TEXPLORER

TEXTILE RESEARCH MAGAZINE

VOL 5 APRIL 2025

ABOUT KUMARAGURU COLLEGE OF TECHNOLOGY

Kumaraguru College of Technology (KCT), Coimbatore, established in 1984, is a premier private engineering institution under the auspices of the Ramanandha Adigalar Foundation, the educational initiative of the Sakthi Group. Spread across a sprawling 156-acre campus in the IT corridor of Coimbatore, KCT is an autonomous institution affiliated to Anna University, Chennai, and approved by the All India Council for Technical Education (AICTE).

KCT has been accredited with an **A++ grade by the National Assessment and Accreditation Council (NAAC)** and its eligible undergraduate programs are **NBA-accredited under Tier I** of the Washington Accord. The institution offers **14 undergraduate** and **16 postgraduate** programs in Engineering, Technology, Management, and Computer Applications, supported by 15 academic departments and 9 research centers.

Under the visionary leadership of **Dr. B. K. Krishnaraj Vanavarayar** (Chairman), **Sri M. Balasubramaniam** (Correspondent), and **Sri Shankar Vanavarayar** (Joint Correspondent), the college has grown into a center of academic excellence. With over **400 experienced teaching faculty** and modern infrastructure including smart classrooms, well-equipped labs, advanced computing facilities, and a vibrant innovation ecosystem, KCT fosters holistic development among its **6,200+ students**.

The campus is also home to **Dr. Mahalingam Vigyan Bhavan**, an architectural landmark that houses administrative operations. KCT continues to empower learners to become socially responsible technocrats and leaders through its commitment to academic excellence, research, innovation, and sustainability.

ABOUT DEPARTMENT

Department of Textile Technology was started in the year 1995 with the Objective of imparting comprehensive knowledge in all the faces of Textile Manufacture to students through UG & PG programmes. Professionally well qualified, highly experienced faculty members and well-equipped laboratory with modern facilities provide ample opportunity to the students to pursue their education with excellence. Students are provided with good industrial exposure taking full advantage of college location in the Textile City, Coimbatore. The accreditation status has been awarded to the B.Tech Textile Technology undergraduate programme by National Board of Accreditation, AICTE, New Delhi for Three Years with effect from September 2019

EDITORIAL MESSAGE

Prof. Pavendhan A,
Associate Dean-Textile Cluster

I am delighted in acknowledging the national level technical project display context, titled, “K-TEX TECH CHALLENGE 2025” conducted by Department of Textile Technology. This edition brings out all papers that were presented during the context which was held on-line. My heartiest congratulations to all participants. I extend my warm appreciation to the students, faculty and Head of the Department who were behind the success of the context as well as this edition of the magazine. Context of this nature provides opportunities to students to explore research areas of their interest (as the theme has not been restricted to any single topic/ area). There are plenty of problem statements around us, and we only need keen eyes and right interactions with industry, researchers, and our professors to unearth them. Projects pursued in under-graduate level by students help exposed to various phases of research including framing research questions, designing, selecting appropriate methodology, experimenting, analysing, and reporting the results. It is noteworthy to mention the successful projects which aimed at problem solving, got top accolades in the last edition. These are

- Effective removal of microfibres from laundry wastewater
- Instrument for Spun Long Staple Bast Fibre
- A system to evaluate crease recovery angle using image processing
- Design and Development of Conductive Knitted Fabric using Core Spun Conductive Yarn
- The convertible Shelter Jacket

I am sure all the participants of this context would have been benefitted from such exposure. I am sure this edition would inspire young students to explore more.

EDITORIAL MESSAGE

Dr.V.Ramesh Babu, Head & Professor

April,2025

On behalf of the editorial staff and students, it is my pleasure to introduce the issue of TEXPLORER, yearly magazine of Department of Textile Technology that showcases technical papers of students and faculty in textile domain and its allied field This new magazine is envisioned and found to represent the technical as well as cultural skill of the students. Its mission is to become a voice of the textile student's community, addressing faculty, industry persons and alumni from various fields of Textile Technology. This volume comprises of technical papers from fibre, yarn, fabric, fashion technical textiles and few new innovations in machinery and textile products. It is our hope that this fine collection of articles will be a valuable resource for Textile Technology. I would also like to thank the faculty members who worked with the students. Students from various colleges submitted their papers and presented the projects using the platform provided exchanged ideas which will enhance further advancement in thrust areas of research. Much appreciation is also due to all the faculty members and students of the editorial team. Finally, I would like to express my appreciation to the students who contributed their writing and to the students who have done a great job in putting this research magazine together. I hope you will enjoy reading these papers, and if you are textile/fashion technology student or faculty or industry expert consider submitting your own writing to be published in next year's K-TEX Research magazine

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ADAPTIVE WEAR

Detachable & Transformable Handloom Multipurpose Jacket

Sibin V

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ABSTRACT

In a world driven by fast-changing lifestyles and fashion trends, the need for versatile, sustainable clothing has never been more urgent. This project introduces ***ADAPTS*** a revolutionary **5-in-1** transformative jacket designed to minimize wardrobe excess and maximize utility, style, and sustainability. Addressing the growing demand for specialized activewear for different activities like cycling, running, trekking, and gym workouts, this innovation offers a single, multifunctional solution adaptable to every situation from morning walks to adventurous treks.

Crafted from 100% recycled polyester and woven using indigenous handloom techniques, *ADAPTS* embodies the ethos of "Sustainable Future: Innovation with Indigenous Knowledge." This fusion of modern adaptive wear design and traditional craftsmanship not only celebrates India's cultural heritage but also supports local artisans and sustainable livelihoods.

The jacket features detachable elements like hood, sleeves, and waist panels, that transform into standalone accessories: the hood becomes a fanny pack, sleeves convert into a chic shoulder bag, the waist-to-hip panel morphs into a stylish mini skirt, and the front and back bodice unzip into a spacious, two-sided shoulder bag. Each component finds a second life, embracing a circular design philosophy that prioritizes upcycling and zero waste.

ADAPTS redefines functional fashion, merging innovation, tradition, and environmental consciousness into a single garment. It aligns with the United Nations Sustainable Development Goals by fostering responsible consumption, empowering communities, and promoting climate action. This project envisions a future where garments adapt to lifestyles - not the other way around - leading the way toward a fashion revolution rooted in purpose, heritage, and sustainability.

Keywords: *Sustainable Fashion, Adaptive Wear, Transformative Jacket, Handloom, Circular Design, Multifunctional Garment, Upcycled Accessories, Community Empowerment, Versatile Activewear, Zero Waste, UN Sustainable Development Goals, Ethical Fashion, Innovation in Textiles.*

1. INTRODUCTION

The global fashion industry is undergoing a paradigm shift, driven by the urgent need for sustainable practices and mindful consumption. With fashion being one of the largest contributors to environmental degradation - generating over 92 million tonnes of textile waste annually and consuming vast amounts of water and energy - there is an increasing emphasis on innovation that not only addresses style but also sustainability. In response to the environmental crises and the growing demand for ethical production, designers and researchers are exploring novel ways to reduce waste, extend the lifecycle of garments, and promote circularity in fashion.

One promising direction in this transformative journey is the development of **Adaptive Wear** garments that offer multifunctionality, personalization, and flexibility. These designs challenge traditional norms by enabling a single piece of clothing to adapt to various needs, occasions, and environments. Adaptive Wear provides users with more value per garment, reduces the need for excessive consumption, and aligns with the principles of minimalism and conscious living.

Simultaneously, the resurgence of **indigenous craftsmanship**, especially India's handloom heritage, offers a rich opportunity to create products that are both culturally rooted and environmentally responsible. Handloom weaving not only preserves traditional knowledge and skills passed down through generations but also supports sustainable livelihoods in rural communities. Unlike power-loom production, handloom uses minimal electricity and water, resulting in a significantly lower carbon footprint.

This paper presents **ADAPTS**, a project that harmoniously fuses **adaptive wear design and indigenous handloom techniques** to create a **detachable and transformative 5-in-1 multifunctional jacket**. Made from 100% recycled polyester handloom fabric, the jacket is designed to be disassembled and reconfigured into five distinct fashion and utility items, including a mini skirt, fanny pack, and shoulder bags. This repurposing of every component exemplifies a circular fashion approach - maximizing the utility of each part and ensuring no material goes to waste.

The **ADAPTS jacket** is not merely a garment but a vision for a new future of fashion - one that respects tradition while embracing innovation. It caters to modern lifestyle demands such as travel, storage efficiency, and versatility, while promoting values of sustainability, slow fashion, and cultural preservation. Through this project, the paper aims to highlight how adaptive design and indigenous practices can together redefine the future of fashion for a more equitable and ecologically sound world.

2. OBJECTIVE

- The objective of this project is to minimize garment consumption by developing a multipurpose sustainable jacket.
- It aims to replace multiple wardrobe items with one adaptable piece featuring detachable components.
- The design supports repurposing each part into functional accessories like bags and a skirt.
- By integrating handloom fabric and recycled materials, it promotes environmental and cultural sustainability.
- The goal is to inspire conscious fashion choices through innovation, versatility, and circular design.

3. MATERIALS

- Main Fabric: 100% Recycled Polyester Handloom Fabric
- Lining Fabric: 100 % Recycled Mesh
- Trims: Zippers (Nickel-free YKK), Snap Buttons, Velcro
- Fabric Details: Yarn Count (50s), GSM (90-100)
- Technique: Handloom weaving, pattern making, detachable garment construction
- Tools: Zippers, Velcro, Snap Mechanisms.

Figure 1
100% Recycled Polyester Yarn

Figure 2
Handloom Fabric

Figure 3
Recycled Mesh

Figure 4
Nickel free Zippers

4. DESIGN CONCEPT AND FUNCTIONALITY

The jacket's innovative **Detachable** design allows it to be styled in **five** distinct ways, catering to diverse needs and situations.
Style 1 - Jacket With Front and back bodice, Hoodie, Sleeve, Hip to waist portion.
Style 2 - Jacket with Front and back bodice, Sleeve, Hoodie and without Waist to Hip portion.
Style 3 - Jacket with Front and back bodice, Sleeve and without Hoodie, Waist to hip portion.
Style 4 - Jacket with Front and back bodice, Hoodie and without Sleeve, waist to hip portion.
Style 5 - Jacket with front and back bodice and without Hoodie, Sleeve, Waist to hip portion.

Figure 5
Front view of 5 in 1 Jacket

Figure 6
Back view of 5 in 1 Jacket

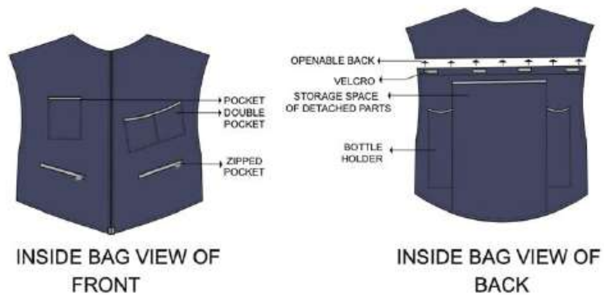

Figure 8
Detailing the features of the jacket

Detachable components such as the hood, sleeves, and waist-to-hip panels provide unparalleled versatility. Beyond functionality, each detached piece finds new life:
1. Sleeves into a chic shoulder bag
2. Hood converts into a fanny pack
3. Waist-to-hip panel into a mini skirt
4. Front and back bodice into a spacious two-sided shoulder bag.

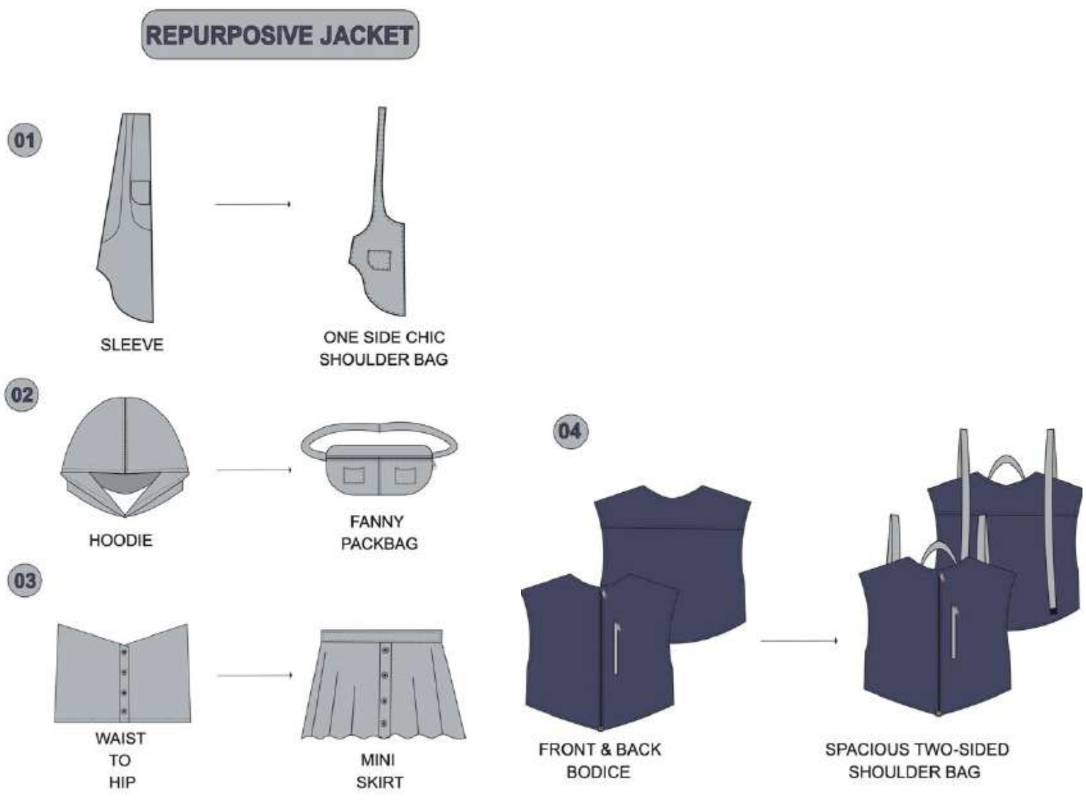

Figure 7
Repurposed panels

5. SUSTAINABILITY ANALYSIS

- Material Circularity: Recycled content, reusability
- Cultural Sustainability: Supporting artisans through handloom use
- Zero-Waste Design: Every component has a secondary use

6. USER-CENTRIC FEATURES

- Detachable and adaptable for diverse body types
- Unisex design
- Urban and rural utility
- Packable and compact
- Fashion + Function = Futurewear

7. RESULTS

The ADAPTS jacket successfully demonstrated its multifunctionality and sustainable potential through its modular design. Each detachable component of the garment was reconfigured into a usable accessory or apparel item, fulfilling the 5-in-1 concept:

- The **Jacket** functioned effectively as a standalone outerwear piece, suitable for various weather conditions.
- The **Hood** was seamlessly converted into a **fanny pack**, providing portability and storage convenience.
- The **Sleeves** transformed into a **stylish one-side shoulder bag**, emphasizing utility and design aesthetics.
- The **Waist-to-Hip panel** served as a **mini skirt**, offering a fashionable secondary use.
- The **Front and Back bodice** formed a **two-sided spacious bag**, enhancing the garment's value as a travel-friendly ccessory.

Figure 8
Detachable Jacket

Figure 9
Repurposed Panels

The detachable system using **zippers and velcro** was smooth, durable, and intuitive, proving that transformation could be achieved without compromising style or structure. Furthermore, the use of **100% recycled handloom fabric** showcased the viability of combining traditional weaving techniques with innovative garment engineering. The design retained strength, breathability, and cultural relevance while aligning with sustainable development goals.

The project demonstrated a clear reduction in the need for multiple garments and accessories, confirming its effectiveness as a practical solution for sustainable, adaptive fashion. A video demonstration of the jacket's transformation process can be viewed here:

https://drive.google.com/file/d/19-Hlukb1AlIA_67CCrG9jLF2h8fjhjuj/view?usp=sharing

8. CONCLUSION

- The ADAPTS jacket project successfully illustrates how fashion can merge sustainability, functionality, and cultural heritage into a single, innovative design. By incorporating detachable and repurposable components, the jacket offers five distinct uses, significantly reducing the need for multiple garments and encouraging mindful consumption. Its construction using 100% recycled handloom fabric not only minimizes environmental impact but also supports indigenous craftsmanship and promotes ethical production.
- This project emphasizes the potential of **adaptivewear** as a future-forward approach to fashion—one that values **versatility, zero-waste principles, and cultural preservation**. ADAPTS is not just a garment; it is a movement toward **conscious design**, where each element is created with purpose, utility, and longevity in mind. As the industry moves toward sustainable innovation, this model stands as a testament to how design thinking can inspire meaningful change in both consumer behavior and production practices.

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A SUSTAINABLE RECYCLING PROCESS AND ITS LIFE CYCLE ASSESSMENT FOR VALORISING POST-CONSUMER TEXTILE WASTE

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ABSTRACT

Textile is one of the most polluting and resource depleting industries. Fueled by fast fashion, huge amount of post-consumer textile waste is generated globally which mostly goes to landfill or incineration, thwarting the implementation of circular economy. This research presents a sustainable and low-cost recycling technology for converting post-consumer textile (denim) wastes to useful insulative liner and seamless recycled apparel. To accomplish the first objective, nonwoven materials were produced using varying proportions of post-consumer recycled denim fibre (r-denim) and hollow polyester (PET) fibre using different punch densities in the needle punching process. Developed nonwoven materials were characterized by thermal resistance and tensile properties. The results show that nonwoven materials containing the minimum proportion (20 %) of r-denim fibres exhibited the highest thermal resistance (0.131 $W^{-1}m^2K$). However, by adjusting the process parameter of the nonwovens, i.e., the punch density, the same thermal resistance (0.131 $W^{-1}m^2K$) is also achieved even with 39 % r-denim fibres. Additionally, the nonwovens produced from this blend proportion (r-denim: PET = 39:61) demonstrate a reasonable strength of 2.43 cN/tex. In second objective different ratios of r-denim and v-cotton yarns were mixed to produce knitted apparel having good handle properties. Environmental benefits of the developed r-denim/PET nonwovens and apparel have been evaluated by the LCA approach. Results show that the use of ~40 % recycled denim fibre has reduced the environmental burden significantly. Therefore, the products produced from post-consumer textile wastes hold tremendous potential as an alternative to virgin fibres in thermal insulation applications. This recycling approach has immense potential to contribute to the efficient utilisation of post-consumer textile waste materials paving the way for environmental sustainability.

Keyword: - *Circular economy, Post-consumer, Sustainability, Life cycle assessment (LCA), Thermal insulation, Textile waste management.*

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1. Introduction

The fundamental necessities of human existence encompass food, clothing, and shelter. Recent trends in clothing consumption indicate that clothing has evolved beyond a mere necessity. It has become a symbol of luxury, often reflecting an individual's social status and economic standing. The worldwide production of textile fibres, the consumption of textiles, and the volume of textile waste generated are consistently on the rise. There was a significant surge in worldwide fibre output from around 112 million tons in 2021 to 116 million tons in 2022. If the present business trend continues, the global fibre production is anticipated to reach 147 million tons by 2030 [1]. The global textile market reached a value of USD 1,695 billion in 2022 and is expected to exhibit a compound annual growth rate (CAGR) of 7.6 % in terms of revenue from 2023 to 2030 [2]. As the second-most polluting industry after petrochemicals, the textile industry consumes 4 % of the global freshwater withdrawal and is responsible for 8 % of the total greenhouse gas emissions. The global per capita consumption of textile fibres is around 11.4 kg whereas for Europe it is around 31.5 kg [3]. The surge in population, economic growth, and the proliferation of fast fashion are the driving forces behind the excessive consumption of textiles [4-5]. In the end, these textiles often find their way into landfills or undergo incineration. The rapid rate at which post-consumer textiles accumulate in landfills, posing a significant environmental hazard and contributing to the depletion of natural resources, is a cause of concern [6-7].

From a terminology perspective, textile waste is typically categorised under two heads, namely pre-consumer or industrial waste and post-consumer waste. The pre-consumer waste is easy to recycle as it is collected in the industry itself and reused either in-house or in industries having symbiotic relations. Post-consumer textiles, on the other hand, have mixed streams and therefore, such waste has a lot of variability in all sorts of aspects.

The textile industry is one of the most resource-intensive sectors, with significant environmental impacts across various stages of the production process. The textile industry is also a major water consumer, especially in activities such as dyeing and finishing. A single cotton t-shirt, for instance, might use up to 2,700 litre of water during production. In addition to this, wastewater from textile companies frequently contains toxic chemicals, dyes, heavy metals and other hazardous compounds that contaminate water bodies and adversely affect both aquatic life and human health.

The production of textiles from synthetic fibres like polyester is energy-intensive and relies heavily on fossil fuels, leading to significant greenhouse gas emissions. The global textile industry is estimated to produce over 1.2 billion tons of CO_2 equivalent annually [8]. Millions of tonnes of textiles are disposed of in landfills annually as a result of the waste generation by the fashion industry. Fast fashion trends exacerbate this issue, leading to a throwaway culture. This industry uses a plethora of chemicals in various processes, including pesticides in cotton farming, dyes, and finishing agents. Many of these chemicals are toxic and pose risks to workers, consumers, and the environment.

In response to this growing concern, research has been conducted to develop thermal liners and seamless recycled apparel from post-consumer textile waste through mechanical recycling.

1.1 Objective of the proposed design solutions:

The proposed design solution has multiple objectives like has the mission and vision to

- Minimize Abate landfill waste and pollution.
- Decrease the amount of post-consumer textile waste.
- Decrease Abridge the dependency on virgin resources and raw materials.
- Lower greenhouse gas emissions and energy consumption are associated with textile production.
- Promote sustainable use of materials by efficient textile waste management.
- Support the development of a circular economy by reusing and recycling textiles.
- Increase awareness about the environmental impact of textile waste.
- Enhance the value and usability of recycled materials in new products.

2. Materials and methods

2.1 Materials

The recycled cotton denim fibre (r-denim) was prepared in an industry involved in post-consumer mechanical recycling of textiles. The process steps are shown in Figure 1. The denim waste, after the removal of zippers and buttons, is fed to a cutting machine which is designed to cut fabric waste into smaller pieces with its sharp blades. Then the small pieces of fabrics are fed to the tearing (shredding) line which performs sequential opening with multiple toothed rollers and thus, recycled fibres are obtained. Virgin hollow polyester (PET) fibre was purchased from Reliance Industries Limited. The physical properties of both fibres are given in Table 1. The schematic of the mechanical recycling process is given in Figure 1.

Table 1: Physical properties of r-denim and hollow PET fibres

r-denim fibres		Hollow polyester fibres	
Effective fibre length (mm)	10	Effective fibre length (mm)	50
Fibre fineness (denier)	1.45	Fibre fineness (denier)	7.0

Tenacity (gf/den)	2.0	Tenacity (gf/den)	2.3
Breaking strain (%)	4.0	Strain (%)	21.1

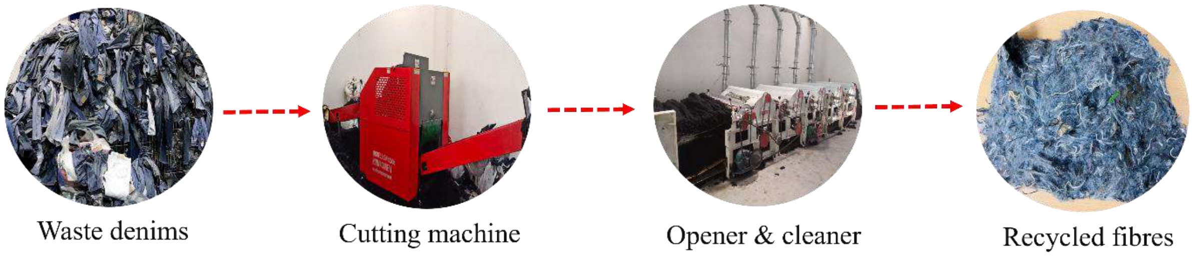

Figure -1: Steps of mechanical recycling.

2.1 Methods

The short length and low resilient r-denim fibre is blended with hollow PET fibres to produce needle-punched nonwovens in six different blend ratios. To attain a basis weight (areal density) of 150 $g.m^{-2}$, multiple layers of carded webs were overlapped and subjected to the needle punching process. The DILO needle loom using punch densities ranging from 75 to 150 cm^{-2} with a 10 mm depth of needle penetration was used for the mechanical punching process. The punch density indicated by the number of punches created by barbed needles per unit area, depends on the stroke frequency of the needle board and speed of the delivery roller. The schematic of manufacturing thermal liner from r-denim fibre is given in Figure 2.

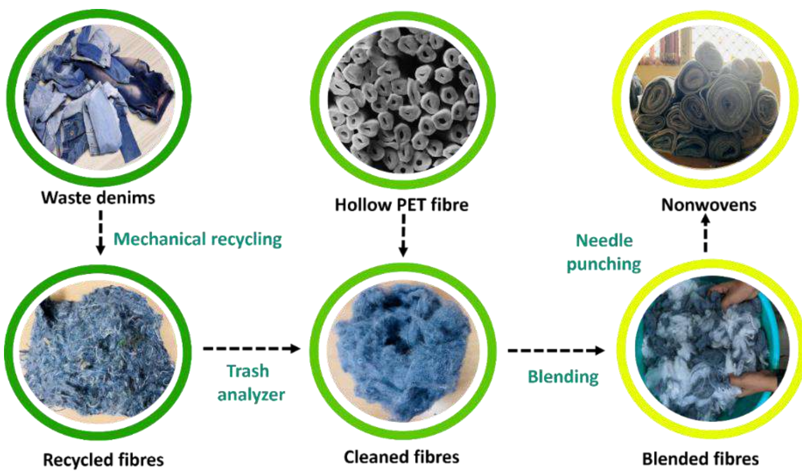

Figure -2: Steps of manufacturing thermal liner using recycled denim fibre

Double jersey knitted fabrics (rib structure) were produced using r-denim and virgin cotton (v-cotton) yarns on a 12-gauge flatbed knitting machine. The blending of r-denim and v-cotton yarns in varying proportions was achieved through an innovative course-mixing technique. In this method, the number of loop rows knitted from recycled and virgin yarns were varied to obtain the desired blend ratio. For instance, alternating rows of recycled and virgin yarns resulted in a 50/50 composition. Using this approach, five distinct blend ratios—0/100, 33/67, 50/50, 67/33, and 100/0 (r-denim/v-cotton)—were developed. Figure 3 presents the images of knitted fabrics with different recycled-to-virgin yarn compositions produced in this study. All fabric samples underwent wet relaxation treatment according to standard procedures to stabilize their structure before further testing.

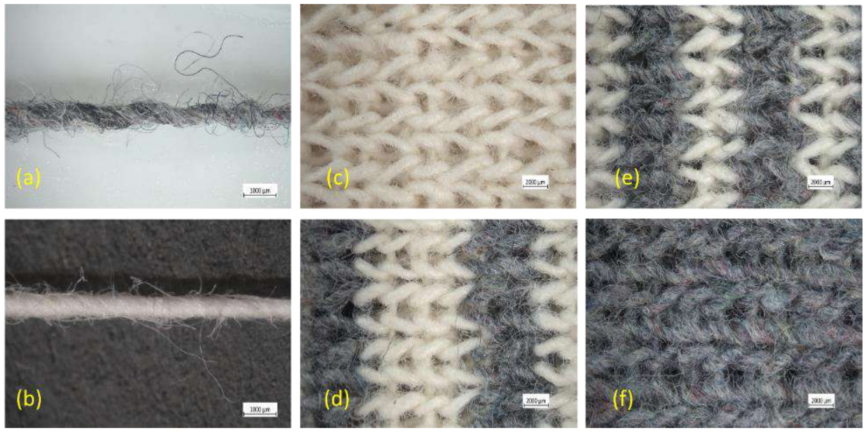

Figure -3: Microscopic images of (a) r-denim yarn, (b) v-cotton yarn, (c) v-cotton (100%), (d) r-denim/v-cotton (33/67), (e) r-denim/v-cotton (50/50) and (f) r-denim (100%)

3. Results and discussions

3.1 Thermal resistance of the developed liner

It is observed from figure 4(b) that thermal resistance is the highest for the blend ratio 20:80 of r-denim-PET having a punch density of 90 cm^{-2}. This is because the blend containing the highest percentage of PET fibre gives additional insulation by entrapping still air inside the hollow core. In addition to this, the punch density of this nonwoven was also on the lower side which produced a fluffy structure. It is fairly known from the literature that as the punch density reduces, the nonwoven structure becomes less compact and thick, leading to an increase in porosity with more entrapped air.

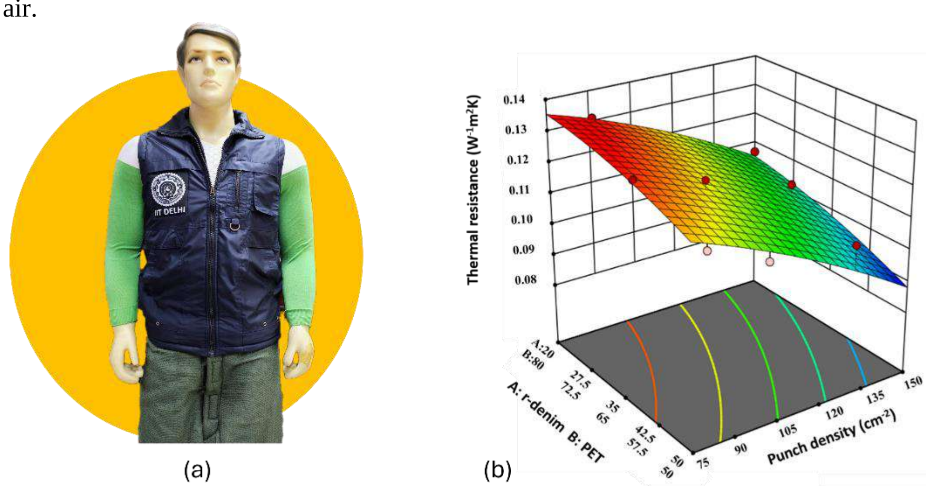

Figure -4: (a) Developed thermal liner prototype (b) Surface plot for thermal resistance of thermal liner.

It can be concluded that it is the internal porosity of hollow PET that plays a vital role in thermal resistance. The lowest thermal resistance (0.089 W^{-1}m^{2}K) was achieved in the case of a 46:54 blend ratio with a punch density of 150 cm-2, which can be justified by the aforementioned logic. The highest thermal resistance (0.131 W^{-1}m^{2}K) was also obtained from a 39:61 blend ratio with 75 cm^{-2} punch density. This is because the proportion of PET fibre was still on the higher side and punch density was the lowest. The results are very promising as almost 40 % of post-consumer recycled denim fibres can be utilised without compromising on thermal insulation by tweaking the process parameter, i.e., punch density.

3.2 low-stress mechanical properties (handle) of seamless recycled garment

A comparative analysis was conducted to evaluate the low-stress mechanical properties of knitted fabrics composed of recycled and virgin cotton yarns (50/50 blend) against those made entirely from 100% virgin cotton yarns. Six critical parameters—shear rigidity, shear hysteresis, bending length, compressional energy, compressional resilience, and the mean coefficient of surface friction—were examined, as they significantly influence the hand-feel behavior of fabrics. Figure 5(b) presents comparative results. For softener-treated fabrics containing 50% recycled yarns, the differences observed relative to 100% virgin cotton fabrics were 6.7% in shear rigidity, 10.4% in shear hysteresis, 1.7% in bending length, 1.3% in compressional energy, and 2.4% in the coefficient of surface friction. These marginal differences indicate that incorporating 50% recycled yarns via course-mixing, followed by a softening treatment, can yield knitted fabrics with tactile qualities closely comparable to those made entirely from virgin yarns

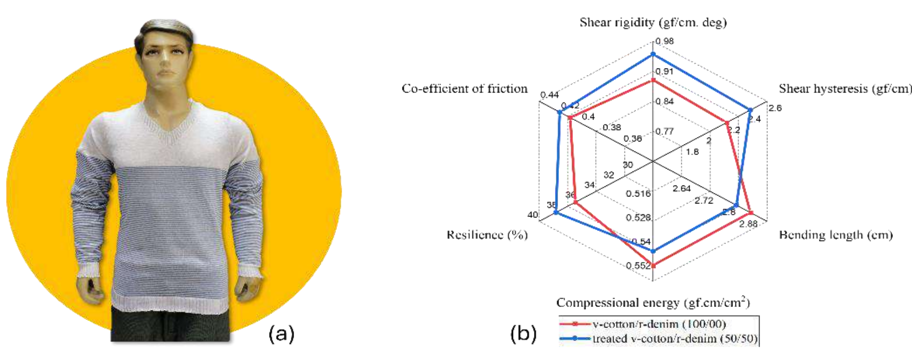

Figure -5: (a) Developed seamless recycled apparel prototype (b) comparison of handle properties of recycled garment.

3.3 Life cycle assessment of the prototypes

It is observed that the production of virgin PET fibre and r-denim/PET (40/60) blended fibre have significant impacts on marine aquatic ecotoxicity, abiotic depletion (fossil fuel), global warming, human toxicity, and acidification whereas their effects on other impact categories are miniscule. Figure 6 presents the relative contributions of the virgin PET fibre and r-denim/PET (40/60) blended fibre productions to five selected impact categories. It is noteworthy that the environmental burden is significantly less (60-80 %) for r-denim/PET (40/60) fibres in all the mid-point impact categories except for human toxicity. This is due to r-denim/PET (40/60) fibre blend consisting of 40 % recycled denim fibre, which does not require land, pesticides, water, and other chemicals for its cultivation. Furthermore, it also helps in eliminating the negative environmental consequences caused by the landfilling of textile waste or incineration. The only additional environmental burden arising here is due to the transportation of waste from collection points to sorting centres, cleaning of the post-consumer textile waste and shredding them into recycled fibres.

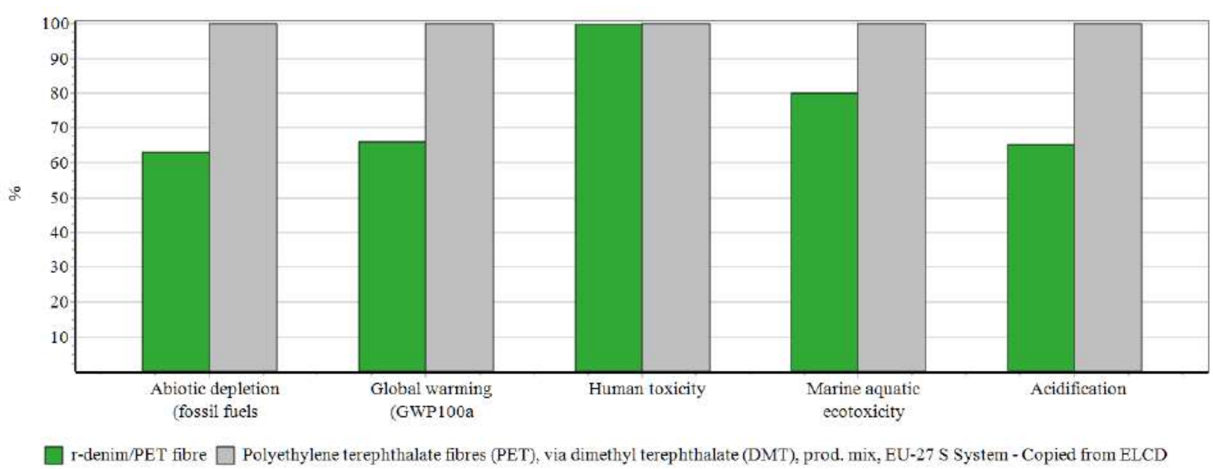

Figure -6: Relative environmental impact of 1 kg of r-denim/PET (40/60) blended fibres versus 1kg of virgin PET fibre.

4. CONCLUSIONS

The results of this research work conclude that the best thermal insulation performance (0.131 $W^{-1}m^2K$) was obtained with a 20:80 blend proportion of r-denim: PET fibre having punch density of 90 cm^{-2}. It was also found that by a suitable choice of punch density (75 cm^{-2}), the same level of thermal insulation can be achieved even with ~40% recycled denim fibres. The developed nonwovens also showed sufficient structural integrity to be used as insulation materials.

A novel course-mixing method has been demonstrated as a simple and practical approach for incorporating varying proportions of recycled (r-denim) yarns into knitted fabrics. Five different blend ratios of r-denim to virgin cotton (v-cotton) yarns—0/100, 33/67, 50/50, 67/33, and 100/0—were explored. While the inclusion of recycled yarns led to a decline in tactile properties such as shear rigidity, bending rigidity, and softness, a post-knitting softening treatment was applied to enhance these properties to levels comparable with those of fabrics made entirely from virgin yarns. This study highlights the potential of r-denim yarns in sustainable fabric development, demonstrating that up to 50% recycled content can be used without significantly compromising tactile performance.

LCA analysis showed that the use of recycled denim fibre can significantly reduce some of the environmental impact categories like marine aquatic ecotoxicity, abiotic depletion (fossil fuel), global warming and acidification. Therefore, the developed nonwovens using post-consumer textile waste can serve as inexpensive and environment-friendly alternative materials for winter jackets in normal cold weather clothing. This study shows the extent to which r-denim fibres could replace synthetic fibres effectively. The use of r-denim fibres will substantially reduce carbon footprint and pave the way for net-zero attainments.

5. ACKNOWLEDGEMENT

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THREE LAYERED THERMAL ONESIE FOR PREEMIES

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ABSTRACT

Preterm babies (preemies) tend to find it difficult to regulate temperature with their immature skin and minimal fat stores, which makes them very prone to hypothermia. To solve this, a three-layered thermal onesie is created that gives maximum heat while allowing the area to breathe and feel comfortable. Such a special onesie has an inner moisture-wicking layer, a mid-layer insulator, and an outer protective layer. The inner layer consists of a soft, hypoallergenic material that pulls moisture away from the skin, avoiding dampness and irritation. The middle layer uses lightweight poly-fill, to keep the body warm while still being flexible. The outer layer is built with fleece which is breathable, wind-resistant material that protects the infant from outside temperature changes while still providing sufficient air circulation.

Designing for ease of use, front-opening fasteners make diaper changing easy and reduce handling stress on medically fragile infants. Flat seams and tag-free construction provide optimal comfort and help avoid skin irritation. Laboratory trials and clinical trials with neonatal care units test the effectiveness of the onesie in maintaining consistent body temperature in comparison to standard preemie wear. Results show enhanced thermal control, diminished external warming device requirements, and increased parental comfort with at-home preemie care. This innovation offers a cost-efficient, non-invasive neonatal thermoregulation solution, minimizing the risk of cold stress and resultant complications. The three-layered thermal onesie is a dramatic step forward in preterm infant care, ensuring their healthy growth and hospital-to-home transition.

Key word: - *Thermal regulation, Breathability, cost-effective*

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1. RESEARCH ON NICU

Neonatal Intensive Care Unit is concerned with enhancing outcomes for sick and premature newborns, including areas such as interventions, care practices, and the psychological effect on families. It offers specialized medical care and monitoring babies who are born prematurely, have low birth weight and they offer emotional support to families.

1.1 RIGHT TIME TO GET DRESSED UP

Baby 's skin might take some time to develop fully, depending on how premature they are. It's not uncommon that when the premature babies are incubated, they are only dressed in just a nappy.
Hospitals would rather do that because it enables them to be able to see and access the chest of the baby easily.
If the premature baby needs to have an umbilical line, this must be taken out prior to dressing them in premature baby clothing.

1.2 OUTFITS TO BE USED

Baby–grows and bodysuits – These are great as they're easy to put on and take off when needed perfect for your tiny baby. Bodysuits are better for babies who do not have umbilical lines and whose skin is fully developed

Sleep-suits – Sleep suits are different to baby grows as they also cover the feet. These are perfect for overnight stays in hospital or when taking baby home
Moderate to late preterm babies (born at gestational age of 32 to 36 weeks) who have no significant medical problems on admission are likely to be discharged at 36 weeks of postmenstrual age

2. REQUIREMENTS CHOOSEN

Figure -1 THERMAL OVERALL GRADE

A tog value is a measure of thermal insulation used to indicate the warmth of textiles. The higher the tog value, the warmer the product will be.
A neutral tog value, typically around 2.5 to 3.5 tog is a good choice for all season wear for pre mature babies

2.1 FABRIC LAYERS
1. Organic cotton
2. Poly-fill
3. Fleece (cotton + poly)

Structure: Quilt

FIGURE -2 Weft Knitting

A) YARN

1)Cotton yarn count – 30’s/1ply 100% Organic cotton
2)Cotton poly yarn count and its composition - 30’s/1 ply 60% BCI 40% Polyester
3)Poly filling - 300D 72 Filament 100% Polyester

B) KNITTING M/C

1)M/C gauge – 18G
2)M/C Dia – 34”
3)No. of needles - 3744

2.2 COLOUR

In search of color theory and thermal properties, grey shades pantones give the warmth effect
It can provide a psychological sense of security and comfort

FIGURE - 3 Cool Gray

2.5 TOG (suitable for room temps around 16–20°C)
The grey color doesn't reflect much body heat, helping maintain a gentle thermal balance.
Mid-tone warm greys: Pair well with 1.5–2.5 TOG fabrics to keep body warmth in, especially in transitional seasons (spring/fall).
Heat Absorption in Materials
- Absorb more infrared radiation (from sunlight or body heat) than white or light colors.
- Retain warmth longer in materials like wool or fleece—useful for thermal clothing or interior insulation.
Psychological Warmth
Grey can offer a soft, cocooning effect—it's neutral and doesn't overstimulate. Paired with warm lighting and materials, it can feel physically warmer, even if the actual temperature doesn't change much.

- because they are not exposed to

c**3. FINISHING**

Finishing plays a significant role in defining a fabric's final characteristics, ensuring it meets specific end-use requirements.

C) DYEING AND FINISHING

Knitting –Batching – Dyeing – Slit open – Stenter – Compacting – Inspection - Packing
Knitting – Fukuhara Double jersey jacquard machine
Dyeing – Reactive dye

DESIGN

FDS – Fukuhara

- DYEING – cold pad dyeing
- SOFTENING - silicon
- DESIGN- Fukuhara design (FDS) S0ftware

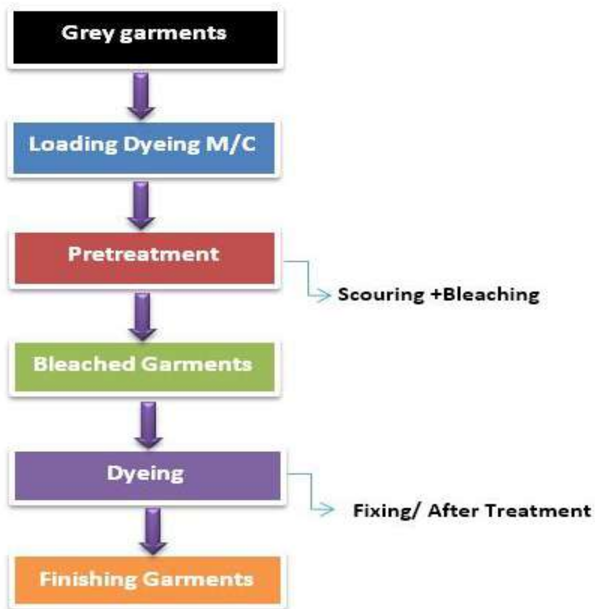

Figure 4 Finishing

3.1 TESTING

Testing for a thermal garment designed for preemies ensures that it is safe, comfortable, and effective in maintaining the body's temperature and they can also provide comprehensive evaluation

Figure – 5 Testing Equipments

1. THERMAL CONDUCTIVITY TEST

Purpose: Measures the fabric's ability to conduct heat
Procedure: A guarded hot plate simulates body heat, and the fabric's thermal resistance is calculated

2. WATER VAPOUR PERMEABILITY TEST

Purpose: Assesses how well the fabric allows moisture to escape
Procedure: The fabric is exposed to controlled humidity, and the vapor transmission rate is measured

3. BURSTING STRENGTH TEST

Purpose: Determines fabric strength
Procedure: Fabric samples are subjected to force until they break and their resistance are recorded

4. PILLING & ABRASION RESISTANCE

Purpose: It evaluates the fabric's ability to abrasive and withstands friction without degrading
Procedure: Fabric should be placed in a pilling box for a set time and the degree of fabric damage is visually assessed

5. pH TEST

Purpose: Verifies the pH level of the fabric is skin-friendly
Procedure: Fabric samples are soaked in distilled water, and the pH of the extract is measured

6. FLAMMABILITY TEST

Purpose: Ensures the garment is flame resistant
Procedure: Fabric samples are exposed to a controlled flame, and the burn time is measured

4. CONCLUSIONS

In summary, the creation of a three-layered thermal onesie for preemies is a thoroughly researched solution to the thermoregulation requirements of premature babies in neonatal intensive care units (NICUs) and home settings. According to NICU guidelines, the garment is constructed to provide a neutral thermal environment, ensuring an appropriate tog value that is warm enough without the possibility of overheating. The thoughtful construction of fabrics, such as a moisture-wicking inner fabric, a middle layer that insulates with poly-fill, and an outer layer that is breathable, adds warmth regulation and comfort. The selection of Pantone colors, such as warm colors like cool gray, also provides psychological warmth and calming effects. The finishing techniques, such as hypoallergenic treatments and soft seam construction, provide skin safety and avoid irritation. Widely used thermal resistance tests, durability testing, and skin sensitivity testing prove that the garment does work. Thermally stable from research-informed design, reducing the need to rely on an external warmer and improving outcomes through better health care, the three-layered thermal onesie itself is a very important innovation for neonatal medical care that in practicality safely addresses the fragility of premature delicate thermal regulation requirements.

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DEVELOPMENT OF SMART STAB-RESISTANT ARMOUR WITH SHEAR THICKENING FLUIDS

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ABSTRACT
Stab-resistant armours are important protective gear for the law enforcement officers and security forces. This research attempts to develop stab-resistant armours for different impact energy levels using multi-layer neat and shear thickening fluid (STF) treated Kevlar® fabrics. The developed panels were tested using NIJ P1 knife at wide range of stabbing energy (from 6 J to 36 J). The panel containing 16 layers of STF-treated Kevlar® fabric met the requirements at normal and over-test conditions showing penetration depth lower than 7 mm and 20 mm, respectively. For stabbing at high energy level (≥ 24 J), the effect of number of Kevlar® fabric layers was found to be highly beneficial in case of STF-treated condition and not so for the neat ones. STF treatment reduced the stab penetration depth by 40-68% at 24-36 J energy level without any increase in effective weight of the panel. The fabric-knife interaction was also studied using a novel sharpness tester and optical microscopy. It was found that the tip of knife is deformed and sharpness declines at a faster rate in case of STF-treated fabric. The study opens up possibilities to explore other materials that would damage the tip of knife during stabbing ensuring better protection.

Keyword : - *Stab resistance, Kevlar®, Shear thickening fluid, NIJ 0115.00*

1. Introduction

In recent years, stab-resistant body armours are gaining importance in the field of protective clothing meant for bullet and stab protection. There are some fundamental differences between the bullet and stab impacts, and the researchers are working on various fabric structures and panel configurations based on high-performance fibres to make them efficacious against both. While the velocity of bullet impact is much higher than that of stab impact, the energy density is much higher in case of the latter. Besides, the fibres undergo cutting under compressive stress in case of a stab impact. Structures commonly used for ballistic protection like woven fabric or UD laminates may or may not be effective against stab. Moreover, high-performance fibre-based body armours are bulky in nature thus adding to higher weight or lower degree of protection. To enhance the level of protection, fabrics are often treated with shear thickening fluid (STF) or coated with protective polymeric films.

STF is a non-Newtonian fluid that shows an abrupt and discontinuous increase in viscosity beyond the critical shear rate changing the phase from liquid to solid. STF is a homogeneous dispersion of two distinct phases, the solid phase is called disperse phase and the liquid phase is called disperse medium [1,2]. Study suggests that STF-treated Kevlar® fabrics provided elevated performance against spike stabbing, as the spike got bent beyond 16 J impact energy. On the other hand, it marginally improved the knife stab resistance of the fabric. Later, several studies reported that STF-treated high-performance fabrics provide enhanced protection against spikes under both quasistatic and dynamic stabbing conditions [3–6]. The knife stab resistance of the STF-treated fabric is found to be dominated by the hardness of the silica particles used in STF. STF application on the fabric restricts the mobility of yarns inside the fabric, which in turn ensures that the knife cuts through the fabric. When delved deeper, it was realised that optimum add-on of STF can significantly improve the stab resistance performance [7,8]. Further studies suggest STF with a specific add-on % and larger particle size offers excellent energy absorption. Large particle size increases the peak viscosity and lowers the critical shear rate[8].

This study aims to fill these lacunae in extant literature by optimising the armour design for different energy levels, using multi-layer fabric panels and STF reinforcement, while also conducting a unique analysis of the damage profile of the knife.

1.1 Objectives

- Design an advanced, lightweight, flexible armour with excellent stab resistant performance.
- Enhanced stab protection with STF treatment at higher impact energies (24–36 J) with reduced panel thickness and weight compared to traditional multi-layered Kevlar®.
- Utilize hard silica particles in STF to induce tip and edge damage to attacking blades, improving multi-hit resistance.
- Establish an objective method to assess knife sharpness and its role in evaluating and optimizing stab-resistant performance.

2. Materials and methods

2.1 Materials and STF Treatment Method

This study used commercially available plain-woven Kevlar® 363 p-aramid fabric (areal density: 210 ± 5 g/m²). Silica (500 nm) ,PEG 200 and ethanol were used for STF. To prepare STF, silica was dried at 120 °C for 3–4 hours, then mixed with PEG 200 in a 65:35 (w/w) ratio. Ethanol (4x PEG volume) was added to reduce viscosity, followed by 20 minutes of ultrasonic sonication to form a milky white, homogeneous STF. For rheological testing, STF was heated at 80 °C to evaporate ethanol.

Fabric samples (30 cm × 30 cm) were treated using a padding mangle, passed twice under 3 bar pressure at 3 m/min speed. Treated samples were dried at 80 °C. STF add-on was calculated using:

Add-on (%) = $(S - N) / N \times 100$,

where S and N are the weights of treated and neat fabric, respectively.

An optimum STF add-on of 18–19% was maintained, as excessive add-on hindered performance. After treatment, the areal density of the fabric increased to 245–250 g/m².

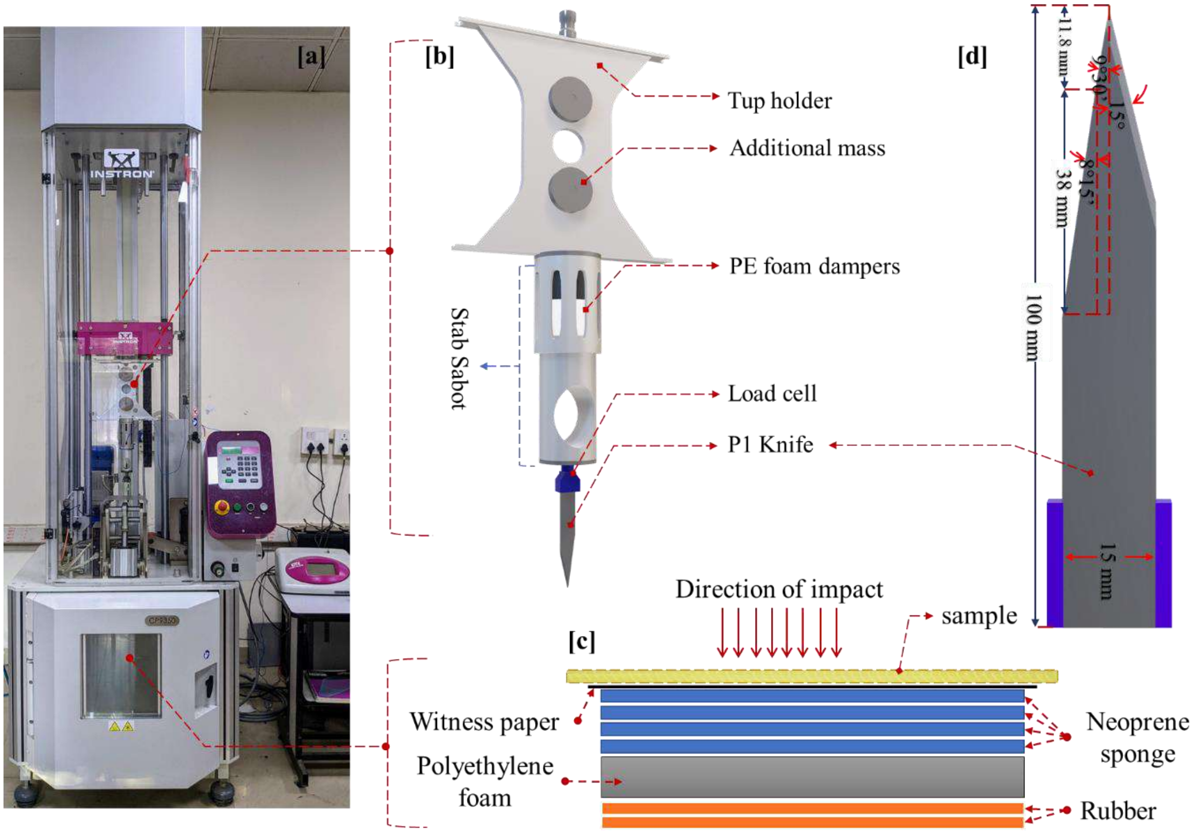

Figure 1: Dynamic stab resistance testing setup. (a) Drop-tower, (b) Tup holder with stab sabot, (c) Assembly of backing materials, (d) Design of NIJ 0115.00 P1 knife

2.2 Dynamic Stab Testing

Dynamic stab tests were conducted using the Instron® CEAST 9350 drop tower system (Figure 1). The 3.9 kg tup assembly was released from specified heights to achieve desired impact energies. Samples were mounted over a backing material comprising four neoprene foam layers, one closed-cell polyethylene foam layer, and two rubber layers. According to NIJ standards, protection levels are based on energy percentiles: Level 1 (85th), Level 2 (90th), and Level 3 (96th), with E1 (standard) and E2 (overtest) energy conditions. For compliance, penetration must not exceed 7 mm (E1) and 20 mm (E2). This study targeted Level 1 protection, using impact energies of 6, 12, 18, 24, 30, and 36 J. For 24 J, the tup was dropped from 0.627 m at 3.51 m/s. Five tests were performed per energy level. After each drop, the back of the sample was photographed, and cut lengths were measured using ImageJ® software. Penetration depth was then determined using the NIJ 0115.00 conversion table.

2.3 Assessment of Knife Sharpness and Damage

After each stabbing, the knife's tip and edge deform, reducing sharpness. To evaluate this, the edge geometry was examined using an optical microscope, and sharpness was measured with a proprietary tester[9]. The tester functions like a sensitive balance, measuring the force (gf) required to cut a standard monofilament yarn—less force indicates a sharper blade. Standard knives were tested under dynamic stabbing conditions against both neat and STF-treated Kevlar® fabrics, using 20-layer panels. Each scenario was repeated four times. Knife sharpness and tip geometry were recorded before testing and after the 2nd, 4th, 6th, and 8th stabs using the sharpness tester and microscope, respectively, to assess progressive blade damage.

3. Results and discussions

3.1 Dynamic stab resistance

Dynamic stab resistance of neat Kevlar® fabric samples was measured in terms of penetration depth of the knife. The graphical representation of penetration depth vs. number of layers (8, 12, 16 and 20) for neat Kevlar® samples is shown in Figure 2(a). It can be observed that at lower energy levels (6 J or 12 J), the penetration depth is drastically reduced with the increase in the number of layers. Considering the 6 J energy level, the penetration depth is 25 mm for 8 layers and it is reduced to 5 mm for 20 layers. However, for 18 J impact energy and beyond, the scenario is quite different as it is found that the role of number of fabric layers is diminishing. For example, for 30 J impact energy level, 8 layer panel shows an average penetration depth of around 30 mm, i.e., the knife totally perforates the structure. Similarly, for 20 layered panel, the penetration depth is around 25 mm, which is well above the permissible limit.

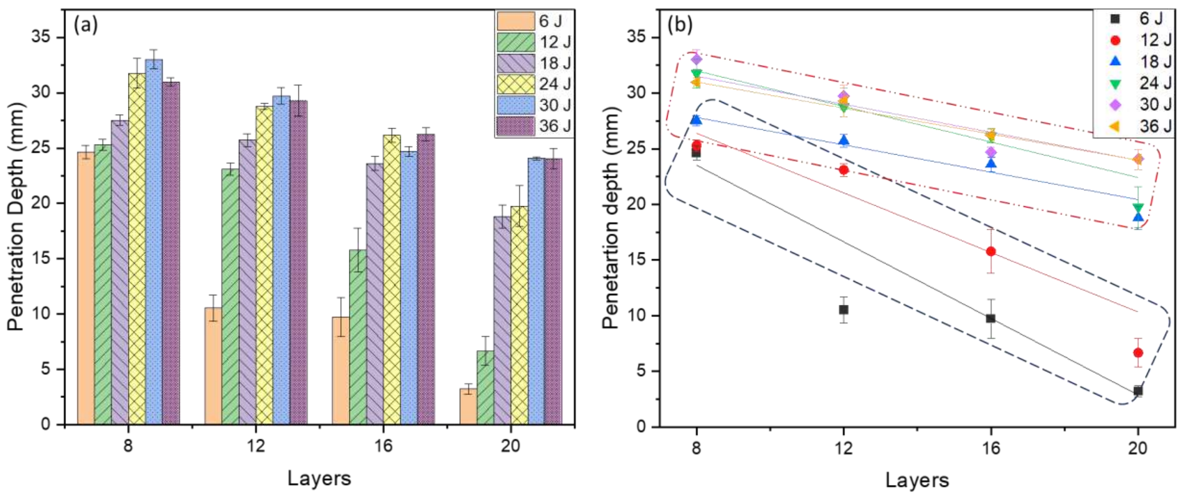

Figure 2: (a) Penetration depth for neat Kevlar® panels, (b) Linear fit of penetration depth

For a better understanding, linear fitting of the data points (penetration depth vs number of fabric layers at different energy levels) was done, as depicted in Figure 2(b). The regression equations and the coefficient of determination (R2) values are listed in Table 1, where y implies penetration depth and x implies number of fabric layers.
It is noted from Table 4 that two distinct ranges of slopes are present. At lower energy level (6-12 J), the slope is steeper (-1.58 to -1.63), signifying a pronounced effect of number of layers in reducing penetration depth. In contrary, at higher energy levels, i.e., beyond 18 J, the slope is much lower (-0.60 to -0.97), indicating that the effect of number of layers is becoming less effective.

Table 1: Linear regression showing the effect of number of fabric layers on penetration depth

Energy level (J)	Regression equation	Coefficient of determination (R2)
6	y = -1.625 x + 34.77	0.87
12	y = -1.578 x + 39.81	0.94
18	y = -0.706 x + 33.80	0.94
24	y = -0.966 x + 40.13	0.95

30	y = -0.796 x + 39.02	0.93
36	y = -0.597 x + 35.98	0.99

To resist knife penetration, a fabric must either absorb impact energy through deformation or damage the knife's edge. Upon contact, the knife indents the surface, displaces yarns, and applies a concentrated load. Primary yarns decrimp and attempt to resist penetration, while inter-yarn friction helps spread the force. However, Kevlar® fabric, with low inter-yarn friction, fails to distribute load effectively. As impact energy increases significantly (e.g., from 6 J to 24 J), the localized force exceeds the fabric's resistance, allowing penetration. Thus, simply adding layers is inadequate at high energies, highlighting the need for alternative solutions, as discussed in the next section.

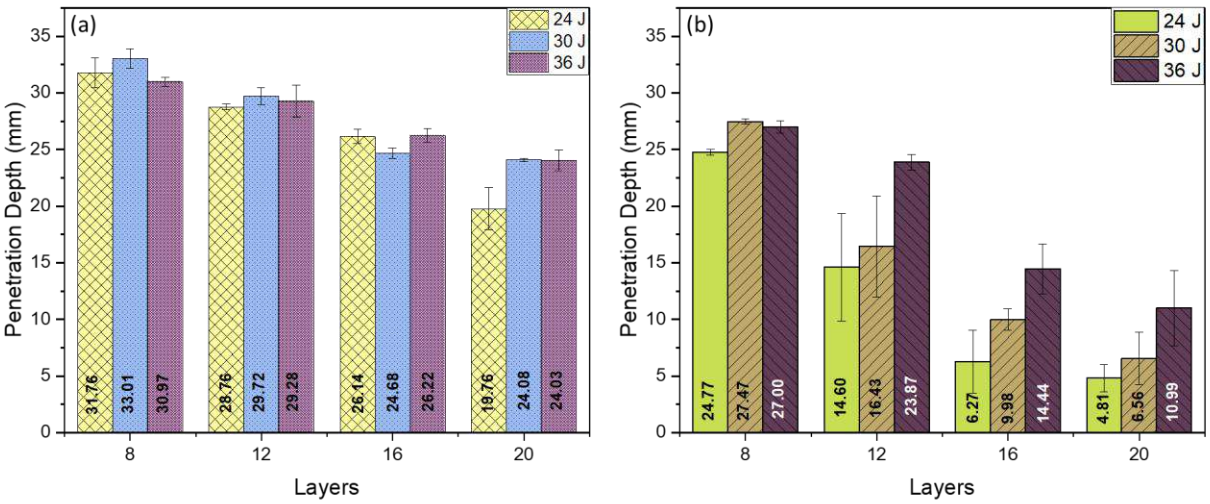

Figure 3: Comparison of penetration depth (a) neat panels (b) STF-treated panels

To address the limitations of neat fabric panels, STF-treated panels were tested at higher impact energies (24–36 J), where neat fabrics showed diminishing effectiveness. As shown in Figure 3, STF treatment significantly reduced penetration depth, especially in 16- and 20-layer panels. For instance, at 24 J, penetration dropped from 19.76 mm to 4.81 mm in 20-layer panels. A 16-layer STF-treated panel also met the NIJ 0115.00 limit of 7 mm. Under elevated energy (36 J), STF-treated panels with 16 and 20 layers maintained penetration depths of 14.44 mm and 10.99 mm, respectively—both within acceptable safety thresholds.

Figure 4 illustrates the stabbing response of neat and STF-treated Kevlar® fabrics. In neat fabrics, the knife applies a concentrated load on primary yarns, leading to localized failure due to low inter-yarn friction. In contrast, STF-treated fabrics engage secondary yarns, enhancing load distribution and structural integrity. Silica particles in the STF increase inter-yarn friction and form hydro clusters under shear, momentarily solidifying and bridging yarns to dissipate energy over a wider area. Additionally, with a Vickers hardness of 1140–1240, silica particles can blunt the knife's edge (hardness 480–500), hindering penetration and improving stab resistance.

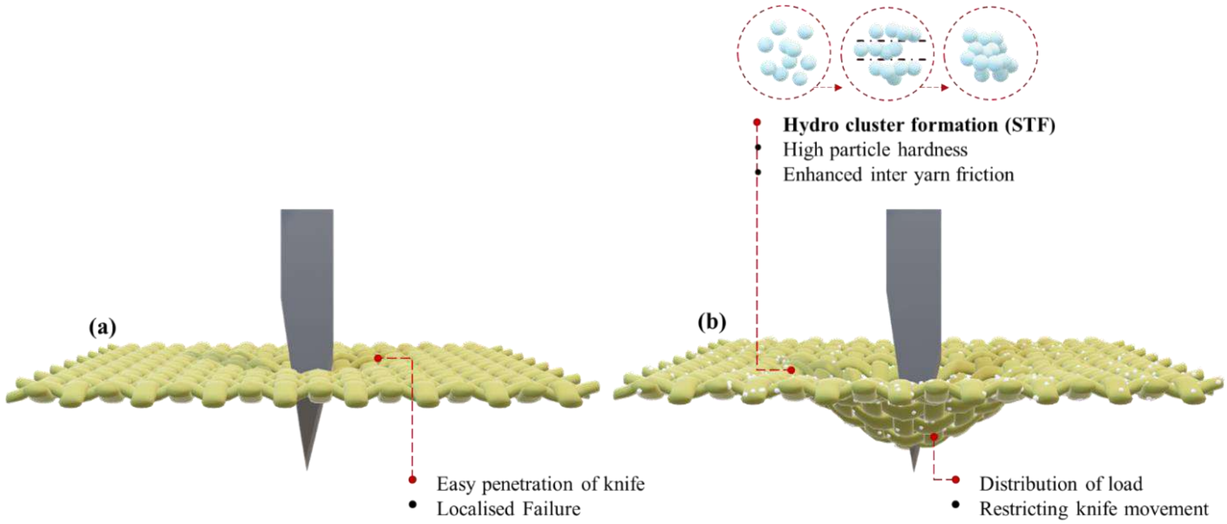

Figure 4: Schematics of dynamic knife stabbing (a) neat fabric (b) STF-treated fabric

3.2 Knife Sharpness Degradation After Repeated Impacts

Figure 5(a) illustrates the change in knife sharpness over multiple stabbings for neat and STF-treated Kevlar® panels. Initially, both knives had similar sharpness, requiring 449 gf (neat) and 433 gf (STF-treated) to cut a monofilament. In neat Kevlar, a gradual increase in cutting force indicates minimal damage to the knife edge. In contrast, STF-treated panels caused a sharp decline in sharpness—a 71% increase in cutting force (to 741 gf) after just two impacts. The gap between cutting forces for neat and STF-treated samples widened with each impact, reaching 796 gf and 1121 gf, respectively, after eight stabs—almost twice and thrice the initial values. This demonstrates that hard silica particles in STF blunt the knife tip and edge, enhancing protection. Optical images in Figure 5(b) confirm visible tip damage, including bending or complete deformation, especially after 2–3 impacts on STF-treated panels. These results highlight STF-treated Kevlar's superior performance in repeated stabbing scenarios, mimicking real-life knife attacks.

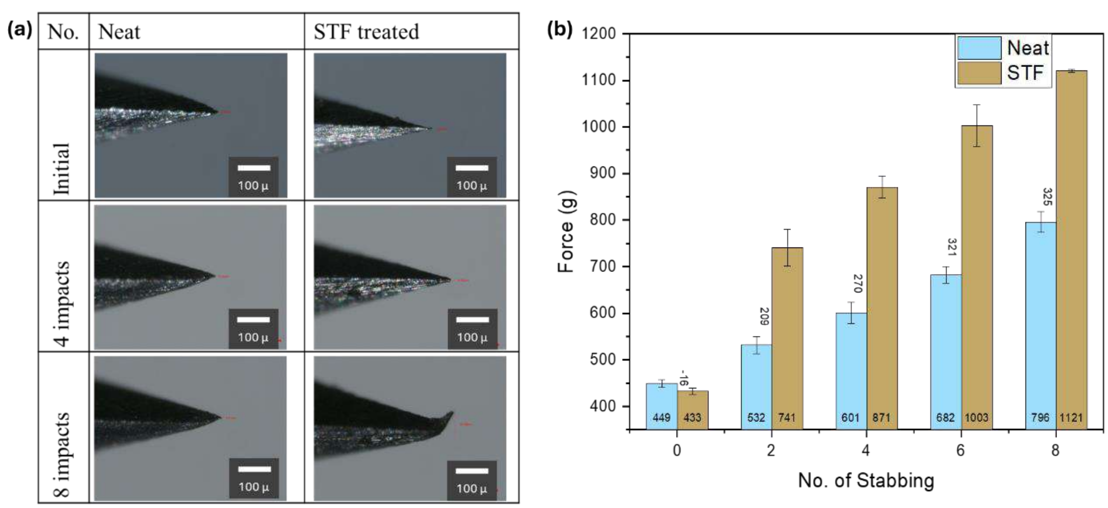

Figure 5: (a) Deformation of the knife tip for neat and STF-treated panels, (b) Increase in filament cutting force after stabbing

4. CONCLUSIONS

Stab resistant armour panels have been developed by using STF-treated Kevlar fabrics for a wide range of energy levels spanning rom 6 J to 36 J. The results highlight the limitations of panels prepared by stacking multiple layers of neat Kevlar fabric specially at high energy levels. While increase in the number of layers of neat fabric is efficacious in reducing the penetration depth at low energy level (up to 12 J), this strategy becomes ineffective at high energy level. STF-treated Kevlar fabric panels yield much lower penetration depth even at higher energy levels (24-36 J). Panel containing 16 layers of STF-treated fabric meets the NIJ specified penetration depth of 7 mm and 20 mm at 24 J and 36 J energy levels, respectively. Analysis of knife sharpness and tip geometry during dynamic stabbing reveals that the high hardness of the silica particles induces additional damages to the knife tip and cutting edge causing better stab resistance by the STF-treated Kevlar fabric panels. While comparing the weight vs stab resistance, it is found that STF-treated panels are lighter while they yield lesser (40-68%) penetration depth than their neat counterparts. This paper presents an objective method to quantify the knife sharpness that plays a decisive role in influencing the stab resistance. The effect of material-knife interaction on the damage of the knife has also been elucidated, paving the way for further development.

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DESIGN AND DEVELOPMENT OF FUSIBLE INTERLINING USED IN GARMENT

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Abstract
This paper focuses on the design and development of fusible interlining used in waistcoats. Fusible interlining provides stability, shape, and durability to garments. The study evaluates different fabric blends and weaves to determine optimal combinations for water repellency, breathability, and wearer comfort. Tests conducted include air permeability, bending modulus, water repellency, wicking, and thermal insulation value (TIV). Results indicate that a 50-50% polyester-cotton blend offers the best performance for formal wear applications.
Keywords—Fusible interlining, garment technology, thermal insulation, water repellency, fabric structure

I. Introduction

In the garment industry, fusing is an essential technique used to bond two layers of fabric together through the application of heat and pressure. This process commonly involves fusible interlining, a material with an adhesive coating on one side that melts when heated, enabling it to bond seamlessly with the fabric. The primary purpose of interlining is to enhance the garment's structure, stability, and insulation. It is typically positioned between the outer shell and the inner lining of the garment, ensuring the fabric maintains its desired shape and durability. This makes fusing a critical step in garment construction, especially in modern manufacturing processes.

Interlining can be classified into two main types: sew-in and fusible interlining. Sew-in interlining is stitched onto the fabric and is predominantly used in tailored garments where precision and exact shaping are necessary, such as formal suits and coats. On the other hand, fusible interlining has gained popularity due to its convenience and efficiency. With its adhesive layer, it bonds to the fabric quickly when heated, eliminating the need for stitching. Fusible interlining is commonly used in collars, cuffs, waistbands, and lapels to provide a defined structure and support. It also strengthens buttonhole areas and stabilizes lightweight fabrics, ensuring durability and a polished appearance. Additionally, fusible interlining is widely applied in accessories such as bags and hats, contributing to their strength and consistency.

Beyond enhancing garment structure, interlinings and fabrics play a vital role in ensuring thermal comfort for the wearer. Clothing serves as a barrier between the body and the external environment, helping to regulate temperature and manage factors like humidity and air movement. Fabrics with properties such as thermal resistance, water-vapor resistance, and air permeability significantly influence the comfort level of clothing. Thermal resistance determines how well the fabric retains heat, water-vapor resistance allows moisture to escape, and air permeability facilitates proper airflow. Together, these attributes ensure that garments not only look and fit well but also provide optimal comfort in varying environmental conditions, making them functional as well as aesthetically pleasing.

II. Objectives

1. Study commercially available fusible interlinings.
2. Manufacture base fabrics with varying structures.

3. Develop fusible interlinings and characterize them.
4. Compare developed interlinings with commercial ones to determine optimal parameters.

III. Methodology

1. Study on available fusible interlinings
2. Raw material procurement
3. Testing of yarn properties
4. Manufacturing Process
5. Testing of base fabric
6. Application of adhesive
7. Fusing
8. Testing required for fusible interlining

1. Study on Available Fusible Interlinings

The study began with sourcing commercially available fusible interlinings and examining their fabric structure. Key characteristics such as Ends Per Inch (EPI), Picks Per Inch (PPI), Grams per Square Meter (GSM), and the weave pattern were analyzed. Understanding these elements helped in evaluating the quality and performance of the interlining, providing a basis for comparison and the development of a customized version.

2. Raw Material

Raw materials, such as 100% polyester yarn with a count of 30s Ne, were procured from Shri Talmavuli Yarn Agency Vikarsnagar, Ichalkaranji. Fabric manufactured with specific parameter such as different weave and fabric composition from Prashant Textiles, Ichalkaranji. Adhesives such as chloroform were sourced from India MART and 3D printing waste (PLA) from DKTE Idea lab.

3. Testing of Yarn

Several key tests were conducted on the polyester yarn to evaluate its performance and quality. The polyester yarn was tested for tensile strength to assess its durability under tension, elongation to measure its stretchability and elasticity, and shrinkage to determine its stability after washing or heat exposure. These tests ensured that the yarn met performance and quality standards.

4 Manufacturing of base fabric

The design and development of fusible interlining involve using different base fabrics with various weaves like plain, twill, and sateen. These base fabrics are made from different compositions including 100% polyester, 100% cotton, and polyester cotton (PC) blends in ratios of 60:40, 40:60, and 50:50.

Table I: Tests details for fusible interlining

Sr. No.	Test	Instruments	Standards
1	Bond strength	Universal Testing Machine	ASTM D638, ISO 527
2	MVTR	MVTR Testing Apparatus	ASTM E96, ISO 2528
3	WVTR	WVTR Testing Apparatus	ASTM E96, ISO 2528
4	TIV	Tensile Impact Tester	ASTM D4812, ISO 180
5	Air Permeability	Air Permeability Tester	ASTM D737, ISO 9237
6	Bending Length	Cantilever Test Apparatus	ASTM D790, ISO 178
7	Abrasion Resistance	Martindal Abrasion Tester	ASTM D1044, ISO 5470
8	Thickness	Thickness Gauge	ASTM D1777, ISO 5084

IV. Results and Discussion

The 100% cotton satin fabric exhibited the highest air permeability, indicating better breathability. The 60-40% PC twill showed the highest bending modulus, ensuring strong structural support. The 50-50% PC blend showed a balanced profile of thermal comfort, water repellency, and flexibility. Thus, it is suitable for waistcoat applications.

V. Conclusion

This study highlights the impact of fiber composition and weave structure on fabric properties. Cotton-rich fabrics offer comfort, while polyester blends improve durability and wrinkle resistance. The choice of weave further influences the texture, strength, and visual appeal of the fabric. These findings provide valuable insights for textile manufacturers in selecting suitable fabric compositions for various applications in fusible interlining. Developing fusible interlining with the right blend and weave significantly improves garment comfort and functionality. The 50-50% PC blend, especially with twill or satin weave, delivers superior performance across parameters and is ideal for formal garments like waistcoats.

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RECYCLING OF TEXTILES AND DEVELOPMENT OF UTILITY PRODUCTS.

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ABSTRACT

This paper explores the development of eco-friendly flat panels using recycled textile waste as the primary material. With growing concern over the environmental impact of textile waste, this initiative aims to create sustainable alternatives to conventional materials like plywood. The process begins by shredding textile waste into smaller fibers, which are then blended with a natural adhesive made from tamarind kernel seed powder and distilled water. The adhesive not only binds the fibers but also enhances the panels' strength and durability. To achieve uniformity, the blended material is compressed using a hydraulic press, ensuring a consistent density and eliminating air pockets. The panels are then cured under controlled conditions to enhance their structural integrity, making them suitable for a variety of applications, such as furniture and construction. These flat panels offer numerous advantages, including cost-effectiveness, sustainability, and versatility, without compromising on quality or functionality. By reusing textile waste and relying on natural, biodegradable materials, the project not only minimizes environmental harm but also contributes to a circular economy. This study demonstrates the potential of innovative recycling processes to address pressing waste management issues while offering practical and scalable solutions for a greener future.

Keywords: *Textile waste recycling, eco-friendly flat panels, sustainable materials, tamarind kernel seed adhesive, hydraulic pressing, curing process, alternative to plywood, waste management, circular economy, sustainable innovation*

1.INTRODUCTION

The accumulation of textile waste has become a pressing global concern, with millions of tons discarded annually, much of it ending up in landfills or incinerators. This waste not only occupies valuable space but also releases harmful pollutants, posing significant risks to the environment. Recognizing the urgency of addressing this issue, this project aims to repurpose textile waste into eco-friendly flat panels, offering a sustainable alternative to conventional materials such as plywood. Flat panels are widely used in industries like furniture and construction due to their versatility and durability. However, their traditional production often involves non-renewable resources and environmentally damaging processes. By utilizing textile waste as a raw material and incorporating natural adhesives like tamarind kernel seed powder, this project adopts a sustainable approach to manufacturing. The production process involves shredding textile waste into smaller fibers, blending it with an adhesive mixture, and compressing it using a hydraulic press to form uniform panels. These panels are then cured under controlled conditions, ensuring enhanced strength and durability for diverse applications. This initiative not only addresses the environmental challenges posed by textile waste but also promotes sustainable manufacturing practices. By turning discarded textiles into valuable products, the project demonstrates how innovation can drive environmental and economic benefits. It serves as a step forward in rethinking resource utilization and supporting a circular economy where waste becomes a resource for creating sustainable solutions.

2. LITERATURE REVIEW

1. Cobb and Cao (2022) explore innovative methods to transform textile waste into utility products like tufted fabrics, toys, and quilts. Their study emphasizes the environmental benefits of diverting waste from landfills by using remanufactured textiles. They also integrate community awareness campaigns and sustainability education into their work. This holistic approach aligns with reducing the fashion industry's environmental footprint

2. Koszewska (2018) investigates the implementation of circular economy principles in the textile sector to reduce waste and create sustainable products. The study identifies challenges in adopting recycling technologies but highlights the potential for resource optimization. It provides insights into the systemic change required for closing the material loop. Circular design and collaboration emerge as key enablers of sustainability

3. Shen and Patel (2020) perform a life-cycle assessment of textiles recycled into utility products, noting significant reductions in emissions and resource usage compared to virgin production. Their analysis highlights the environmental advantages of creating durable goods from waste. The study advocates for scaling up recycling technologies to mainstream sustainable practices. It emphasizes measurable environmental savings

4. Khan and Khan (2021) explore advancements in recycling textile waste into composite materials and industrial textiles. They focus on innovations that add value to recycled products, making them competitive with conventional materials. The research underscores economic feasibility and environmental benefits. Practical applications include automotive, furniture, and construction sectors

5. Kulshreshtha and Sharma (2023) present strategies to recycle textile waste into functional utility products, focusing on resource conservation and profitability. They assess consumer demand for eco-friendly goods and the scalability of manufacturing processes. The study provides a roadmap for integrating recycled products into the market. It highlights industry collaboration to achieve sustainability goals

6. Woolridge (2006) evaluate the use of recycled textiles in insulation and carpeting, demonstrating a reduction in landfill waste. They highlight cost benefits alongside environmental advantages, emphasizing large-scale applications. Their work encourages industry partnerships to adopt recycling solutions. It bridges the gap between waste management and product development.

7. Zamani (2015) discuss the environmental impact of textile recycling, particularly in reducing virgin material use and landfill dependency. Their study provides evidence of energy savings and emission reductions achieved through recycling. It encourages industry adoption of closed-loop systems. The findings support scaling up recycling efforts for sustainability.

8. Radhakrishnan and Desai (2020) focus on creating bio-composites from textile waste, offering insights into sustainable material innovation. Their work highlights the versatility of recycled fibers in product design. The study identifies potential industrial applications of bio-composites. It promotes eco-friendly alternatives for mainstream manufacturing.

9. Sandin and Peters (2018) explore recycling technologies for polyester and cotton blends, highlighting their environmental and economic benefits. They advocate for mechanical and chemical recycling to reduce raw material dependency. The study identifies barriers to adoption, such as cost and process efficiency. It calls for policy interventions to incentivize recycling.

10. Wang (2010) examines challenges in post-consumer textile recycling, including collection inefficiencies and lack of technological infrastructure. The study offers solutions such as decentralized recycling systems and public awareness campaigns. It emphasizes market potential for recycled textiles in consumer goods. Collaboration across industries is presented as a critical factor for success.

3. MATERIALS

<u>Tamarind Kernel Seed Powder</u>

Tamarind kernel seed powder is a versatile and high-demand product, extensively used across various industries such as textiles, adhesives, food, and pharmaceuticals. The manufacturing process involves several critical steps that transform tamarind seeds into a fine, high-quality powder with consistent properties.

The production process begins with the cleaning stage, where raw tamarind seeds are thoroughly washed to remove dirt, dust, and other impurities. This ensures a clean raw material free from contaminants.

Next, the cleaned seeds undergo roasting in specially designed ovens or furnaces. Roasting serves a dual purpose: it reduces the seeds' moisture content to an optimal level and loosens the hard outer seed coat, facilitating efficient processing. The roasting temperature and duration are carefully controlled to preserve the seed kernel's quality.

Following roasting, the seeds are subjected to a dehulling process, where the outer seed coat is mechanically separated from the inner kernel. Advanced dehulling machines ensure minimal kernel loss while efficiently separating the husk. The outer husk is discarded, and the extracted kernels are collected for further processing.

The kernels are then processed in two grinding stages. Initially, they are subjected to coarse grinding, breaking them into smaller granules. These granules are further refined through pulverization, resulting in a finely ground powder with uniform consistency suitable for industrial applications.

From 1 kilogram of raw tamarind seeds, approximately 60–65% of the weight constitutes the kernel after dehulling. This means that about 600–650 grams of kernel can be extracted per kilogram of seeds, depending on the seed quality and dehulling efficiency.

During the grinding and pulverization process, the weight of the final tamarind kernel seed powder is slightly reduced due to minor losses (such as dust and residue in equipment). From 1 kilogram of tamarind kernel, approximately 90–95% of the kernel weight is converted into usable powder. Thus, from 1 kilogram of tamarind seeds, one can expect to produce approximately 540–620 grams of tamarind kernel seed powder.

The fine powder produced is highly valued for its binding and thickening properties. Tamarind kernel seed powder acts as a natural adhesive, making it an integral component in creating sustainable flat panels from textile waste. Its eco-friendly nature, coupled with excellent performance characteristics, makes it an ideal choice for environmentally conscious manufacturing processes.

Distilled Water

Distilled water is a highly purified form of water obtained through the process of distillation. The process involves heating water to its boiling point, which converts it into steam. This steam rises, leaving behind impurities, minerals, and contaminants. The steam is then collected and condensed back into a liquid form, resulting in distilled water that is free from dissolved solids, organic impurities, and microorganisms. Distilled water is characterized by its high purity, making it an excellent medium for various applications requiring the absence of contaminants. It is odorless, tasteless, and neutral in pH, making it suitable for use in industries where chemical reactions or product consistency can be affected by impurities. Distilled water plays a critical role as a hydrating agent. When mixed with other materials like tamarind kernel seed powder and textile waste, distilled water ensures uniform hydration of the fibers and adhesive. This uniformity is essential for achieving the desired dough-like consistency of the blend. The use of distilled water is advantageous because its impurity-free nature prevents undesirable chemical reactions or weakening of the adhesive bond during blending and curing processes. It facilitates smooth mixing and enhances the bonding capabilities of the tamarind kernel seed powder. The resulting dough acts as the foundational mixture for creating robust and durable flat panels. When distilled water is added to the tamarind kernel seed powder, it initiates a reaction that activates the adhesive properties of the powder. The water molecules interact with the natural starches and gums present in the tamarind kernel, forming a thick, cohesive paste. This paste binds the shredded textile fibers effectively, creating a uniform blend that can be shaped and pressed into panels.

The precise amount of distilled water used is critical to achieving the right consistency. Insufficient hydration can lead to a dry, uneven mixture, while excessive water may weaken the adhesive bond and extend the curing time.

Benefits of Using Distilled Water

1. Consistency: Its impurity-free nature ensures predictable and repeatable results in the blending process.
2. Enhanced Adhesion: By enabling a strong bond between the adhesive and textile fibers, it contributes to the structural integrity of the flat panels.
3. Improved Durability: The absence of contaminants helps prevent weakening of the adhesive over time, enhancing the longevity of the final product.
4. Eco-friendliness: Distilled water aligns with the project's sustainable approach, avoiding potential issues that can arise from impurities in untreated water.

Curing Agent (Lime Adhesive)

The curing agent used in this project is a lime-based adhesive, which plays a critical role in transforming the adhesive mixture from a liquid or semi-liquid state into a solid, durable material. Lime adhesive is well-regarded for its binding properties and its ability to form strong, long-lasting bonds in a relatively short time. Lime adhesive is derived from calcium hydroxide (slaked lime) and often includes other additives to enhance its reactivity and binding strength.

When combined with water, lime undergoes a chemical reaction known as carbonation, where it reacts with atmospheric carbon dioxide to form calcium carbonate. This reaction strengthens the adhesive over time, creating a robust bond between the fibers and other components of the mixture.

Key properties of lime adhesive include:

- Fast setting: Lime adhesive rapidly transitions from a liquid to a solid state, significantly reducing curing time.
- High bonding strength: The chemical reaction enhances the adhesive's ability to bind fibers effectively.
- Eco-friendliness: Lime is a natural, biodegradable material, aligning with sustainable production goals.
- Durability: The bonds formed are resistant to cracking and provide long-term stability.

In the production of flat panels, the lime adhesive acts as a curing agent, initiating the chemical reactions necessary to solidify the mixture of textile waste and tamarind kernel seed powder. When the mixture is subjected to hydraulic pressing and subsequently cured, the lime adhesive ensures:

1. Quick setting: The adhesive mixture solidifies rapidly, allowing for efficient production cycles.
2. Improved strength: The chemical bonding between fibers and adhesive creates a dense, durable structure.
3. Enhanced durability: The resulting panels exhibit excellent resistance to wear and deformation, suitable for applications in furniture and construction.

The curing process involves maintaining the panels under controlled conditions to allow the adhesive to set completely. Once the panels are formed and pressed, they are transferred to an electric curing chamber. Here, the controlled temperature and humidity accelerate the curing process, facilitating the complete carbonation of lime adhesive. This step ensures that the panels reach their maximum strength and stability, preparing them for trimming and finishing.

<u>Textile Waste:</u>

Textile waste is broadly categorized into pre-consumer waste (generated during manufacturing, like fabric scraps) and post-consumer waste (discarded by users, like old garments). The recycling process begins with the collection of these wastes from factories, households, and industries.

1. Sorting:

Textile waste is sorted based on material type (such as cotton, polyester, wool, etc.) and color. This helps reduce the need for dyeing during the recycling process, making it more efficient and environmentally friendly.

2. Fastener Removal:

Items like buttons, zippers, and hooks are removed from the textiles. These fasteners are made of materials like metal or plastic, which need to be separated from the fabric to avoid contamination during recycling.

3. Storage:

The sorted and cleaned textile waste is stored in designated areas. Proper storage ensures that the materials are kept in good condition and ready for further processing when needed.

Shredding Machine:

The shredding machine plays a crucial role in the textile recycling process, as it helps break down textile waste into smaller, more manageable pieces or fibers. This is an essential step for preparing the material for further processing, such as fiber regeneration, repurposing, or conversion into new products. Here's a more detailed look at how shredding works in textile recycling:

Shredding machines are designed to cut and tear fabric into smaller fragments or fibers. These machines come in different designs and use various cutting mechanisms, depending on the material type and desired output. Some common shredding technologies include:

- Rotary Cutters: These shredding machines use rotating blades to cut the fabric into pieces. The rotary cutters work by pushing the fabric through a series of sharp blades that rotate at high speeds. The fabric is fed into the machine, and the rotary cutters slice it into smaller pieces or strips.

- Blade Systems: In blade shredders, fixed or rotating blades are used to shear the fabric apart. The blades are set at specific angles, which help achieve a clean and consistent cut. These machines are more suitable for fabrics with moderate thickness or those that require a precise shredding result.

The first step in the shredding process typically reduces the fabric to pieces approximately 2 inches in size. This size is a common starting point for most textile recycling operations, as it allows for efficient handling and further processing.

- The material may still retain its original shape, with some larger pieces remaining intact, but it has been sufficiently broken down to allow for more detailed recycling or repurposing.

Once the material has been shredded into larger pieces, it may be subjected to further shredding, depending on the intended end-use of the processed waste. Additional shredding can break the material down into smaller sizes, ranging from small fibers to tiny fragments.

- The finer the shredding, the more versatile the material becomes for applications like fiber regeneration, making new yarns, or creating nonwoven fabrics. For instance, when the fabric is shredded into finer particles, it can be used for products like insulation, padding, or as filler material for new products.

- The level of shredding required often depends on the specific requirements of the recycling process or the type of product that will be created. For instance, if the end product is intended to be spun into new yarn, the fabric may need to be shredded into smaller pieces or fibers.

Shredding is one of the first critical steps in textile recycling, as it breaks down large pieces of waste into smaller, uniform components that can be further processed into new products. The quality of the shredded material is essential for the subsequent stages of recycling, as it influences the efficiency and output of the entire recycling process. It also helps to ensure that the material is suitable for its intended application, whether that's creating new fibers, fabric, or other textile-based products.

In conclusion, shredding is a vital process in textile recycling that prepares the material for further treatment. The size and quality of the shred depend on both the characteristics of the textile waste and the end-product requirements, making it a versatile and crucial step in the circular economy of textiles.

<u>Hydraulic Presser:</u>

Hydraulic compression is a process that uses hydraulic systems to apply force to materials, typically through a press or other mechanical system. In textile processes, hydraulic compression plays a vital role in shaping, compacting, or bonding materials by applying consistent and controlled pressure.

a. Uniformity:

Hydraulic compression provides a consistent force across the entire surface area of the material being processed. This uniform application is crucial for processes like fabric compaction (reducing thickness) or lamination (bonding layers of fabric). By ensuring an even pressure distribution, hydraulic systems prevent inconsistencies such as wrinkles, uneven thickness, or non-uniform bonding, leading to more reliable and high-quality outcomes in textile products.

b. Precision:

One of the key advantages of hydraulic compression is the precision it offers. Hydraulic presses allow for highly accurate control over the compression process, ensuring that the required force is applied in a repeatable manner. This is particularly important for achieving consistent product quality in processes that require specific thickness, densities, or shapes. For example, in fabric lamination or textile molding, precision ensures that each batch meets the same specifications, reducing defects and improving manufacturing efficiency.

Hydraulic compression is an effective and versatile method in textile manufacturing, providing uniformity, versatility, and precision to ensure high-quality, consistent, and repeatable results in a wide range of textile processes.

<u>Blender:</u>

The blender is responsible for mixing textile waste with tamarind kernel powder to create a uniform dough-like mixture. The tamarind kernel powder, acting as a natural binder, is evenly distributed throughout the textile fibers during the blending process. The blender applies mechanical force to thoroughly combine the materials, ensuring that the powder and fibers are uniformly mixed. This results in a smooth, consistent texture that allows the mixture to be easily molded into flat panels. The blender's function is critical, as it ensures the dough has the right consistency for shaping and forming, making it the first step in creating durable, eco-friendly products from textile waste.

<u>Perforated Sheet:</u>

A perforated sheet is often used in the textile or manufacturing industry during the curing process to prevent deformation of the product. The perforations allow air circulation and ensure even heat distribution during curing, which helps maintain the shape and structure of the product. This is especially important when curing adhesives, coatings, or materials that require precise temperature control. By preventing the buildup of excessive moisture or heat in specific areas, perforated sheets help avoid warping, bubbling, or other forms of deformation that could compromise the quality of the final product.

3.1 Methodology

Once the fabric is prepared, it is fed into a fabric shredding machine. This machine cuts the fabric into smaller pieces or strips. The size and shape of the shredded fabric can vary depending on the specific recycling requirements or end products.

Blending:

In the blender, textile waste, distilled water, and lime adhesive are added to create a uniform mixture. The process begins with adding the textile waste (such as shredded fabric or fibers) into the blender. Distilled water is then added to hydrate the textile fibers, facilitating easier blending and helping to form a cohesive mixture. The lime adhesive (or any binder) is incorporated to bind the fibers together, enhancing the consistency and strength of the blend. The blender mixes these components evenly, ensuring a smooth, uniform mixture, they form like a dough-like structure.

Calculate the adhesive amount:

If fabric weighs 100 grams, the calculation would be 200 grams of adhesive.

Hydraulic Press:

Once the blended dough (made from textile waste, distilled water, and lime adhesive) reaches the desired consistency, it is placed into a hydraulic press. The hydraulic pressure applies force to compress the mixture, ensuring an evenly spread panel. This process helps the dough take a uniform shape and density, eliminating air pockets and ensuring consistency throughout the panel. The high pressure also improves the bonding between the fibers and the adhesive, creating a solid and durable composite material. Once pressed, the panel is typically cured to further strengthen the structure.

Perforated Sheet:

After the blended dough is pressed into a panel using the hydraulic press, it is placed on a perforated sheet. The perforated sheet allows for air circulation and even heat distribution during the curing process. This step is crucial to prevent the panel from deforming or warping, as the perforations help maintain an even temperature and moisture level throughout the panel. The perforated sheet ensures that the panel maintains its shape and structure as it cures, resulting in a consistent, high-quality final product.

Curing Process:

After the panel is placed on the perforated sheet, it is transferred to an electric chamber for curing. The chamber provides a controlled environment with consistent temperature and humidity, essential for the curing process. The panel is left to cure for 48 hours, allowing the adhesive to fully set and bond the fibers together. This curing time ensures that the panel reaches its maximum strength, stability, and durability. The electric chamber helps maintain optimal conditions, preventing any deformation or shrinkage during the curing process and ensuring a high-quality, finished composite panel.

Trimming:

After the curing process in the electric chamber, the panel is fully set and ready for shaping. It is carefully removed from the chamber and trimmed into the desired shapes such as square, rectangle, or circle using precision cutting tools. This allows the panel to be customized for different applications and products. The trimming process ensures uniformity and smooth edges, making the panel suitable for various uses, such as in construction, furniture, or eco-friendly products. The final, shaped panels maintain the strength and stability gained during the curing process.

Finishing:

After the panel is trimmed into the desired shapes, it undergoes a finishing process to enhance its appearance and overall quality. This process typically involves:

1. Surface Smoothing: The panel's surface is smoothed using sandpaper or polishing machines to eliminate rough edges and imperfections, ensuring a smooth, even finish.

2. Application of White Putty: A layer of white putty is applied to fill any minor cracks or uneven areas, ensuring a uniform surface. This step also helps improve the overall texture of the panel.

3. Painting: After the putty has dried, the panel is painted to enhance its aesthetic appeal. The paint provides a protective coating that further strengthens the panel's surface, giving it a clean, polished look.

This finishing process ensures that the final panel is visually appealing, durable, and ready for its intended use in various products.

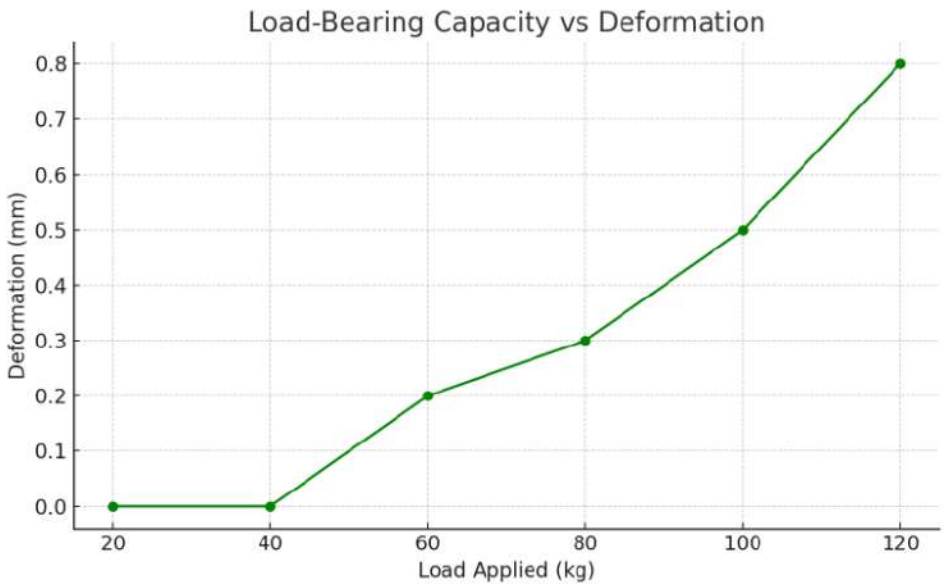
4. CONCLUSIONS

- The composite panel developed using shredded textile waste, distilled water, and lime adhesive was subjected to compressive strength testing.
- The panel demonstrated the ability to withstand a load of up to 120 kilograms without any signs of structural failure or deformation.
- The hydraulic pressing process ensured uniform density and effective bonding of fibers.
- The curing period of 48 hours in a controlled electric chamber enhanced the panel's overall stability and durability.
- Post-finishing, the panel exhibited a smooth surface, consistent thickness, and aesthetically pleasing appearance, suitable for various applications.

Conclusion:
The recycling of textile waste into composite panels using a blend of natural binders and controlled processing techniques has proven to be an effective and sustainable method. The final panel not only repurposes textile waste but also delivers impressive strength and structural integrity, withstanding loads up to 120 kg. The uniformity achieved through hydraulic pressing and the durability ensured by the curing process make this panel suitable for eco-friendly construction materials, furniture manufacturing, and other sustainable product applications. This method represents a viable solution to textile waste management while contributing to circular economy practices.

Parameter	Observed Result	Remarks
Load-bearing Capacity	Up to 120 kg	No visible deformation or failure
Curing Time	48 hours	Achieved optimal strength and bonding
Panel Thickness	~10 mm	Uniform across all samples
Surface Finish Quality	Smooth after sanding & putty	Ready for final use after finishing
Adhesive to Fabric Ratio	2:1	Provided strong bonding and consistency
Durability Post-Curing	High	Maintained structural integrity post load
Suitability for End Use	High	Construction, furniture, utility products

Load (kg)	Deformation (mm)
20	0
40	0
60	0.2
80	0.3
100	0.5
120	0.8



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STUDY ON MICROFIBER SHEDDING CHARACTERISTICS IN DENIM FABRICS

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ABSTRACT

Microfibre pollution has emerged as a significant environmental concern, with synthetic and natural textile fibres contaminating water bodies, soil, and even the air. Microfibre emission occurs from various sources like face masks, wet wipes, electric dryers, where textile and apparel industrial emissions standout to be a significant source of microfibre emission, especially, denim. At present, research on microfibres have been confined to the area of synthetic fibres and there is lack of research on the microfibre release of union denim fabrics which simultaneously release cotton and polyester microfibres. Studies have shown that indigo dye gets adsorbed to cellulose fibres producing anthropogenically modified cellulose (AC), which is a major concern. According to statistics, about half of the world's population is wearing blue jeans and other denim garments. In this study, we aim to analyse the amount of microfibres released from union denim fabrics of commercially available compositions and yarn types. Analysis of microfiber release data reveals a substantial difference between cotton and polyester shedding in denim textiles. Cotton microfibers are being released at a ratio exceeding 10:1 compared to polyester microfibers under standard washing conditions, which shows that indigo dyed cotton microfibres has significant impact. The obtained results shows that enzyme wash releases more amount of microfibre than other washes. The open-end yarn type shows lesser microfibre release than other yarn types, serving as a potentially more sustainable option. Meanwhile, ring slub and ring spun yarn types tend to release more microfibres compared to open end yarn type. The irregularity in the ring slub yarn and protrusions leads to more microfibre emissions.
Keyword: - *Microfibres, Denim, Union fabric, Domestic washing, Emissions, Environmental sustainability.*

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1. INTRODUCTION

In our fast-paced world, where fashion drives daily choices, there lies an invisible danger—microfibre pollution. Every wash cycle, every stretch of synthetic fabric, releases microscopic fibres that move silently into our waterways, travel across rivers and oceans, and enter our ecosystems and food chains.
These strands, which are left over from our contemporary lifestyles, build up with every wash and item of clothing, posing a hidden environmental cost to the textile and apparel industry.
Microfibres can enter the human body through inhalation and poses serious health risks and problems, with studies showing that about 66.4% settle in the respiratory tract, 1% can enter the bloodstream, and 0.0004% may reach the immune system. Understanding these impacts is crucial as we navigate the complexities of fabric choices in our everyday lives [1].

1.1 Textile and apparel supply chain

It might seem easy for a customer to choose a garment from the vast varieties they see in stores and online, but there are huge back processes gone through to showcase the product in a warm light in the store. From the raw material of fibre to the trimming and packing of the garment, there are more processes involved. The primary contributor are the textile and apparel Industry for microfibre pollution, where synthetic fibres are shed during manufacturing processes

like spinning, weaving, dyeing, and finishing. Each stage contributes to fibre loss, adding microfibres to the environment [2].
A study shows that in different manufacturing processes, the cotton fibre loss rates for different end products are listed below.

Table 2.2 Microfibre Shredding Across the Supply Chain [2]

Loss rate (%)	Home textiles	Apparel: denim	Apparel: wovens	Apparel: flat knits	Apparel: circular knits
Fiber-to-yarn (open-end)	10%	–	–	–	–
Fiber-to-yarn (carded)	–	12%	12%	–	–
Fiber-to-yarn (combed)	–	–	–	21%	21%
Fiber-to-fabric	20%	17%	21%	–	31%
Yarn-to-fabric	11%	6%	10%	13%	18%
Fiber-to-end-product	24%	30%	35%	31%	43%
Fabric-to-end-product	5%	15%	18%	13%	18%

Although there is a notable difference between intermediate items, such as yarn and fabric, and final products, such as home textiles and four different types of clothing, a significant proportion of fibre loss is recorded. More than 35.0 million bales of cotton, or around 7,000 million kilograms of cotton, were wasted worldwide in 2020 if the projected fibre loss from fibre to end product is set at 30% [2].
There will be an enormous quantity of microfibre in solid wastes and pollutants in wastewater due to the improper management of fibre loss in textile and apparel manufacturing sectors.

1.2 Denim

Denim is considered to be the most used garment all over the world. Denim fabric started for the purpose of mining has now evolved to everyday fashion. According to statistics, in China the average consumption of jeans is one jean per person, and the average consumption in the USA is already eight jean per person. As mentioned earlier, the things we want to sustain are not sustaining, while the things that are sustaining are polluting the environment. To open up, denim fabric contributes to a major microfibre pollution among the various other fabrics.
Denim is primarily composed of polyester and cotton fibres with a minimal percentage of elastane and other fibres. The warp thread of denim is composed of cotton, and the weft thread is polyester. According to a study, cotton microfibre was almost found in all the environmental samples collected from the Canadian Arctic Archipelago, Laurentian Great Lake, and shallow suburban lakes in South Ontario. In the case of 100% cotton denim fabrics, clear white undyed cotton fibre was obtained from the blue jean-washed water. About 40–57% of indigo-dyed denim fibres were identified among all the microfibres analysed in WWTPs. Cotton microfibres from denim are identified on the basis of the blue colour of indigo dyes.
Crucially, the research found that a single pair of old jeans may emit over 56,000±4,100 microfibres every time they are washed. There is a clear connection between denim washing and microfibre contamination in aquatic systems since the chemical makeup and morphology of the microfibres generated during laundry match with those in the environment [3].
The shredding of microfibres varies according to the type of fabric, weave structure, yarn properties, and chemical properties of fibres washing parameters like temperature, time drum speed, type of detergent, hardness of water, washing load and number of washes. Heavier fabrics tend to release more microfibres compare to light weight fabrics. It is also found that microfibres release increases with usage of detergent powder [4]. An increase in the washing load leads to an increase in microfibre release due to higher surface wear of the fabric yarn. Moreover, microfibres released at higher temperatures are greater than those released at lower temperatures. Microfibre length varies very little, remaining in the 600–900 µm range as the washing temperature increases above 50 °C [5].
Another study states that the annual emissions of cotton and polyester microfibres are1,54,000 kg and 4,11,000 kg, respectively. It is also found that the mass of cotton and polyester microfibres released varied with consequent washes with first wash lying in the range of 0.12% to 0.33% w/w in the subsequent washes [6].

2. METHODOLOGY

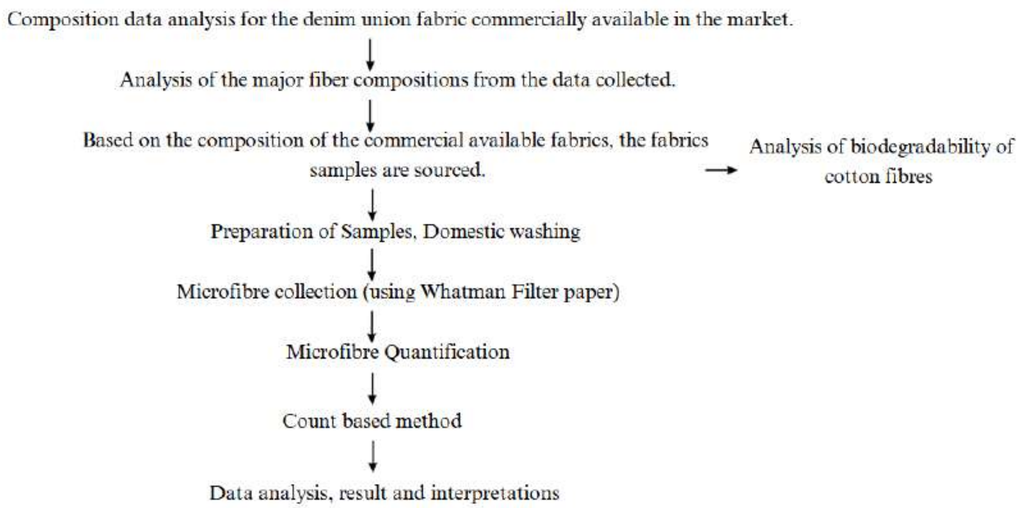

Figure-1 Process flow

2.1 Data collection of denim garments

Denim union fabrics are available in various cotton and polyester blend compositions, where only a smaller proportion of synthetic fibres like elastane is used. The percentage of cotton fibres is proportionally higher than the synthetic fibres used in the blend composition. In order to determine the most widely used proportion range in the market, data is collected from different brands to identify the commercially used compositions, and the sample compositions are decided accordingly.

2.2 Software

ImageJ software is used for analysing microscopic pictures of microfibre that aids in quantification of fibre. The length of the microfibers is calculated using the pixels in 1 mm marked dot followed by individual fibre length calculation. The average microfibre length is calculated using the microfiber length taken from sample pictures.

2.3 Sample Preparation

Denim fabric samples are cut into uniform dimension of 15cm x 15cm specimens with surface area of $225cm^2$. The raw edges of each specimen are double-folded on all four sides by 1 cm and are enclosed by folding along the edges and sewing. This technique not only creates a neat, finished appearance but also strengthens the specimen, reducing fraying or unravelling over time. A contrasting sewing thread colour is used during sewing to distinguish denim microfibres from other fibres.

2.4 Washing procedure

According to ISO standard 105-C06, the washing process is followed. With a water volume of 150 ml and a detergent concentration of 4 grams per litre (gpl), 10 steel balls, altogether washed for a duration of 45 minutes at the temperature of 30 °C, respectively. Washing is performed using a launder-o-meter to simulate domestic washing conditions. Each test is conducted in duplicate, with water volume, detergent concentration, number of steel balls, washing time, and temperature held constant at 150 mL, 4 grams per litre (gpl), 10, 45 minutes, and 30 °C, respectively.

2.5 Filtration process

The effluent released from the washing process of denim fabric are collected separately in beakers. The wash effluent is to be filtered using 7-set Whatman Grade filter paper with pore size of 11µm. The filter papers are folded into conical shape and placed at the mouth of the beaker. This configuration prevents cross-contamination by enabling the simultaneous filtration of microfibres in each beaker. The fibres that are shed from the fabrics are examined under a 1000x digital microscope.

Filtration of the entire washing liquid effluent is required within the filter paper. To make sure that any moisture in the filter paper is gone, the filter paper is allowed to dry in a dark place after the filtration. To ensure accurate results during further analysis or experimentation, this step is essential. The filter paper can be gently taken out of the beaker and put away for additional analysis once it has dried. To avoid contaminating subsequent samples, make sure that no dirt particles build up on the filter paper.

2.6 Microfibre quantification–Counting method

To find the average number of fibres in a square, a total of 40 squares, each 2 mm x 2 mm, are selected randomly on the filter paper. Using a microscope, the fibres in each square are counted, and then the total count is divided by 40 to determine the average fibre count per square. This approach ensures a reliable sample size and provides an accurate average for a single square. After calculating this average, it is divided by the number of squares on the filter paper that contain microfibres, resulting in the total fibre count on the filter paper. The squares are chosen along the diagonals of the filter paper, with both the full filter image and a magnified view of the fibres provided for better visualization. The fibres are then calculated per square centimetre and per gram of the fabric, giving a clear assessment of fibre density in the area sampled. This method yields valuable insights into the fibre distribution and concentration across the filter paper. The inclusion of visual references like the filter image and microscopic view further supports the analysis and interpretation of data.

2.6 Analysis of fibre composition

From the data analysed, the cotton composition percentage of commercially available denim fabrics are 1.35%, 12.02%, 86.63% for the range 53-66%, 70-80%, 81-100% respectively. Similarly, for the polyester composition percentage of commercially available denim fabrics are 88.54%, 9.38%, 2.08% for the range 0-20%, 21-28%, 29-46% respectively. For other fibre composition the overall percentage are 29.56%, 58.48%, 11.97% for the percentages 1, 2 and 3 respectively.

From the data collected, we could infer that the commercially produced samples mostly have the composition as follows:

- Cotton: 80 to 95%
- Polyester: 3 to 12%
- Spandex and other fibres: 0 to 2%

With reference to the data analysis, two different categories of samples are planned and to be obtained as samples with:

- Composition 1 – 85% Cotton, 14% Polyester, 1% Elastane
- Composition 2 – 90% Cotton, 9% Polyester, 1% Elastane

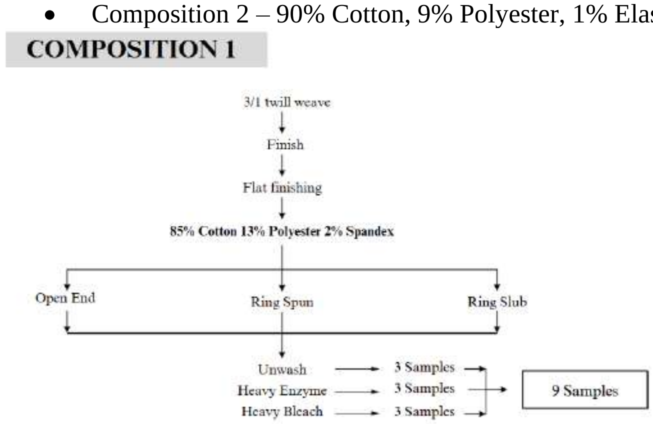

Figure -2 Composition 1

Composition 1 comprises of 85% cotton, 13% polyester and 2% spandex, which lies in the range of the commercial cotton fibres used. The total number of samples for this composition are 9 samples, which consists of three different types of yarns and denim washes.

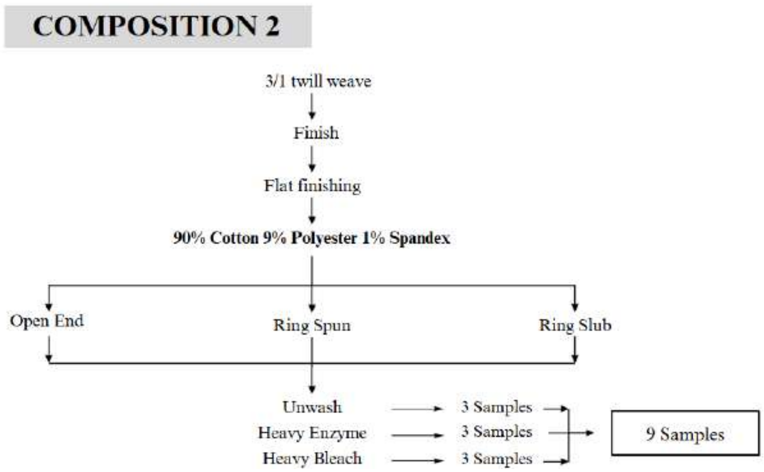

Figure -3 Composition 2

Composition 2 comprises of 90% cotton, 9% polyester and 1% spandex, which lies in the range of the commercial cotton fibres used. The total number of samples for this composition are 9 samples, which consists of three different types of yarns and denim washes similar to the first composition.

3. RESULTS AND DISCUSSION

The samples are washed and counted which provides the following insights

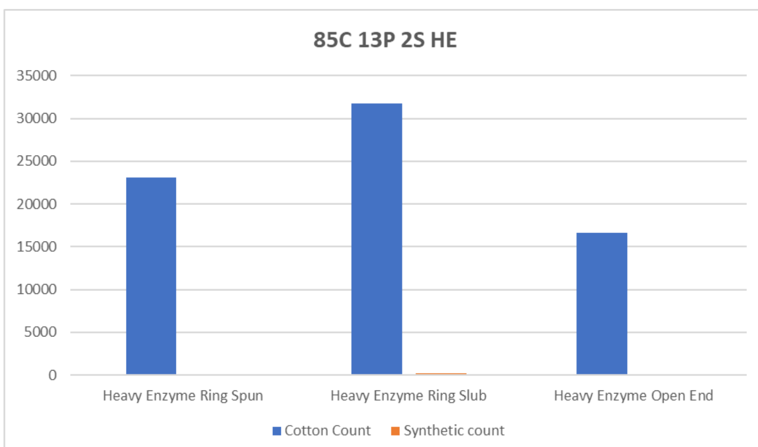

Figure -4 Count of 85C 13P 2S Heavy Enzyme

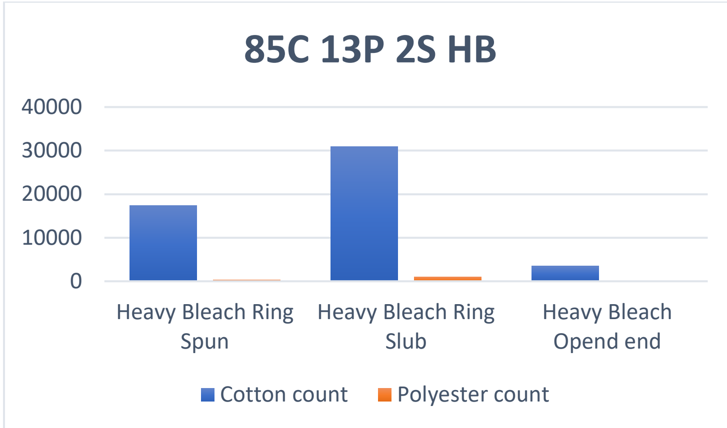

Figure -6 Count of 85C 13P 2S Heavy Bleach

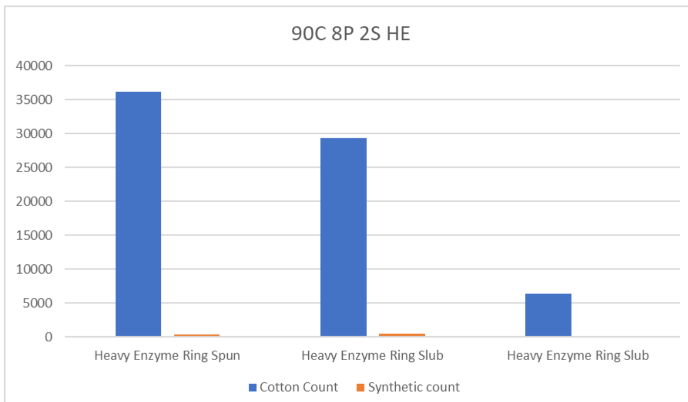

Figure -5 Count of 90C 8P 2S Heavy Enzyme

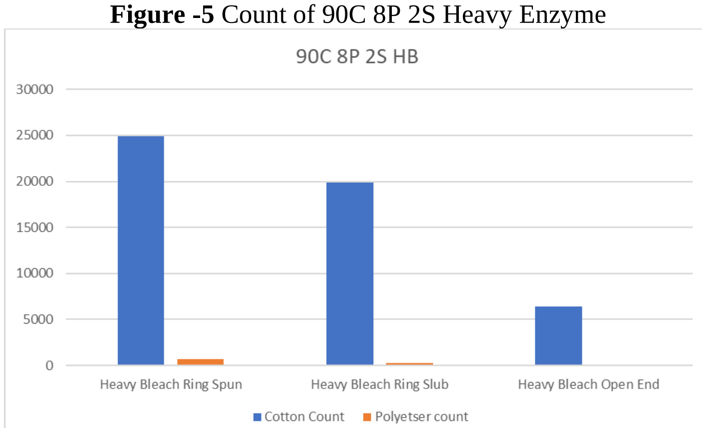

Figure -7 Count of 90C 8P 2S Heavy Bleach

Under standard washing conditions, number of microfibre released from open end yarn is comparatively lesser than ring spun and ring slub yarn for both cotton and polyester microfibre. Based on the wash treatment, heavy enzyme wash tends to emit more cotton microfibres, especially for ring spun and ring slub yarns. Higher release of cotton microfibres can be seen which can be due to the structure of the ring slub which has an irregular structure that might cause to shed higher. Meanwhile, heavy bleach treated denim fabric leads to higher polyester microfiber release with respect to other denim fabric wash treatments. Based on the yarn type, ring slub yarn consistently releases high amounts of cotton microfibres under heavy enzyme and heavy bleach treatments. Open end yarn generally releases fewer microfibres (both cotton and polyester) compared to ring spun and ring slub. With regards to the composition of the denim fabric it is observed that the release of microfibres varies proportionally to the composition. The number of cotton microfibres released increases with increase in cotton percentage in the cotton polyester blend composition. (e.g., 36,187.27 for cotton in heavy enzyme - ring spun).

3.1 Conclusion

The cotton microfibres shred higher than the polyester microfibres exceeding the ratio of 1:10 which is a proof that indigo dyed cotton microfibres has a significant impact. The ring slub and ring spun yarn type tends to shed more cotton microfibres. In other hand, open end yarn type has comparatively low microfibre release serving as a potentially more sustainable option. The physical properties like count, GSM and thickness contributes to the shedding behaviour of the samples.

Therefore, careful consideration should be given while choosing fabric composition, yarn type, and finishing methods—especially for denim garments, which are globally consumed in high volumes. A shift towards open-end yarns, along with optimized washing techniques, can help mitigate the release of microfibres into the environment. Further research and innovation in sustainable denim manufacturing can pave the way for a more environmentally responsible fashion industry.

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AUTOMATED SMART TROLLEY FOR RETAIL AND APPAREL MANUFACTURING

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ABSTRACT
The Automated Smart Trolley is an innovative solution aimed at transforming both material handling in the apparel industry and the retail shopping experience. In garment production, the distribution of materials plays a pivotal role in ensuring a streamlined workflow. The Smart Trolley automates this process by minimizing human intervention, reducing errors, and improving overall production efficiency. By incorporating real-time tracking capabilities—such as monitoring bundle counts, in-pieces, out-pieces, and defective garments—manufacturers gain enhanced visibility and control over their operations. Leveraging Internet of Things (IoT) technologies, including ThingSpeak Cloud for data analytics and remote monitoring, this system ensures seamless communication between supervisors and the production floor.
In the retail sector, the Smart Trolley addresses common inefficiencies such as prolonged checkout times and customer congestion. Equipped with RFID-based item scanning, mobile app integration through the Blynk App, and motorized navigation, the trolley enables customers to scan and manage their purchases in real time. This eliminates the need for manual barcode scanning and reduces long queues at checkout counters. Furthermore, the integration of IoT and cloud computing facilitates data-driven inventory management and enhances the overall shopping experience.
This paper explores the design, development, and applications of the Automated Smart Trolley, highlighting its dual impact on industrial workflow automation and retail convenience. The fusion of RFID technology, IoT, and automated navigation introduces a smart, responsive solution for both production and retail environments, marking a significant advancement in smart systems and customer-centric innovations.
Keywords: *Smart Trolley, IoT, RFID, Apparel Industry, Retail Automation, Workflow Efficiency, ThingSpeak, Blynk App.*

INTRODUCTION

The rapid advancement of automation and smart technologies is transforming traditional industrial and retail workflows, leading to increased efficiency, cost reduction, and improved user experiences. The Automated Smart Trolley is a novel solution aimed at addressing existing inefficiencies in both the apparel manufacturing process and retail shopping. By integrating intelligent automation and IoT technologies, this system provides a streamlined approach to material handling and consumer shopping, ensuring minimal human intervention and maximizing efficiency.

1.1 AUTOMATED SMART TROLLEY IN THE APPAREL INDUSTRY

In the garment manufacturing sector, traditional manual transportation of materials within sewing lines often results in delays, errors, and overall productivity loss. Workers are required to physically carry garment bundles between different production stations, which increases handling time and the likelihood of misplacement or incorrect sequencing. The Automated Smart Trolley eliminates these issues by autonomously transporting materials within the production facility.

The system integrates an array of sensors, including IR sensors and RFID scanners, to facilitate precise tracking of garment bundles as they move through the production line. Real-time production metrics, such as the number of in-pieces, out-pieces, and defective garments, are continuously updated and stored in the ThingSpeak Cloud database. This enables supervisors and production managers to monitor the production line remotely, gaining valuable insights into workflow efficiency and identifying bottlenecks for process optimization.

Additionally, the trolley's motor-driven mechanism ensures smooth, automated movement between workstations, allowing for efficient material distribution with minimal human intervention. The implementation of such a system significantly enhances the productivity of apparel manufacturing facilities, improving accuracy, reducing labor costs, and increasing overall throughput.

1.2 AUTOMATED SMART TROLLEY IN THE RETAIL SECTOR

In retail environments, customer shopping experiences are often hindered by long checkout queues and manual item scanning. Traditional shopping carts require customers to place items into the cart and later wait in line at checkout counters, where cashiers manually scan each product's barcode. This process not only consumes time but also contributes to congestion, especially during peak hours.

The Automated Smart Trolley introduces a more efficient alternative through RFID-based auto-scanning and app-controlled navigation. Each item in the store is equipped with an RFID tag, allowing the trolley to automatically detect and register products as they are placed inside. This eliminates the need for barcode scanning at checkout counters, enabling a frictionless and expedited checkout process.

Furthermore, the trolley is equipped with mobile app integration via the Blynk App, allowing users to navigate the store, track their purchases, and receive personalized shopping recommendations. Customers can also access real-time pricing and product details, enhancing their shopping experience while minimizing physical interactions and wait times.

OBJECTIVES

To automate material handling in the apparel industry

Replace manual transportation of garment bundles with an intelligent trolley system to streamline workflow and reduce labor dependency.

To implement real-time monitoring and tracking

Utilize IoT and RFID technologies to monitor bundle counts, in-pieces, out-pieces, and defective garments for enhanced production visibility.

To optimize the retail shopping experience

Reduce checkout time and customer congestion through RFID-based item scanning and automated billing within the trolley system.

To integrate mobile app-based control and communication

Employ the Blynk App for user-friendly interaction, remote monitoring, and control of the trolley in both industrial and retail environments.

To enhance operational efficiency through data analytics

Leverage ThingSpeak Cloud for data collection, analysis, and communication between supervisors and the production floor, enabling informed decision-making.

TECHNOLOGICAL FRAMEWORK AND IMPLEMENTATION

The core functionalities of the Automated Smart Trolley are powered by IoT integration, cloud computing, and automation technologies. The system architecture consists of:

RFID Scanners: For seamless item identification and tracking in retail stores.

IR Sensors: Enabling obstacle detection and safe navigation in industrial environments.

Motor-Driven Navigation: Allowing autonomous movement within both factory floors and retail spaces.

ThingSpeak Cloud: Providing real-time data analytics for production monitoring and inventory management.

Blynk App: Offering user-friendly control for shoppers and supervisors alike.

By leveraging these technologies, the Automated Smart Trolley ensures a seamless and efficient workflow in both manufacturing and retail operations. The integration of automation into these industries marks a significant step toward the future of smart logistics and intelligent consumer shopping.

This paper delves into the technical specifications, implementation strategies, and potential future developments of the Automated Smart Trolley, offering insights into how businesses can adopt this technology to improve their operational efficiency and customer engagement. By combining automation, IoT, and smart retail solutions, this innovation represents a paradigm shift in material handling and shopping experiences.

MATERIALS USED

4.1 RFID

RFID, or Radio Frequency Identification, is a wireless technology that uses radio waves to identify and track objects. It consists of tags (or labels) and readers. Tags, which can be passive or active, store data that is transmitted to readers using radio waves. This technology is used in various applications like inventory management, access control, and tracking objects.

Figure 1 - RFID

4.2 LCD display

LCD (Liquid Crystal Display) is a type of flat panel display which uses liquid crystals in its primary form of operation. LEDs have a large and varying set of use cases for consumers and businesses, as they can be commonly found in smart phones, televisions, computer monitors and instrument panels.

Figure 2 – Lcd Display

4.3 Rechargeable Battery

A rechargeable battery is defined as a battery that uses reversible cell reactions, allowing them to regain their electrical potential when exposed to passing electric currents. In other words, a rechargeable battery is simply a reversible battery.

Figure 3 – Rechargeable battery

4.4 IR sensor

An IR sensor is an electronic device that detects infrared (IR) radiation. It works by emitting or detecting IR radiation, which is invisible to the human eye. IR sensors can be used to detect the presence of objects, measure temperature, and even detect movement.

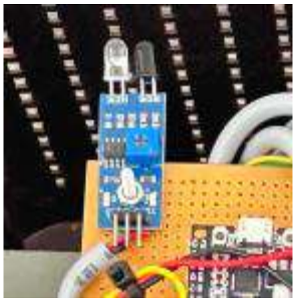
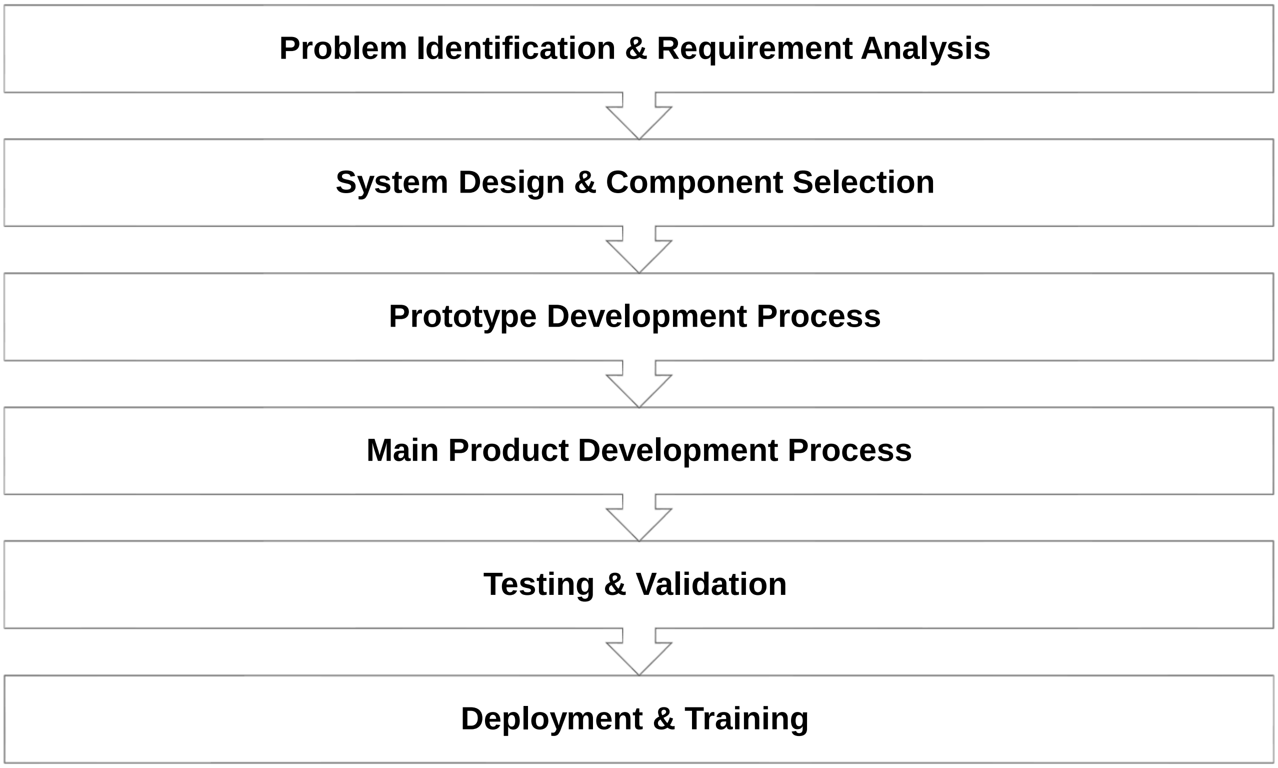


Figure 4 - IR Sensor

4.5 Motor setup

Figure 5 – Motor Setup

METHODOLOGY



Problem Identification & Requirement Analysis The first phase involves identifying inefficiencies in material handling within the apparel industry and retail shopping. Through market research, user feedback, and operational studies, the core challenges are assessed, and requirements are documented to define the project's objectives.
System Design & Component Selection A blueprint of the Automated Smart Trolley is created, detailing hardware and software specifications. Components such as RFID scanners, IR sensors, motor-driven navigation systems, and cloud integration tools are selected based on cost-effectiveness, efficiency, and reliability.
Prototype Development Process A functional prototype is built to validate the system's design. This phase involves assembling hardware, integrating software, and testing core functionalities like automated movement, scanning, and data transmission.
Main Product Development Process After successful prototype testing, a full-scale product is developed with enhanced durability, optimized performance, and refined user interface components. Advanced coding and circuit design are implemented for improved automation and efficiency.
Testing & Validation The Smart Trolley undergoes rigorous testing in real-world industrial and retail environments. Performance metrics such as scanning accuracy, navigation precision, and system responsiveness are analyzed to ensure seamless functionality.
Deployment & Training The finalized system is deployed in garment factories and retail stores. Employees and customers receive training on system usage, including app navigation and troubleshooting.
Evaluation & Optimization Post-deployment performance is continuously monitored. User feedback and operational data are analyzed to enhance efficiency, refine software algorithms, and optimize hardware components for future updates.

PROTOTYPE DEVELOPMENT
Size: 12*9*14 inch

Figure 6 – Prototype Development

PRODUCT DEVELOPMENT

Size: 23.6*15.7*14.9 inch

Figure 7 – Product Development

QR CODES

BUNDLE DETAILS

SCAN ME

BLYNK - ANDROID

SCAN ME

BILLING DETAILS

SCAN ME

BLYNK - APPLE

SCAN ME

Figure 8 – QR Codes

APP USED

THINK SPEAK – DATA COLLECTION

Bundle count

Number of pieces

IN pieces

OUT pieces

Damaged Pieces

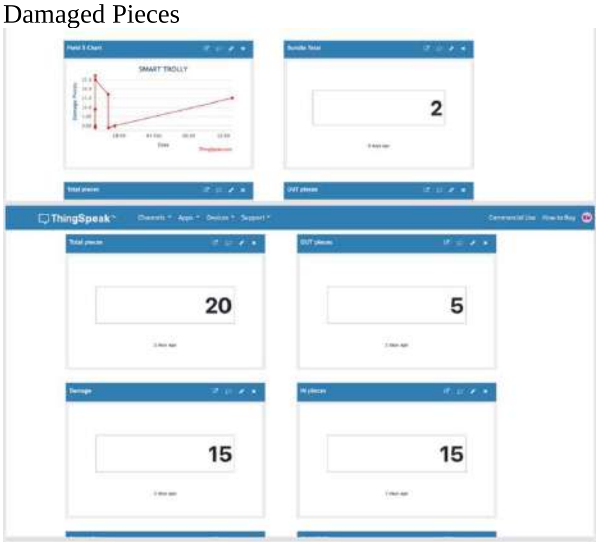


Figure 9 – Thinkspeak Data

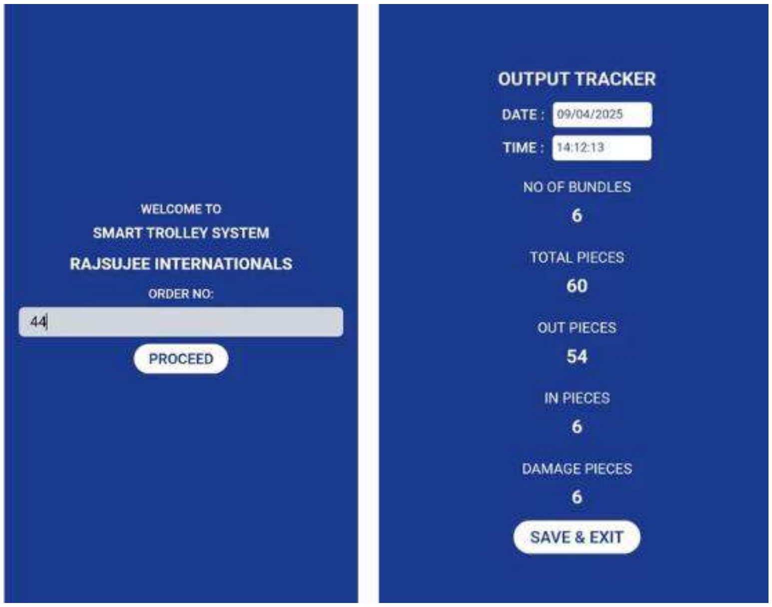


Figure 10 – Productivity Details

BLYNK IOT – TROLLEY MOVEMENT

Figure 11 – Blynk Working

CIRCUIT DIAGRAM

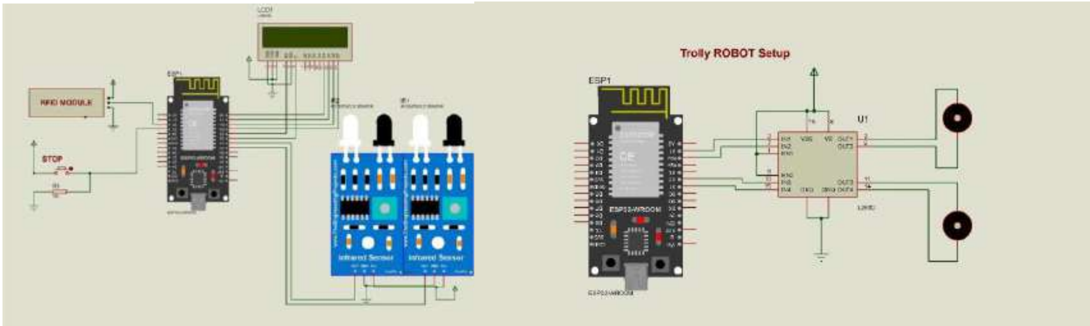
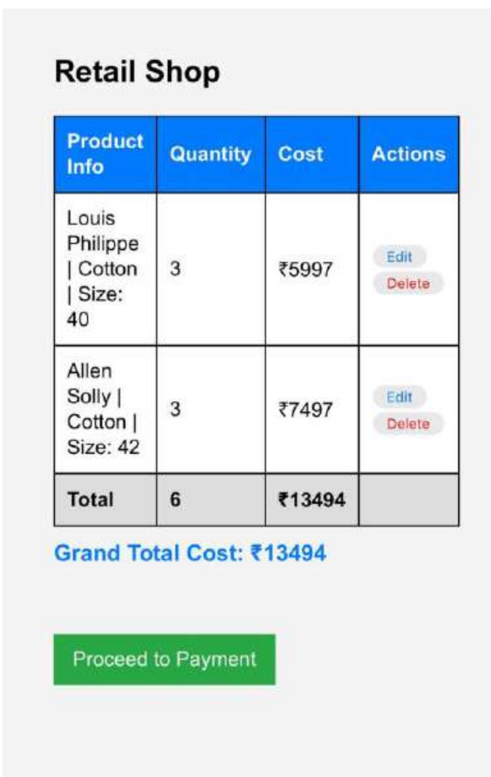


Figure 12 – Circuit Diagram

RETAIL BILLING DETAILS WEB



Retail Shop

Product Info	Quantity	Cost	Actions
Louis Philippe | Cotton | Size: 40	3	₹5997	Edit Delete
Allen Solly | Cotton | Size: 42	3	₹7497	Edit Delete
Total	**6**	**₹13494**	

Grand Total Cost: ₹13494

Proceed to Payment

Figure 13– Billing Details Web

RESULTS

Working of Trolley in Retail unit

This project involves the development of an **automated, remote-controlled smart trolley** designed to enhance the retail shopping experience. When a user enters the retail unit, they can access the trolley by scanning a QR code provided at the entrance. This QR code connects the user to the **Blynk IoT mobile application**, which allows them to remotely control and navigate the trolley as they move through the store.

As the user selects garments or products for purchase, each item is scanned using the RFID or scanning system located at the top of the trolley. Once scanned, the item is placed inside the trolley. The garment's details—such as description, quantity, and price—are automatically recorded and displayed on a **dedicated web page** linked to the trolley.

At the end of the shopping process, the user can review their bill directly on their mobile device through the webpage. They also have the option to **edit the cart**, if needed, before proceeding with **online payment** through the same interface. Once the payment is completed, the user can collect the purchased garments and exit the retail unit—completely bypassing traditional checkout counters.

This system significantly **reduces congestion** and **wait times at billing sections**, offering a **seamless and contactless shopping experience** through the integration of **IoT, mobile control, and automated data handling**.

Video attached here:
https://drive.google.com/file/d/1ufr8qvnE8N8V8TT3FYUACcpxlU24zEJp/view?usp=sharing

Working of Trolley Industry

In the apparel manufacturing unit, the smart trolley is used to automate and streamline operations in the sewing line. The trolley is controlled remotely using the **Blynk IoT App**, allowing it to automatically transport garment bundles from one section to another without manual handling.

As the trolley delivers the bundles to the sewing line, it **automatically counts the number of bundles and individual pieces** being supplied. Once the stitching is complete, the trolley also **counts the number of finished garments** at the end of the production line. This ensures accurate tracking of in-progress and completed work.

All production data—such as bundle count, piece count, and finished output—is collected and **stored in real-time**. These details are accessible to anyone in the unit by simply **scanning a QR code** located at the sewing line. This promotes transparency, improves communication between departments, and helps supervisors **monitor the production flow efficiently**.

The integration of automation and IoT reduces the need for manual tracking, minimizes errors, and improves productivity across the production floor.

Video attached here:
https://drive.google.com/file/d/1AW1D6pt2ZW5lOu3BEMycP6wnPBMKLgLE/view?usp=sharing

CONCLUSION

The Automated Smart Trolley presents a significant advancement in both the retail and apparel manufacturing sectors by integrating automation, IoT, and real-time data tracking. In the retail environment, it enhances the shopping experience by minimizing customer wait times, reducing billing counter congestion, and providing a seamless, app-controlled, and contactless purchasing process. Simultaneously, in the apparel manufacturing unit, the trolley streamlines material handling by automating bundle distribution, monitoring production outputs, and maintaining accurate inventory records.

By leveraging technologies such as RFID, Blynk IoT App, and ThingSpeak Cloud, this system not only improves operational efficiency but also enables transparent and accessible production monitoring through QR-based access. The dual functionality of the trolley demonstrates its adaptability and potential to revolutionize traditional practices in both commercial and industrial settings.

Overall, the project successfully showcases how smart automation and IoT integration can drive productivity, reduce human error, and enhance user experience—laying the foundation for future innovations in smart retail and Industry 4.0 applications.

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DEVELOPMENT OF AEROGEL EMBEDDED NON-WOVEN FROM POLYPROPYLENE MASK WASTE FOR THERMAL INSULATION APPLICATIONS

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ABSTRACT

The growing concern over plastic waste management has sparked interest in upcycling discarded materials into valuable products. This study focuses on developing a novel thermal insulation material from polypropylene face mask waste, converting it into a polypropylene aerogel embedded polypropylene non-woven composite. Using polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) as processing aids, a sustainable and eco-friendly method was employed to create a lightweight, porous material with enhanced thermal insulation properties.

The developed composite exhibits reduced thermal conductivity, improved mechanical strength, and environmentally friendly characteristics, making it suitable for energy-efficient building insulation and other applications. This innovative approach promotes a circular economy by transforming waste into a valuable resource, reducing plastic waste, and contributing to sustainable development. The polypropylene aerogel embedded non-woven composite has significant potential for various industries, including construction, textiles, and packaging, offering a promising solution for reducing energy consumption and environmental impact.

The benefits of this approach are multifaceted. It reduces plastic waste, conserves natural resources, and decreases energy consumption. The developed material can be used in various applications, such as building insulation, cold storage, and packaging, providing a sustainable alternative to traditional materials. By upcycling polypropylene face mask waste, this study contributes to a more circular and sustainable economy, mitigating the environmental concerns associated with plastic waste disposal. This innovative solution has the potential to make a significant impact on reducing plastic waste and promoting sustainable development.

Keywords: Polypropylene face mask waste, thermal insulation, aerogel, non-woven composite, sustainable development, circular economy, plastic waste management, energy efficiency.

1 Introduction

The building sector is one of the largest consumers of global energy, accounting for approximately 40% of energy usage, 45% of greenhouse gas emissions, and 35% of carbon emissions. To mitigate these environmental impacts, it is essential to adopt sustainable practices and materials in building construction. One effective way to reduce energy demand and improve comfort is by incorporating renewable energy, sustainable materials, and thermal insulation in buildings. Traditional insulation materials such as extruded/expanded polystyrene, foam glass, glass wool, and mineral wool are widely used, but there is a growing need for innovative, eco-friendly solutions. This study focuses on developing a novel thermal insulation material from recycled polypropylene face mask waste, converting it into a polypropylene aerogel embedded polypropylene non-woven composite. By transforming waste into a valuable resource, this approach can contribute to sustainable development, reduce plastic waste, and improve energy efficiency in buildings.

2 THERMAL INSULATION

Thermal insulation is the process of reduction of heat transfer between objects in thermal contact or in range of radiative influence. Thermal insulations consist of low thermal conductivity materials combined to achieve an even lower system thermal conductivity.

2.1 **Drawbacks of Commercial Thermal Insulation Panels**

Thermal insulation panels offer numerous advantages in terms of energy efficiency and comfort, but they also come with some drawbacks:
Cost: The initial investment for thermal insulation panels can be higher compared to traditional insulation materials like fiberglass or foam boards. However, their long-term energy-saving benefits often offset this initial cost.
Fire Hazard: Some insulation materials, especially those made from synthetic substances, can be flammable. Without proper treatment with fire-retardant chemicals or adequate fire protection measures, insulation panels can contribute to the spread of fire in a building.
Environmental impact: The production of insulation materials, particularly those derived from non-renewable resources or involving high-energy manufacturing processes, can have significant environmental consequences. Additionally, some insulation materials contain harmful chemicals or greenhouse gases that contribute to environmental degradation.
Disposal Challenges: Some insulation materials can be difficult to recycle or dispose of responsibly, posing challenges for end-of-life management and contributing to landfill waste.
Health Concerns: Certain insulation materials may release volatile organic compounds (VOCs) or other harmful chemicals into the indoor air, especially if they are not properly sealed or if occupants are exposed to them during installation or maintenance. Choosing low-emission or non-toxic insulation materials can help mitigate this risk.

3 THERMAL INSULATION MATERIALS

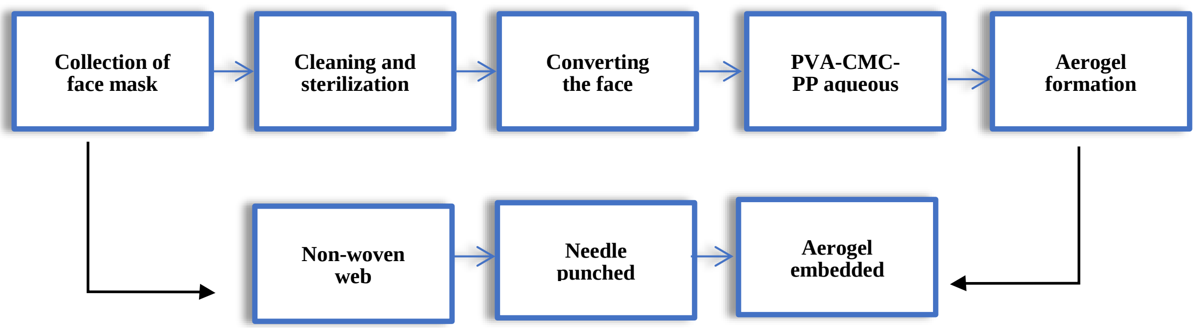
3.1 Nonwoven Fabric

Non-woven have properties such as high porosity, light weight, flexibility, low density, and low manufacturing cost. The performance of thermal insulation can be increased by lowering density, increasing porosity, and increasing mass per unit area. Nonwoven are normally made from fiber web or batts strengthened by bonding using various techniques such as adhesive bonding, mechanical interlocking by needle punching or fluid jet entanglement, thermal bonding and stitch bonding.

3.1.1 Needle - punched nonwoven

Needle punching nonwoven fabrication is one of the simplest and oldest methods of textile fabric. The needle punched nonwoven fabrics have the feasibility for new application called acoustics and thermal insulation. The nonwoven fabric has a porous structure to hold the sound and take much time to transfer the heat. Needled or needle-punched fabrics are produced when barbed needles are pushed through a fibrous cross-laid web, forcing some fibers through the web where they remain when the needles are withdrawn. The needles are normally triangular in cross section, with three barbs on each of the three corners at different distances along the edge. This illustrates the main parts of a needle-punching machine. If sufficient fibers are suitably displaced, the web is converted into a fabric by the consolidating effect of these fibrous plugs or tufts. This action occurs in needle-punching machines where a board, usually containing several thousand barbed needles, is reciprocated at speeds depending on the machine width. This action normally occurs in a vertical direction and some machines may have two sets of needles, one operating downwards and the other upwards, so that both sides of the web are needled Some webs can be superimposed with a woven or non-woven scrim fabric to assist fiber interlocking and fabric consolidation.

4 Methodology



A concentrated PVA solution is initially prepared by dissolving 5 g of PVA powder in 100 mL distilled water at 80 °C. A viscous CMC solution of 1.0 wt.% CMC is made as well but at a lower temperature of 50 °C. PP fibers are cut down to 16 mm in length. The cut fibers are then dispersed into a mixture of PVA and CMC solution with various concentrations of PP fiber. The suspension is sonicated for 10 min at 250–300 W to remove air bubbles hindering interaction between polymer chains. The homogenous mixture is then cured at 80 °C for 2 h to promote the physically cross-linking between PP, PVA, and CMC. The mixture is subsequently lyophilized by Vacuum freeze dryer to produce PP aerogel. The primary drying is conducted at −50 °C in 5 h under vacuum condition for sublimation followed by secondary drying at 70 °C within the next 43 h.

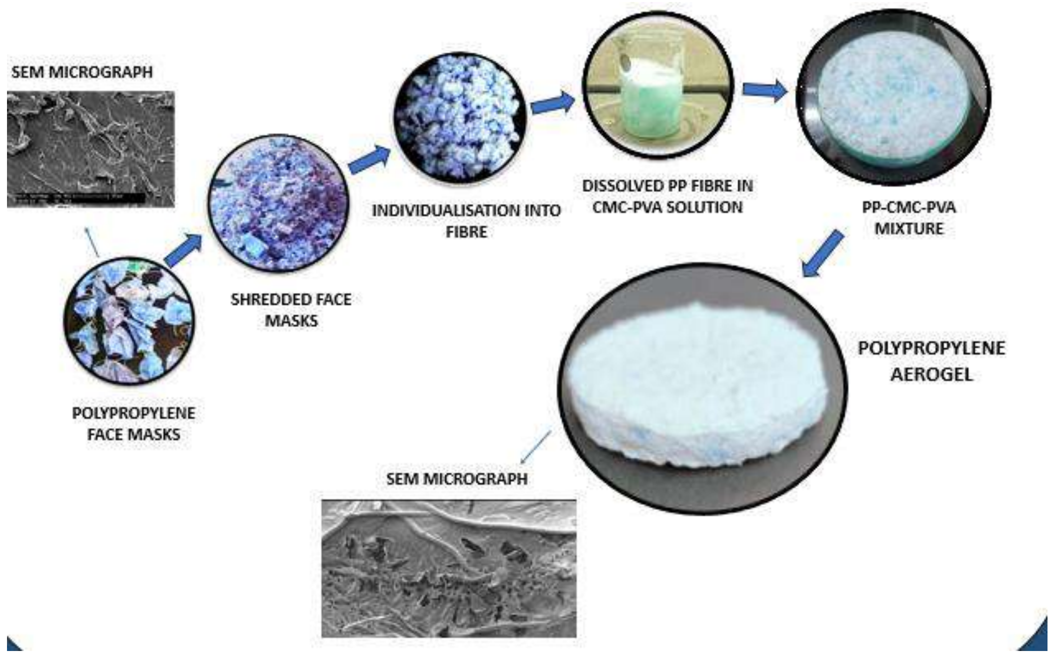


Figure-1: PP Aerogel

Figure-2: PP Aerogel

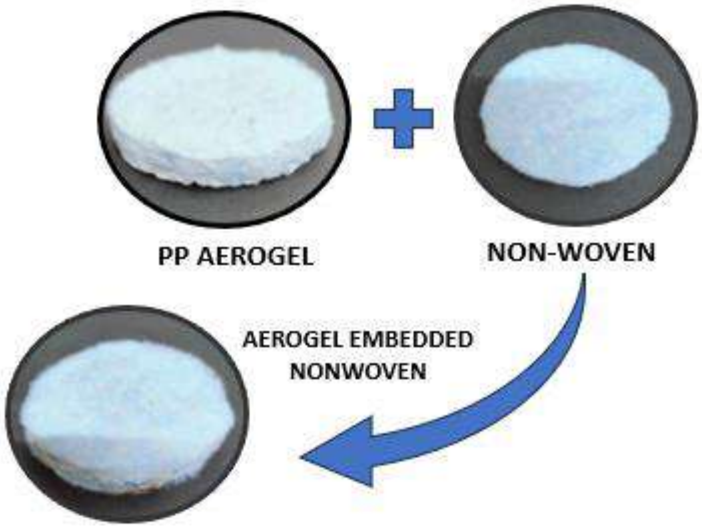


Figure-3: Aerogel Embedded Non-woven

5 Results

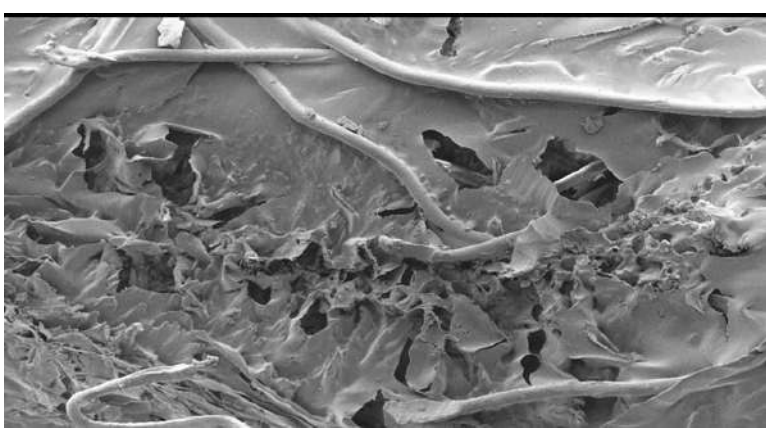


Figure-4: SEM Image of PP aerogel

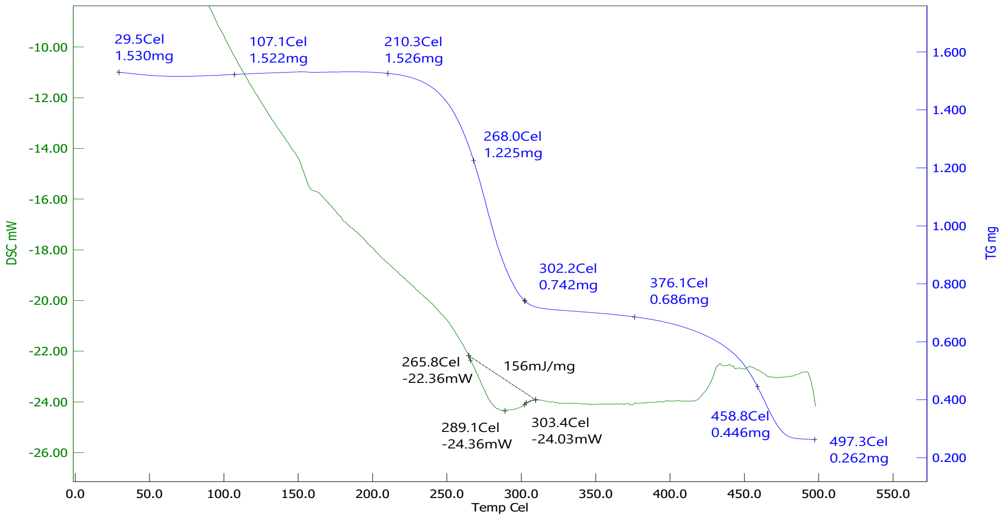


Figure-5: DSC & TGA ANALYSIS

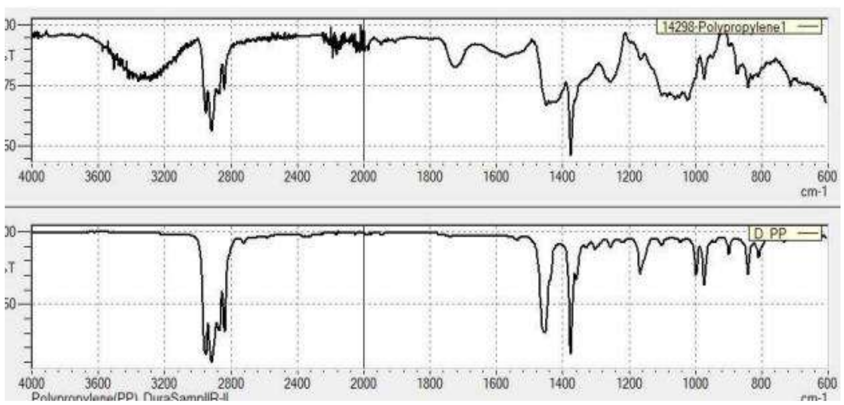


Figure-6: FTIR of PP aerogel

Table-1: Comparison with other thermal insulators

INSULATING MATERIAL	VALUE (W/m K)
Mineral wool	0.034 – 0.045
Aerogel embedded recycled wool	0.0395
Aerogel embedded polypropylene	0.0413
Aerogel embedded apparel waste	0.0420

6 Conclusion

The development of sustainable materials is crucial for reducing environmental impacts. One innovative approach is creating aerogel/nonwoven composites with excellent thermal resistance properties from discarded waste materials. By transforming waste into valuable products, this strategy not only reduces landfill waste but also promotes a low-carbon approach to waste management. This study focuses on developing a novel polypropylene aerogel embedded polypropylene non-woven composite from polypropylene face mask waste, offering a promising solution for improving energy efficiency and reducing plastic waste. By adopting this approach, we can conserve natural resources, decrease greenhouse gas emissions, and promote sustainable development.

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DEVELOPMENT OF ANTIBACTERIAL AND UV PROTECTIVE CLOTHING USING NATURAL DYES AND BIO-MORDANTS

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Abstract
In response to the growing demand for sustainable and functional textiles, this study explores using natural dyes and bio-mordants to enhance antibacterial and UV protection properties in lyocell fabric. Turmeric, catechu, and coffee were utilized as natural dye sources, while *Terminalia chebula* (Harad) served as a tannin-rich bio-mordant. The dyed fabrics were evaluated for their ultraviolet protection factor (UPF) and antibacterial activity against *E. coli*. Results indicated significant improvement in both UV protection and antibacterial efficacy, affirming the potential of this method for eco-conscious and functional clothing development.

Keywords
Natural dyes, Lyocell, UV protection, Antibacterial textiles, Bio-mordant, Harad, Sustainable fashion

1. Introduction
Textile industries are increasingly exploring environmentally friendly alternatives to synthetic dyes and chemical treatments due to the ecological and health concerns associated with conventional processing. These concerns include chemical effluents, allergic reactions, and non-biodegradability. In light of this, natural dyes are being reconsidered for their aesthetic value and potential functional properties, such as antimicrobial and ultraviolet (UV) protection.

Historically, natural dyes have been used across civilizations for their non-toxic, biodegradable, and renewable nature. Furthermore, their application has been reported to impart various functional properties to fabrics, including resistance to microbial growth, UV light absorption, and reduced skin irritation. This study aims to explore the functional finishing of lyocell, a regenerated cellulose-based fiber, using natural dye sources such as turmeric (Curcuma longa), catechu (Acacia catechu), and coffee (Coffea arabica), in combination with Terminalia chebula (Harad) as a bio-mordant.

Lyocell is a sustainable fiber derived from wood pulp using a closed-loop solvent spinning process. It is known for its high absorbency, softness, and biodegradability. Its chemical composition, rich in hydroxyl groups, makes it particularly amenable to dye absorption and chemical modification. Given these characteristics, lyocell was selected as the substrate for this study.

2. Materials and Methods

2.1 Materials

Fabric: 100% lyocell fabric with a plain weave construction was procured from a certified supplier.
Natural Dyes:
-Turmeric: Rich in curcumin, known for its antibacterial and antioxidant properties.
-Catechu: Contains catechin and tannins, which contribute to antimicrobial and UV-absorbing capabilities.
-Coffee: Contains caffeine and polyphenols that offer antibacterial action.
-Mordant: Terminalia chebula (Harad), a tannin-rich fruit, used for its ability to form complexes with textile fibers and dye molecules.

2.2 Dye Extraction

Natural dye powders were extracted using a water bath at 90°C for 1 hour. The extracts were filtered and concentrated to prepare a dye solution of 5% concentration based on the weight of the fabric (of).

2.3 Pre-Treatment

Lyocell fabrics were washed in a non-ionic detergent (1.5% owf) at 60°C for 30 minutes to remove impurities and enhance dye uptake. After washing, the fabric was rinsed and air-dried.

2.4 Mordanting

Mordanting was done using Harad at a concentration of 5% owf. Two methods were explored:
- Pre-mordanting: Fabric was treated with the mordant solution at 90°C for 30 minutes before dyeing.
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2.5 Dyeing

Dyeing was performed at 90°C for 30 minutes with a dye concentration of 5% owf. The fabric-to-liquor ratio was maintained at 1:20. After dyeing, fabrics were rinsed thoroughly and dried.

2.6 Testing and Evaluation

- UV Protection Factor (UPF): Measured using the AS/NZS 4399:1996 standard to assess the UV blocking ability of the fabrics.
- Antibacterial Activity: Evaluated against Escherichia coli using the AATCC 100 test method, which measures bacterial reduction percentage.
- FTIR Spectroscopy: Used to confirm the interaction of dye molecules with lyocell fabric.
- Visual Analysis: Color swatches were evaluated for aesthetic and fastness properties.

3. Results and Discussion

3.1 Functional Properties

The untreated lyocell fabric displayed negligible UV protection (UPF 5) and no antibacterial activity. The application of Harad as a mordant alone improved the antibacterial activity to 40% bacterial reduction and increased the UPF to 11. This may be attributed to the tannin content in Harad, which exhibits inherent antimicrobial properties.

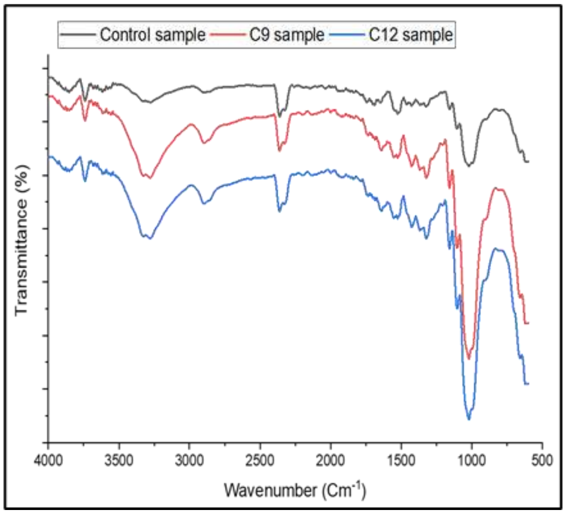
The natural dye treatments, when combined with Harad, significantly improved both UPF and antibacterial performance:

	Fabric's Samples	UV Protection Factor (AS/NZS 4399:1996)	Antibacterial Values (BCR %) (Test AATCC:100) *E. Coli*	Color Swatches
1.	Untreated	5	0	
2.	With Harda	11	40	
3.	Turmeric Dyed	27	86	
4.	Catechu Dyed	19	83	
5.	Coffee Dyed	21	76	

Turmeric-dyed samples showed the highest functional performance, which is consistent with earlier research highlighting curcumin's efficacy as a natural antimicrobial and UV blocker. Catechu and coffee also imparted significant improvements, though to a lesser extent.

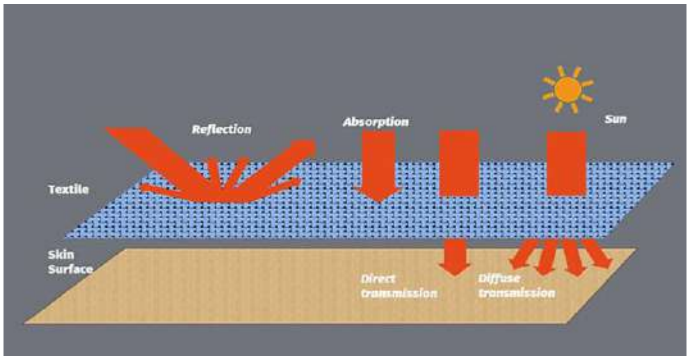
3.2 Spectroscopic Analysis

FTIR spectra revealed the presence of functional groups (e.g., -OH, -COOH) associated with phenolic and flavonoid compounds from the dyes. Shifts in peak positions confirmed the interaction between the dye molecules and the hydroxyl groups of lyocell, indicating successful dye binding.



3.3 Mechanism of Protection

The functional performance is attributed to both absorption and surface interaction mechanisms. Natural dye molecules absorb harmful UV rays, while phenolic compounds disrupt bacterial cell walls. Harad, acting as a bio-mordant, enhances binding and fastness by forming dye-fiber-metal complexes.



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This study demonstrates that lyocell fabric can be effectively functionalized using natural dyes in combination with a bio-mordant. The treated fabrics exhibited excellent UV protection and antibacterial activity, particularly with turmeric. The dyeing process is simple, cost-effective, and environmentally friendly.

Such sustainable practices in textile processing not only reduce the ecological impact but also align with the increasing consumer demand for eco-conscious functional clothing. The research supports further exploration into natural dye applications for specialized textiles such as medical gowns, sportswear, and outdoor clothing.

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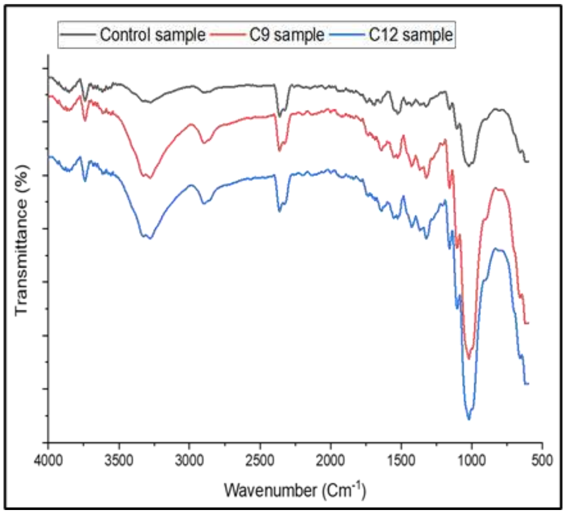

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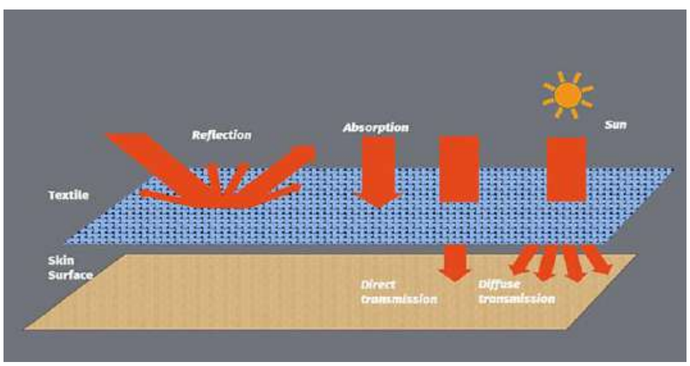

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DEPARTMENT OF TEXTILE TECHNOLOGY

Vision

To be a Centre of Excellence in Textile Technology and Management with basic and applied research for the fulfilment of societal needs.

Mission

- **Develop industry relevant curriculum**, innovative teaching and project based learning methods that enables students to be efficient professionals.
- **Motivate Faculty** to update their knowledge and skills through continuous learning.
- **Provide holistic student development** by creating opportunities for lifelong learning and to develop entrepreneurship skills.
- **Undertake inter-disciplinary research and development**/ Internship/Consultancy in the field of Textile Technology to support the industry and society.

B.TECH (TEXTILE TECHNOLOGY)

PROGRAM EDUCATIONAL OBJECTIVES (PEOS)

Graduates of B.Tech Textile Technology programme will

- PEO: 1 Hold leadership responsibilities in Textile and related segments such as product development, production, technical services, quality assurance and marketing.
- PEO: 2 Become successful entrepreneur in Textile and related field and contributing to societal, technological and industry development.
- PEO: 3 Partake professional qualifications/ certifications in Textile Technology related areas by pursuing specialized studies in engineering and business.

PROGRAM SPECIFIC OUTCOMES (PSO'S)

- PSO1: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization for Process Optimization, Cost and Value analysis, Productivity improvement, Solutions to quality issues and Product development in textile and related fields.
- PSO2: Demonstrate learned techniques, experiments, modern engineering tools and software to estimate the optimum utilization resources such as raw materials, machineries, manpower and to predict the properties of fibre, yarn, fabric and garments as per the end uses.