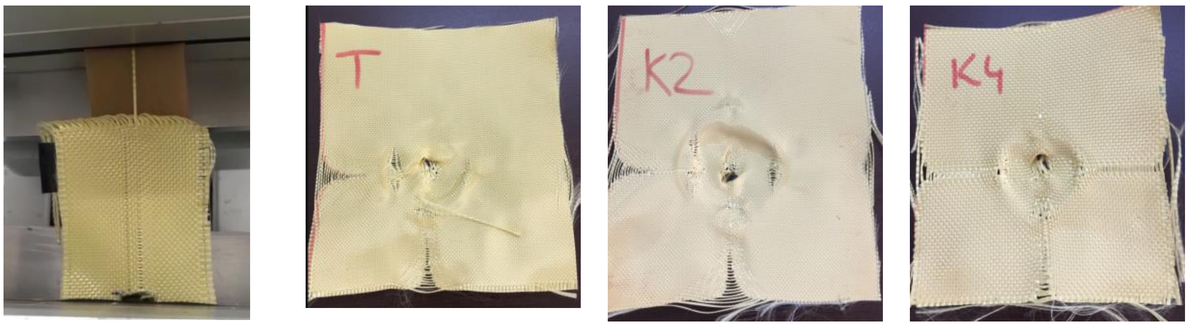
STFs prepared at two concentrations and diluted with ethanol at ratio of 1:1 were applied onto yarn pull-out and drop impact samples. Yarn pull-out samples and their characteristics were given in Table 2.

Table 2. The impregnation of STF onto fabrics and weight increase.

Sample Code	STF concentration (%)	Initial weight (g)	Change in weight			Yarn pull-out speed (mm/ min)	Maximum tensile force (cN)
			Weight after impregnation (g)	Weight after drying (g)	Add-on (%)		
T-Weft	Neat fabric	1.111				20	305.67
T-Warp	Neat fabric	1.134				20	318.50
T-5-Weft	5	1.183	2.409	1.327	12.1	20	305.51
T-5-Warp	5	1.172	2.277	1.312	11.9	20	618.30
T-10-Weft	10	1.150	2.348	1.341	16.6	20	345.50
T-10-Warp	10	1.113	2.307	1.299	16.7	20	749.89
T-Weft	Neat fabric	1.097				100	136.82
T-Warp	Neat fabric	1.157				100	141.14
T-5-Weft	5	1.182	2.392	1.299	9.9	100	314.59
T-5-Warp	5	1.144	2.297	1.268	10.8	100	615.84
T-10-Weft	10	1.143	2.298	1.297	13.5	100	352.65
T-10-Warp	10	1.193	2.318	1.385	16.1	100	743.27
K2-Weft	Neat fabric	1.057				20	169.62
K2-Warp	Neat fabric	1.147				20	136.69
K2-5-Weft	5	1.189	2.300	1.341	12.8	20	378.97
K2-5-Warp	5	1.125	2.220	1.290	14.7	20	219.53
K2-10-Weft	10	1.133	2.145	1.333	17.6	20	327.43
K2-10-Warp	10	1.169	2.367	1.380	18.0	20	223.20
K2-Weft	Neat fabric	1.051				100	180.43
K2-Warp	Neat fabric	1.203				100	135.82
K2-5-Weft	5	1.183	2.400	1.332	12.6	100	300.67
K2-5-Warp	5	1.148	2.382	1.311	14.2	100	260.96
K2-10-Weft	10	1.170	2.303	1.368	16.9	100	381.88
K2-10-Warp	10	1.136	2.186	1.363	20.0	100	243.00
K4-Weft	Neat fabric	2.606				20	248.19
K4-Warp	Neat fabric	2.774				20	391.10

K4-5-Weft	5	2.860	5.728	3.090	8.0	20	314.97
K4-5-Warp	5	2.880	5.777	3.091	7.3	20	532.13
K4-10-Weft	10	2.769	5.577	3.175	14.7	20	352.65
K4-10-Warp	10	2.897	5.741	3.088	6.6	20	588.56
K4-Weft	Neat fabric	2.756				100	218.50
K4-Warp	Neat fabric	2.338				100	277.87
K4-5-Weft	5	2.740	5.066	3.322	21.2	100	283.14
K4-5-Warp	5	2.907	6.013	3.223	10.9	100	539.11
K4-10-Weft	10	2.790	5.503	3.394	21.6	100	344.35
K4-10-Warp	10	2.702	5.314	3.131	15.9	100	565.24

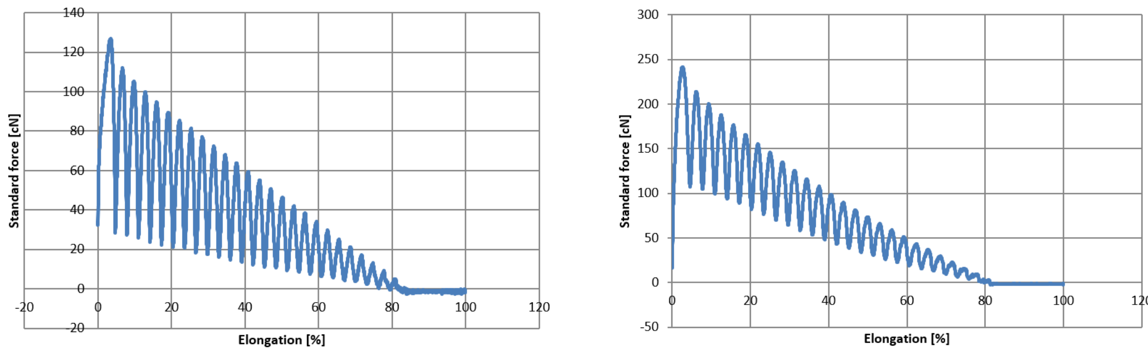
Table 2 revealed that the average add-on values were around 12.5% and 15.5% at STF concentrations of 5% and 10% respectively.



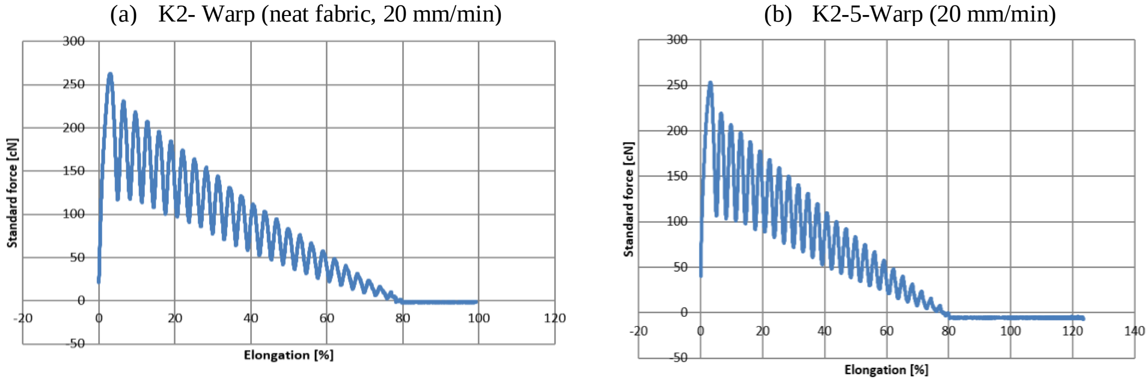
(a) Yarn pull out test (b) Twaron (c) Kevlar 200 (d) Kevlar 410

Figure 2. Yarn pull-out and drop weight impact test samples.

The yarn pull out test was applied in the tensile tester at two speed of 20mm/min and 100mm/min as depicted in Figure 2a. Moreover, the maximum tensile force obtained was recorded in Table 2. The maximum force was higher for Twaron and Kevlar 410 fabrics than Kevlar 200 fabric. This might be explained with the higher yarn count and higher thickness of Kevlar 410 fabric and higher warp and weft densities of Twaron fabric.



(a) K2- Warp (neat fabric, 20 mm/min) (b) K2-5-Warp (20 mm/min)



(c) K2-10-Warp (20 mm/min) (d) K2-10-Warp (100 mm/min)

Figure 3. Force elongation curve example for one sample.

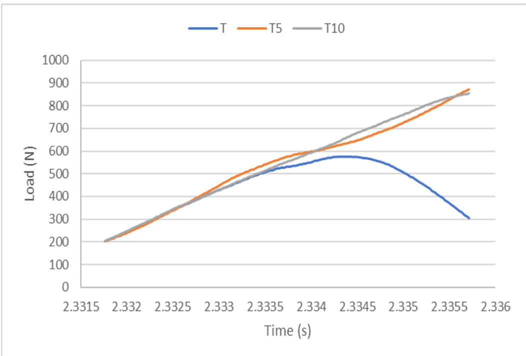
The results of yarn pull-out test for one sample of Kevlar 200 was shown in Figure 3. It was observed that peak force increased with the amount of STF impregnated. No specific difference was observed for the speeds of 20 mm/min and 100 mm/min.

Drop weight impact tests were applied on the neat and impregnated fabrics. The drop weight impact was applied on the single ply of fabrics and all the test samples were damaged as seen in Figure 2b, 2c and 2d. The results of the drop weight impact tester were given in Table 3. Kevlar 200 was found to absorb higher amount of energy in both neat form and STF-impregnated form (at the concentration of 10%). Twaron fabric was found to absorb more energy when impregnated with STF at a concentration of 5%. Kevlar 410 fabric was found to show the minimum performance in terms of energy absorbtion probably because of lower warp and weft densities as the striker moving with high velocity might well pass through the fabric.

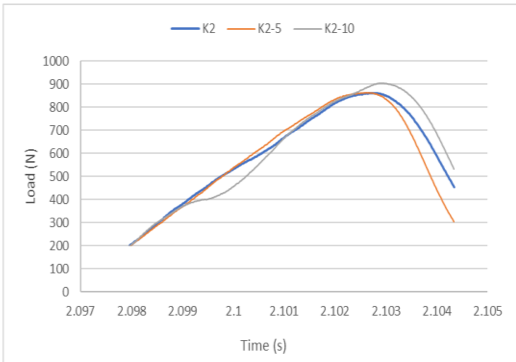
Table 3. Drop weight impact test results of the neat and STF impregnated fabrics.

	Max Load [KN]	Absorbed Energy [J]	Max Displacement [mm]
T	0.577	2.939	12.314
T-5	0.992	9.002	20.578
T-10	0.854	6.708	17.779
K2	0.859	8.133	20.937
K2-5	0.863	7.686	19.677
K2-10	0.905	8.481	21.425
K4	0.846	5.260	15.244
K4-5	0.400	3.719	28.077
K4-10	0.663	4.365	15.357

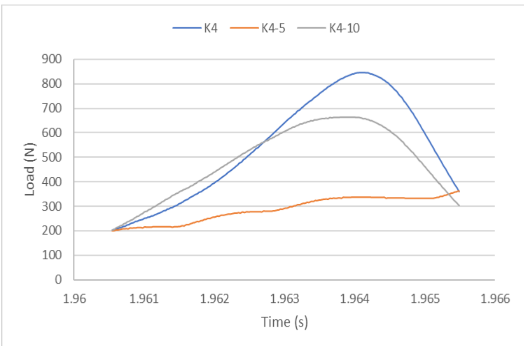
Apart from the comparison of absorbed energy, the load versus time sketches for each fabric type were shown in Figure 4.



(a) Twaron fabric



(b) Kevlar 200 fabric



(c) Kevlar 410 fabric

Figure 4. Load-time curves for different fabric types.

The findings revealed that whereas STF impregnation was seen to increase impact resistance of Twaron but it did not change that for Kevlar 200 fabric. Even the impact resistance was seen to decrease when impregnated with STF for Kevlar 410 fabric. Thus, further evidence is needed to claim that STF impregnation improved the performance. STF impregnation at these concentrations did not suggest an improvement in the performance of ballistic fabrics in this study. The reason, why good performance achieved in yarn pull-out test was not reflected on the impact behaviour, might be attributed to the fact that the impact mechanism is not interpreted with only yarn-to-yarn friction.

4. CONCLUSION

This study attempted to show that STF impregnation can improve the performance of ballistic fabrics even at low concentrations. The performance was measured with yarn pull-out and drop weight impact test.

The findings revealed that STF-impregnated fabrics had a higher yarn-to-yarn surface friction than the neat fabrics even at low concentrations and low add-on values. But, the level of energy absorption as well as the impact resistance did not differ for the neat and impregnated fabrics even though some improvements have been realized for some specimens. Based on these results, it is suggested to apply STF at higher concentrations for ballistic purposes.

ACKNOWLEDGMENT

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REFERENCES

[1] Tria, D. E., Hemmouche, L., Allal, A., & Benouali, A. (2018). Experimental and numerical analysis of high and low velocity impacts against neat and shear thickening fluid (STF) impregnated weave fabrics. *In EPJ Web of Conferences*, *183*, 01044, EDP Sciences.
[2] Bajya, M., Majumdar, A., Butola, B. S., Verma, S. K., & Bhattacharjee, D. (2020). Design strategy for optimising weight and ballistic performance of soft body armour reinforced with shear thickening fluid. *Composites Part B: Engineering*, *183*, 107721.
[3] Alikarami, S., Kordani, N., SadoughVanini, A., & Amiri, H. (2016). Effect of the yarn pull-out velocity of shear thickening fluid-impregnated Kevlar fabric on the coefficient of friction. *Journal of Mechanical Science and Technology*, *30*(8), 3559-3565.
[4] Bai, R., Ma, Y., Lei, Z., Feng, Y., & Liu, C. (2019). Energy analysis of fabric impregnated by shear thickening fluid in yarn pullout test. *Composites Part B: Engineering*, *174*, 106901.
[5] Saraloğlu Güler, E. (2018). Rheological behaviours of silica/water, silica/PEG systems and mechanical properties of shear thickening fluid impregnated Kevlar composites. *Bulletin of Materials Science*, *41*(4), 1-8.
[6] Gürgen, S., & Kuşhan, M. C. (2017). The ballistic performance of aramid based fabrics impregnated with multi-phase shear thickening fluids. *Polymer Testing*, *64*, 296-306.
[7] Li, D., Wang, R., Liu, X., Zhang, S., Fang, S., & Yan, R. (2020). Effect of dispersing media and temperature on inter-yarn frictional properties of Kevlar fabrics impregnated with shear thickening fluid. *Composite Structures*, *249*, 112557.
[8] Zhao, M., Zhang, J., Peng, Z., & Zhang, J. (2021). Effect of nano-solid particles on the mechanical properties of shear thickening fluid (STF) and STF-Kevlar composite fabric. *Journal of Engineered Fibers and Fabrics*, *16*, 15589250211044817.
[9] Majumdar, A., Butola, B. S., & Srivastava, A. (2014). Development of soft composite materials with improved impact resistance using Kevlar fabric and nano-silica based shear thickening fluid. *Materials & Design (1980-2015)*, *54*, 295-300.

[10] Srivastava, A., Majumdar, A., & Butola, B. S. (2011). Improving the impact resistance performance of Kevlar fabrics using silica based shear thickening fluid. *Materials Science and Engineering: A*, *529*, 224-229.
[11] Taş, H., & Soykok, I. F. (2021). Investigation of the Low Velocity Impact Behaviour of Shear Thickening Fluid Impregnated Kevlar, Hybrid (Kevlar/Carbon) and Carbon Fabrics. *Fibers and Polymers*, *22*(9), 2626-2634.
[12] Gürgen, S. (2020). Numerical modeling of fabrics treated with multi-phase shear thickening fluids under high velocity impacts. *Thin-Walled Structures*, *148*, 106573.

A DESIGN OF A MULTIFUNCTIONAL HEATED COAT

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ABSTRACT

Smart textiles have been the most intriguing prospect in the textile industry. In the smart textile area, the work prospects are limitless and it is evolving. In this novel design, we have produced a heated coat from composite carbon fibers with layers that can be heated and work under the 45°C-55°C weather conditions. The heater works with a module inside and can be charged with a USB. Heating starts in seconds but the time can vary regarding its power supply. The heat can be adjusted using only a button. The design is also water and wind proof.

Keyword: *Smart textile, Thermal applications, Carbon fiber, Water repellent, Wind repellent*

1. INTRODUCTION

In contrast to mobile devices, wearable electronics are primarily created to be worn in order to perform their functions. This is a rapidly expanding segment of the global market. Mobile gadgets shrunk, got more portable, and became more accessible in the middle of the 1990s as internet and mobile phone technologies dramatically increased their penetration into daily life. Most individuals in the world, especially those between the ages of 15 and 35, are familiar with using computers and smartphones, and the IT sector is paying a lot of attention to them [1]. Therefore, it is anticipated that within ten years, the body worn computer devices would become widely popular [2].

Each conductive material that receives an electric current produces heat. According to the fundamental concept of Ohm's law, the quantity of heat produced by an electric current flowing through a resistor in an electric resistance heating system depends on its level [3]. Nevertheless, the current flow is constrained by the resistance and applied voltage in a circuit (Figure 1) [1].

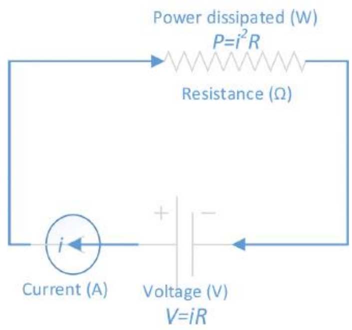

Figure 1. Ohm's law illustration.

In a textile-based heating system, the production and insertion of conductive tracks are crucial because damage to the tracks during manufacture might lower conductivity levels [4,5].

Depending on the resistor conductivity level, every square centimetre of cloth will dissipate heat in the form of several watts of power. The resistor can be scaled up in the fabric area to achieve larger power dissipation, however in the case of high-power dissipation, high level power supply is primarily required.

The purpose of textile-based heating systems is to give the user or surroundings the necessary warmth in a cooler environment. The human body system requires a warm environment to remain functional [4]. Any decrease in body temperature that results from extended exposure to cold temperatures can result in hypothermia and be dangerous for human survival; the ideal body temperature for maintaining bodily functions is 37°C [5–7]. As a result, heating systems are crucial in maintaining the body's essential temperature levels [1].

2. EXPERIMENTAL STUDY

2.1 Material and Method

Polyester carbon composite has been used for the material of the coat. Dark reflective print has been used for the fabric for thermal insulation. Inside of the coat pocket was made for the USB power bank and a charger with Velcro for easy usage.

2.2 The Design

The design of heated coat will be presented in two stages, first one being the general design and second one being the detailed design. The general design comprises of parts and design putting details on the front look, while the detailed design gives details on the inside of the product mostly.

2.1.1. General Design

Details on general design of the heated coat is given in Figure 2.

Figure 2. General design of heated coat.

Black elastic cord with eyelet has been used for the hood. Inside the collar magnetic snaps have been used. Body zip way type with black vislon gripper and black plastic puller while having metal snaps. Inside the pocket invisible reverse coil zip and black puller have been used. On the right side of the coat the on/off button has been attached, linked with the coils.

2.1.2 Detailed Design

Figure 3. Detailed design of heated coat.

Details on general design of the heated coat is given in Figure 3.

On the right side of the coat you can see the pocket with Velcro where we put the charger. Lining and resistant are used as original as Wrangler© coat.

3. RESULTS

A heated coat was designed, developed and manufactured. Polyester and carbon fibers were used. The coat has heating panels smartly designed such that heating can be achieved with as low as 5V. As part of the study, one pocket of the coat was used as container for energy supply which was chargeable via USB adaptor. The On/Off button was placed such that it can be reached and used easily during any kind of physical activity. Moreover, special reflective lining was used inside the coat in order to reflect back the heat dissipated from the body. Also, polyester fabric used for outer layer of the coat brought wind and water proof features while the dark print design on the fabric further contributed to thermal insulation. Heat dissipation was lowered by use of functional accessories including grippers, pullers, snaps and zippers.

4. CONCLUSION

An e-textile based heated coat was designed and manufactured. Maximum thermal insulation was achieved with minimum heat dissipation thanks to heating accompanied with multi-layer composite textile structural design. In our further study, we will focus on increasing the efficiency of heating so that the effective heating time will be increased under various weather conditions.

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REFERENCES

[1] Bahadir, S. K., & Sahin, U. K. (2018). A wearable heating system with a controllable e-textile-based thermal panel. *Wearable Technol*. doi: 10.5772/intechopen.76192
[2] Malmivaara, M. (2009). The emergence of wearable computing, Smart Clothes and Wearable Technology, Editör: J. McCann and D. Bryson. Cambridge: Woodhead Publishing.
[3] Kursun Bahadir, S., Sahin, U. K., & Kiraz, A. (2019). Modeling of surface temperature distributions on powered e-textile structures using an artificial neural network. *Textile Research Journal*, *89*(3), 311-321. doi: 10.1177/0040517517743689
[4] Sampath, M. B., Aruputharaj, A., Senthilkumar, M., & Nalankilli, G. (2012). Analysis of thermal comfort characteristics of moisture management finished knitted fabrics made from different yarns. *Journal of industrial textiles*, *42*(1), 19-33.
[5] Au, K. F. (Ed.). (2011). *Advances in knitting technology*. Cambridge: Woodhead Publishing.
[6] Kar, F., Fan, J., Yu, W., & Wan, X. (2007). Effects of thermal and moisture transport properties of T-shirts on wearer's comfort sensations. *Fibers and Polymers*, *8*, 537-542.
[7] Kissa, E. (1996). Wetting and wicking. *Textile research journal*, *66*(10), 660-668.

ENVIRONMENTALLY FRIENDLY ACOUSTIC PANEL DESIGN FROM CURTAIN WASTE

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ABSTRACT

The goal of this study is to develop environmentally friendly acoustic panels using discarded industrial curtain fabrics. In this context, fabric wastes were split into fibers using a shredder and blended with polyester fiber with a low melting temperature used as binder. The samples were then subjected to pressure and heat in the hot press to complete the panel manufacture. The sound absorption coefficient and sound transmission loss of the produced panels were tested by impedance tube, and the results were given comparatively. The developed panels have contributed to solid waste management with minimum consumption of virgin raw material, and an important step has been taken towards the development of sustainable, functional and decorative panels.

Keyword: *Recycling, Acoustic Panel, Fabric Waste*

1. INTRODUCTION

Noise pollution has become a major health and ecological concern as a result of urbanization, industrial growth, and increased use of vehicles, electrical and mechanical devices. Noise pollution causes a variety of health problems, such as sensory impairment, stress, high blood pressure, coronary heart disease, and stroke [1,2]. Noise control materials used in the construction industry are primarily inorganic and synthetic composites, such as glass wool, stone wool, and polystyrene. Despite having high sound absorption coefficients, these materials have a significant environmental impact [3].

Global textile consumption has risen gradually over the last two decades. The rising rate of consumption has had a huge effect on both manufacturing amounts and generation of waste [4]. Every year, approximately 150 million tons of textile waste are produced globally [5]. Textile wastes are mostly incinerated or ends up in landfills in the lack of adequate waste management strategies, posing environmental and social risks. Since synthetic textiles are non-biodegradable, they cause higher environmental and social problems [4]. Polyester accounts for roughly 60% of all man-made fibers [6].

Textile waste has been one of the most important innovative raw materials used in the development of sound insulation materials in recent years. When the literature is examined, it is discovered that there are studies in which sound insulation materials are designed and manufactured using a variety of textile wastes [5-9]. In this study, it is aimed to develop an environmentally friendly, sustainable, value-added acoustic panel from the fabric wastes generated in our factory. In this way, it is aimed to recover approximately 4 tons of fabric waste generated every month.

2. EXPERIMENTAL STUDY

2.1. Materials

Within the scope of the project, two types of fabric wastes generated within Oba Perdesan were utilized:

i. Blackout roller blind fabric wastes were generated from tightly woven fabric, including 100% polyester fibers with a special foam coating on the back to prevent light from passing through.

ii. Mixed fabric wastes include both blackout roller blind fabric wastes and translucent roller blind fabrics that are coated with an acrylic mixture but without a foam layer on the back.

As a binder, low melting temperature (T_m ~150C) polyester fibers were used for mixed fabric waste samples.

2.2 Methods

2.2.1 Waste Collection

A total of 40 waste bins were placed throughout OBA Perdesan and employees were trained to properly collect the waste in the relevant bins.

2.2.2 Production and Analysis of Composite Panels

Both blackout and mixed fabric wastes collected throughout Oba Perdesan were opened into fiber form using a shredder (Figure 1). For only mixed fabric wastes, low melting temperature polyester fiber were added as a binder with a weight ratio of 10%. Blackout roller blind fabric wastes were used without a binder.

a. **b.**

Figure 1. Shredded fibers of **a.** blackout curtain fabric **b.** mixed curtain fabric.

Composite structures were produced by hot press machine. Samples placed between Teflon papers were waited for 15 minutes at 160°C. Then the samples were left to cool down in press to avoid curling. Produced samples were cut into the relevant dimensions for acoustic tests (Figure 2).

a. **b.**

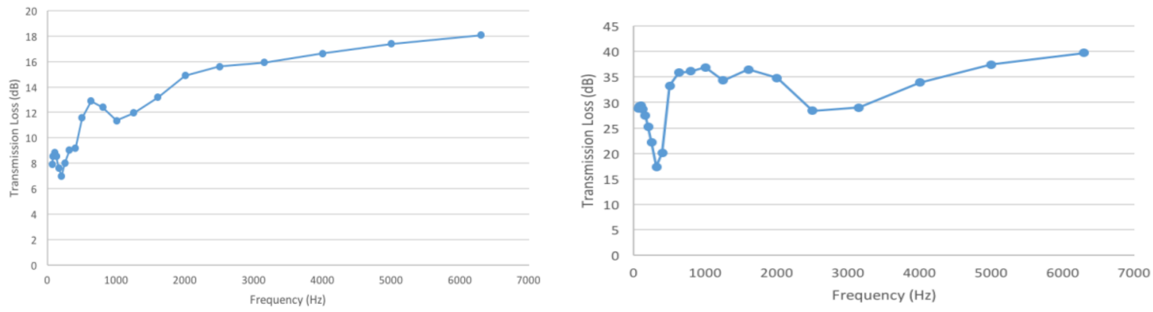
Figure 2. Composite samples including **a.** mixed curtain fabric wastes **b.** blackout curtain fabric wastes.

The thickness of the samples were measured by a digital microgauge. The acoustic performance of composite samples in terms of sound absorption coefficient (ISO 10534-2 standard) and sound transmission loss (ASTM E2611-09) was carried out using the TestSens Sound tube. For sound absorption coefficient measurement, TestSens Two Microphone Impedance Measurement Tubes in the frequency range from 50 Hz to 6400 Hz was used while the sound transmission loss was measured using the TestSens Four Microphone Impedance Measurement Tube.

3. RESULTS

The thickness of composite structures including blackout fabric wastes and mixed fabric wastes was measured as 2.82 mm and 2.62 mm, respectively. Since both sample thicknesses are very close to each other, the results were compared independently of the sample thicknesses.

Sound transmission loss test results can be seen in Figure 3.

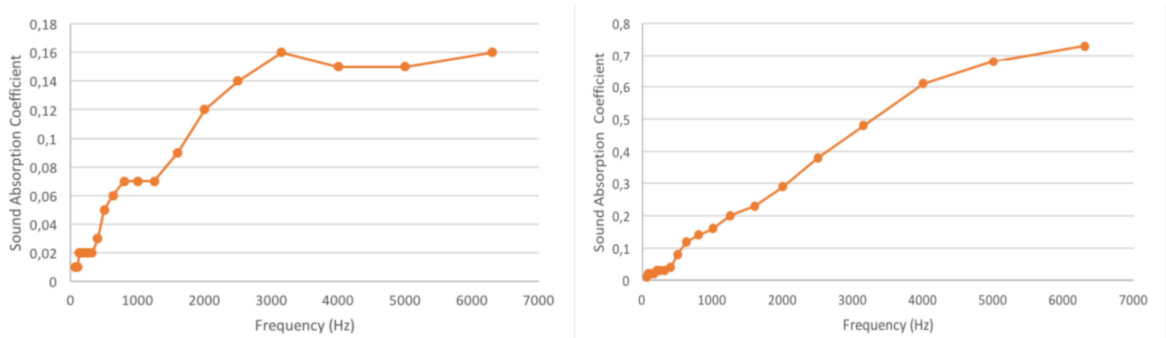


a. **b.**

Figure 3. Sound transmission loss test results of composites including wastes of **a.** mixed curtain fabric **b.** blackout curtain fabric.

The results obtained were particularly promising for composite structures produced from blackout fabric waste. Samples containing blackout fabric waste with a thickness of 2.65 mm showed that 30-35 dB sound transmission loss can be achieved for 1000 Hz and lower frequencies. In composite structures produced from mixed curtain wastes, this value reached a maximum of 13 dB at low frequency values, and remained between 14-18 dB values in the 2000–6400 Hz range. During the manufacturing process, the coating material in the blackout fabrics melted, making the composite structure more rigid. However, since various fabric types were combined in mixed curtain wastes, the ratio of coating material remained low, and a bulkier structure was obtained. The results obtained support the production results.

Sound absorption coefficient test results can be seen in Figure 4.



a. **b.**

Figure 4. Sound absorption coefficient test results including wastes of **a.** blackout curtain fabric **b.** mixed curtain fabric.

Sound absorption coefficient test results were found to support the sound transmission loss test results. As expected, composite samples produced from mixed curtain fabric wastes, which have a bulkier structure, exhibited better sound absorption performance. For this sample group, the sound absorption coefficient was obtained as approximately 0.45 at a medium-high frequency value such as 3000Hz. Considering the thickness (2.82mm) of the produced sample, this result was found to meet the expectations. On the other hand, the highest absorption coefficient obtained in blackout fabric-added composites, which take a plastic form and lose their air gaps considerably, is 0.16, and it has been observed that this value is well below the targeted coefficients.

CONCLUSION

Within the scope of the study, acoustic panel material with a thickness of 2.82 mm with a sound absorption coefficient of approximately 0.45 at mid-high frequency was successfully developed. In addition, 30-35 dB sound transmission loss was obtained at 1000Hz frequency values in samples containing blackout fabric waste. The results were found promising, and it is aimed to improve these values further by changing the thickness and raw material content. It is thought that the acoustic panels produced can be used especially in open offices and meeting rooms with both functional and decorative features.

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REFERENCES

[1] Islam, S. & Bhat G. (2019). Environmentally-friendly thermal and acoustic insulation materials from recycled textiles, Journal of Environmental Management, 251, 109536.
[2] Ismail, A.Y., Chen, M.J., Azizi, M.F. & Sis, M.A. (2016). Experimental investigation on the use of natural waste fibres as acoustic material of noise silencer, Journal of Advanced Research in Materials Science, 22(1), 1-10.
[3] Rubino, C., Aracil, M.B., Gisbert-Payá, J., Liuzzi, S., Stefanizzi, P., Cantó, M.Z. & Martellotta, F. (2019). Composite eco-friendly sound absorbing materials made of recycled textile waste and biopolymers, Materials, 12(23), 4020.
[4] Dissanayake, D.G.K., Weerasinghe, D.U. Thebuwanage, L.M. & Bandara, U.A.A.N. (2021). An environmentally friendly sound insulation material from post-industrial textile waste and natural rubber, Journal of Building Engineering, 33, 101606.
[5] Vėjelis, S., Vaitkus, S., Kremensas, A., Kairytė, A. & Šeputytė-Jucikė, J. (2023). Reuse of textile waste in the production of sound absorption boards, Materials, 16(5), 1987.
[6] Trajković, D., Jordeva, S., Tomovska, E. & Zafirova, K. (2017). Polyester apparel cutting waste as insulation material, Journal of Textile Institue, 108, 1238–1245.
[7] Antolinc, D. & Filipič, K.E. (2021). Recycling of nonwoven polyethylene terephthalate textile into thermal and acoustic insulation for more sustainable buildings, Polymers, 13(18), 3090.
[8] Patnaik, A., Mvubu, M., Muniyasamy, S., Botha, A. & Anandjiwala, R.D. (2015). Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies, Energy and Buildings, 92, 161–169.
[9] Juciene, M., Dobilaite, V., Albrektas, D. & Bliudzius, R. (2022). Investigation and evaluation of the performance of interior finishing panels made from denim textile waste, Textile Research Journal, 92(23–24), 4666–4677.

POSTER PRESENTATION

PERFORMANCE OF KNITTED FABRICS OF CONVENTIONAL AND SPECIALLY PROCESSED PA YARNS INTENDED FOR SPORTSWEAR

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ABSTRACT

For the production of the materials intended for sportswear five PA yarns (conventional, recycled, and performance yarns: antibacterial, water management, and thermal) of counts 15-18 tex were used. Produced materials were tested for mass per unit area, thickness, compressibility, heat resistance, water vapour transfer rate, and moisture management. It was shown that the compressibility of knitted fabrics depends mostly on the density of the knitted fabric and on the thickness. Heat transfer resistance mostly depends on the mass per unit area of the knitted fabrics, and knitting density has biggest, and inversely proportional influence on water vapour permeability. PA thermal yarn provided better properties in terms of the comfort of the athlete than a fabric made of conventional or recycled PA yarn.

Keyword: *knitted fabric, comfort, PA yarns, sportswear*

1. INTRODUCTION

Comfort affects the choices while buying clothes because it is one of the essential aspects, and various research has been done on this topic. An important role in clothing comfort has a garment fit and pressure comfort, primarily in thight-fit sportswear. In the study by Babalık et al. [1], a new approach for objective comfort assessment of knitted fabrics used in the sportswear industry was developed. The skin is extremely sensitive to light pressure. Under ideal condition, displacements of the skin less than 0.001mm can result in a sensation of pressure or touch [2]. To use a functional compression garment has become extensively common in sportswear, as it helps sportsmen boost performance at the competition. Close-fitting compression garments with pressure designed for body shaping functions are becoming preferred [3].

The choice of fibre properties and the structural parameters of the knitted fabrics, which affect compression, also have an impact on the comfort of the garment, and they are important for thermal balance between human body and environment. Processes between raw fabrics and garment production i.e., clothing design have an effect on thermal comfort, and the thermal properties of sportswear are important.

The heat and moisture transfer capacity of a garment from the skin to the environment affects thermal comfort [4]. Evrim Kanat and Özdil [5] investigated the prediction of thermal resistance of knitted fabrics at different moisture content, since sportswear may become wet during use and their thermal properties can be changed. In recent studies, a 3D avatar is used in the assessment of thermal comfort under different conditions, with the aim of detailed analysation of the temperature and heat transfer distribution [6]. New multifilaments were developed to improve the moisture management properties of textiles. To influence the performance of the clothing meant for sportswear, choice of fibre type, blending nature, yarn and fabric structure and the finishing treatment are crucial [7].

2. MATERIALS AND METHODS

For the production of the materials intended for sportswear are used five polyamide yarns of counts 15-18 tex. The selected yarns are conventional, recycled, and performance yarns, i.e. antibacterial, water vapour management, and thermal. Using the circular knitting machine (E17), single jersey knitted fabrics were produced. The details related to the produced materials (raw material, specific of each yarn and yarn count) are given in Table 1.

Table 1. Yarn details

Designation	Yarn raw material	Yarn specifics	Yarn count, tex
SY1	100% PA 6	conventional	18
SY3	100% PA 6.6	recycled	18
SY4	100% PA 6.6	antibacterial	18
SY5	100% PA 6.6	water management	15
SY6	100% PA 6.6	thermal	17

In the experimental part of this investigation, produced materials were tested for mass per unit area, thickness, compressibility, heat resistance, water vapour transfer rate, and moisture management.

The mass per unit area of the fabric was measured according to the ISO 3801 standard (method 5), [7]. The specimen size was 100x100 cm, and the accuracy of the analytic scale used +/- 0.001 g. Fabric thickness was determined according to EN ISO 5084: 1996 [8] using the thickness meter DM 2000 - Wolf.

Fabric compressibility was measured on a cylinder of a 240 mm circumference with a PicoPress device produced by Microlab. During the measurement, the circular specimen was pulled on a cylinder under which a PicoPress sensor was placed. The results were expressed in mmHg.

The heat resistance (R_{ct}) of fabric was measured using the sweating guarded hot plate (SGHP). During the measurement, the air temperature was set to 20˚C, the relative humidity to 65% and the air speed to 1 ± 0.05 m/s.

The measurement of water vapour permeability was conducted using the PCE - MA 100 instrument. The size of the specimen was 100x100 mm and the temperature of the apparatus was set to 41°C. To assure the transfer of water vapour, and to prevent the transfer of distilled water, a selectively permeable membrane was installed between the water cup and material before the test was conducted. The material was weighted before and after the heating and results were used to calculate the water vapour transfer rate.

The evaluation of the moisture management of fabrics was conducted using the M290 moisture management tester (MMT). The measurement was performed according to the AATCC TM 195-2021 standard [9]. The following properties were measured and determined: Wetting Time (WT), Absorption Rate (AR), Maximum Wetted Radius (MWR), Spreading Speed (SS).

3. RESULTS

Fabrics were knitted from very similar yarns in terms of fineness and raw material composition, on the same machine, with the same depth of needle withdrawal, with the same yarn tension. Therefore, the test results for mass, thickness, horizontal and vertical density, and compressibility of the knitted fabric are relatively similar.

Two fabrics of slightly lower mass per unit area were knitted from two finer yarns (Tab. 1, Tab. 2). The compression on the base, according to this measurement, depends more on the vertical density of the knitted fabric (r=0,8076) than on the thickness (r=0,671), or any other parameter, including yarn finnenes (Tab. 2, Tab. 3).

Table 2. Test results of mass per unit area, thickness, density (horizontal and vertical), and compressibility of knitted fabric

Sample	mass per unit area, g/m^2	thickness, mm	density horizontal, loops/cm	density vertical, loops/cm	compressibility, mmHg
Y1	111,61	0,800	11	15	4
Y3	109,02	0,646	11	13	3
Y4	110,81	0,664	11	12	1
Y5	105,45	0,669	11	14	2
Y6	95,44	0,705	11	13	2

Table 3. Correlation coefficient between surface mass, thickness, density and compressibility of knitted fabric

	mass per unit area, g/m^2	thickness, mm	density horizontal, loops/cm	density vertical, loops/cm	compressibility, mmHg
mass per unit area, g/m^2	1				
thickness, mm	0,12085	1			
density horiz., loops/cm	-0,10629	0,58300	1		
density vertic., loops/cm	0,16361	0,75325	-0,08006	1	
compressibility, mmHg	0,28214	0,671303	-0,08006	0,8076	1

The lowest resistance to heat transfer was provided by a fabric made of PA 6.6 thermal yarn (Y6), intended for this purpose. In principle, heat transfer resistance mostly depends on the mass per unit area of the knitted fabric, r=0,81346 (Table 4, Table 5).

However, the most water vapour permeable fabric was not knitted from Y5 PA 6.6 water management yarn. Most water vapour permeable fabric is least dense knitted fabric (Y4). Vertical knitting density has biggest, and inversely proportional influence, on water vapour permeability of all properties (r= -0,7439), and in this case had a greater influence than finishing of PA fiber (Table 4, Table 5).

Table 4. Results of heat resistance and water vapor permeability tests

Sample	R_{ct}, m^2KW^{-1}	W, g/m^2h
Y1	0,0371	314,3666
Y3	0,0257	335,7435
Y4	0,0279	348,9469
Y5	0,0253	314,3666
Y6	0,0194	311,8516

Table 5. Correlation coefficient between heat resistance and water vapor permeability and variables

	mass per unit area, g/m^2	thickness, mm	density horizontal, loops/cm	density vertical, loops/cm	Rct, m^2KW-1	W, g/m^2h
Rct, m^2KW-1	0,81346	0,67263	0,22448	0,59516	1	
W, g/m^2h	0,53378	-0,55201	-0,000001	-0,7439	0,0428	1

Moisture management test (MMT) shows that the minimum time to begin to be wetted on top and bottom side of the knitted fabric (WT, s) was shown by sample Y6, PA with thermal finishing. The same sample showed the fastest spreading speed (SS, mm/s) of surface wetting from the center where the test solution was dropped to the maximum wetted radius. Sample Y3, recycled PA showed the highest ability of absorption rate (AR, %/s) i.e. the average speed of liquid moisture absorption. Only best result of PA 6.6, with water management finishing (Y5) is in maximum wetted radius (MWR, mm) measured on top and bottom surfaces.

Table 4. Results of moisture management test (MMT)

Sample	WT, s		AR , %/s		MWR, mm		SS mm/sec	
	top surface	bottom surface	top surface	bottom surface	top surface, max	bottom surface, max	top surface	bottom surface
Y1	17,11	10,69	12,73	14,16	18,33	18,33	0,81	0,79
Y3	5,94	6,01	73,69	70,24	20,00	20,00	3,69	3,69
Y4	7,21	4,44	52,10	55,38	20,00	20,00	2,25	2,24
Y5	19,59	4,30	24,35	24,77	25,00	26,67	1,46	1,96
Y6	3,57	3,60	59,43	56,34	21,67	21,67	4,72	4,65

4. CONCLUSION

The lowest resistance to heat transfer was provided by a fabric made of PA 6.6 thermal yarn (Y6), the same sample showed the fastest spreading speed (SS, mm/s) of surface wetting, thus it has better properties in terms of the comfort of the athlete than a knitted fabric made of conventional PA or recycled PA yarn. The compressibility depended mostly on the density of the knitted fabric, heat transfer resistance mostly depended on the mass per unit area of the knitted fabrics, and on water vapour permeability knitting density had the biggest, inversely proportional influence.

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REFERENCES

[1] Babalık, E., Güneşoğlu, S., Ütebay, B., Çetmeli Bakadur, A. & Güneşoğlu, C. (2021). A New Objective Method for Comfort Assessment of Sportswear Knitted Fabrics. Tekstil ve Konfeksiyon, 30(4), 318-328.
[2] Schiffman H.R. (1995). The Skin, Body, and Chemical Senses; Companion Encyclopedia of Psychology, Longman, London and New York, 224-251.
[3] Xiong, Y. & Tao, X. (2018). Compression garments for medical therapy and sports. Polymers, 10(6), 1-19.
[4] Öner, E., & Okur, A. (2014). Thermophysiological comfort properties of selected knitted fabrics and design of T-shirts. The Journal of The Textile Institute, 106(12), 1403–1414.
[5] Evrim Kanat, Z. & Özdil, N. (2018). Application of artificial neural network (ANN) for the prediction of thermal resistance of knitted fabrics at different moisture content. The Journal of The Textile Institute, 109(9), 1247–1253.
[6] Zhang, Y., Jia, J. & Guo Z. (2022). Numerical investigation of heat transfer in a garment convective cooling system. Fashion and Textiles, 9(1), 1-14.
[7] Yang, Y., Ju, Z, Tam, P.Y., Hua, T. & Hu, H. (2022). Sustainable profiled poly(lactic acid) multifilaments with high moisture management performance for textiles. Textile Research Journal, 92(21-22), 4298-4312.
[8] ISO 3801:1977 Textiles — Woven fabrics — Determination of mass per unit length and mass per unit area
[9] ISO 5084:1996 Textiles — Determination of thickness of textiles and textile products
[10] AATCC 195 Test Method for Liquid Moisture Management Properties of Textile Fabrics

LETTUCE QUALITY CONDITIONED BY BIODEGRADATION OF NONWOVEN TEXTILES FROM CELLULOSE REGENERATE AND PLA BIOPOLYMER

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ABSTRACT

Mulches are used for weed suppression, reducing evaporation, increasing moisture retention, regulating temperature, increasing the availability of nutrients and improvement of crop yields. The use of organic mulches contributes to the possibility of recycling through decomposition, which can serve as a source of nutrients. Therefore, the impact of the application and degradability of CV regenerate and PLA biodegradable mulches (compared to standard PE Agro foil) on the yield and quality of lettuce, i.e. the concentration of nutrients (macroelements in dry substance), was investigated.

Keyword: *Biodegradation, CV regenerate, PLA, Nutrient elements*

1. INTRODUCTION

Mulches from nonwoven fabrics are the most often used for weed suppression. Besides this basic function, mulches also reduce evaporation, increase moisture retention, regulate temperature and increases the availability of nutrients, which all affects the improvement of crop yields. In terms of environmental protection and waste management problems, the application of biodegradable materials is very important. Fabric biodegradation is an irreversible process carried out by microorganisms, where organic material is broken down (by organisms like bacteria, fungi, insects, worms and many others) into simpler components. This is why organic mulches are an increasingly important option for agronomy purposes, especially when considering the possibility of recycling through decomposition, which can serve as a source of nutrients during growing seasons [1-3].

Polylactic acid (PLA) is a 100% biodegradable, ecological polymer that can decompose in nature (in a short period of 2 years) without any danger and does not contaminate the soil during its degradation. Viscose (CV) among cellulose-based materials, is popular for mulching and production of plant seedlings due to its good sorption properties and fast biodegradation (time depends on many factors). Regenerated cellulose additionally has multiple advantages, mainly due to the emphasis on reuse and the circular economy [4].

Nutrients or plant elements, which were investigated in this research, to define the plant (lettuce) quality, belong to the group of essential elements, which include the macroelements N, P, K, S, Ca, Mg and Fe:

- The dry matter of plants contains on average between 2 and 5% of nitrogen (N). Plants are great collectors of nitrogen, incorporating it into the organic matter during the entire growing season.

Increased nitrate content in plants can be the result of drought, high temperature, shading of plants in a dense crop or cloudy weather, and a lack of phosphorus, potassium or calcium in the soil.

- Phosphorus (P) is a non-metal that is in the composition of important organic compounds. Plants absorb phosphorus exclusively in anionic form and incorporate it into organic matter without reduction, which is evolutionarily understandable because the energy metabolism of all living beings is based on phosphorus. Daily requirements for phosphorus are 800 g/day. Phosphorus is irreplaceable in the metabolism of energy and substances, the functioning of enzymes, the construction of nucleic acids, phospholipids, phosphoproteins, participates in the construction of a large number of coenzymes, the metabolism of erythrocytes, etc.

- Potassium (K) is an alkaline metal that is not a part of organic matter but still plays a vital role in the development of the plant. Potassium is extremely important in the regulation of water content in plants and plays a key role in the adaptation of plants to unfavourable climatic and soil conditions, for example, drought, frost and salinity. The daily human need for potassium is ~ 3.5 g. It is necessary for the work of muscle cells, and the consequences of its deficiency are cramps, weaker bowel activity and weakening of the heart.

- Calcium (Ca) is an alkaline earth metal that can build complex compounds but does not participate in the structure of living matter. The concentration of calcium in plants is on average about 0.5 % in dry substances (0.1 to >5%). There is more calcium in the leaves compared to the root, while older leaves are richer than younger ones. The daily human need for calcium is 1.2 g, and extreme deficiencies of this element result in muscle spasms, brittle and brittle bones, bad teeth and nails, and dry and weak skin.

- Magnesium (Mg) is an alkaline earth metal that is capable of building complex compounds, and the most important is chlorophyll. Magnesium concentration in plants averages 0.1-1.0% in dry substance, and in well-supplied plants 0.15-0.35% in dry substance. Daily human needs for magnesium are 300-400 mg. It affects the work of more than 300 enzymes, and its deficiency leads to problems with muscle cells in addition to heart problems, leg pain, circulatory system, digestion, concentration, irritability, chronic fatigue, depression and stress.

- Iron (Fe) is a heavy metal, which can build complex compounds, and in plants, it is mainly in the Fe(III) oxidation state. A person's daily need for iron is 10-15 mg. It is a constituent of red blood cells that carry oxygen, carbon dioxide and some other compounds. Therefore, its deficiency leads to lower mobility, poor blood circulation to the skin, migraines, deconcentration, etc [5].

2. EXPERIMENTAL STUDY

In this research, the impact of nonwoven mulches of 400 g/m^2 mass per unit area, produced from recycled CV and PLA fibres and compared to conventional PE Agro foil as well control field, on lettuce yield and concentration of nutrients in dry substance was investigated. The research was conducted for a period of 8 weeks from the day of planting lettuce seedlings (Gentilina Lettuce) in late April 2022. The experimental plots were randomly arranged in blocks of four replications. Nonwoven mulches and PE Agro foil were laid on the soil, and the seedlings were planted in a spacing of 30x25 cm. After harvesting, the mulches were removed and subjected to tests, as well as the plant itself. The fabric biodegradation was defined by the determination of relative weight loss, thickness and tensile properties. Furthermore, the influence of the aforementioned on the lettuce yield was investigated, and the concentration of nutrient elements in the plant was determined by analysing the dry substance.

3. RESULTS AND DISCUSSION

The research resulted in significant changes in the mass, thickness and air permeability of the tested materials after 8 weeks of exposure to real application conditions. The study showed varied biodegradability for nonwovens made of CV and PLA. The greatest mass loss (Figure 1) and thus the most significant material degradation, was recorded with the CV nonwoven fabric sample (22% after 8 weeks), following a 45% reduction in thickness. The PLA nonwoven fabric degraded by only 3.5%, while the thickness even increased by 7% due to the composition and structure of the material. The results of material mass loss are strongly correlated with the air permeability property of the tested samples ($R^2 = -0.99707$).

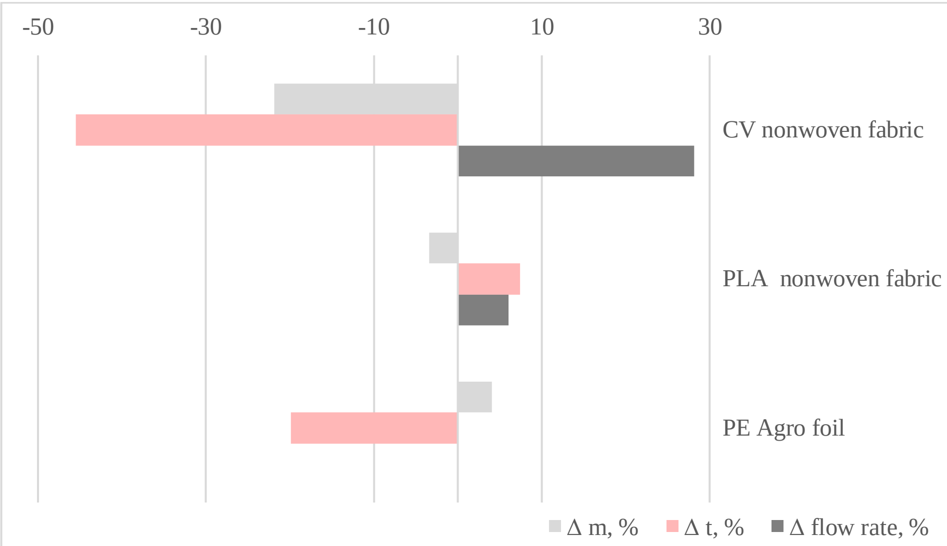

Figure 1. Changes in materials mass, thickness and air permeability after 8 weeks of exposure to actual application conditions.

The results of breaking forces of both CV and PLA nonwoven fabric samples show a significant increase after the first period of 4 weeks (I), especially in the cmd direction of nonwoven fabric (Figure 2). CV samples show an increase of 775%/640% (cmd/md direction), while for PLA samples this increase was 290%/220%. Afterwards, the CV samples show a breaking force drop, in the second period up to the 8th week (II), of 43%/37%, while for PLA nonwoven fabric samples force additionally increases by 18%/25%, and jet in the following period it starts to decrease. PE agro foil does not show significant changes during the tested period. The total percentage difference in breaking forces throughout the tested 8 weeks period is shown in Figure 3.

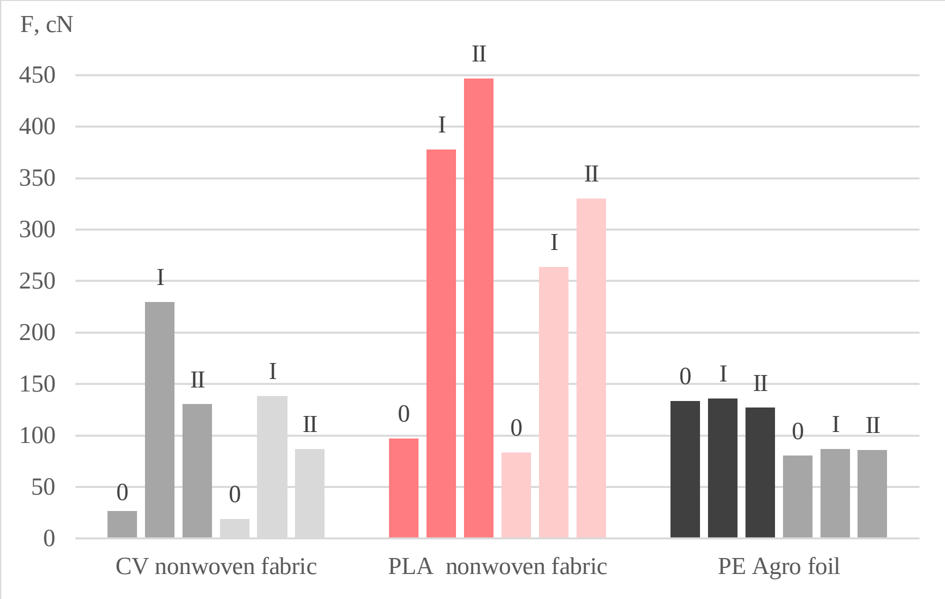

Figure 2. Breaking forces of tested nonwoven samples through periods I and II.

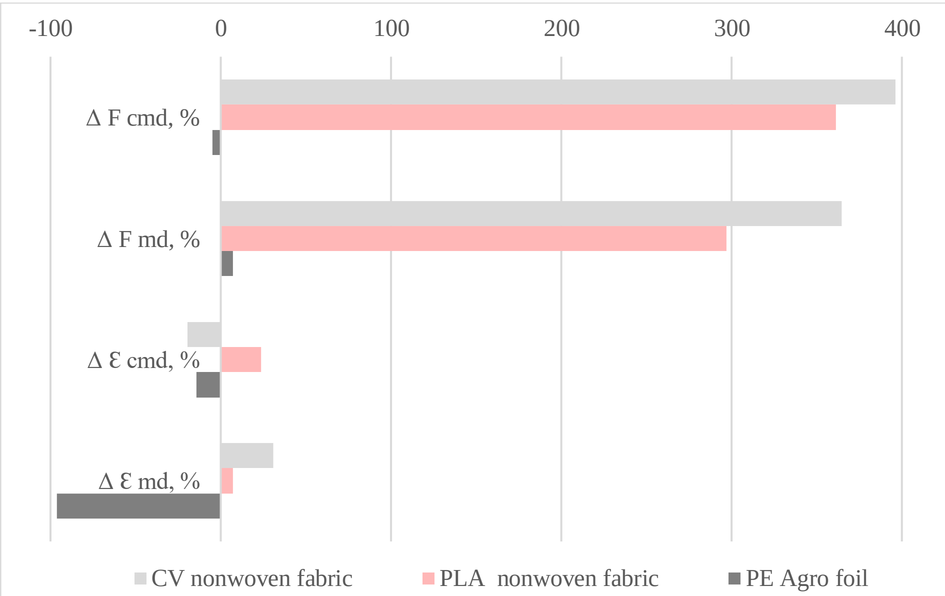

Figure 3. Tensile properties of tested nonwoven samples.

Comparing the fabric degradation and lettuce yield, it is clear that the highest yield crop was recorded in the field covered with the CV nonwoven fabric sample, i.e. the sample that degraded the most in the tested period (Figure 4). The reason for this can be found in the fact that the CV nonwoven fabric retained a greater amount of soil moisture and better regulates the soil temperature, which favoured faster and better plant development. It is also important to point out that the total yield on a field covered with CV nonwoven fabric is almost 11% higher than the yield on an uncovered field and 5.5% higher than on a field covered with standard PE Agro foil.

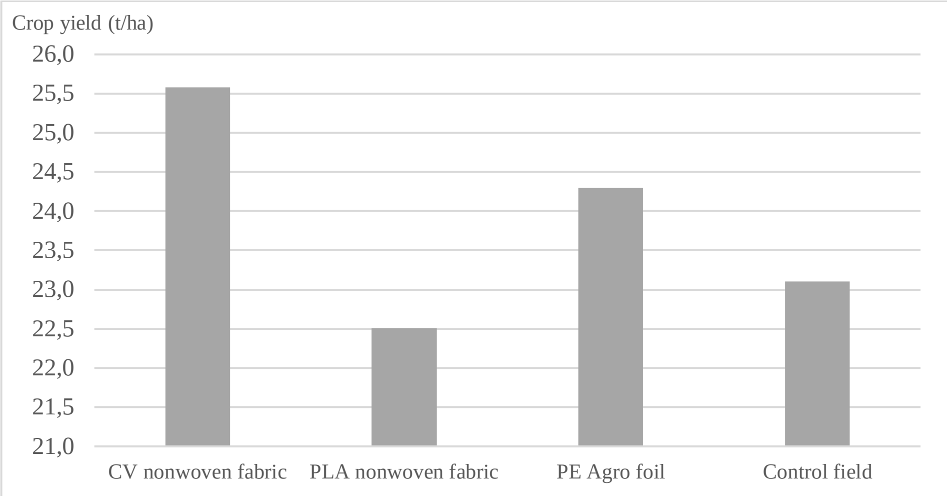

Figure 4. Crop yield in fields covered with tested nonwoven samples.

By analysing the concentrations of certain elements (macroelements N, P, K, S, Ca, Mg, Fe) in the dry substance of plant, which grew in fields covered with different types of mulches (as well as in an uncovered field), conclusions can be made about the quality of the lettuce and the influence of applied mulches on the concentrations of certain elements in the lettuce (Figure 5).

Lettuce grown on the field covered with CV nonwoven fabric recorded the highest percentage of K (5.45%), but also the lowest percentage of Mg (0.25%). Lettuce developed on the field covered with PLA nonwoven fabric shows similar values of K, Ca and P, the lowest values of N (20% compared to the control field) and Ca (13% compared to the control field), but at the same time the highest value of Fe (almost twice as high compared to PE Agro foil). Lettuce that was grown on a field covered with PE Agro foil stands out for its much lower concentration of K and Fe compared to the other fields. The mineral composition of the plants growing in the control field was not affected, but the consequences of the absence of mulch were enormous (amount of weeds).

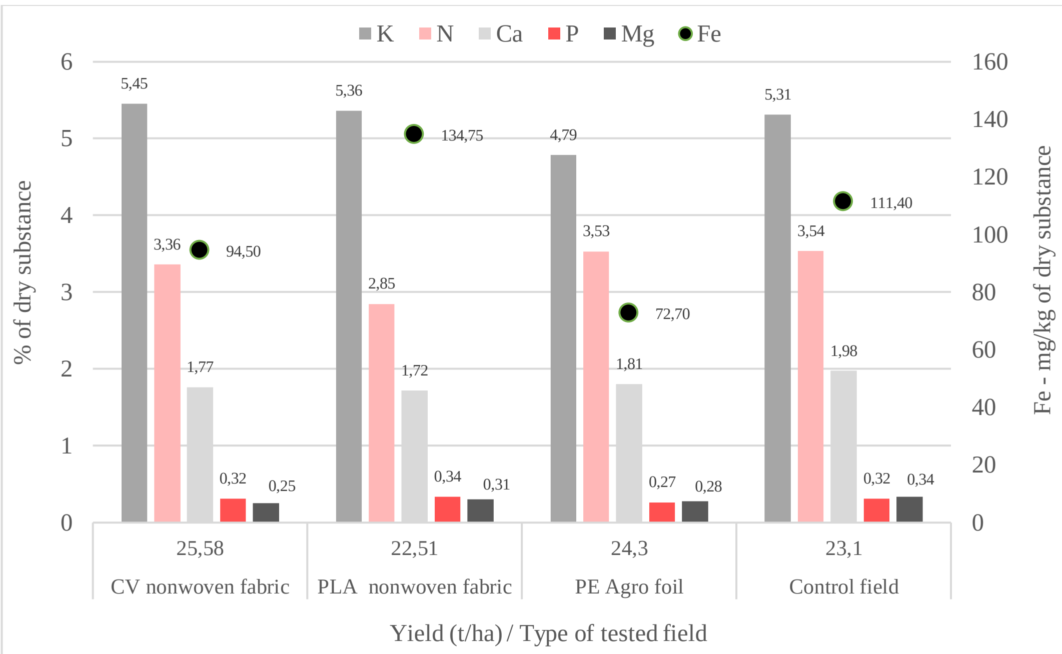

Figure 5. Crop yield and nutrient elements concentrations.

4. CONCLUSION

This research gave interesting indications about the influence of the use of mulches of different raw material composition and their biodegradation on the yield and quality of crops. For the stated test period of 8 weeks, the CV nonwoven mulch shows the highest degradation, simultaneously affecting the highest yield crop with satisfactory nutrient element concentrations.

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REFERENCES

[1] Restrepo-Osorio, A., et al. (2019). Agrotextiles and Crop Protection Textiles. In High Performance Technical Textiles. Roshan, P. (Ed.). John Wiley & Sons Ltd.: Chichester, UK, 279–318.
[2] Marczak, D., Lejcu´s, K., & Misiewicz, J. (2020). Characteristics of biodegradable textiles used in environmental engineering: A comprehensive review. Journal of Cleaner Production. 268, 122129.
[3] Fang, C.C., et al. (2020). Characterization and analyses of degradable composites made with needlepunched jute nonwoven and polylactic acid (PLA) membrane. Cellulose, 27, 5971–5980.
[4] Madej-Kiełbik, L., Gzyra-Jagieła, K., Józwik-Pruska, J., Wisniewskia-Wrona, M., and Dymel, M. (2022). Biodegradable Nonwoven Materials with Antipathogenic Layer. Environments. 9, 79.
[5] Vukadinović, V., and Vukadinović, V. (2011). Ishrana bilja. Poljoprivredni fakultet u Osijeku, Osijek, Croatia.

HEAT PUMP TUMBLE DRYER DRUM REVOLUTION SPEED IMPACT on DIMENSIONAL STABILITY of JERSEY KNITS

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ABSTRACT

Knit garments are prone to change dimensionally during washing and tumble drying. This paper focuses on tumble dryer shrinkage of single jersey knit fabrics. 4 different tumble dryer drum revolution speed is tracked as 30, 41, 52, 63 rpm and 4 single jersey knit samples which contain different fiber share as 100% cotton, 95/5% cotton/elastane, 70/30% cotton/polyester and 100% polyester are tested. The dimensional stability of single jersey knit fabrics are evaluated after 5 washing and tumble-drying cycles. Statistical evaluation is found textile fiber type and drum revolution speed as statistically significant factors. 100% cotton sample resulted on highest shrinkage as 9.28% on average. Cotton/elastane is differed statistically from other samples and its shrinkage is found 8.02%, cotton/polyester and polyester are found statistically same for shrinkage but they both differed from 100% cotton and 95/5% cotton/elastane. Shrinkage value for cotton/polyester and polyester samples on average is evaluated as 4.49% and 4.95%, respectively. From all 4 different drum revolution speeds, 63 rpm is differed statistically significantly and resulted in lowest shrinkage for 100% cotton fabric.

Keyword: *Tumble dryer, Dimensional stability, Shrinkage, Single jersey knit*

1. INTRODUCTION

Textiles are the products that are developed and used to protect human against nature, but need periodic care due to staining or unwanted smell during use. Nowadays, textile care is carried out automatically in white goods known as washing and drying machine. During the washing and drying processes, textiles may be damaged. The damages that occur in the washing step and the damages that occur in the drying step can differ from each other in terms of type and magnitude. The major damage which occur in the tumble drying step is dimensional change. Recent studies about damages which found in the waste clothes indicate that 20% of total cloth waste has dimensional stability problem [1, 2]. Also, shrinkage is the most complained subject of the tumble dryer consumers.

Dimensional change has been studied mostly for wool fabrics [3–12]. Mechanical impacts given to textiles during tumble drying is found effective on felting shrinkage of wool [3, 6]. The shrinkage studies of another textile fibers during tumble drying are quite limited. Other than wool, cotton is the second fiber type which is focused mostly. Cotton Incorparated studied cotton shrinkage by changing temperature on 3 level as 38^{o}C, 66^{o}C and 94^{o}C and it is found that temperature is not effective on cotton shrinkage. Moreover, the shrinkage of single jersey and interlock knits were more than lacoste knits

[13]. Another studies also indicated that the temperature is not effective on the cotton shrinkage [14, 15]. Polyester fabrics are found more dimensionally stable than wool and cotton after tumble drying [16]. When blends are compered, it is evaluated that cotton/polyester blends shrink less than 100% cotton fabrics [17]. When woven and knit structures of cotton and polyester fabrics are compared, cotton plain jersey knit structure is found the most problematic fabric type for shrinkage. Different drum revolution speeds are resulted in different shrinkage. Shrinkage rate of the garments decreased in the order of drum rotation speed 50 > 35 > 65 rpm [18, 19]. The fiber blend fabrics are not evaluated by changing drum revolution speed in the literature.

In this study, it is aimed to test and determine tumble dryer drum revolution speed effect on the shrinkage of different fiber based single jersey knit fabrics.

2. EXPERIMENTAL STUDY

To evaluate shrinkage of single jersey knit fabrics, customer general usage is considered, and samples are firstly washed in washing machine as 4 kg mixture load and then tumble dried. 8 kg capacity washing machine (Grundig GWNE68E69) and 8 kg capacity heat pump tumble dryer (Beko B5T4824RW) are used for the tests.

2.1 Material

Test samples are chosen as 100% cotton, 95/5% cotton/elastane, 70/30% cotton/polyester and 100% polyester single jersey knits. Details of the testing fabrics are given at Table 1. 1.5 kg cotton single jersey knits, 1.5 kg standard polyester ballast (IEC 60456), 5 standard hand towels (IEC 60456) and 2 pieces from every sample is combined to make totally 4 kg washing and drying load. The single jersey knit fabrics are cut as 50cm*50cm.

Table 1. The fiber, yarn and fabric feature of test fabrics.

Fiber Composition	Yarn Type	Yarn Number	Fabric Construction	Fabric Weight (g/m^2)	Course & Wale (per cm)
Cotton 100%	Ring	Ne 30/1	Single Jersey Knit	150	15 course/cm 21 wale/cm
Cotton/Elastane 95/5%	Ring	Ne 30/1 20 D	Single Jersey Knit	165	15 course/cm 27 wale/cm
Cotton/Polyester 70/30%	Ring	Ne 30/1	Single Jersey Knit	150	15 course/cm 21 wale/cm
Polyester 100%	Ring	Ne 60/1	Single Jersey Knit	125	19 course/cm 22 wale/cm

2.2 Method

Test load is washed with standard detergent (IEC 60456) in wash machine cotton program at 40°C, 1200 rpm. After washing the clothes are tumble dried with 4 different drum revolution speeds as 30, 41 ,52, 63 rpm. The dimensional stability of test samples is evaluated with EN ISO 5077:2008 standard procedures. The length shrinkage is taken as shrinkage result of the fabric.

$$\frac{X_t - X_o}{X_o} \qquad \text{Eq. 1}$$

In equation 1 X_o is original length and X_t is length after washing/drying.

3. RESULTS

Test results are evaluated with Minitab program. Factor details are given at Table 2, 4 different fiber composition and 4 different drum revolution speed is analysed together.

Table 2. Factor information table for statistical analysis.

Factor	Type	Levels	Values
Fiber Composition	Fixed	4	Cotton, Cotton/Elastane, Cotton/Polyester, Polyester
Drum Revolution Speed (rpm)	Fixed	4	30, 41, 52, 63

The results showed that the fiber composition of single jersey knit fabrics, tumble dryer drum revolution speed and their interactions are statistically significant for dimensional stability (Table 3).

Table 3. ANOVA results for experimental test design.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fiber Composition	3	130.838	43.6128	228.99	0.000
Drum Revolution Speed (rpm)	3	7.764	2.5879	13.59	0.000
Fiber Composition*Drum Revolution Speed (rpm)	9	12.917	1.4352	7.54	0.000
Error	16	3.047	0.1905		
Total	31	154.566			

Tukey method is applied to see levels difference of factors, this method results means that levels which do not share a letter are significantly different. When fiber compositions are categorized statistically, 100% cotton was in group A, 95/5% cotton/elastane in group B and both 70/30 cotton/polyester and 100% polyester in group C (Table 4). The categorial results shows that cotton polyester blend and pure polyester fabrics are resulted in same shrinkage value. Pure cotton has the highest shrinkage value as 9.28% on average.

Table 4. Tukey grouping results for fiber composition.

Fiber Composition	N	Mean	Grouping		
Cotton	8	9.27765	A		
Cotton/Elastane	8	8.01988		B	
Polyester	8	4.95019			C
Cotton/Polyester	8	4.48466			C

When drum revolution speeds are categorized statistically, 30, 41, 52 rpm were in A group and 63 rpm was in B group (Table 5). Only 63 rpm showed difference statistically significantly for dimensional stability.

Table 5. Tukey grouping results for drum revolution speed.

Drum Revolution Speed (rpm)	N	Mean	Grouping	
41	8	7.20559	A	
52	8	6.95360	A	
30	8	6.68021	A	
63	8	5.89297		B

Main effect plot for fiber composition and drum revolution speed on shrinkage is given in Figure 1.

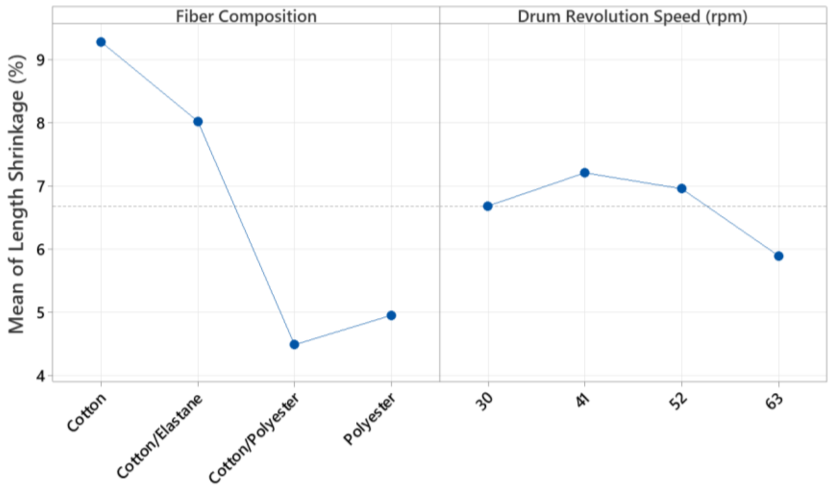

Figure 1. Main effect plot for length shrinkage.

4. CONCLUSION

The tumble dryer drum revolution speed and fiber composition effect on single jersey knit fabrics' dimensional stability is studied. The shrinkage problem was high for pure cotton and middle for cotton/elastane fabrics; cotton polyester blend and pure polyester fabrics have the lowest shrinkage. Importance of the study was to test different fiber compositions on different tumble dryer drum speed values and 70/30% cotton/polyester blend gave the same result as 100% polyester fabric. It indicates that polyester adding to cotton fibers is increasing dimensional stability highly significantly for single jersey knit fabrics. Moreover, results found that only for cotton rpm changings are differed shrinkage values significantly. For other fabrics, rpm changings did not affect shrinkage statically significantly. 63 rpm was found the only solution for shrinkage of %100 percent cotton single jersey knit fabrics. Except for cotton, it is possible to use any drum revolution speed since the drum revolution speed changes did not differ the shrinkage results, significantly. This freedom about drum revolution speed might be used to improve the subjects as energy usage and other textile damages. For the next studies it is advised to study on cotton polyester optimum mixture for improving dimensional stability and to compare flat drying and tumble drying for different fiber compositions.

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REFERENCES

[1] Cooper, T., & Claxton, S. (2022). Garment failure causes and solutions: Slowing the cycles for circular fashion. *Journal of Cleaner Production*, 351. https://doi.org/10.1016/J.JCLEPRO.2022.131394

[2] Cooper, T., Oxborrow, L., Claxton, S., Goworek, H., Hill, H., & McLaren, A. (2016). Strategies to improve design and testing for clothing longevity. Defra: London, Project EV0553.

[3] Bao, W., Shen, J., & Ding, X. (2020). The influence of mechanical action on felting shrinkage of wool fabric in the tumble dryer. *Textile Research Journal*, *90*(21–22), 2367–2375. https://doi.org/10.1177/0040517520918665

[4] Bao, W., Shen, J., & Ding, X. (2021). The Influence of Moisture Content on Shrinkage of Wool Fabrics during Domestic Tumble Drying Process. *Fibers and Polymers*, *22*(2), 559–566. https://doi.org/10.1007/s12221-021-9207-x

[5] Bao, W., Shen, J., Ding, X., & Wu, X. (2019). Dimensional change of wool fabrics in the process of a tumble-drying cycle. *Textile Research Journal*, *89*(21–22), 4702–4709. https://doi.org/10.1177/0040517519841370

[6] Bao, W., Shen, J., Wu, X., & Ding, X. (2021). Investigation of fabric movement in a tumble dryer for the development of drying methods for wool fabrics to save energy. *Textile Research Journal*, *92*(9–10), 1598–1610. https://doi.org/10.1177/00405175211062097

[7] Knapton, J. J. F., Ahrens, F. J., Ingenthron, W. W., & Fong, W. (1968a). The Dimensional Properties of Knitted Wool Fabrics: Part I: The Plain-Knitted Structure. *Textile Research Journal*, *38*(10), 999–1012. https://doi.org/10.1177/004051756803801004

[8] Knapton, J. J. F., Ahrens, F. J., Ingenthron, W. W., & Fong, W. (1968b). The Dimensional Properties of Knitted Wool Fabrics: Part II: 1 ×1, 2×2 Rib and Half-Cardigan Structures. *Textile Research Journal*, *38*(10), 1013–1026. https://doi.org/10.1177/004051756803801005

[9] Knapton, J. J. F., & Fong, W. (1970). The Dimensional Properties of Knitted Wool Fabrics: Part IV: 1 X 1 Rib and Half-Cardigan Structures in Machine-Washing and Tumble-Drying. *Textile Research Journal*, *40*(12), 1095–1106. https://doi.org/10.1177/004051757004001208

[10] Knapton, J. J. F., & Fong, W. (1971a). The Dimensional Properties of Knitted Wool Fabrics: Part V : Interlock and Swiss Double-Piqué Structures Fully-Relaxed and in Machine-Washing and Tumble-Drying. *Textile Research Journal*, *41*(2), 158–166. https://doi.org/10.1177/004051757104100212

[11] Knapton, J. J. F., & Fong, W. (1971b). The Dimensional Properties of Knitted Wool Fabrics: Part VI: Some Observations of Completely-Relaxed Fabric Geometry. *Textile Research Journal*, *41*(11), 894–899. https://doi.org/10.1177/004051757104101103

[12] Knapton, J. J. F., Richards, S., & Fong, W. (1970). The Dimensional Properties of Knitted Wool Fabrics: Part III: The Plain-Knit Structure in Machine-Washing and Tumble-Drying. *Textile Research Journal*, *40*(6), 543–553. https://doi.org/10.1177/004051757004000609

[13] Cotton Incorporated. (2004). *A guide to improved shrinkage performance of cotton fabrics*. https://www.cottoninc.com/wp-content/uploads/2017/12/ISP-1009-Guide-to-Improved-Shrinkage-Performance-of-Cotton-Fabrics.pdf

[14] Higgins, L., Anand, S. C., Hall, M. E., & Holmes, D. A. (2003b). Effect of Tumble-drying on Selected Properties of Knitted and Woven Cotton Fabrics: Part II: Effect of Moisture Content, Temperature Setting, and Time in Dryer on Cotton Fabrics. *The Journal of The Textile Institute*, *94*(1–2), 129–139. https://doi.org/10.1080/00405000308630601

[15] Higgins, L., Anand, S. C., Hall, M. E., & Holmes, D. A. (2003a). Effect of Tumble-drying on Selected Properties of Knitted and Woven Cotton Fabrics: Part I: Experimental Overview and the Relationship between Temperature Setting, Time in the Dryer and Moisture Content. *The Journal of The Textile Institute*, *94*(1–2), 119–128. https://doi.org/10.1080/00405000308630600

[16] Cheriaa, R., Marzoug, B., & Sakli, F. (n.d.). Effects of various home drying practices on smoothness appearance, shrinkage, handle and other properties of woven fabrics. *Fibres and Textiles*, 1, 2020.

[17] Onal, L., & Candan, C. (2003). Contribution of Fabric Characteristics and Laundering to Shrinkage of Weft Knitted Fabrics. *Textile Research Journal*, *73*(3), 187–191. https://doi.org/10.1177/004051750307300301

[18] Kim, H., Kim, S., & Park, C. H. (2022). Improvement in drying performance through sample movement change in tumble dryers. *Textile Research Journal*, 92(23–24), 4814–4833. https://doi.org/10.1177/00405175221111485/ASSET/IMAGES/10.1177_00405175221111485-IMG2.PNG

[19] Lee, J., Yun, C., & Park, C. H. (2022). Effect of Fabric Characteristics and Drum Rotation Speeds on the Movements and Drying Performances of Clothes in a Tumble Dryer. *Fibers and Polymers 2022* 23:6, *23*(6), 1741–1752. https://doi.org/10.1007/S12221-022-4802-Z

BIODEGRADATION PROPERTIES OF NATURAL FIBRES FROM RENEWABLE RESOURCES

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ABSTRACT

Nowadays, the term biodegradation is becoming important, as it converts materials into water and minerals, carbon dioxide and new biomass, which presence does not harm the environment. By burying textiles in the soil, microorganisms play a major role in the biodegradation process. The biodegradation analysis is often taken as a standard measurement for environmentally friendly textile materials. It is important to investigate in detail the biodegradation behaviour of natural fibres under controlled conditions, which enables the selection of suitable fibres for the production of biodegradable agrotextile nonwoven materials with targeted properties for a specific purpose.

Therefore, the aim of this paper is to investigate the biodegradation properties of Jute and PLA fibres by soil burial test. The fibres were exposed to the farmland soil for 11 days. The efficiency of the biodegradability was determined by comparison of mass loss, mechanical properties (finesses and tenacity) and morphological analysis by SEM microscope. With the purpose of a better understanding of biodegradation, the number of total fungi and bacteria in the soil is also determined.

Keywords: *biodegradability, natural fibres, properties, soil burial test*

1. INTRODUCTION

With the huge increase in the global population and advances in technology, synthetic polymers play a major role in everyday life, primarily due to the wide range of properties that enable a wide variety of products and areas of use. Growing global environmental concerns and awareness of renewable green resources are constantly increasing the demand for environmentally friendly, sustainable and biodegradable fibre which synthetic polymers are not. A major disadvantage of synthetic polymers is the long-term decomposition process which has a negative environmental impact with excessive accumulation as well as soil and water pollution. Synthetic polymers are characteristically inert and resistant to microbial attack and therefore they remain in nature without any deformation for a very long time. Increased pollution and inadequate disposal of non-biodegradable materials into nature are increasingly endangering the environment. Using natural fibres as a substitute for non-biodegradable polymers in the production of biomaterials is considered a viable alternative in many industrial sectors, to reduce the impact on the environment [1-4].

The biodegradability of fibres depends on the physical and chemical properties of the material, as well as on the conditions under which biodegradation is considered. Thus, the conditions of biodegradation vary between composting, soil biodegradation, marine biodegradation, sewage sludge biodegradation, anaerobic biodegradation, landfill biodegradation and others. Under controlled conditions, it is possible to lead the biodegradation process to the desired result by controlling the biodegradation conditions. Biodegradation in real conditions is much more complex considering that many factors from the environment can affect the biodegradation process (rate and magnitude of biodegradation) which cannot be influenced or managed.

Natural fibres are favourable resources of raw materials for industrial application, as they are environmentally efficient with high strength, biodegradability, renewability and sustainability. Due to their biodegradable nature, natural fibres are gradually replacing synthetic fibres in the field of non-woven agrotextiles [1, 2]. Natural fibres are constituted of cellulose, hemicellulose, lignin, waxes and some water-soluble compounds. Natural cellulose fibres differ in the percentage of chemical composition, crystallinity, degree of polymerization and method of fibre production. All these differences affect the degradation behaviour, which results in different biodegradability [3, 4].

Jute fibres, as a lignocellulosic fibre, are biodegradable and recyclable, i.e. environmentally friendly fibres. The use of Jute fibres is also justified by their low cost and high availability, low density, easy biodegradability, nontoxicity, better physical and mechanical properties than other natural fibres and no energy consumption during fibre production. The chemical composition of Jute fibre includes cellulose (64.4%), hemicellulose (12%), pectin (0.2%), lignin (11.8%), water soluble (1.1%), wax (0.5%), and water (10%) [5]. Like any other natural fibre, the performance of the Jute fibre varies due to the natural variability in surface and internal microstructural characteristics, which can be influenced by a number of factors including growing conditions (i.e., temperature, humidity, soil condition), retting (water, dew or enzymatic) and fibre extraction processes, fibre length and diameter, chemical constituents and their proportional amounts [6].

In addition to natural cellulose fibres, today biopolymers obtained from starch are also gaining in importance due to their availability, biodegradability and low price. Degradation of starch (from corn, wheat, rice) and sugar (from sugar beet, molasses) can produce lactic (lactic) acid. One of the most important biopolymers which are obtained from corn starch is polylactic acid (PLA) mainly due to its high mechanical and thermal properties, biodegradability and renewable properties and very simple production from lactic acid monomer [7]. Polylactic acid is a renewable, recyclable, biodegradable and compostable polymer because it dissolves quickly by simple hydrolysis under the right conditions [8, 9]. Its application comprises several industries, such as packaging, textile, biomedical, automotive and agriculture. PLA biopolymers have a number of characteristics that are similar to many other thermoplastic fibres, such as controlled crimp, smooth surface and low moisture regain. One unique property in comparison is that it is the only melt-processable fibre from annually renewable natural resources [10]. Compared to the solvent-spinning process required for synthetic cellulose fibres, melt spinning allows PLA fibres to be made with both lower financial and environmental costs. PLA is ideally suited for many applications in environments where recovery of the product is not practical, such as agricultural mulch films and bags [4]. PLA is known to be entirely biodegradable. Through hydrolysis, microorganisms convert LA (lactic acids) into the water and carbon monoxide. Degradation mainly depends on the molecular weight and other factors such as the temperature, time, impurities and residual catalyst concretisation which increases the rate of PLA biodegradation.

Nowadays, the term biodegradation is becoming important, as it converts materials into water and minerals, carbon dioxide and new biomass, which presence does not harm the environment. By burying textiles in the soil, microorganisms play a major role in the biodegradation process. The biodegradation analysis is often taken as a standard measurement for environmentally friendly textile materials [4, 5]. Therefore, it is important to investigate in detail the biodegradation behaviour of natural fibres under controlled conditions, which enables the selection of suitable fibres for the production of biodegradable agrotextile nonwoven materials with targeted properties for a specific purpose [1, 2]. Research on the biodegradation of materials provides a better understanding of materials' behaviour in the environment, the degradation process, the period and other products that are involved in the biodegradation process. When researching biodegradability, either by microorganisms or by external influences, it is of great importance to accurately define the rate and magnitude of biodegradation to determine sufficient biodegradability of the product in soil and soil conditions [10, 11].

2. EXPERIMENTAL STUDY

The aim of this paper is to investigate the biodegradation properties of natural fibres from renewable resources. An analysis of the biodegradation properties of Jute and PLA fibres (supplied by NatureWorks LLC Company) was performed by a simple soil burial test (ISO 11721) conducted under controlled conditions in the laboratory.

The fibres were exposed to the farmland soil for 11 days. For the optimal activity of microorganisms, the soil moisture was 60 ± 5% and the pH of the test soil was 6.8. The samples are buried in containers of unglazed pottery at the depth of 150 mm. The container with the samples is placed in an environment where 95 ± 5% air moisture and a temperature of 29 ± 1 °C are maintained. After the defined burial time the samples were removed from the soil and rinsed in ethanol/ water (70/ 30 vol. %) solution for approximately 40 min before drying at room temperature.

Along with determining the mass loss (%), an analysis of changes in fineness and tenacity, compared to unexposed samples, were determined on tensile testers Vibroscop and Vibrodyn 400 (Lenzing Instruments, Austria). Used standards and regulations are adapted to testing technical Jute fibres. For this purpose, cogged steel clamps are placed on the standard clamps, and the selected testing speed was 3 mm/ min. The selected gauge length of the sample is 5 mm to ensure that all elementary fibres are included in the tested sample during fineness and tenacity testing. Due to the non-homogeneity of Jute fibres, the number of measurements was increased (from 50 to 100), determined according to statistical indications of the degree of reliability. The fineness and tenacity of PLA fibres were determined according to the standards HRN EN ISO 1973 and HRN EN ISO 5079. Measurements of fibre's tested properties were performed on conditioned samples.

The control and buried Jute and PLA fibres were analysed by using a scanning electron microscope (FE-SEM//Mira, Tescan) at a magnification of 2000x. SEM images were obtained with an accelerating voltage of 5kV. Before the SEM investigation, samples were steamed with chrome for 180 seconds to increase their electrical conductivity.

With the purpose of a better understanding of biodegradation, the number of total fungi and bacteria in the soil is also determined.

3. RESULTS AND DISCUSSION

The results of mass loss and mechanical properties of the tested fibre samples obtained after burying the fibres in the soil are shown in Table 1. The mass loss of Jute fibres is higher compared to PLA fibres, which is expected considering that Jute fibres have a greater ability to absorb moisture, resulting in an increase in the fibre biodegradation degree.

Table 1. Mechanical properties.

	Jute		PLA	
	Control	**11 days**	**Control**	**11 days**
Mass loss				
$\overline{x}$ [%]	/	24.84	/	4.00
Finesess				
$\overline{x}$ [dtex]	31.02	26.14	6.84	6.65
CV [%]	39.19	31.62	9.57	6.74
Tenacity				
$\overline{x}$ [cN/tex]	43.94	33.39	17.86	11.21
CV [%]	28.30	32.41	30.04	13.66
Δ [%]	/	24.01	/	37.23

Considering that Jute fibres are characterized by great non-homogeneity of morphology, a relatively high variation coefficient of Jute fibres is evident when testing the mechanical properties. Fineness analysis showed that the decrease in fineness of PLA fibres is slightly less (14.61%) than of Jute fibres (15.73%). It can be assumed that the breakage and degradation of the Jute fibres facilitate the colonization of microorganisms into the fibres.
In addition, it can be noticed that the decrease in PLA fibre tenacity (37.23%) is higher compared to Jute fibres (24.01%). This can be explained by the fact that Jute fibres consist of 60% cellulose (responsible for the fibres' high mechanical properties) and around 12% lignin. Lignin is one of the main components that create a protective layer preventing the fiber internal structure from degrading. Lignin is durable and not soluble in water, acting as a glue to cellulose and hemicellulose thus preserving the fibres.

PLA degradation upon disposal in the environment is challenging because PLA is largely resistant to microorganisms attack in the soil. However, under conditions of high temperature and high humidity, PLA will degrade quickly. In this research, PLA is in the form of fibres that are free and without the protection of the structural parameters characteristic for woven or non-woven materials. In addition, favourable conditions for the activation of microorganisms are ensured. For these reasons, PLA fibees show an unexpectedly large tenacity decrease. The obtained results were confirmed with surface microscopic images before and after the biodegradation processes (Table 2) and by the number of Fungi and Bacteria in the soil (Table 3). As is shown in Table 3 the highest amount of Fungi and Bacteria was determined in the soil in which the PLA fibres were buried and these results follow the obtained results of a tenacity decrease of buried PLA fibres.

Table 2. Morphological analysis

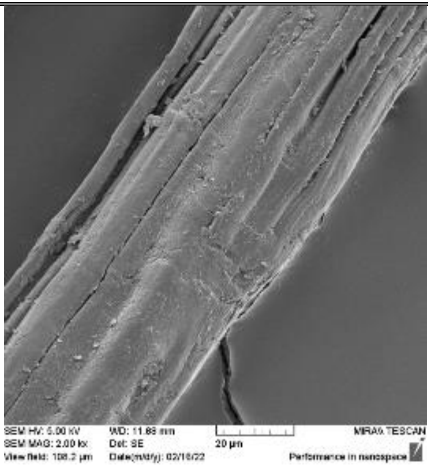
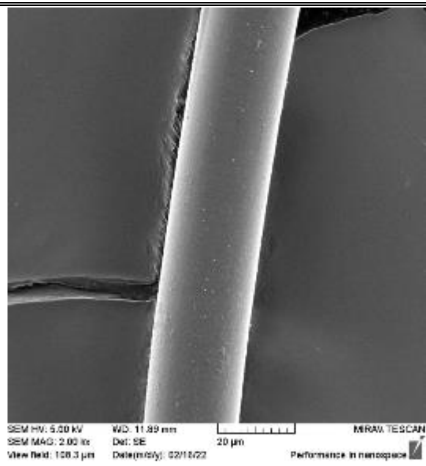
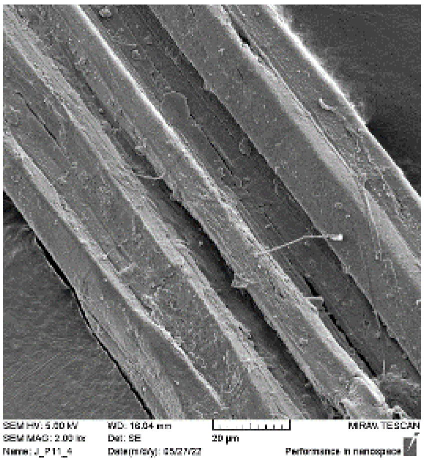
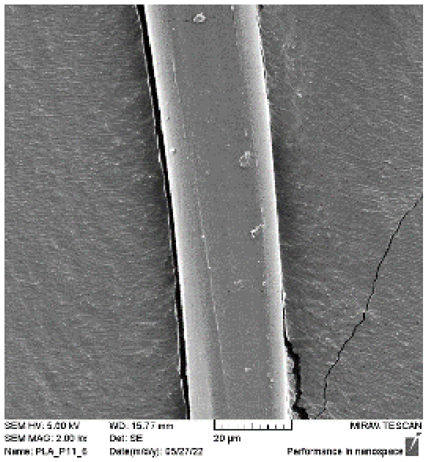
	Jute	PLA
control		
11 days		

Table 3. Total number of fungi and bacteria in the soil.

	Jute		PLA	
	Control	**11 days**	**Control**	**11 days**
Fungi x̄ (CFU/ml) stDEV	8.50E+04 7.55E+03	1.03E+05 3.21E+03	8.50E+04 7.55E+03	1.10E+05 9.85E+03
Bacteria x̄ (CFU/ml) stDEV	1.28E+07 7.64E+05	1.42E+07 4.36E+05	1.28E+07 7.64E+05	1.66E+07 1.97E+06

4. CONCLUSION

This research provides important insights for the selection of suitable natural biodegradable fibres for the production of agrotextile products for a specific purpose. The results of the conducted research indicate the fact that PLA fibres show better biodegradation properties compared to Jute fibres. This provides significant guidance for conducting further research in this wide area.

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REFERENCES

[1] Gabrys, T., Fryczkowska, F., Grzybowska-Pietras, J., et al. (2021). Modification and Properties of Cellulose Nonwoven Fabric—Multifunctional Mulching Material for Agricultural Applications, Materials, 14(15), 1-16.
[2] Čolnik, M., Hrnčić Knez, M., Škerget, M., et al. (2020). Biodegradable polymers, current trends of research and their applications, a review, Chemical Industry & Chemical Engineering Quarterly, 26(4), 401−418.
[3] Smith, R. (2005). *Biodegradable Polymers for Industrial Applications*. England: Woodhead Publishing.
[4] Bastioli, C. (2005). *Handbook of Biodegradable Polymers.* England: Rapra Technology Limited.
[5] Chand, N., Fahim, M. (2021). *Natural fibres and their composites*. England: Woodhead Publishing.
[6] Sayem, A.S.M., Haider, J. (2019). *An Overview on the Development of Natural Renewable Materials for Textile Applications.* Amsterdam, Netherlands: Elsevier.
[7] Čolnik M, Hrnčić Knez M, Škerget M, Knez Ž (2020). Biodegradable polymers, current trends of research and their applications, a review, Chemical Industry and Chemical Engineering Quarterly, 26(4), 401-418.
[8] Sular, V., Devrim, G. (2019). Biodegradation Behaviour of Different Textile Fibres: Visual, Morphological, Structural Properties and Soil Analyses, Fibres and Textiles in Eastern Europe 27(1), 100-111.
[9] Avinc, O., Khoddami, A. (2009). Overview of Poly(lactic acid) (PLA) Fibre. Fibre Chemistre, 41, 391–401.
[10] Sanivada, U.K., et al. (2020). PLA Composites Reinforced with Flax and Jute Fibers—A Review of Recent Trends, Processing Parameters and Mechanical Properties. Polymers, 12, 2373.
[11] Marasovic, P., Kopitar, D. (2019). Overview and perspective of nonwoven agrotextile, Textile & Leather Review, 2(1), 32–45.

DESIGN OF A NIPPLE PROTECTOR NURSING BRA

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ABSTRACT

In this article, it is aimed to design a bra to prevent nipple sores which are frequently seen in nursing mothers. In order to achieve this purpose, it was decided to integrate silver nursing cups into the nursing bra. Silver nursing cups are normally completely separate from the bra. They prevent the formation of nipple sores and protect nipples. Silver nursing cups placed in the bra cup will be in removable form. Thus, ease of use will be provided in matters such as cleaning. Also, the cups that will be placed on the inside of the bra and they will not be visible from the outside of the bra. Furthermore, the bra to be designed will be in the form of a nursing bra to provide ease of use during breastfeeding. So that the benefits that are provided by the two different products can be met by a single product.

Keyword: *Breastfeeding, Breast protector, Nipple pain, Nursing bra, Silver nipple cups*

1. INTRODUCTION

One of the most common problems in breastfeeding mothers is sores and tenderness on the nipples as a result of breastfeeding. [1] Two factors cause this situation to occur: anatomical factors and infectious factors. While the anatomical factors are poor positioning and poor latch-on, the infectious factor is usually fungus Candida albicans. [2] There are a variety of methods to heal these sores. [3] In addition to these methods, silver nursing caps can also be used because silver shows high antimicrobial properties that has been known since 69 B.C. and it can be used in wound treatments. [4] Therefore, in this project, it is planned to use silver nursing cups in the bra. Thanks to the integrating silver nursing cups into the bra, nipple sores can heal and also we can prevent the formaiton of that sores. It was decided that the bra model to be used would be a nursing bra in order to keep the comfort level higher during breastfeeding for both mother and the baby.

2. DESIGN

In this design, it is needed that silver nursing cups and nursing bra. Also, these two product should be appropriate to integrate to each other. The design will be held on these purposes.

2.1 Silver Nipple Cup

Silver nursing cups have a classic design. They have two different size options. One of the options has a standard size, the other option has x-large size. In this project, the design of the silver nursing bra will not be changed and it will be in standard size.

Figure 1. Appearance of the silver nursing cups.

2.2 Nursing Bra

The bra model to be used in this design will be a nursing bra due to the comfort it provides during breastfeeding. In normal nursing bras, the layer containing the cup consisting of a single layer of fabric will be designed as two layers in this design and this layer will be the layer where the silver nursing cups will be placed. Silver nursing cups will be attached to the area created within this layer. Thanks to the space left on the edge of this layer, the silver nursing cups will be in a removable form when desired. The cups of the bra will be fixed from the underwire part and will provide the ability to open and close on the hanger part. In addition, the innermost layer will be smaller than normal nursing bras thanks to this property it will not prevent silver nursing cups from touching the breast.

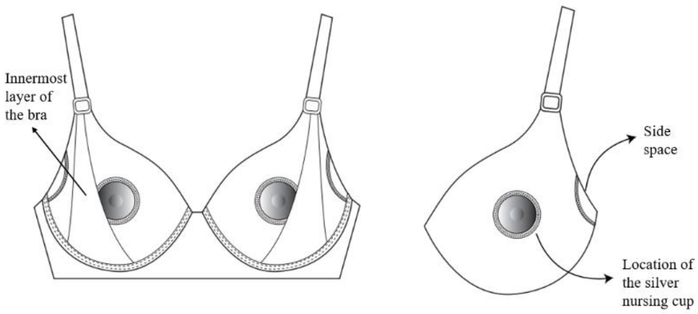

Figure 2. Design of the bra.

3. RESULTS

The end product to be obtained as a result of this project will provide both the comfort of nursing bras and the benefits of silver nursing cups with a single product. Thanks to the ability of the silver nursing cups to be put on and taken off at any time, the operations will be easily done when the bra needs to be washed or when the silver breastfeeding caps need to be cleaned. Thus, the end product will have a design that was not available on the market before. In this case, breastfeeding mothers will be able to procure a single product instead of two different products.

4. CONCLUSION

While silver nursing cups and nursing bras are currently available separately, in this case, a design that is not currently available in the market will be made. According to the results of the user tests to be made with people who have bought and used this model, if the design is liked, the same design can be tried on different bra models. Thus, it will be beneficial not only to breastfeeding mothers, but also to other users who have nipple sore problems.

REFERENCES

[1] Kent, J. C., Ashton, E., Hardwick, C. M., Rowan, M. K., Chia, E. S., Fairclough, K. A., Menon, L. L., Scott, C., Mather-McCaw, G., Navarro, K., & Geddes, D. T. (2015). Nipple pain in breastfeeding mothers: Incidence, causes and treatments. *International Journal of Environmental Research and Public Health*, *12*(10), 12247-12263. https://doi.org/10.3390/ijerph121012247

[2] Tait, P. (2000). Nipple pain in breastfeeding women: Causes, treatment, and prevention strategies. *Journal of Midwifery & Women's Health*, *45*(3), 212-215. https://doi.org/10.1016/S1526-9523(00)00011-8

[3] *Cracked nipples and moist wound healing* (2019) *The Breastfeeding Network*. Available at: https://www.breastfeedingnetwork.org.uk/moist-wound-healing/ (Accessed: January 3, 2023).

[4] Khansa, I., Schoenbrunner, A. R., Kraft, C. T., & Janis, J. E. (2019). Silver in Wound Care-Friend or Foe?: A Comprehensive Review. Plastic and reconstructive surgery. Global open, 7(8), e2390. https://doi.org/10.1097/GOX.0000000000002390

THE IMPACT OF CELLULOSE AND BIOPOLYMER NONWOVEN MULCHES ON THE SOIL HEALTH

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ABSTRACT

The nonwoven mulches produced from regenerated viscose and PLA fibers as well as conventional agro foil were placed on the soil by randomly arranged blocks of four replication plots. After 50 days, the soil samples beneath each mulch and on the control field were collected, where the bacteria and fungi population as well as the physio-chemical properties of the soil were measured. The severe reduction in bacterial population in soil under the agro foil and mulches made of PLA fibers occurs due to the prevalence of high soil temperature. The bacterial population of soil beneath the mulches made of viscose fiber significantly increased due to favourable anaerobic conditions, soil temperature and moisture. Under all mulches, compared to the control field, a higher fungal population was observed. The fungal population under the nonwoven mulch produced by viscose fibers was 161% higher in comparison to the control field. The available nutrient contents of soils under the nonwoven mulches were higher compared to the control field. The control field showed higher available nutrient contents of soil than the field covered by conventional agro foil.

The results of the study reveal that usage of nonwoven mulches made of viscose fibers is most appropriate for short-term mulching application since successfully increases microbial population and improves the physio-chemical properties of soil.

Keyword: *Viscose, PLA, Nonwoven mulches, Bacterial and fungi population, Physio-chemical properties of soil*

1. INTRODUCTION

Using mulches for crop production can increase yields, extend the growing season, reduce weed pressure, increase fertilizer use efficiency, conserve soil moisture and increase soil temperature [1-3]. The LDPE (low-density polyethylene) agro foil mulches have been used in agriculture for over half a century [3]. Plastic mulch can modify the soil microclimate, which can affect microbial activity and populations. Studies have shown that plastic mulch can increase or decrease microbial activity, depending on factors such as temperature and soil moisture. The response is most likely dependent on the temperature under the mulches. When ambient temperatures are cool, mulches bring soil temperature closer to microbial optima and increase activity, respectively when ambient temperatures are warm, mulches may push temperatures above optima, limiting soil microbial activity [4].

The major limitations of agro foil mulches are related to their disposal after usage and remaining plastic residues in agricultural soil, reduced field capacity, changing the soil habitat, and microplastic are thought to be the possible cause of microorganisms' change [5,6]. The continuous application of LDPE mulches results in a situation of persistent plastic fragments and chemicals accumulating in agricultural soils, jeopardizing agricultural soil health, food security, and environmental sustainability [7].

Nonwoven mulches from natural sources and biopolymers showed to be superior compared to plastic mulches in increasing yield, microbial activity and soil quality. The studies revealed that using nonwoven mulches, such as jute natural fiber, increased yield, suppressed weeds, increased moisture and available N, P and K contents, the organic carbon, available N, P_2O_5 and K_2O to the plant and microbial population of the soil in comparison to the conventional plastic agrotextiles [8,9]. Likewise, mulching with nonwoven biodegradable PLA fabric, in a two-year study on the yield and quality of tomato, resulted in fruits with a higher content of soluble sugars and dry matter as well as a smaller concentration of nitrate ions than in the control field [10]. Among cellulose-based materials, viscose is becoming popular for mulching and production of plant seedlings due to its good sorption properties and fast biodegradation. One of the main benefits of viscose nonwoven mulch is that they improve soil moisture retention to due its porose structure. This can be especially beneficial in dry or arid regions, where water conservation is critical for crop growth and productivity [11].

The objective of this study was to determine the possible replacement of conventional agro foil with nonwoven mulches produced from recycled viscose and PLA fibers regarding the impact of produced mulches on microbial population and physio-chemical properties of soil.

2. EXPERIMENTAL STUDY

The nonwoven fabrics are produced mechanically on the card and bonded by needle punching from regenerated viscose fibers of 410 g m^{-2} and PLA fibers of 360 g m^{-2} mass per unit area. Nonwoven fabrics were made with the same production parameters, to compare the performance of the nonwoven fabrics produced by different raw materials.

In the experiment, commercial agro foil of 28.17 g m^{-2} mass per unit area and control field (not covered, bare soil) were used in order to compare results with conventionally used material for mulching and soil where mulching is not applied.

The nonwoven fabrics and agro foil of 1.65 m^2 (1.5 x 1.1 m) were placed on the soil by randomly arranged blocks of four replication plots. The four replication plots included the control fields (Figure 1). During 50 days of trial soil temperature and moisture were recorded (once per week).

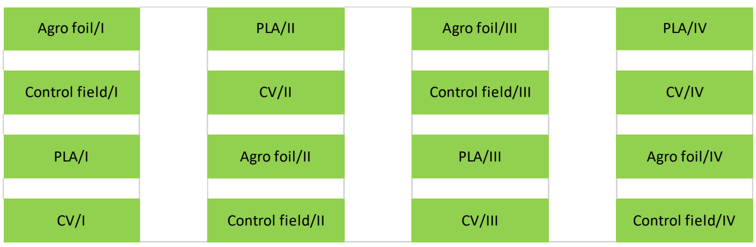


Figure 1. Field experiment with four replication plots.

The samples were placed on the soil in late April, and after 50 days the soil samples beneath each mulch and control field of four replication plots are collected.

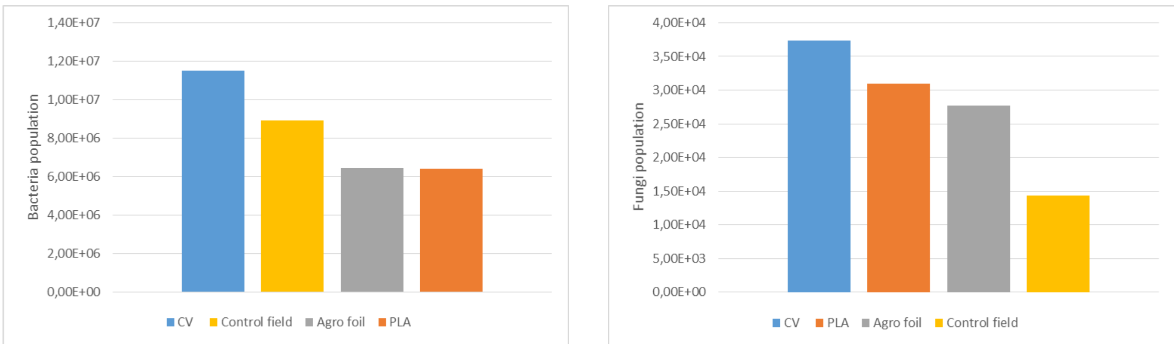
After 50 days of mulches exposure to the environmental condition, using classic microbiological methods, the total number of bacteria and fungi in the soil beneath mulches was analyzed. Nutrient agar

(NA) was used to determine the total number of bacteria, while Czapek agar was used to determine the total number of fungi.

Physio-chemical properties were measured according to the standards on the initial soil (soil before the experiment starts), the soil beneath nonwoven mulches and on the control field.

3. RESULTS AND DISCUSSION

The average bacterial population in soil was lowest beneath mulches made of PLA fibers (6.4×10^6 CFU per ml) and highest beneath mulches made of viscose fibers (1.15×10^7 CFU per ml) (Figure 2).



a) Bacteria population b) Fungi population

Figure 2. Bacteria and fungi population beneath nonwoven mulches.

The bacterial population in the control field soil were higher than under the agro foil. Only under the mulches made of viscose fiber, due to favorable anaerobic conditions, soil temperature and moisture, bacterial population in soil significantly increased. During the 7 weeks of the experiment, the temperature under mulch made of viscose fibers was the lowest (Table 1). The severe reduction in bacterial population in soil under the mulches made of PLA fibers and especially under the agro foil, occurs due to the prevalence of high soil temperature.

Table 1. Soil temperature and humidity beneath mulches and on control field in 2022.

DATE	5.5.		12.5.		16.5.		26.05.		2.6.		6.6.		13.6.	
SOIL	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%
CV	13.8	31.2	15.3	39.4	16.9	45.5	18.6	46.1	17.1	43.2	20.7	46.4	18.9	46.1
PLA	15.3	34.2	17.3	39.2	18.6	45.1	19.8	45.2	18.2	45.9	21.2	45.3	19.6	43.3
AGRO FOIL	16.1	26.6	17.9	40.0	19.4	45.8	21.1	45.8	19.1	44.4	22.0	46.4	20.3	43.9
CONTROL FIELD	16.3	42.9	17.8	37.1	18.6	43.0	20.0	43.0	18.1	43.1	21.2	47.3	18.8	45.5

The higher fungal population under all mulches, including agro foil, compared to the control field was observed. The highest fungal population (3.73×10^4 CFU per ml) under nonwoven mulch produced by viscose fibers was recorded, where fungal population was 161% higher in comparison to the control field.

The number of microorganisms colonies in the soil beneath mulches made of viscose fibers showed the highest number due to optimal conditions for the development of bacteria and fungi. The mulches made of viscose fibers had lower average temperatures during the field experiment compared to PLA (for 1.25°C), the control field (for 1.34°C) and agro foil (for 2.08°C).

Microorganisms consume organic matter and nutrients in the soil for energy and growth, so soil with higher levels of organic matter and essential nutrients will support more diverse and abundant microbial communities. Additionally, competition for limited resources can also impact the number and diversity of microorganisms in the soil. The trend of the greater abundance of nutrients in the soil, especially C and N, was shown in the soil under the viscose nonwoven mulch, which has the highest number of bacteria and fungi.

There is no significant variation of soil pH under nonwoven mulches and agro foil regarding to the control field (Table 2). Soil organic carbon content on the control field and under the nonwoven mulches increased compared to the initial soil, while under the agro foil remained the same. The highest organic carbon content beneath mulch made of viscose could be explained by the decomposition of material with high content of organic matter that was incorporated in the soil, improving the soil properties (an increase of bacteria and fungi as well as organic carbon).

Table 2. Physio-chemical properties of soil beneath nonwoven mulches.

	pH	Organic C, %	Total N, %	P_2O_5, mg/100 g	K_2O, mg/100 g
Initial soil	7.65	2.23	0.13	3.03	31.32
Control field	7.54	2.55	0.58	10.55	29.61
CV	7.58	2.71	0.60	9.15	27.00
PLA	7.68	2.68	0.56	5.71	30.00
Agro foil	7.66	2.23	0.54	5.47	20.67

Total N content was significantly increased compared to the initial soil, and its value was highest under the mulches made of viscose fibers (0.60%). The increase in total nitrogen was probably due to optimum moisture availability and increased mineralization of soil organic N.

The higher phytoavailable phosphorus (P_2O_5) content of soils on the control field and under mulching may be attributed to better hydrothermal regimes and reduced weeds.

Phytoavailable potassium did not show any significant increase under the nonwoven mulches mainly due to less decomposition of mulching material during the short duration of the experiment. Under the agro foil, phytoavailable potassium significantly decreased regarding the control field.

Overall, the available nutrient contents of soils under the mulches were higher compared to the control field (bare soil) because of decomposition under appropriate water and temperature levels as well as the release of available nutrients in the soil. The available nutrition contents were lower under the conventional agro foil regarding to the initial soil. Even the control field, i.e. bare soil that wasn't mulched during the experiment, showed higher available nutrient contents of soil regarding the field covered by conventional agro foil.

4. CONCLUSION

The conducted research confirms the possibility of replacing conventional agro foil with nonwoven mulches produced by viscose and PLA fibers. The severe reduction in soil bacterial population under the agro foil and mulches made of PLA fibers are recorded, while the bacterial population of soil beneath the mulches made of viscose fiber significantly increased. Under all mulches, compared to the control field, a higher fungal population was observed. The fungal population under the nonwoven mulch produced by viscose fibers was 161% higher in comparison to the control field. The available nutrient contents of soils under the nonwoven mulches were higher compared to the control field, while the soil under the conventional agro foil showed a decrease in the soil available nutrients.

Increased available nutrient contents of soils as well as bacteria and fungi populations beneath nonwoven mulches made from viscose fibers showed the best performance regarding nonwoven mulches made from PLA biopolymer and conventional agro foil. The results indicate positive properties of nonwoven fabrics made from viscose fibers for mulching application, where further research should be done to confirm their overall performance.

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REFERENCES

[1] Manickam, L., Thilagam, V.K., Balakrishnan N., Mansour, M. M. (2010). Effect of Plastic Mulch on Soil Properties and Crop Growth - A Review. Agricultural Reviews, 31(2):145–149.
[2] Lament, W. J. (1993). Plastic Mulches for the Production of Vegetable Crops. HortTechnology, 3(1), 35-39.
[3] Lamont W.J. (2005). Plastics: Modifying the Microclimate for the Production of Vegetable Crops. HortTechnology, 15(3):477-481
[4] Bandopadhyay, S., Martin-Closas, L., Pelacho, A.M., DeBruyn, J.M. (2018). Biodegradable Plastic Mulch Films: Impacts on Soil Microbial Communities and Ecosystem Functions. Front. Microbiol., 9, 819.
[5] Qi, Y. et. al. (2020). Impact of plastic mulch film debris on soil physicochemical and hydrological properties. Environmental Pollution, 266, 115097.
[6] Zhang, J. et.al. (2022). Effects of plastic residues and microplastics on soil ecosystems: A global meta-analysis. Journal of Hazardous Materials, 435, 129065.
[7] Serrano-Ruiz, H., Martin-Closas, L., Pelacho, A.M. (2020). Biodegradable plastic mulches: Impact on the agricultural biotic environment. Science of the Total Environment, 141228.
[8] Manna, K., Kundu, M.C., Saha, B., Ghosh, G.K. (2018). Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (Brassica oleracea L.) in lateritic soil. Environmental Monitoring and Assessment, 190(2), 82.
[9] Parasar Das, S. et al. (2017). Efficacy of Geotextile Jute Mulches on Yield, Soil Nutrient Dynamics and Weed Suppression in French bean (Phaseolus vulgaris L.)–Capsicum (Capsicum annum L.) Cropping System. International Journal of Bio-resource and Stress Management, 8(1), 057-063.
[10] Zawiska, I., Siwek, P. (2014). The effects of PLA biodegradable and polypropylene nonwoven crop mulches on selected components of tomato grown in the field. Folia Hort., 26(2), 163-167.
[11] Gabrys, T., Fryczkowska, B., Grzybowska-Pietras, J., Binias, D. (2021). Modification and Properties of Cellulose Nonwoven Fabric—Multifunctional Mulching Material for Agricultural Applications. Materials 2021, 14(15), 4335.

VIRTUAL GARMENT DESIGN: A CASE OF EXCLUSIVE FABRICS AND TRIMS

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ABSTRACT

In fashion design education and in fashion industry, 3D virtual garment design is offered as a sustainable solution for the product development as it allows its users to minimize the number of samples produced, therefore minimize the fabric consumption and many more operational processes relevant to garment fitting. However, the use of 3D virtual garment design is often practiced for sportswear or more basic garments with simple construction and fabrics. In this study, three looks designed by an undergraduate fashion design student for her graduation project was implemented virtually by using Browzwear's VStitcher. The subject looks of this collection were created by using exclusive fabric types (woven fabric with holographic effect) and trims (sequins and rhinestones) and more complex silhouettes which brings the research question of the study: "To what extend 3D virtual garment design allows users to implement fashion collection ideas when the fabrics are more exclusive, and constructions are more complex?". The outcomes were be presented visually while the methods to offer alternative solutions to overcome the difficulties to create exclusive garments were discussed.

Keyword: *Virtual garment design, 3D garment simulation, Fashion design education*

1. INTRODUCTION

Virtual garment design became more important in the last couple of years in fashion design education due to the impact of COVID-19 pandemic [1, 2]. Nowadays, many fashion design schools teach how to design garments virtually by using alternative software such as VStitchery by Browzwear and Clo 3D as well as Vidya by Human Solutions, Modaris by Lectra and AccuMark 3D by Gerber and Optitex PDS [3]. All of these software offer its users a set of fabric in their library to use for the designs. It is possible to select any of the offered fabrics in the library and change its fabric properties such as its physics (mass, thickness, bending rigidity etc.), color, texture, and optical features. However, there are still uncountable number of fabrics available in the market that varies in terms of their construction, physics, and surface properties which make it impossible to offer all these fabrics in the software library. Also, many of these software offer a set of garments that are already created virtually and can be downloaded by the users and altered according to the desired look. However, like many fabric options available in the market, the design features of a garment are also limitless. A designer may want to use exclusive fabrics and trims and unusual silhouettes while designing a collection. Especially, fashion design students are encouraged to be experimental and use alternative fabrics and silhouettes during their education.

In this study, as a part of her graduation project, a fashion design student prepared three looks with exclusive fabrics, trims and silhouettes to be digitally created by using VStitcher. The purpose of this study was to see how much of the design ideas can be implemented virtually with a satisfactory visual standard and to pinpoint the difficulties encountered during the project.

2. EXPERIMENTAL STUDY

To implement the project, as a starting point, design ideas were developed by making some visual research. The concept of the collection was “Comfortable Party Collection” where the designed pieces were suitable for a party wear but at the same time provides comfort to the wearer during the occasion. The main fabric of the designs was a %100 polyester fabric with a holographic print on top which created an iridescent effect. Figure 1.a illustrates the physical fabric used in the study.

a b

Figure 1. a) Fabrics, iridescent sequins and rhinestones to be used for the design. b) Artistic sketches of the collection.

On the other hand, the design had some iridescent sequins and rhinestones (Figure 1.a) on various locations of the garments. The artistic sketches of the looks are given in Figure 1.b.

The fabric’s textures were captured by using Vizoo 3D (a coloured fabric scanner), and the fabric physics were tested by using FAB (a set of instruments that is designed by Browzwear to test fabric properties). The trims (sequins and rhinestones) were developed by using Photoshop and were exported to be used in VStitcher 2021.V2.

3. RESULTS

As it is demonstrated in Figure 1.b., the first look has a tailored iridescent sequin jacket with a rhinestone bra-top inside and combined with a wrap skirt. The second design has a wrap jacket combined with trousers decorated with iridescent sequins. Finally, the third look has a flared trouser and a jacket with iridescent sequins and with a rhinestone belt and on top of the jacket. The problems encountered during the digital garment production stages are classified in Table 1.

Table 1. The problems encountered during the digital garment production stages.

Category	Problem	Solution offer	Conclusion
Fabric	The digital fabric obtained from Vizoo scanner didn't give the required effect on 2021.2 version of VStitcher.	2022.2 version used.	Solved
	Fabric scan received from Vizoo had roughness, normal, diffuse, metalness, displacement and subsurface maps. However, the final view of the digital fabric had slightly different texture and iridescent effect than the physical fabric. It was less metallic, less shinny and less iridescent.	The roughness value of the fabric was decreased and metalness were increased.	Partially solved
Patterns	Creation of the complicated patterns (such as wrap belt, crossover jackets)	Browzwear library was used for finding similar patterns. The patterns in the library was adjusted according to the designs.	Solved
Accessories and Trims	The sequins didn't exist in the program library as accessories.	The sequins were created as fabric patterns one by one and sewn on the required parts on the garment individually; a PVC fabric was used as material. Its physics properties were changed.	Solved
	Difficulty to create hologram effect of the sequin.	The internet-found hologram image was used as the diffuse map and assigned to each sequin as an artwork. A proper background colour (purple) was used for the diffuse map.	Partially-solved
	The rhine stones didn't exist in the program library as accessories.	A jpeg of a rhine stone arrangement was transformed as black and white image and used as displacement map to be assigned as artwork to the related patterns. White pixels pop out of the surface (creating the dome of the stones) and black pixels recede into the surface (creating the shallower parts on the stones).	Solved
Shoulder pad as design detail	Uncertainty of how to create shoulder pads as it is not offered as an accessory in the program.	Browzwear University and Browzwear online community help was searched for clarification. Some ready-garments offered in the program has shoulder pads. These were used. However, it is not easy to modify the pads measurements according to a new design and fit it well on the model.	Solved

Simulation	Difficulty to simulate pattern pieces and slowness of the simulation (The computer used in this project had system properties of: Intel (R) Core (TM) i5-10300 H, CPU 2.50 GHz, RAM 8 GB, 64 bit)	Deleting unnecessary fabrics, snapshots in the working file and closing other programs running at the background were among solutions tried.	Unsolved
	The slowness of V-ray trace rendering (The software offers different rendering options. However, the displacement maps used for hologram fabric and rhine stones are only visible in V-ray rendering and the rendering is so slow.)	Deleting unnecessary fabrics, snapshots in the working file and closing other programs running at the background were among solutions tried.	Unsolved

Finally, the digital clothes are illustrated in Figure 2. When the real fabric picture (Figure 1.a) compares to the fabric of the digitals, it is possible to say that the iridescent effect is slightly lost. The two-tone reflection (green and pink) on the digital fabric is less noticeable from different angles. Even thought, the 3D environment light option of the software improves the reflection, still the expected effect wasn't completely achieved. The rhinestone effect was achieved successfully, however, the crystal clearness of the stones was not present for the digitals.

Figure 2. Digital clothes created by Browzwear VStitcher and close details of rhinestone belt and iridescent sequins.

4. CONCLUSION

This study explored what kind of problems are encountered while creating a fashion collection with exclusive fabrics, more complex patterns and detailed accessories. According to the results of the study, it is possible to develop alternative solutions for the encountered problems. Especially, Browzwear VStitcher has some useful offerings such as Browzwear University, Browzwear support and online video's that explain complicated processes in detail and give guidelines. However, not every problem mentioned in this study was successfully solved. Even if Browzwear support is a very detailed website to provide information for the users, it is not very easy to find the information that the user is looking for. Some information are scattered under different menus which actually cover the same topic.

The program advances in latest versions and offers easier solutions to its users. Even though, the versions are updated, the offered garment library, accessories, trims and fabrics are still limited and there is still room for improvement (i.e., hologram fabric, rhinestones, and hologram sequins). The system requirements to work the program sufficiently is difficult to be met by a students' PC. Therefore, program providers may think of certain hubs that can allow its users to work with more advanced computers on a booking-based system.

This study might be useful for university students, or 3D garment design entrepreneurs to address their problems and the solutions. Moreover, the 3D garment simulation program developers may take this study as a case to develop alternative tools for its users.

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REFERENCES

[1] Casini, L.,& Roccetti, M.(2020). Fashion, Digital Technologies, and AI. Is the 2020 Pandemic Really Driving a Paradigm Shift?. *ZoneModa Journal*, *10*(2), 1–10. https://doi.org/10.6092/issn.2611-0563/11802

[2] Vaid, M. (2020, March 23). Covid-19 pushes fashion design schools into an increasingly digital future. *Fashionista*. Retrieved January 5, 2023, from https://fashionista.com/2020/03/coronavirus-fashion-design-education

[3] Choi, KH. 3D dynamic fashion design development using digital technology and its potential in online platforms. *Fashion and Textiles*, *9*, 9 (2022). https://doi.org/10.1186/s40691-021-00286-1

THE IMPACT OF MICRO CLIMATE UNDER CELLULOSE AND BIOPOLYMER NONWOVEN MULCHES ON THE LETTUCE WEIGHT

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ABSTRACT

The nonwoven fabrics were produced from recycled viscose and PLA fibres, on cards bonded by a needle-punching process, to investigate the influence of the mulches on soil temperature and humidity as well as lettuce growth and yield. In the spring of 2022, the mulches were placed on the soil by randomly arranged blocks of four replication plots including a conventional agro foil. On each subplot, 20 lettuce seedlings were planted. The soil temperature and humidity beneath nonwoven mulches were recorded once per week during the whole experiment. After harvesting, the weight of the fresh lettuce head and root were measured. Significantly heaviest fresh lettuce heads on plots covered by nonwoven mulch made of viscose fibres regarding fields covered by mulches made of PLA fibres were recorded. The lettuce yield in the field mulched with viscose nonwoven mulch is 13.6% higher comparing to field mulched with conventional agro foil. By choosing the suitable fibre type and nonwoven mulches structure parameters, the temperature and humidity of the soil can be influenced consequently increasing the lettuce yield.

Keyword: V*iscose, PLA, Nonwoven mulches, Lettuce*

1. INTRODUCTION

Because of their lightweight and convenience, plastic products have become omnipresent in all areas of the economy, including agronomy and food production [1]. Usage of plastic agro foil in mulching is common, where the accompanying plastic residues in agricultural soil are a source of concern. The presence of LDPE (Low-density polyethylene) debris, as a result of decomposition conventionally used agro foil, reduces field capacity as well as fundamental soil features [2].

Plant growth and development rate are influenced by the temperature and moisture of the soil surrounding the plant. Each plant type has a specific soil temperature range with minimum, maximum, and optimum values. High soil temperatures can harm plant growth, while low temperatures reduce soil fertility [3]. Optimal soil moisture is 60% of available soil pore space. Excess water reduces soil oxygen and slows down microbial activity, while low soil moisture decreases enzyme activity and limits nitrogen cycling [4,5].

There are many studies that confirm that the use of mulch, including PLA biopolymer nonwoven mulches produced by melt-blowing and spun bonding technology, not only increases the yield but also gives better quality crops [6-9]. Organic mulches' microporous structure allows light, air, and water to be transferred to the soil improving soil structure and increasing soil nutrient availability, leading to improved crop yield and quality [10]. The organic mulch pore configurations have an important role in the air and water transfer through a non-woven fabric. During exposure to environmental conditions, nonwoven fabric degradation changes its structure, where determining the positive influence of organic mulches on the soil during a certain period can be complex. Besides the raw material and technology of nonwoven fabric production, mass per unit area as well as thickness affects soil temperature and humidity changes [11,12]. Recyclable natural fibers, cellulose- and protein-based (flax and wool), produced by the needle-punched nonwoven technology, improved soil temperature moderation capacity, as well as weed germination suppression in the control sample, while yield of the cotton was relatively the same for all treatments including control [13]. Similar research with nonwoven jute agrotextile has provided the most favourable soil condition compared to other mulches and control field resulting in the highest growth and yield of the broccoli crop [14]. Usage of jute needle-punched nonwoven increased the yield of cauliflower and sweet lime fruits substantially and tomato yirrld to a lesser extent [15].

Considering previous studies, nonwoven cellulose and biopolymer-based mulches could be a replacement for conventional agro foils for growing certain plants. For the research, nonwoven fabrics from recycled viscose and PLA fibres were produced, on cards bonded by a needle-punching process, to investigate the influence of the mulches on soil temperature and humidity as well as lettuce growth and yield. In the field experiment, the uncovered field and field covered by conventional foil were included to investigate possible positive effects of the produced mulches regarding the un-mulched field as well as field covered by conventional agro foil.

2. EXPERIMENTAL STUDY

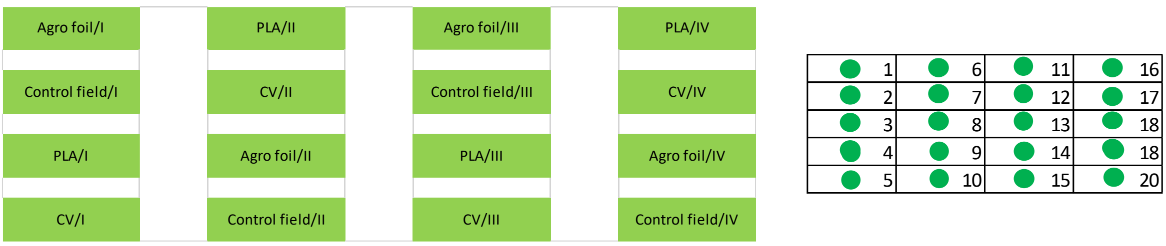
2.1 Nonwoven mulches

The nonwoven fabrics were produced with the same production parameters, on cards and bonded with the needle-punching process. The fabrics were made from recycled viscose fibres fineness of 1.38 dtex, and PLA fibres with a fineness of 6.84 dtex.

With the same production parameters, produced viscose nonwoven fabric has an average mass per unit area of 410 g m^{-2}, whereas the mass per unit area of fabric produced from PLA fibres was 360 g m^{-2}. To compare the performance of the nonwoven fabrics regarding conventional mulching material, the commercial agro foil of mass 28.17 g m^{-2} was purchased.

2.2 Field experiment

Before placing the nonwoven mulches on soil, the dripping irrigation system was set up. On the 25 of April 2022, the nonwoven fabric mulches and agro foil dimensions of 1.5 x 1.1 m were placed on the soil by randomly arranged blocks of four replication plots (Figure 1a). Each replication plot had a control field as well.



a) Randomly arranged blocks of four replication plots b) Subplot with 20 lettuce plants

Figure 1. Field experiment with replication plots and subplot with lettuce plants

On each subplot 20 lettuce seedlings from containers were planted (Figure 1b). On 13 June, the lettuce is harvested and the fresh mass of the lettuce heads and roots were measured.

2.3 Tests methods

Using a measuring probe, the soil temperature and humidity beneath nonwoven mulches were recorded once per week during the whole experiment.

To record changes in fabric structure, the parameters of the nonwoven fabric were tested on unexposed samples and samples after lettuce harvesting. The nonwoven mulches' mass per unit area and thickness (applied pressures of 0.5 kPa and 1 kPa) were measured according to the standards ISO 9073-1:1989 and ISO 9073-2:1995. On Mesdan Air Tronic Plus device, according to ISO 9073-15:2007 standard, air permeability of nonwoven mulches were measured. The samples testing area were 10 cm^2 while the pressure was 150 Pa.

The mass of fresh (just-harvested) lettuce heads and lettuce root was first measured separately, directly on the field, and afterward on an analytical balance after the drying process to determine the dry matter.

3. RESULTS AND DISCUSSION

The results of nonwoven mulches mass per unit area, thickness under applied loads (0.5 kPa and 1 kPa) and air permeability before exposure to the field conditions and after 7 weeks of exposure (right after lettuce harvesting) are shown in Table 1.

Table 1. The nonwoven mulches properties before and after exposure to the field condition.

Mulches		Mass per unit area, g m^{-2}	Thickness, mm		Air permeability, $cm^3/cm^2/s$
			0.5 kPa	1 kPa	
Viscose	unexposed	410.8	6.66	6.24	44.46
	after harvesting	320.9	3.63	3.51	56.98
PLA	unexposed	363.9	5.59	5.38	160.24
	after harvesting	351.5	6.01	5.71	169.98
Agro foil	unexposed	28.17	0.08	0.07	-
	after harvesting	29.31	0.07	0.06	-

The mass per unit area of nonwoven mulches after exposure to field conditions was reduced. The mulch made of viscose fibre has a significantly higher mass per unit area reduction compared to mulch made of PLA fibres. The thickness of mulch made of viscose fibres decrease by 46% (measured under a pressure of 0.5 kPa) respectively 44% (under a pressure of 1 kPa). Contrary to viscose mulches, the thickness of mulches produced by PLA fibres after field exposure slightly increases. The air permeability of both nonwoven mulches after field exposure increases, where a greater increase is visible in mulch made of viscose fibre.

According to biodegradation theory and previously published studies, mass per unit area and thickness of nonwoven mulches' produced by melt-blowing and spun-bond technology decrease due to their degradation. The reason for the increase in mass per unit area, and thickness of tested mulches' could be found in the different nonwoven fabric structures compared to melt-blowing and spun-bonding fabric structures.

The structure of nonwoven fabrics produced on cards and bonded by needling consists of multiple web layers of orientated fibres that, by their crossing, form pores filled with air. The change of nonwoven fabrics' structures made of viscose and PLA fibre after exposure to the field conditions differs (Figure

2). The viscose nonwoven mulch fibres came closer to each other, the structure lost its voluminousness, and the surface of the nonwoven fabric stiffened and took a paper-like appearance. The appearance of mulch made of PLA fibres did not changed. Although the structures of unexposed mulches were produced by the same production parameters, the only difference was in raw material (viscose and PLA fibres), their structural changes after 7 weeks of exposure to the field conditions significantly differ.

a) Nonwoven mulch made of viscose fibres b) Nonwoven mulch made of PLA fibres

Figure 2. Images of nonwoven mulches during exposure to the field conditions.

The average lowest weights of lettuce heads and roots under PLA non-woven mulch were recorded. Significantly, the highest weights of lettuce heads (fresh) in plots covered with nonwoven mulch made of viscose fibre were recorded (Figure 3). The best lettuce root development was on the control, uncovered field. Mulch made of viscose fibre provides a better microclimate for lettuce development than conventionally used agro foil.

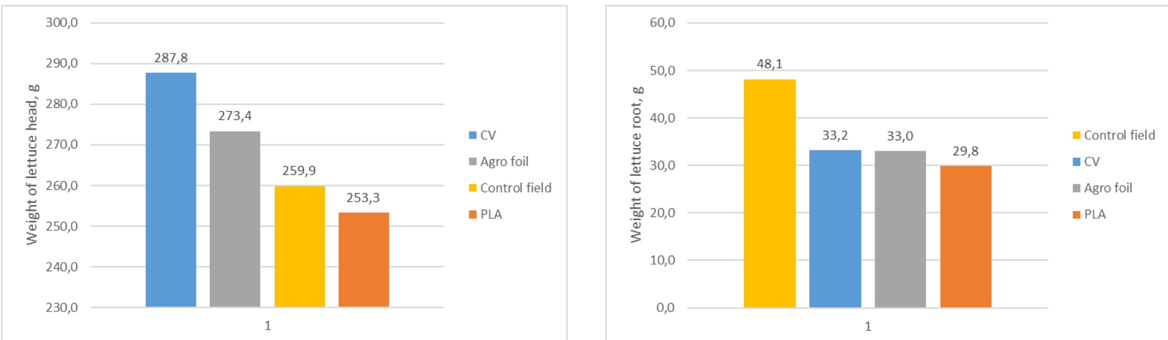


Figure 3. Weight of lettuce head and root.

The reason can be found in the highest soil moisture under mulch cover that encourages optimal transpiration, nutrient uptake and rate of photosynthesis required for plant growth (Figure 4). For lettuce growth, temperatures (of air and soil) during the whole day should be taken into consideration. Agro film is impermeable to air, where due to the rise in air temperature during the day, developed water vapour under the film cannot pass through the material increasing the temperature of the soil around the lettuce plants.

On the other hand, PLA nonwoven fabric has the highest air permeability, whereby by taking away developed water vapour under the fabric, the soil under the fabric dries out. Nonwoven fabric made of viscose fibres maintains a cooler soil temperature and the highest soil moisture during the day, providing less stress for the plant due to temperature increases throughout the day. Soil moisture retention and the lowest soil temperatures during the last week before lettuce harvesting were especially noticeable under the viscose mulches when the highest air temperatures during the experiment were recorded.

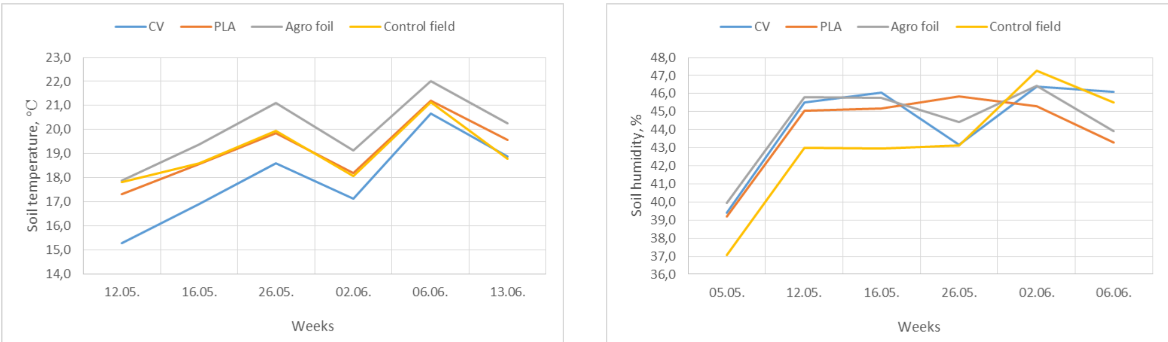


Figure 4. Soil temperature and humidity beneath nonwoven mulches.

The lettuce yield in the field mulched with viscose nonwoven mulch is 25.58 t/ha, while the field mulched with nonwoven fabrics made by PLA fibre is 22.51 t/ha. By comparing the yield of lettuce mulched with mulch produced by viscose fibres with the field mulched with conventional agro foil, the yield is 13.6% higher for viscose mulches.

4. CONCLUSION

The structural change of nonwoven fabrics made of viscose and PLA fibres, produced on cards and bonded by needling, after exposure to the field conditions differs significantly. The mass per unit area and thickness reduction of mulch made of viscose fibre are significantly higher compared to mulch made of PLA fibres. The air permeability of both nonwoven mulches after field exposure increases, where a greater increase is visible in mulch made of viscose fibre. Although the mulch structures were produced with the same production parameters, the difference in raw materials (viscose and PLA fibres) provides different structure changes under the influence of external conditions during exposure. The difference in structure changes significantly affected the growth and yield of lettuce. The lowest weights of lettuce heads and roots were recorded under PLA non-woven mulch, while the highest was on the plot covered by nonwoven mulch made of viscose fibre.

Mulches made of viscose fibres have a better ability to absorb and retain soil humidity as well as maintain a suitable soil temperature providing 13.6% higher lettuce yield compared to conventional agro foil. By choosing the suitable type of fibre and structure parameters of the nonwoven mulch, the temperature and humidity of the soil can be significantly influenced, consequently influencing the growth, development and yield of lettuce.

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REFERENCES

[1] Roy, P., Mohanty, A. K., & Misra, M. (2022). Microplastics in ecosystems: their implications and mitigation pathways. Environ. Sci.: Adv., 1(1), 9-29.
[2] Qi, Y. et. al. (2020). Impact of plastic mulch film debris on soil physicochemical and hydrological properties. Environmental Pollution, 266, 115097.
[3] Hatfield, J. L. et al. (2011). Climate Impacts on Agriculture: Implications for Crop Production. Agronomy Journal, 103(2), 351.
[4] Bot, A., Benites, J. (2005). The importance of soil organic matter; key to drought-resistant soil and sustained food and production. FAO Soils Bulletin 80. Rome: Food and Agriculture Organization of the United Nations, ISSN 0253-2050.
[5] Sardans, J., Peñuelas, J. (2005). Drought decreases soil enzyme activity in a Mediterranean Quercus ilex L. forest. Soil Biology and Biochemistry, 37(3), 455–461.
[6] Zawiska, I., Siwek, P. (2014). The effects of PLA biodegradable and polypropylene nonwoven crop mulches on selected components of tomato grown in the field. Folia Hort., 26(2), 163-167.
[7] Siwek, P., Libik, A., Kalisz, A., Zawiska, I. (2013). The effect of biodegradable nonwoven direct covers on yield and quality of winter leek. Folia Hortic., 25, 61–65.
[8] Siwek, P., Domagala-Swiatkiewicz, I., Bucki, P., Puchalski, M. (2019). Biodegradable agroplastics in 21st century horticulture. Polimery, 64, 480–486.
[9] Siwek, P., Kalisz, A., Domagala-Swiatkiewicz, I. (2015). The influence of degradable polymer mulches on soil properties and cucumber yield. Agrochim. Pisa, 59, 108–123.
[10] Bakshi, P., Kumar Wali, V., Iqbal, M., Jasrotia, A., Kour, K., Ahmed, R., Bakshi, M. (2015). Sustainable fruit production by soil moisture conservation with different mulches: A review. African Journal of Agricultural Research, 10(52), 1-12.
[11] Zhu, G., Kremenakova, D., Wang, Y., Militky, J. (2015). Air permeability of polyester nonwoven fabrics. Autex Res. J., 15(1), 8–12.
[12] Abdel-Rehim, Z.S., Saad, M.M., El-Shakankery, M., Hanafy, I. (2006). Textile fabrics as thermal insulators. Autex Res. J., 6(3), 148–161.
[13] Liu, X., Chen, C., Sun, J., Wang, X. (2021). Development of natural fiber-based degradable nonwoven mulch from recyclable mill waste. Waste Management, 121, 432-440.
[14] Manna, K., Kundu M.C., Saha, B., Ghosh, G.K. (2018) Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (Brassica oleracea L.) in lateritic soil. Environ Monit Assess., 190(2):82.
[15] Debnath, D. (2016) Design, Development, Characterization, and Application of Jute-based Needle-Punched Nonwoven, IntechOpen.

UPCYCLING DESIGNS OF WOMEN'S DENIM TROUSERS WITH PEINTURE METHOD

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ABSTRACT

It is known that the word penture derives from the French word "peinture". Its Turkish equivalent is translated as "painting". However, it has an artistic painting meaning in our language [1]. The peinture was a symbol of richness in the past years. When we apply nature-friendly paints and peinture technique on products that we do not use, it also aims to protect nature by upcycling. General purpose: To prevent textile products from going to waste in line with recycling and sustainability trends.

Keyword: *Upcycling, Peinture, Unique, Environmentally-Friendly, Denim*

1. INTRODUCTION

People who use this technique often use their furniture, their walls, their clothes to look unique, like paintings. They used this technique to apply manual labor, using a brush of various types of paints suitable for the desired surfaces. At the same time, we see it in the pincur archaic, classical and baroque modes of expression. This technique is a forgotten technique made by hand on various materials [2]. This painting supports us to produce unique pieces using our technical creative power.

Peintur is a handmade painting technique. Contrasting colors are used together in compositions inspired by nature and expressed with sensations. The hot-cold relationship was tried to be balanced with gray values. In compositions where the surface and depth phenomenon are achieved with plastic transitions, the peinture circulates over the entire surface with small-large brush strokes [3].

Although it seems to be of first-class importance in the design concept, in the design of products for use in the industry, such as textiles, the focus of personal tastes and personalized designs is more important today in terms of creative process, especially aesthetic safety [4].

Clothing is primarily products prepared for the function of dressing. When we perceive clothing as a work of art, we can evaluate the artist's creation as a method of expression in which he presents his aesthetic concerns and visual and conceptual thinking with visual language [5].

Women's denim pants, which were not used in our project. We used trend pattern works which were applied to the front parts of the trousers and the back-applique pockets. In the design, blue and mid blue denims with 100% cotton fabric and 12/13-ounce weight were preferred. Two different patterns were applied to denim trousers with the peinture method. Water-based paints were used in the pattern design. From these tested studies, multiple product designs were made.

2. EXPERIMENTAL STUDY

This method is especially applied to cotton-containing fabrics. It is made using water-based and fabric dyes. While applying this technique on the fabric, each process should be allowed to dry so that the paints do not overlap and get dirty. When the dyeing process is finished, a piece of fabric should be laid on it and ironed with a heated iron at the maximum level.

2.1 Testing

Prior to testing all samples were conditioned according to ISO-139. Samples were tested for color fastness to light (ISO 105-B02), color fastness to rubbing (ISO 105-X12), abrasion resistance (ISO 12947-2), tensile strength (Grab Method ISO 13934-2), tear strength (ISO 13937-1), seam strength (Grab Method ISO 13935-2), and appearance after care (ISO 6330).

3. RESULTS

Color fastness to artificial light result is presented in Table 1. As can be seen from the table tested samples have very high color fastness to light performance.

Table 1. Color fastness to artificial light results.

	Rating
Color Change	4/5

Color fastness to rubbing test results are presented in Table 2. As can be seen the dry results is very high, but the wet result is mediocre. Because the peinture technique is a surface application, very high wet rubbing performance was not expected. After-treatments including fixing agents application may be added after coloration.

Table 2. Color fastness to rubbing results.

	Dry	**Wet**
Sample	4/5	2/3

Abrasion resistance test results are presented in Table 3. As can be seen, high abrasion resistance with very limited color change was achieved on different parts of the product.

Table 3. Abrasion resistance results.

Sampling location	**Cycles**	**Color Change**
Crotch	20000	4
Knee	20000	4
Back	20000	4

Tensile strength test results are presented in Table 4. All samples have shown high strength performance.

Table 4. Tensile strength results.

Sample ID	Peak Load at Break
Warp Sample 1	80,8 kg
Warp Sample 2	86 kg
Warp Sample 3	81 kg
Warp Average	**82,6 kg**
Weft Sample 1	42,8 kg
Weft Sample 2	37,5 kg
Weft Sample 3	42,3 kg
Weft Average	**40,9 kg**

Tear strength test results are presented in Table 5. All samples have shown high strength performance.

Table 5. Tear strength results.

Sample ID	Average Tear Load
Sample 1	6340 g
Sample 2	6267 g
Sample 3	6350 g
Average	**6319 g**

Seam strength test results and the failure types are presented in Table 6. Seams have shown high strength properties and the failures shows us the areas that should be strengthened if needed.

Table 6. Seam strength results.

Sample Taken From	Breakdown	Type of Failure
Waist Seam	74,3 kg	Fabric Tear at Jaws
Zipper Seam	35 kg	Fabric Tear at Seam
Hip Seam	51,2 kg	Fabric Tear at Seam
Pocket Side Seam 1	48,3 kg	Fabric Tear at Seam
Pocket Side Seam 2	45,5 kg	Fabric Tear at Seam
Pocket Puntarez Seam	16,2 kg	Fabric Tear at Seam
Front Rise Seam	39,4 kg	Breakage of Sewing Threads
Back Rise Seam	69,2 kg	Fabric Tear at Jaws
In Seam	41,2 kg	-

Side Seam	36,6 kg	Fabric Tear at Seam

Appearance evaluation results are presented in Table 7. Sample has shown low shrinking after 1 and 3 washing procedures. They have shown high staining proof properties.

Table 7. Appearance evolution results.

Observation Made On	**After 1 Wash**	**After 3 Washes**
Waist	0%	-2,5%
Thigh	-0,7%	-2,5%
Calf	0%	0%
In Seam	-0,4%	-1,4%
Out Seam	-0,4%	-1,6%
Spirality	0%	0%
Color Change	4-5	4-5
Staining on Acetate	4-5	4-5
Staining on Cotton	4-5	4
Staining on Polyamide	4-5	4-5
Staining on Polyester	4-5	4-5
Staining on Acrylic	4-5	4-5
Staining on Wool	4-5	4-5
Seam Puckering	5	5
Free Running of Zip Fastening	Yes	Yes
Detachment of Trims	No	No
Pilling	4-5	4-5
Change on Prints	5	5
Pile Loss	5	5
Unraveling in Stitching	5	5
Corrosion on Metal Components	5	5
Delamination of Fused Components	5	5

4. CONCLUSION

We applicated the method of upcycle which is now trending on the world. The peinture method has been applied to the cotton denim products. Performance test were applied, and it was shown that high color fastness, abrasion resistance and strength performance were achieved. The result of our study was used to design a collection of 100 women's denim products. The designs and technique were noticed immediately and appreciated by female consumers.

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REFERENCES

[1] Araç, O., & Yerli, S. (2022). *Pentür Ile Illüstrasyon arasındaki farklılıklar bağlamında Sanat Eğitimine Chiaroscuro Tekniğinin Katkısı*. Handle Proxy. Retrieved from https://hdl.handle.net/11499/45692
[2] Dha. (2020, December 25). *Bir Dönemin Zenginlik sembolüydü...* www.haberturk.com. Retrieved March 14, 2023, from https://www.haberturk.com/bir-donemin-zenginlik-sembolu-pentur-sanati-zamana-yenildi-2916052
[3] Kodaman, L. & Sarı, S. (2016). An İnvestigation into the Application of Canvas Pictures on Clothes from an İnterdisciplinary Perspective . Cumhuriyet Uluslararası Eğitim Dergisi , 2 (4) , 72-83 . Retrieved from http://cije.cumhuriyet.edu.tr/en/pub/issue/4277/57636
[4] Önlü, N. (2010). Tasarımda Yaratıcılık ve İşlevsellik Tekstil Tasarımındaki Konumu. Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi , 3 (1) , . Retrieved from https://dergipark.org.tr/tr/pub/ataunisosbil/issue/2813/37843
[5] Arslan, C. (2007). *Çizginin Sanatsal Tekstildeki Yeri* (dissertation). ProQuest Dissertations Publishing.

THERMAL COMFORT IN RELATION TO WOVEN FABRIC STRUCTURE

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ABSTRACT

The woven fabric is a porous and flexible flat material, which makes it very suitable for making garments. The structural properties and construction of the woven fabric partly define its thermal properties, and by manipulating them it is possible to develop a woven fabric with improved thermal comfort. The results of the research showed that fabrics with lower thickness values and greater density at the same time conduct heat better. Also, fabrics with a large number of interlacements (plain weave) and, at the same time, a lower density, conduct heat well due to a greater proportion of vertical pores.

Keyword: *Thermal comfort, Heat flux, Woven fabric, Structure, Porosity*

1. INTRODUCTION

The human body releases body heat and moisture during body rest and activity when heat and moisture accumulate in increased amounts. If the release of heat and moisture from the body surface is not done efficiently, the accumulated heat and moisture next to the body can lead to heat stress, which, in extreme cases, can have fatal consequences. Thermal properties of textile materials intended for clothing are essential for wearing comfort[1]. The structural properties and construction of the woven fabric partly define its thermal properties, and by manipulating them it is possible to develop a woven fabric with improved thermal comfort[2]. The task of textile material for clothing is to enable the exchange of heat and moisture with the environment, which implies the release of accumulated metabolic heat out to the environment. The optimal release of excess heat and moisture and the movement of air against the skin provides a feeling of comfort. Structural and construction characteristics of woven fabrics such as weave, thickness, density, etc. affect their ability to transport moisture (vapour perspiration) and heat away from the body. Air has low thermal transmittance, so the trapped air in the pores of the woven fabric will contribute to the thermal insulation of the fabric. The porosity of the fabric is an important parameter in assessing the fabric comfort. Woven fabric porosity is defined as the ratio of total void area/volume to total woven surface/volume where all air-filled spaces can be considered pores in the fabric[3]. Fabric porosity is divided into two basic types: volume and vertical porosity [4]. During a person's movement, the woven fabric bends and stretches in different directions, facilitating the passage of air through the fabric. A more porous fabric structure can be considered less compact, so it is expected that more compact fabric structures will have less porosity, which has an impact on thermal conductivity.

2. EXPERIMENTAL STUDY

2.1 Materials

Eight woven fabric samples were woven on a laboratory weaving machine (Fig. 1) in four different weaves with two weft densities each. The yarn used for the warp and weft was the same, i.e. twisted yarn composed from polyamide and cotton fiber blend, fineness 15x2 tex and 750S twists/m. Structural characteristics were determined on all samples, compactness parameters were calculated and thermal characteristics were tested on the Fabric Touch Tester (Fig. 2).

Figure 1. Sample weaving machine, Fanyuan Instrument, DW 598.

Figure 2. Fabric touch tester, SDL Atlas.

2.2 Methodology

All samples are designed and produced on the same warp and on a sample weaving machine, with a straight draft in eight shafts and adjusted weft density.

Fabric firmness factor is a measure of fabric compactness determined by its structural characteristics. It is calculated according to the equation (1) where T1, T2 and $T_{average}$ are respectively warp fineness, weft fineness, average thread fineness (tex); P_1 is Milasius weave factor, ρ- fiber density, S_1 and S_2 are warp and weft densities per 10 cm.

$$\varphi = \sqrt{\frac{12}{\pi}} \cdot \frac{1}{P_1} \cdot \sqrt{\frac{T_{average}}{\rho}} \cdot S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}} \cdot S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}} \qquad \text{Eq. 1}$$

The FTT device for testing the thermal characteristics of fabric consists of an upper plate in which a heater and a heat flow sensor are installed, and a lower plate. A sample of fabric is placed on the lower plate, on which the upper plate is lowered and pressed to a certain pressure. Finally, the top plate is lifted and allows the sample to compressively relax. Obtained test results are maximum thermal heat flux and thermal conductivity under compression and recovery.

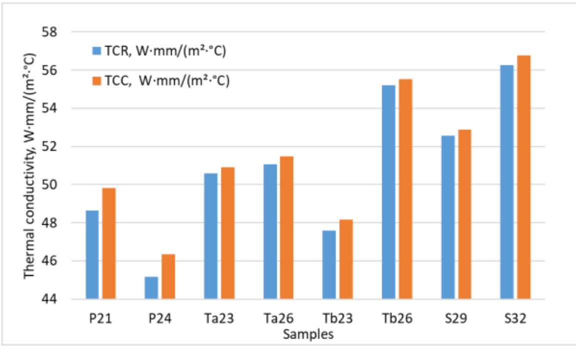
3. RESULTS

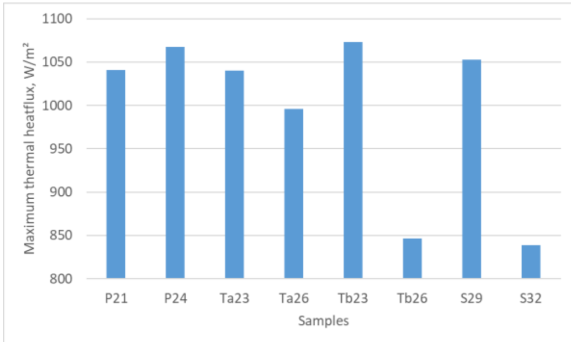
Table 1 shows the weave and density of the fabric samples, the measured thickness and mass area, the calculated weave factor and fabric firmness factor, and the test results of thermal properties measured on the Fabric Touch Tester device[5].

Table 1. Samples structural characteristics.

Weave	Designation	Dwa, thr./dm	Dwe, thr./dm	Thickness at 0,5kPa, mm	Thickness at 4,018 kPa, mm	Mass area, g/m^2	Weave factor (P)	Fabric firmness factor (φ), %
Plain	P21	300	210	0,59	0,50	170,8	1,00	67,18
Plain	P24	300	240	0,62	0,45	185,5	1,00	72,78
Twill 2/2	Ta23	300	230	0,66	0,51	175,0	1,26	56,09
Twill 2/2	Ta26	300	260	0,66	0,53	186,8	1,26	60,37
Twill 1/3	Tb23	300	230	0,68	0,46	175,1	1,33	53,21
Twill 1/3	Tb26	300	260	0,67	0,72	188,1	1,33	57,27
Satin 7/1(3)	S29	300	290	0,88	0,53	184,8	1,79	45,58
Satin 7/1(3)	S32	300	320	0,88	0,73	196,4	1,79	48,35

From the results shown in table 1, it is evident that the weaves with more flotations leads to higher values of fabric thickness and that denser samples with a greater number of interlacements are more compact, however, they have lower thickness values.

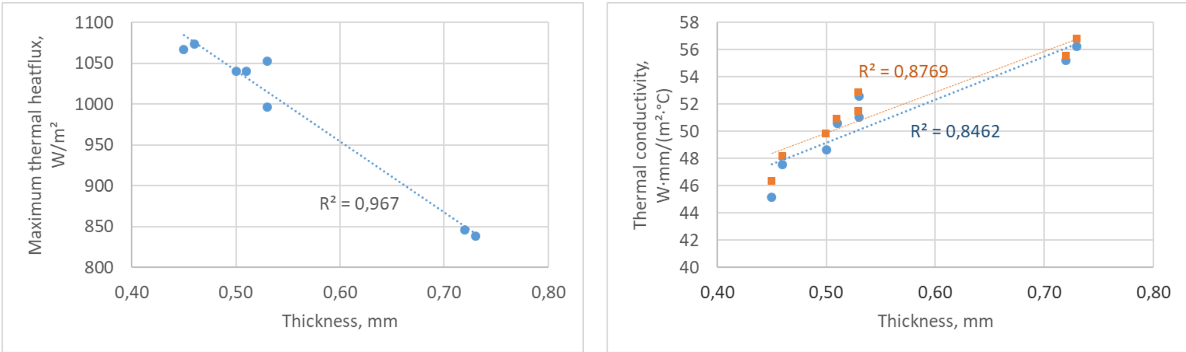




a. b.

Figure 3. Samples thermal properties: a. thermal conductivity under compression and recovery; b. maximum thermal heat flux.

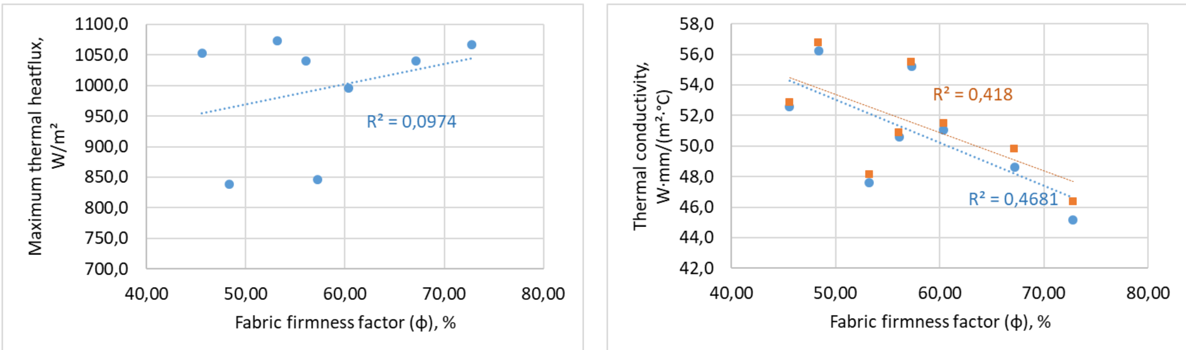
Fig. 3 shows thermal properties of fabric samples. On Fig.3 a. it can be seen that samples in twill and satin weave with higher weft density, which are also more compact, have higher values of thermal conductivity under compression (TCC) and thermal conductivity under recovery (TCR). That means that they conduct heat better and can provide greater thermal comfort in case of increased activity. Structures that are more compact contain fewer pores in their volume and knowing that air is a thermal insulator, a smaller proportion of volume pores in the material will contribute to a freer transfer of heat through the material. In the case of plain weave samples, a more compact woven conducts less heat than a less compact one (a weave with a lower weft density). A possible reason for this is the specific maximum interlacement in the plain weave structure and the domination of vertical pores that enable direct vertical heat transfer. By increasing the density of the plain weave fabric, the surface cover factor increases and the relative surface area of the pores decreases, which leads to reduction of heat transfer. From the graph in Fig.3. b. it is evident that the denser samples has the lower Qmax values, except the one in the plain weave. It means that non-plain samples with lower density has higher values of Qmax which means that they provide more rapid transfer of heat from the body to the fabric surface resulting in a cooler feeling fabric. Inconsistent behaviour of the fabric sample in the plain weave is possible due to the pores morphology, which is explained in the text above and in the conclusion.



a. b.

Figure 4. Correlation of fabric thickness and thermal characteristics.

Figures 4. a and b show the correlation between fabric thickness and its thermal characteristics. It is visible how thermal conductivity highly depends on material thickness. From the coefficient of determination, a large negative linear relationship between Qmax (Fig. 4a.) and fabric thickness is visible. TCC and TCR (Fig. 4.b) also greatly depends on fabric thickness but not as much as Qmax. The deformational changes that occurs during the compression and relaxation of the fabric has a slight effect on the thermal characteristics of the fabric, not strong enough to significantly affect thermal conductivity of the woven fabric.



a. b.

Figure 5. Correlation of fabric firmness factor and thermal characteristics.

Fabric Firmness Factor is a measure that considers both the weave and the setting (density, yarn count, fiber composition). Fabric firmness factor can be used to evaluate the fabric structure throughout the weaving process, as well as some fabric properties and it can be used to compare woven fabrics with different structural parameters [6]. From the graphs on Fig. 5, a weak negative linear relationship of thermal conductivity parameters and fabric firmness factor is visible, while Qmax almost does not depend on the fabric firmness factor at all. This result confirms the statement in the interpretation of the correlation graphs from Figure 4 that the weave, warp and weft fineness and fabric density as well as raw material composition have very little influence on the properties of thermal conductivity and have no influence on the maximum thermal heat flux of the woven material.

4. CONCLUSION

Thickness, density and pores morphology of the woven fabric have an influence on its thermal characteristics. Less compact fabrics (in fabrics with a lot of flotations and higher density) conduct heat better. Fabric structures with more flotations have a greater thickness and contain a higher proportion of volume pores in which still air is retained, acting as a heat insulator. By increasing the compactness (density), the proportion of air in the volume decreases as well as heat conduction through the material increases. Fabric structures with a large number of interlacements, such as plain weave, contain mostly vertical pores through which air passes unimpeded and as such does not act as an insulator. The same happens with the heat that passes freely through the vertical pores from one side of the fabric to the other. By increasing the density of any thread system, the vertical pores are closed, their surface area is reduced, and consequently the thermal conductivity is also reduced.

ACKNOWLEDGMENT

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REFERENCES

[1] Song, G. (Ed.). (2011). Improving comfort in clothing. Elsevier.
[2] Bhatia, D., & Malhotra, U. (2016). Thermophysiological wear comfort of clothing: an overview. *J. Text. Sci. Eng*, *6*(2), 1-8.
[3] Ragab, A., Fouda, A., El-Deeb, H., & Abou-Taleb, H. (2017). Determination of pore size, porosity and pore size distribution of woven structures by image analysis techniques. *J. Text. Sci. Eng*, *7*(05), 1-9.
[4] Oner, E., Seckin, A. C., Coskun, H., & Kole, D. E. (2022). Thermophysiological comfort properties of woven fabrics produced from hybrid yarns containing copper wires. *Journal of Industrial Textiles*, *51*(6), 926-952.
[5] Liao, X., Li, Y., Hu, J., Wu, X., & Li, Q. (2014). A simultaneous measurement method to characterize touch properties of textile materials. *Fibers and Polymers*, *15*, 1548-1559.
[6] Begum, M.S., & Milašius, R. (2022). Factors of Weave Estimation and the Effect of Weave Structure on Fabric Properties: A Review. *Fibers*, *10*, 74. https://doi.org/10.3390/fib10090074

THERMAL COMFORT EXPERIMENT IN POLYESTER FILAMENT YARN

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ABSTRACT

The primary need of people to dress has changed as time passed, because different high-tech fibers, yarns, fabrics and finishing applications have completely changed. In our modern day, the most important property of all readymade garment product is comfort. Welfare and comfort properties have become decisive components to make a product appreciated and successful. The clothing comfort is divided into some groups and thermal comfort is the most important one. In this study, masterbatch loaded polyester filament yarn was developed intended for improving thermal insulation properties. The developed yarns were knitted and tested according to TS EN 11092: 2014 method. Test results showed that fabric made with masterbatch had better thermal insulation values comparing to standard fabric.

Keyword: *Comfort, Clothing Comfort, Polyester yarn, Thermal insulation*

1. INTRODUCTION

The term comfort is defined as “the absence of unpleasantness or discomfort” or “a neutral state compared to the more active state of pleasure” [1]. With other words, comfort is an experience that is caused by integration of impulses passed up the nerves from a variety of peripheral receptor smell, smoothness, consistency and color etc. in the brain. It is a qualitative term and it is one of the most important aspects of clothing. The clothing comfort can be divided into three groups such as psychological, tactile and thermal comfort. Psychological comfort is mainly related to the latest fashion trend and acceptability in the society and bears little relation to the properties of fabrics. The tactile comfort has relationship with fabric surface and mechanical properties. The thermal comfort is related to the ability of fabric to maintain the temperature of skin through transfer of heat and perspiration generated within the human body [2]. Today numerous consumers consider thermal comfort to be one of the most significant attributes when purchasing textile and apparel products [3]. There is a general agreement that the transmission of air, heat and water vapor through a garment are probably the most important factors in clothing comfort. Comfort, as felt by the user, is a complex factor depending on the above attributes [2]. Thermal properties are among the most important features of textiles. Most of the studies hitherto carried out are devoted to measuring static thermal properties such as thermal conductivity, thermal resistance, and thermal diffusion [4]. The thermal properties of clothing materials, which relate thermal comfort of the user, involve the heat and mass transfer between a clothed body and the environment. The thermal resistance of a clothing system represents a quantitative evaluation of how good the clothing provides thermal barrier to the wearer [5]. Thermal insulation properties are determined not only by the physical parameters of fabrics but also by structural parameters such as weave and drape [4]. The human body is adapted to function within a narrow temperature range. Generally, the human body keeps its body temperature constant at 37±0.5°C under different climatic conditions. The human body converts the chemical energy of its food into work and heat. The amount of heat generated and lost varies markedly with activity and clothing levels. The heat produced is transferred from the body's skin to the environment. In a steady-state heat balance, the heat energy produced by the metabolism equals the rate of heat transferred from the body by conduction, convection, radiation, evaporation and respiration. Therefore, clothing is needed to protect the body against climatic influence and to assist its own thermal control functions under various combinations of environmental conditions and physical activities. Human thermal comfort depends on combinations of clothing, climate, and physical activity [6].

In studying the physical factors determining the comfort performance of textiles, it is concluded that heat transfer between people and the environment, together with the movement of moisture for insensible heat transfer, constitutes the major comfort. Depending on the particular functional requirements of clothes, the parameters which can be evaluated for physical aspects of comfort are thermal conductivity, water-vapor resistance, air-permeability, moisture holding ability, air resistance, abrasion resistance etc. It is obvious that comfort involves a complex combination of properties, both subjective and physical. There is general agreement that the movements of heat, moisture and air through a fabric are the major factors governing comfort, but some of the subjective factors such as size, fit and aesthetic behavior like softness, handle and drape are obviously very important in the textile field [1].

In textile, thermal comfort property is generally gained by finishing and coating processes. These processes have limited functionality over time. In addition they caused water consumption. Therefore there is demand to more enviromentally firendly and durable thermal comfort fabrics. This study trials meet the requirements of the market. To achieve this goal, masterbach was loaded to polyester yarn in melt spinning process.

2. EXPERIMENTAL STUDY

Experiment provides instant heat emission by storing heat thanks to the embedded nanoparticles in the yarn. Absorbed heat; it is stored and released when the body temperature drops and maintains the body's temperature in cold weather. Experimental trials aim to develop comfortable and high tech special thermal fabrics.

2.1 Material

Polyester (KORTEKS) was used as main polymer and a thermal masterbatch outsourced.

2.2 Method

2.2.1 Filament Production

Functional (masterbatch added) and standard polyester yarns had produced with same processes. Firstly, 75 denier 72 filaments Partially Oriented Yarn (POY) was produced with melt spinning process. Masterbatch was added in extrusion step of melt spinning. Masterbatch and polyester polymer were melted and blended in this process. At further step POY was texturized by false twisting method in order to gain natural fiber view and touch.

2.2.2 Filament Yarn Analyses

After texturizing process, elongation and tenacity tests were carried out according to DIN 2062 standard. Five measurements were made for each sample and average value was calculated. Boiling shrinkage analyses of filaments were carried out according to DIN 53866 standard. Three measurements were made for each sample and average value was calculated. Dtex value was testing by DIN EN ISO 2060 skein method. Five measurements were made for each sample and average value was calculated.

2.2.3 Functionality Test

In the study, fabrics made with masterbatch added yarns and standard yarns were tested according to ISO Standard TS EN 11092:2014 test method in order to find out water vapor resistance and thermal resistance values.

3. RESULTS

3.1 Yarn Analyses

Yarn analyze results of standard and functional yarns were shown in Table 1.

Table 1. Filament yarn analyses.

Sample	DTEX	ELONGATION AT BREAK (%)	TENACITY (CN/ DTEX)	SHRINKAGE AT BOILING WATER (%)
STANDARD YARN	86	23	4,18	3,78
FUNCTIONAL YARN	87	25	4,20	3,76

3.2 Functionality Test

The functionality test results of standard and functional yarns were shown in Table 2.

Table 2. Functionality Test Results (TS EN 11092:2014).

Sample	WATER VAPOUR RESISTANCE R_{ET}-($M^2 \cdot PA/W$)	THERMAL RESISTANCE R_{ET}-($M^2 \cdot PA/W$)
STANDARD YARN	1,10	0,0074
FUNCTIONAL YARN	0,88	0,0191

4. CONCLUSION

When the yarn analyses results were examined, it could be seen that the additive has no effect on the physical properties of the yarn and is suitable for knitting and weaving processes. Functionality results were examined and it could be seen that there is a 20% improvement in water vapor resistance and 158 % improvement in thermal resistance compared to standard yarn.

Especially, functional fabric thermal resistance value was increased dramatically. The thermal comfort values accepted in the market are defined as the basic category between 0,010 R_{ET}-($M^2 \cdot PA/W$) and 0,015 R_{ET}-($M^2 \cdot PA/W$), the medium category between 0,015 R_{ET}-($M^2 \cdot PA/W$) and 0,030 R_{ET}-($M^2 \cdot PA/W$), and higher category if it is higher than 0,030 R_{ET}-($M^2 \cdot PA/W$). According to test results, the thermal value of functional yarn is accepted as medium category in textile market.

In future studies, different types of yarns and functional yarns will be mixed in various proportions in fabrics to search for comfort properties. Furthermore, this functional yarn will be produced in different cross sections (hollow, etc.) and thermal comfort values will be examined.

REFERENCES

[1] Milenkovic, L., Skundric, P., Sokolovic, R., & Nikolic, T. (1999). Comfort properties of defence protective clothing. *The Scientific Journal Facta Universitatis*, *1*(4), 101-106.
[2] Das, A., & Ishtiaque, S. M. (2004). Comfort characteristics of fabrics containing twist-less and hollow fibrous assemblies in weft. *Journal of Textile and Apparel, Technology and Management*, *3*(4), 1-7.
[3] Luo, X., Hou, W., Li, Y., & Wang, Z. (2007). A fuzzy neural network model for predicting clothing thermal comfort. *Computers & Mathematics with Applications*, *53*(12), 1840-1846.
[4] Frydrych, I., Dziworska, G., & Bilska, J. (2002). Comparative analysis of the thermal insulation properties of fabrics made of natural and man-made cellulose fibres. *Fibres and Textiles in Eastern Europe*, *10*(4), 40-44.
[5] PAMUK, O. (2008). Determination of Clothıng Comfort for Textile Industry. *Engineering Sciences*, *3*(1), 69-74.
[6] Oğulata, R. T. (2007). The effect of thermal insulation of clothing on human thermal comfort. *Fibres & Textiles in Eastern Europe*, *15*(2), 67-72.

ZERO WASTE DENIM & NON-DENIM GARMENT DESIGN

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ABSTRACT

Zero waste is one of the very important consider topics in the global textile Industry. The agenda of Fashion garment industry about waste in terms of textile occupied textile science and applications. Especially recent developments and solutions about the textile waste bring enormous ideas. In terms of fashion design, designers conceptually creating "upcycle" garment to make an affection to join this globalisation movement is a new approach in trends. In this specific project, a minimum number of six womenswear garment created as trendy fashion collection. Fabric waste from the garment collection minimized to zero with the technical solutions of patterns. During the experimental but creative fabric cutting process, work explained how basic patterns easy-to geometry can be adjusted to downsizing for the zero waste. However, the discarded and very small pieces of fabric still after the cutting process, needed handmade applications to create textured new fabric material. Especially combining denim and non-denim fabrics challenges unusual new surface by the aid of sewing machines and/or steamed with the fusible for the new material's durability. New textured material completely made from disposal of cut-patterns applied not only to create embellishment on the garment but also mend in scaled size pattern to complete the design.

Keyword: *zero waste design, denim design, upcycle garment design, denim scraps*

1. INTRODUCTION

This is an Industry-University collaboration project which practised with a team of fashion design students and supervised under instructor.

Group of fashion design students gather the information about trends towards sustainability and made research garment pattern cutting techniques. Garment designs individualy executed on a dress form after general fashion trend ideas shared in the team.

The materials provided from one of the pioneer textile company's design department in Istanbul-Turkey. The methods practised with draping tech and pattern making tech. Students involved with their own creative ideas, how to shape and design garments under the supervision of the instructor. Solutions of the pattern, fit, fabric ensemble studied. Finishing details as trim and closure (zip, hook-eye) added to garments.

1.1 Design progress

Examples of figures and captions are given below.

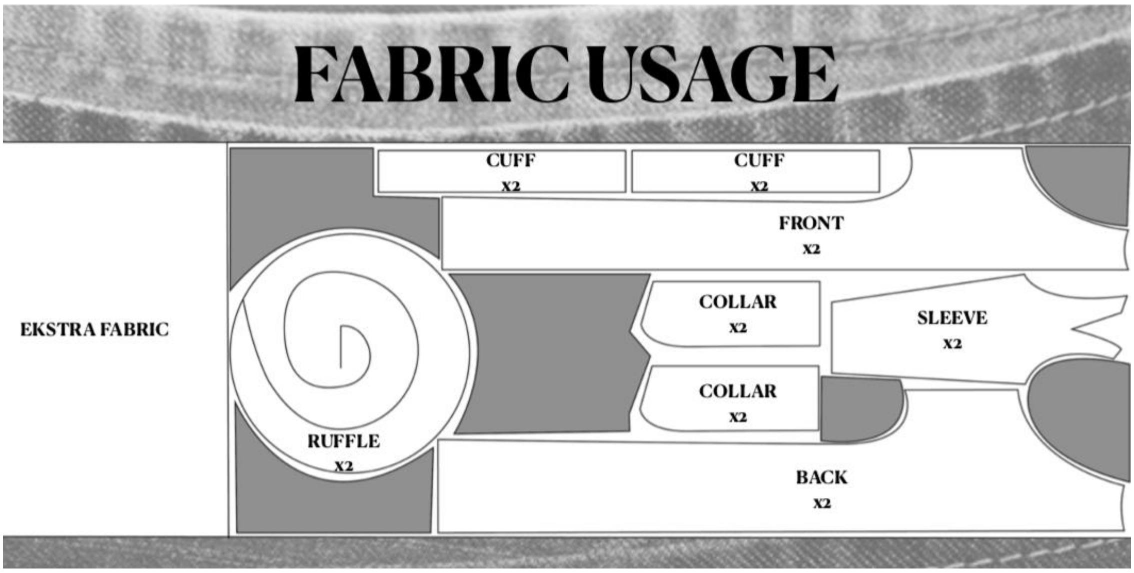

Figure 1. Pattern lay-out.

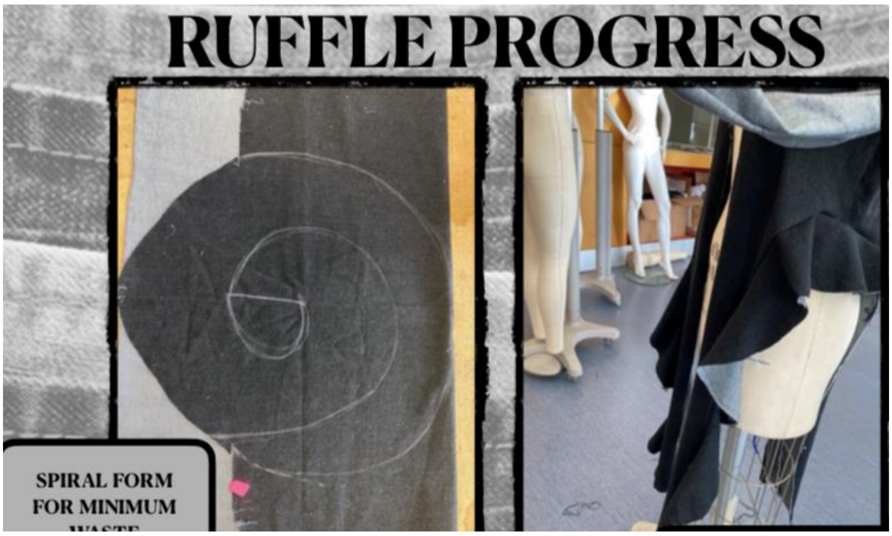

Figure 2. Pattern.

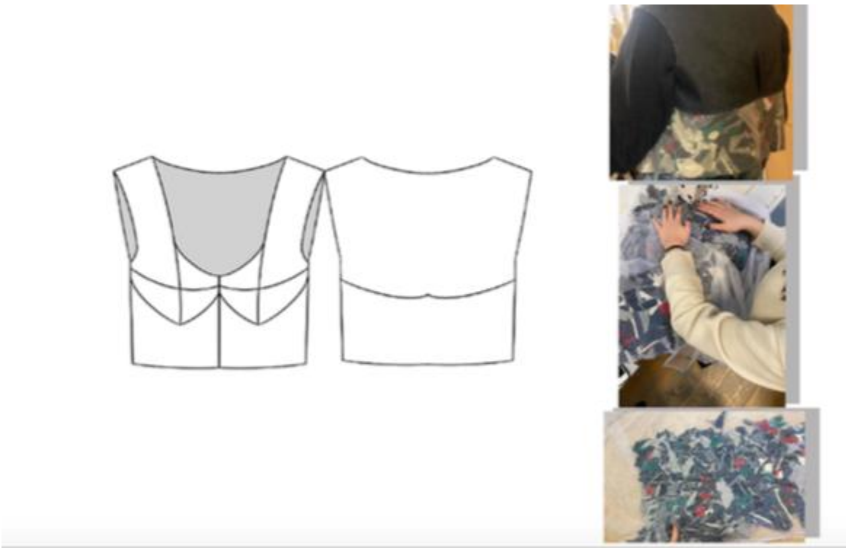

Figure 3. Scraps.

Figure 4. Trend board.

2. RESULTS

The study's results presented as fashion collection.

Figure 5. finished garment

Figure 6. final look

3. CONCLUSION

The exhibition of the fashion design garments will be presented.

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REFERENCES

[1] https://www.jeanologia.com/about-us/

[2] https://bsamply.com/denim-trend-fall-winter-2021-2022

[3] Chambers A. (2022, May 21) *Global Denim Market 2022 Trends, Research, Analysis & Review Forecast.* Retrieved from https://www.openpr.com/news/2205447/global-denim-market- 2020-trends-research-analysis-review.

[4] Armstrong, H. J. (2008). *Draping for Apparel Design.* (2nd ed). New York: Fairchild Publications Inc.

[5] Jaffe, H., Relis, N. (2005). *Draping for Fashion Design*. (4th ed). Upper Saddle River, NJ: Prentice Hall.

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