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**EXPLORE | ENGAGE | EXCEL**

# REDEFINE TEXTILES

78TH ALL INDIA TEXTILE CONFERENCE

## Global Textiles Unearthing Opportunities

The Textile Association (India)
South India Unit

**21st & 22nd November, 2025**
**Hotel Le Meridien, Coimbatore, Tamil Nadu, India.**

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# Functionality v/s Sustainability
## Together will sustain in the Technical Textiles Industry

Dear Readers,
Greetings and the best wishes!!!

The Technical Textile Sector accounts approximately 13% of India's total textile and apparel market and contributes to India's GDP at 0.7%. There is a huge potential to fulfil a large demand gap as the consumption of technical textiles in India is still only at 5-10% against 30-70% in some of the advanced countries. The industry is projected to reach a market value of $350 billion by 2025, growing at a blended annual growth rate (CAGR) of 14.8% from 2021 to 2025.

The National Technical Textiles Mission (NTTM) has been set up that aims at an average growth rate of 15-20% to increase the domestic market size of technical textiles to $ 40-50 Bn by the year and boost India's position as a global leader in technical textile sector. The technical textile industry faces several future challenges including rising raw material costs, Supply chain disruptions, need of skilled labour and the need for increased sustainability and compliance with stringent regulations.

Today one of the most debatable issue is functional v/s Sustainable technical textiles products. Functionality is the prime consent. When designing technical textiles, advancements should be viewed as opportunities to solve real-world problems, enhance efficiency, and create new possibilities, rather than just chasing the latest trends. Instead of focusing on short-lived fads, designers should prioritize using technology to address specific needs and improve existing applications. That's the responsibility for future-ready technical textile sector.

By committing to eco-friendly materials and processes, technical textiles can evolve to meet the demands of a changing world and contribute to a sustainable future. This shift requires vision, investment, and collaboration. With a renewed focus on sustainability aspect in technical textiles industry can embody the promise of progress, proving that functionality and environmental responsibility can indeed go hand in hand. Together, we have the power to reshape the future, from pollution to solutions. But without compromising the main goal of high performance, functional technical textiles products, which are robust having long life, smart and responsive to nature.

The need of today's hi-tech application need to balance.

With best wishes,

**Dr. Hireni Mankodi**
Editorial Board Member
Associate Professor
M.S. University, Baroda

*T. L. PATEL, President*

# Industry Trends

Greetings to all the members of The Textile Association (India)!!!

The textile industry is witnessing a significant shift towards digitalization, with technologies like artificial intelligence and block chain gaining traction. We're also seeing a growing demand for sustainable and eco-friendly textiles, driven by consumer awareness and regulatory requirements.

## Association Initiatives.

The Textile Association India is committed to supporting its members through various initiatives, including training programs, industry events, and advocacy efforts. We're working closely with government agencies, industry partners, and other stakeholders to promote the growth and development of the textile sector.

## Member Benefits

As a member of the Textile Association India, you'll have access to a range of benefits, including networking opportunities, industry insights, and professional development resources. Our members are at the forefront of the industry, and we're proud to provide them with the support and resources they need to succeed.

## Future Plans

Looking ahead, we're planning to launch several new initiatives, including a mentorship program, industry-specific workshops, and a research grant program. These initiatives will help our members stay ahead of the curve and drive innovation in the textile sector.

## Call to Action

I encourage all members to get involved and contribute to the association's efforts. Your participation and expertise are invaluable to our success, and we're committed to working together to drive growth and progress in the textile industry.

The textile industry is undergoing a significant transformation, driven by digitalization and sustainability. Technologies like artificial intelligence and block chain are gaining traction, while consumer awareness and regulatory requirements are fuel demand for eco-friendly textiles.

**T. L. PATEL**
President
The Textile Association (India)

# Box Behnken Design Model-Optimising Dyeing Conditions of Cotton Fabric with Turmeric Extract

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**Abstract:**

***Background***

*Curcuma longa L. (turmeric) is a non-toxic medicinal plant that possesses yellow colour and antioxidant properties. A recent study suggests using curcuma dye extract on cotton fabric as a sustainable and eco-friendly dye alternative.*

***Design/methodology/approach***

*Using alum as a mordant, the cotton fabric was pre-mordanted. The dyeing optimisation using the "Box and Behnken Design" (BBD) model was systematically explored to elucidate the outcomes of dyeing temperature (oC), dyeing time (min), and shade %(o.w.f.). The dyed cotton fabrics were examined for colour strength on spectrophotometer.*

***Results and Conclusion***

*The dyed sample employed a shade of 30% (o.w.f.), a 90°C and 60 min of temperature and time conditions gave colour strength (K/S) of 3.96. The findings reveal that Curcuma longa (root) as a dye could be a better option for the textile and fashion sectors.*

**Keywords:** *box and behnken, curcumin, cotton, colour strength, natural dye*

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## 1. Introduction

Historically, nature offered a plethora of natural dyes obtained from plants, minerals and animal sources to hue textile materials (natural and synthetic) until synthetic dyes such as reactive, disperse, direct, and so on were developed and commercialized [1, 2]. Natural colours are increasingly popular due to environmental concerns, as they are non-polluting, non-carcinogenic, and environmentally friendly, leading to a shift toward sustainable or green chemistry techniques [4-6]. Natural dyes are popular in textiles, food processing and cosmetics [1, 3]. Synthetic dyes are less expensive, permanent, and easier to handle than natural dyes. However, they can cause dermatological troubles like skin allergies and eye uneasiness due to their unfavorable eco-toxicological consequences [7].

Natural dyes are gaining prominence since they offer distinctive shades [8-9]. Natural dye, an alternative option for food colouring, natural cellulosic and protein fibres, and leather from prehistoric times, and their waste matter as compost for crops [11]. Natural dyeing processes promote rural free enterprise by generating professional opportunities [10]. For a sustainable approach, natural dye can be utilised for health and safety requirements, such as baby garments with pale colours [10].

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### *1.1. Turmeric dye*

One fragrant flowering plant that has medicinal uses is turmeric [12]. Due to its numerous ethno-botanical uses [14], Curcuma longa L (scientific name), also known as the "spice of life"[13] and "golden spice" [13] contains phenolic compounds, such as curcuminoids [5]. In turmeric, the main active ingredient is curcumin, sometimes referred to as "C.I.75300" [13] or "C.I. Natural Yellow 3" [12]. Diaroyl methane group, a natural yellow dye, is extracted from the rhizome [15]. When colouring natural fibres, such as protein and cellulosic fibres, curcumin exits in keto-enol form [16]. Figures 1 and 2 displayed the chemical formula of curcumin and Curcuma longa plant, rhizomes and powdered forms.

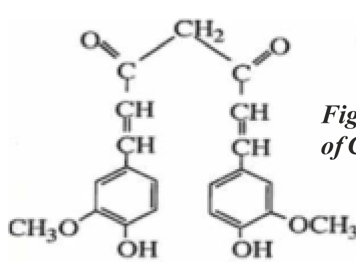

***Figure1- Chemical formula of Curcumin [17]***

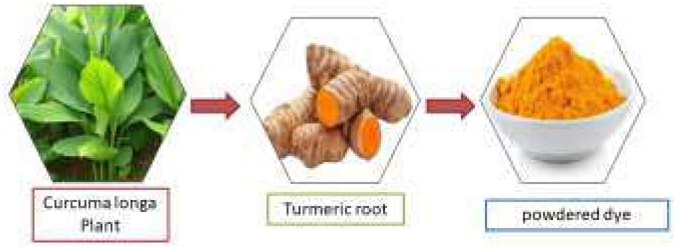


*Figure 2 - Curcuma Longa plant, Turmeric rhizomes and powdered turmeric*

### *1.2. Innovations in natural dye extraction methods*

Researchers have explored various methods of dye extraction include aqueous extraction [18], solvent extraction [19], "neutral, acid and alkaline extraction" [20], enzymatic extraction and fermentation [21], supercritical CO2 extraction [22], ultrasound-assisted [23], and microwave-assisted extraction [24] etc.We analysed the colour strength of dyed cotton in an ecologically conscious method (aqueous extraction) by optimisation technique using "BBD model".

## 2. Materials and Methods

### *2.1. Materials*

For this experiment, 100% bleached cotton fabric with a warp and weft count of 60s, an EPI of 100, a PPI of 85, and a GSM of 78 g/m2 bought at a nearby market. Turmeric roots were procured from Panipat local market. The mordant was alum ($KAl\ (SO_4)_2.12H_2O$), purchased from Central Drug House Private Limited (New Delhi), India.

### *2.2. Methods*

*2.2.1. Mordant's (alum) extraction*

Apply alum mordant, ten grams of alum powder were soaked in one thousand millilitres of water for an hour to create a 1% stock solution. After extraction, the mordant solution was filtered to return to the required volume and used to continue the mordanting process [25].

*2.2.2. Dye extraction process*

The dried turmeric rhizomes were grinded and then converted in powdered form. The dye solution was prepared by applying an aqueous technique. Make a 10% stock solution of turmeric powder, ten grams of dried root powder were separately prepared in one hundred millilitres of water at boiling water for 60 min. The extract's volume increased to one hundred millilitres after filtering and was used for dyeing [25]. (Khatun et al., 2019) suggested that maximum dye absorption was achieved at 90°C at 60 min [40]. Prolonged heating time may result in dye degradation and a costly process. Figure 3 shows schematic view of dye extraction steps.


*Figure 3 - Schematic view of dye extraction steps*

*2.2.3. Process of Pre-mordanting*

Table 1 shows premordanting variables. Alum mordant (20% o.w.f.) [27] was applied to the pre-wetted cotton specimens to attain MLR-1:30 at ambient temperature. Following one hour, a gradual elevation in temperature performed until reaching the boiling point. Afterwards, the mordanted samples were squeezed and dried. The cotton fabric samples that had undergone mordanting were used dyeing procedures without delay. Because specific mordants, including potassium dichromate, demonstrate photo-reactivity and may undergo a reduction in colour intensity when subjected to light exposure [26].

*Table 1 - Pre-mordanting variables*

| Technique | Mordant |
|---|---|
| Pre -mordanting | Alum (20%o.w.f.) |

### *2.3. Design of Experiment*

To study the individual interactive effects of dyeing temperature (°C), shade % (o.w.f.) and time of treatment (min), Box and Behnken factorial design was used. These three factors were chosen because they were potentially affecting the dyeing process as the independent variables. Table 2 lists the coded values of these variables. Colour strength (K/S) obtained on treatment was taken as the response factor.

*Table 2 - Variable and their coded levels*

| Variable | Coded Levels | | |
|---|---|---|---|
| | -1 | 0 | +1 |
| Temperature(°C) | 30 | 60 | 90 |
| Shade%(o.w.f) | 10 | 20 | 30 |
| Time(min) | 30 | 60 | 90 |

*2.3.1 Dyeing procedure*

Premordanted cotton fabric dyed with turmeric according to the Box-Behnken design, as indicated in Tables 2 and 3. We used a water bath for the dyeing process. Following dyeing, the soaping was done in water for ten minutes using non-ionic detergent at 60°C. The specimen was allowed to air dry. A schematic view of detailed pre-mordanting and dyeing steps is illustrated in Figure 4.

*Figure4 - Schematic view of pre-mordanting and dyeing steps*

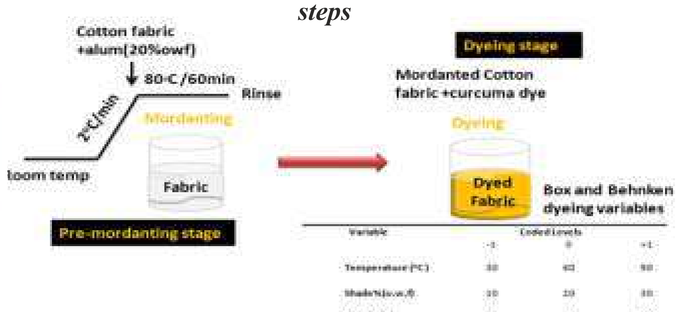

*Table 3 - Experimental design based upon coded level*

| Sample No. | Temperature ($^oC$) | Shade% (owf) | Time (min) |
|---|---|---|---|
| 1 | -1 | 0 | 1 |
| 2 | -1 | 0 | -1 |
| 3 | -1 | 1 | 0 |
| 4 | -1 | -1 | 0 |
| 5 | 0 | -1 | -1 |
| 6 | 0 | 1 | -1 |
| 7 | 0 | -1 | 1 |
| 8 | 0 | 1 | 1 |
| 9 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 |
| 14 | 1 | 0 | -1 |
| 15 | 1 | -1 | 0 |
| 16 | 1 | 0 | 1 |
| 17 | 1 | 1 | 0 |

## 3. Test methods

### *3.1. Measurement of colour strength*

The spectral reflectance of coloured samples was measured with spectrophotometer (Premier colour scan) at 400-700nm spectral range.

$K/S = (1-R)^2 / 2R$ - Kubleka Munk equation [28]

R - (Reflectance), S - (Scattering coefficient) and K - (Absorption coefficient) [28]

## 4. Results and Discussion

### *4.1. Colour strength*

For cotton fabric, the K/S measurements of the 17 samples gave maximum peak at 425nm [29] that dyed by the Box and Behnken experimental design using Design Expert 13 in Table 4. Regression analysis was used to know how the independent variables affected the measured response. Contour and surface plots diagrams were analysed using the best-fit equations to show how different parameters affected the measured responses [30].

*Table 4 - Experimental conditions and measured values of cotton fabric*

| Run | Temperature ($^oC$) | Shade% (owf) | Time (min) | Actual response K/S | Predicted response K/S |
|---|---|---|---|---|---|
| 1 | 30 | 20 | 90 | 1.63 | 1.59 |
| 2 | 30 | 20 | 30 | 1.57 | 1.60 |
| 3 | 30 | 30 | 60 | 1.73 | 1.76 |
| 4 | 30 | 10 | 60 | 1.45 | 1.44 |
| 5 | 60 | 10 | 30 | 2.56 | 2.54 |
| 6 | 60 | 30 | 30 | 3.21 | 3.16 |
| 7 | 60 | 10 | 90 | 2.77 | 2.82 |
| 8 | 60 | 30 | 90 | 3.23 | 3.25 |
| 9 | 60 | 20 | 60 | 2.88 | 3.03 |
| 10 | 60 | 20 | 60 | 2.92 | 3.03 |
| 11 | 60 | 20 | 60 | 3.09 | 3.03 |
| 12 | 60 | 20 | 60 | 3.14 | 3.03 |
| 13 | 60 | 20 | 60 | 3.15 | 3.03 |
| 14 | 90 | 20 | 30 | 3.35 | 3.40 |
| 15 | 90 | 10 | 60 | 3.25 | 3.22 |
| 16 | 90 | 20 | 90 | 3.8 | 3.77 |
| 17 | 90 | 30 | 60 | 3.96 | 3.96 |

#### *4.1.1. Statistical Analysis for Quadratic Model*

*Table 5 - Statistics of FIT*

| | | | |
|---|---|---|---|
| Standard Deviation | 0.1070 | $R^2$(Coefficient of Determination) | 0.9915 |
| Mean | 2.80 | Adjusted $R^2$(Coefficient of Determination) | 0.9806 |
| Coefficient of Variation (%) | 3.81 | Predicted $R^2$(Coefficient of Determination) | 0.9675 |
| | | Adequate Precision | 30.6725 |

Based on K/S, the regression equation for cotton fabric that has been dyed was evaluated.

*Table 6 - Regression equation*

**K/S=**3.03+0.9966***Temperature**+0.2620***Shade**+0.0914***Time**+0.1067***Temperature*Shade**+0.0955***Temp-erature*Time**-0.0507***Shade*Time**-0.3955* **(Temperature)** $^2$-0.0417***(Shade)$^2$** -

*Table 7- Analysis of variance (ANOVA) for the fitted quadratic polynomial model of colour strength (K/S)*

| Result | F-value | p-value | |
|---|---|---|---|
| | 90.76 | < 0.0001 | Significant |
| Temp =(A) | 693.98 | < 0.0001 | |
| Shade =(B) | 47.96 | 0.0002 | |
| Time =(C) | 5.83 | 0.0464 | |
| Temp*Shade =(AB) | 3.98 | 0.0862 | |
| Temp*Time =(AC) | 3.19 | 0.1174 | |
| Shade*Time =(BC) | 0.8998 | 0.3744 | |
| $(Temp)^2 = (A)^2$ | 57.52 | 0.0001 | |
| $(Shade)^2 = (B)^2$ | 0.6410 | 0.4497 | |
| $(Time)^{2=} (C)^2$ | 0.9010 | 0.3741 | |
| Lack of Fit | 0.2473 | 0.8598 | not significant |

The analysis of variance (ANOVA) is employed to evaluate the adequacy of the model and its statistical relevance [31], as illustrated in Table 7. It can be seen from Table 7 significant result in terms of the computed F value ($p< 0.0001$, "p value less than 0.05" [32] for the colour strength of turmeric-dyed cotton fabric. The lack of fit (p=0.8598 (0>0.10) and F value=0.2473) are insignificant, suggested the fitness of the experimental data. Furthermore, strong correlation and determination coefficient values suggested that the model was substantially fitted (Table 5 and Table 6). The regression equation, articulated as coded values, elucidates its impact on colour strength [19]. Table 6 represents the coded levels of temperature, shade, and time by their corresponding coefficients (+0.9966, +0.2620, and +0.0914) signify both the "direction and magnitude of each level" [19] on the colour strength. Consequently, the coefficient (temperature) indicates how an increment of temperature by one coded level [33] corresponds to an enhancement of 0.9960 units in colour strength. Similarly, an increase in dye concentration by one unit showed an increment of colour strength by 0.2620 units. In comparison, an increase in dyeing time by unit showed an increment in colour strength by 0.0914 units. It shows that all three factors exert a more pronounced influence on colour strength [19].

*4.1.2. Contour plot and 3D plot*

Figures (5, 6 and 7) highlight the impact of independent variables on response by means of contour plot and surface plots. The presence of an optimal level for each dyeing variables that maintains both minimum and maximum levels to optimise K/S were verified using response surface plots.

Figure 5 depicts, outcomes of temperature(A) and shade(B) related to colour strength on dyed cotton samples while maintaining the ideal dyeing time(C) of 60 minutes. The variables about dye temperature (A) and shade (B) exhibited a positive influence, reaching a significant impact on the dyed cotton fabric samples. The colour strength escalated from 1.45 to 3.25 at a shade level (%o.w.f), while increasing dye temperature from 30°C-90°C. While varying the shade from 10 to 30% o.w.f. at a predetermined extraction time, which altered the colour strength from 1.45 to 1.73 at a constant temperature of 30°C and increased from 3.25 to 3.96 with fixed temperature at 90°C. The fluctuation in colour strength concerning colour change was evident as the colour strength augmented from 1.73 to 3.96 at a fixed shade of 30% o.w.f and with an elevation in temperature from 30°C-90°C [36]. The possible reason may be attributable due to escalation in "translational energy of dye molecules" [34], which facilitate enhanced "dye diffusion" [34] and aggregation thus better dye penetration into the fibres. The augmentation of dye concentration within the dye bath yields a greater availability of dye molecules for attachment to the fibres, resulting in elevated K/S values characterized by deeper colours [34]. Turmeric dyed cotton fabrics display a light to dark yellow colour due to natural phenols. The colour strength increases with turmeric concentration (10-30%), indicating deeper colour absorption [35].

Figure 6 illustrates the combined outcomes of shade and dyeing time at fixed temperature of 60°C on K/S value of cotton fabric. Both dyeing variables both had a positive, up to elevated level, impact on the dyed cotton fabric colour strength.

The colour strength increased from a fixed shade of 10% o.w.f, with values escalating from 2.56 to 2.77 as the dyeing duration advanced from 30 to 90 minutes. However, when the shade increased from 10% to 30% o.w.f, significant outcome observed regarding the trend in colour strength as

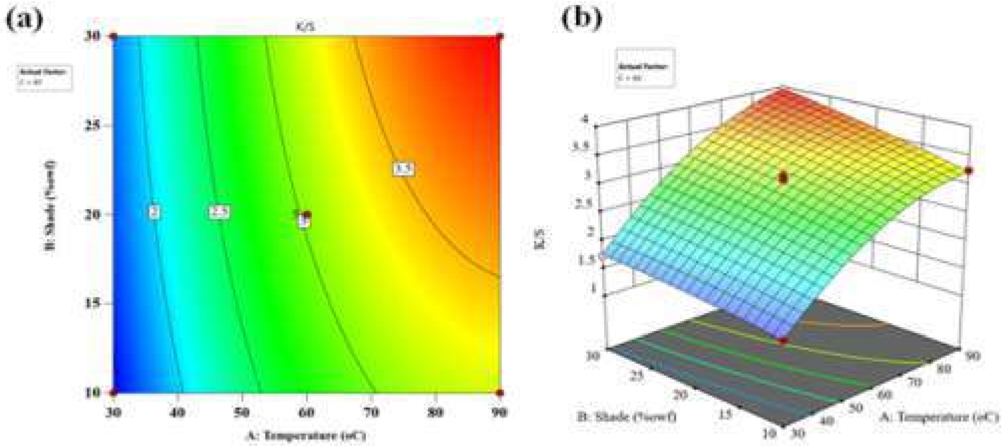


*Figure 5 - Contour plot (a) and Surface plot (b) for the Temperature (A) and shade (B) vs. K/S*

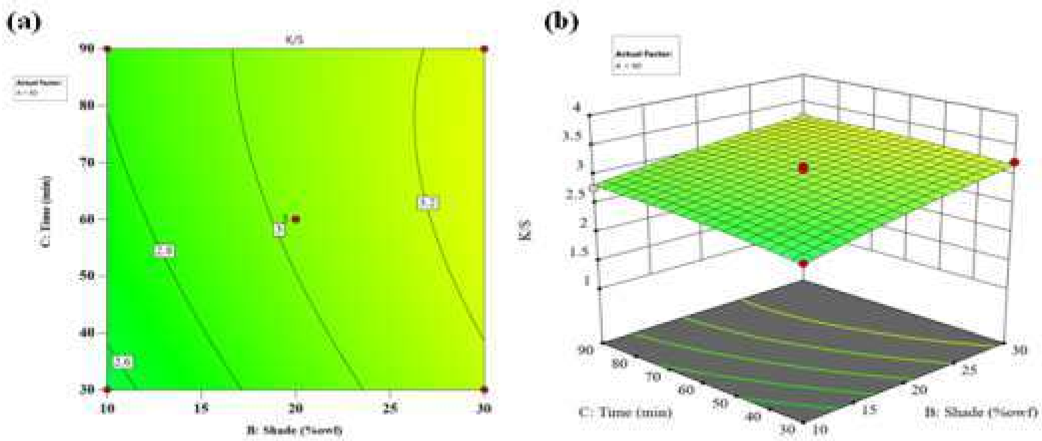


*Figure 6 - Contour plot (a) and Surface plot (b) for the Shade (B) and Time (C) vs. K/S*

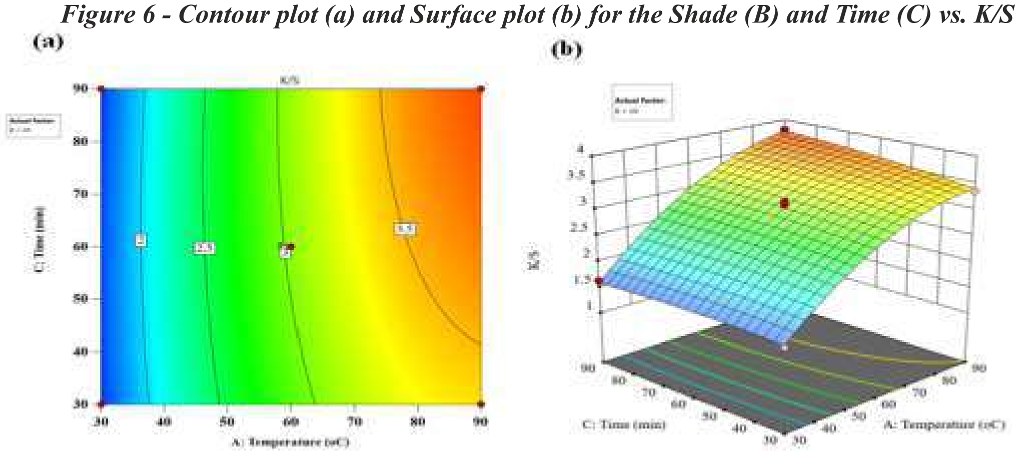


*Figure 7 - Contour plot (a) and Surface plot (b) for the Temperature (A) and Time (C) vs. K/S*

2.56 to 3.21. The graphical representation indicates that the colour strength reaches a peak value of 3.14 to a minimum value of 2.6 [36]. The statement could be justified because of dye absorption capacity will rise as the dye concentration does, primarily due "to a rise in mass transfer from the concentration gradient" [37].

Figure 7 depicts, combined outcomes of temperature (°C) and time (min) at shade (20%o.w.f.) on colour strength of turmeric dyed cotton fabrics. It is possible to look at how longer dyeing time and higher dyeing temperatures affected the turmeric dyed cotton fabric ability to hold colour [38]. Longer dyeing time helped to increase colour strength values until dye equilibrium attained with dye exhaustion [38]. The colour strength showed a remarkable increment from 1.57 to 3.35 while maintaining a constant shade (%o.w.f), at rise in temperature, 30 to 90°C. Beyond dyeing temperature,90°C and the duration exceeding 90 minutes result in the colour strength, diminishing from 3.8 to 3.35 as evidenced by the colour transition (blue to red) of the lines indicated by the response variable. The graphical representation implies the functionality of the shade%, wherein the colour strength attains a peak value, 3.14 compared to the region characterized by the blue lines with 1.57 [36].

*4.1.3. Model verification*

There was close interaction between experimented and predicted response of colour strength generated by the software. The diagnostic plots generated by the system validate the Box-Behnken model, thereby mitigating the risk of erroneous and misleading results [39]. The normal probability plot, illustrated in Figure 8(a), demonstrates that the residuals conform to a normal probability distribution. The plotted points closely align with the "straight line, further certifying that the quadratic model fits the assumption of the analysis of variance (ANOVA)" [36]. The predicted and actual response values for each experimental run showed a straight line illustrated in Figure 8(b) [32]. The studentized residuals and predicted colour strength values of turmeric on dyed fabric depicted in Figure 8(c) exhibit a random scatter of variance with adequate dispersion within the acceptable range, suggesting that all response values display consistent and significant variability [39].

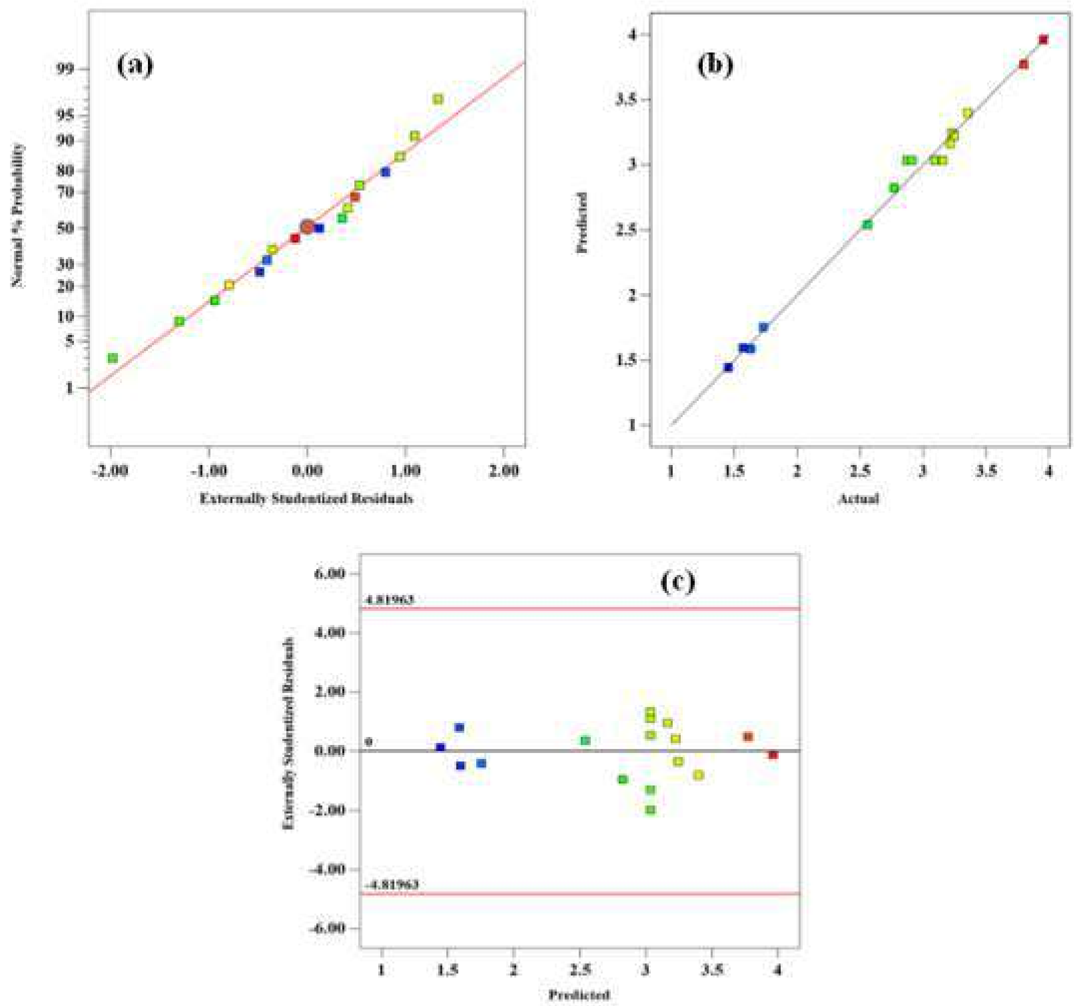


***Figure 8 - (a) plot of normal probability (b) plot of predicted vs. actual values (c) plot predicted values against externally studentized residuals***

**5. Conclusion and Future Prospects**

This research study exposes the dyeing on alum pre-mordant cotton fabric with turmeric as a natural colouring matter utilising RSM (response surface methodology) with (BBD) model to optimise the dyeing factors on colour strength. The dyed sample employed a dye concentration 30% (o.w.f.), 90°C and 60 min of temperature and time, resulting in optimum colour strength (K/S) of 3.96. The recent outcomes demonstrate that natural dye extracted from the root portion is sustainable for waste utilisation. Future research will concentrate on utilising novel methods for extracting natural pigments, while also examining aspects such as fabric strength, longevity, and public knowledge in order to scale up for textile industries [48].

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# Innovation, Sustainability and Growth: MSMEs as Catalysts in India's Textile Manufacturing Ecosystem

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**Abstract:**

*This research investigates the dynamic interplay between innovation, sustainability, and growth in Micro, Small, and Medium Enterprises (MSMEs) within India's textile manufacturing sector an industry that accounts for approximately 45% of national textile exports and employs over 7 million individuals in decentralized units. The primary objective is to evaluate how the strategic integration of digital technologies and sustainable practices influences operational efficiency, global competitiveness, and long-term economic viability of textile MSMEs. Employing a mixed-methods framework, the study synthesizes data from structured surveys across 125 MSMEs and expert interviews with 20 stakeholders, including policymakers and industry consultants. The analysis leverages multi-variable regression models to assess the correlation between innovation inputs (e.g., R&D intensity, automation levels, ERP adoption) and key performance indicators (e.g., productivity growth, export volume, and energy efficiency index). Additionally, sustainability maturity was measured through indices such as compliance with ISO 14001/50001, effluent treatment capabilities, and participation in ZED and TUFS schemes. Findings reveal a statistically significant impact ($p < 0.01$) of combined innovation-sustainability strategies on annual productivity and export growth. However, the results also highlight systemic constraints such as financial inaccessibility, technological inertia, and limited workforce up-skilling, which impede scalable transformation. The study proposes a triadic policy model focusing on green financing, digital upskilling, and innovation cluster incubation to accelerate industrial modernization. This research advances scholarly understanding of MSME transformation pathways in emerging economies and provides actionable insights for policy architects aiming to align industrial development with national sustainability targets and global trade integration in the textile domain.*

**Keywords :** *Digital Transformation, Innovation, Indian Manufacturing, MSMEs, Textile Industry*

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## 1. Introduction

The Indian textile industry, often referred to as the "spine of Indian manufacturing," plays a pivotal role in the national economy, contributing approximately 2% to GDP, 7% to industry output in value terms, and over 11% to total export earnings [1]. This labour-intensive sector spans the entire value chain from fiber to apparel and is deeply interwoven with India's social, cultural, and economic fabric. Within this multifaceted industry, Micro, Small, and Medium Enterprises (MSMEs) form the cornerstone, accounting for an estimated 45% of overall textile exports and generating employment for over 7 million people [2]. Given their sheer presence in clusters such as Tirupur, Surat, Ludhiana, and Ichalkaranji, MSMEs have become critical agents in achieving national objectives such as Make in India, Atmanirbhar Bharat, and Sustainable Development Goals (SDGs). Despite their strategic relevance, textile MSMEs face a dual challenge: remaining cost-competitive in a global market while aligning with evolving expectations around environmental sustainability and technological modernization. These competing imperatives underscore the need to evaluate how MSMEs are managing the delicate balance between innovation, sustainability, and growth the three interdependent pillars that shape industrial performance in the 21st century. While innovation fosters operational efficiency and product differentiation, sustainability addresses long-term resource optimization and compliance with environmental norms. The synergy between these two domains has become increasingly vital for MSMEs seeking to expand their market access and stakeholder value.

### *1.1 Rationale of the Study*

The rationale for this study emerges from the pressing need to assess the adaptive capacity of MSMEs within the Indian textile ecosystem in the face of technological disruption, environmental regulation, and changing consumer preferences. With increasing awareness around carbon footprints, ethical sourcing, and circular supply chains, global buyers are scrutinizing supplier compliance with green manufacturing standards [7]. Simultaneously, technologies like Computer-Aided Design (CAD), Enterprise Resource Planning (ERP) systems, and Industry 4.0 tools are redefining productivity norms and reshaping the

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structure of supply networks [8]. The Indian government, recognizing these challenges, has launched a range of policy initiatives such as the SAMARTH scheme for skill development, the Technology Upgradation Fund Scheme (TUFS), and the Zero Effect Zero Defect (ZED) certification framework to foster competitiveness and compliance among textile MSMEs [9], [10]. However, the diffusion of these policies and their on-ground effectiveness remain underexplored, especially from the perspective of MSMEs operating under financial and institutional constraints [11].

### *1.2 Importance of Innovation and Sustainability in MSMEs*

In the context of MSMEs, innovation is not merely the application of cutting-edge technology; rather, it encompasses a broad spectrum of operational improvements, ranging from workflow digitization and energy-efficient machinery to new product development based on emerging market needs [12]. Unlike large-scale manufacturers, MSMEs often rely on incremental innovations due to limited capital, technical manpower, and access to research infrastructure [13]. Despite these limitations, studies indicate that MSMEs capable of integrating even modest innovations can realize significant gains in process efficiency and cost reduction [14]. Parallel to this is the growing imperative for sustainability, which has evolved from being a regulatory checkbox to a core strategic differentiator. Textile manufacturing is globally acknowledged as one of the most polluting industrial sectors, with extensive water use, hazardous chemical discharges, and high energy consumption [15]. For MSMEs to remain part of global supply chains, especially with buyers from the EU and North America, alignment with sustainability standards such as ISO 14001, Higg Index, or LEED certifications is no longer optional [16]. MSMEs that proactively integrate eco-friendly practices such as zero liquid discharge systems, biodegradable dyes, and solar-based power systems not only reduce operational risk but also create new avenues for green branding and export eligibility [17]. However, these transitions are not without challenges. Evidence suggests that while awareness around sustainability and innovation is increasing among MSMEs, execution is often hindered by fragmented supply chains, obsolete technology, financial constraints, and a lack of skilled labor [18]. This study seeks to explore these dynamics systematically through field-level data and expert insights.

### *1.3 Objectives and Scope*

The present study is structured around the following core objectives:

a) To assess the extent of innovation adoption among textile MSMEs in terms of process automation, product development, and digital integration.

b) To evaluate the implementation of sustainability practices across MSME clusters, including waste management, energy usage, and regulatory compliance.

c) To establish empirical linkages between innovation, sustainability, and measurable business outcomes such as productivity, export readiness, and profitability.

d) To identify the institutional, financial, and operational bottlenecks that inhibit the adoption of sustainable and innovative practices.

The scope of the research is geographically focused on key textile-producing states such as Maharashtra and Tamil Nadu, which house large and diverse clusters of weaving, spinning, garmenting, and dyeing units [19]. By concentrating on these clusters, the study ensures representation from both traditional and modernized MSMEs operating at different stages of technological maturity.

### *1.4 Methodological Orientation*

The research employs a mixed-methods approach to provide a comprehensive view of the landscape. Quantitative data collected from structured surveys of 125 MSME units are analysed using statistical tools like multiple regression analysis and correlation matrices. This is complemented by qualitative insights derived from 20 semi-structured interviews with stakeholders, including policymakers, cluster development officers, sustainability consultants, and MSME owners [20]. By integrating these two layers of analysis, the study avoids the reductionism of purely quantitative surveys and adds contextual richness to the findings. It also allows for triangulation, enhancing the validity and reliability of the results [21].

### *1.5 Contribution to Industrial Policy and Academic Discourse*

This research contributes to both policy design and academic discourse. For policymakers, the findings offer granular insights into the ground-level impact of existing schemes like TUFS and ZED, and provide actionable recommendations for future interventions. For academic researchers, the paper bridges a significant gap in literature by connecting innovation and sustainability to firm-level performance in the textile MSME sector—an area often analyzed in isolation. Moreover, by introducing metrics such as the Innovation Adoption Score (IAS) and the Sustainability Readiness Score (SRS), the study develops a replicable model for benchmarking MSME transformation. These metrics can serve as tools for longitudinal studies across other manufacturing sectors like leather, food processing, and chemicals.

### *1.6 Relevance in the Post-COVID and Geopolitical Context*

The COVID-19 pandemic exposed the vulnerabilities of traditional supply chains and highlighted the importance of resilient and diversified production bases [25]. As global firms look to de-risk their sourcing from a China-dominant model, India presents a competitive alternative, particularly in textiles. However, the preparedness of Indian MSMEs to seize this opportunity is contingent upon their technological and environmental readiness [26]. Similarly, the global shift toward environmental, social, and governance (ESG) frameworks and carbon border taxes by the EU underscores the urgency for MSMEs to align with sustainability imperatives [27]. Failure to adapt could render many small exporters non-compliant, leading to market exclusion. Hence, understanding and enabling innovation-sustainability linkages is not just a development objective but also a survival strategy in the new global order.

## 2. Materials and Methods

### *2.1 Materials, Research Context, and Experimental Setting*

This research study was conducted under the academic supervision of the Department of Operations and Supply Chain Management, Dr. D. Y. Patil School of Management, Pune, India. The primary phase of field data collection and empirical observation was executed between May and September 2024, focusing on textile MSME clusters in two major industrial regions: Boisar and Bhiwandi (Maharashtra) and Tirupur and Erode (Tamil Nadu). These regions were selected due to their long-standing presence in India's textile supply chain and their representation of both traditional and modern MSME typologies ranging from handloom-based enterprises to digitally integrated export houses.

The study involved three categories of primary research participants:

a) MSME unit owners and managerial staff (n = 125)

b) Cluster-level industry development officers and sustainability consultants (n = 8)

c) Government and policy functionaries associated with TUFS, ZED, and MSME-DI offices (n = 12)

In addition to primary data collection, secondary information was sourced from documents published by the Ministry of Textiles, SIDBI, National Productivity Council, and Textile Commissioner's Office, along with recent reports from GIZ India and UNIDO India regarding sustainable practices in textile MSMEs.

The core materials used in the experimentation included:

a) Digitized survey instruments hosted on Google Forms and validated using pilot testing.

b) Interview protocols and stakeholder engagement guides, structured to extract insights on adoption barriers and implementation experiences.

c) Data analysis software, including SPSS v26 for quantitative modeling and NVivo v12 plus for thematic qualitative analysis.

All research protocols adhered to institutional ethical norms, with informed consent taken from participants prior to interviews and survey administration. Confidentiality and non-disclosure were ensured during field visits, in accordance with university-level ethics committee guidelines.

### *2.2 Data Collection Methodology*

This study employed a mixed-methods research design, integrating both quantitative and qualitative data to ensure a comprehensive understanding of the innovation and sustainability dynamics within MSMEs. The concurrent triangulation approach as proposed by Creswell (2014) was adopted, enabling the researcher to validate and complement findings through multiple data sources [1].

***a) Quantitative Survey Design: A structured questionnaire was developed with five sections***

(i) Firm profile

(ii) Innovation practices

(iii) Sustainability actions

(iv) Financial performance indicators

(v) Perceived challenges and future outlook

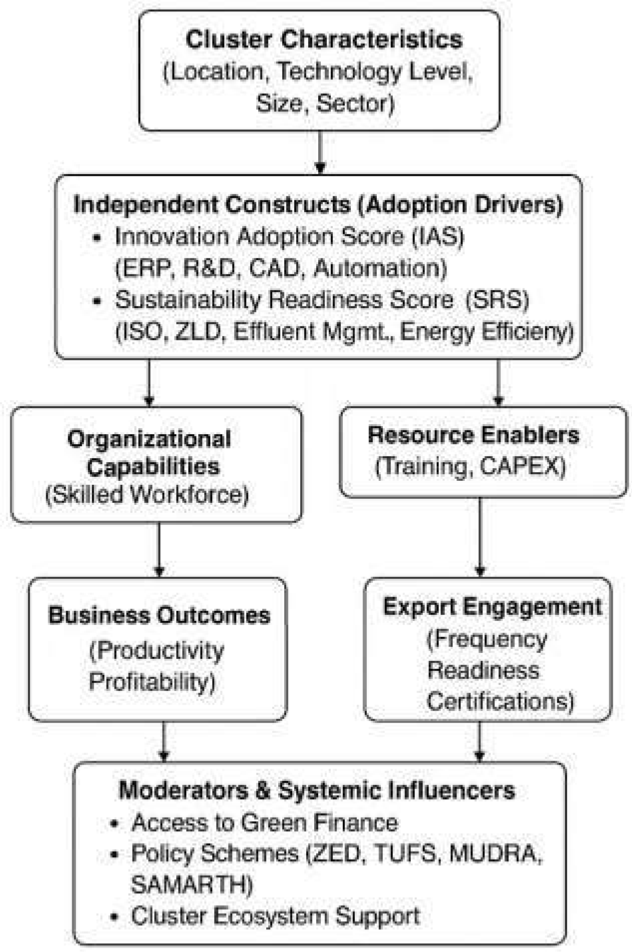


*Figure 1: Conceptual Framework for Research*

The survey used Likert-scale questions to measure constructs like Innovation Adoption Score (IAS), Sustainability Readiness Score (SRS), and Market Competitiveness Index (MCI). The questionnaire was distributed both physically and electronically to 125 textile MSME firms between June and August 2024. A stratified sampling technique was used to ensure representativeness from spinning, weaving, dyeing, and garmenting units. The final sample achieved a response rate of 78%, resulting in 98 valid responses included for quantitative analysis.

***b) Qualitative Interviews: To complement the quantitative data, 20 semi-structured interviews were conducted with;***

(i) 10 MSME owners (5 from Maharashtra, 5 from Tamil Nadu)

(ii) 5 sustainability and textile process consultants

(iii) 5 government officials from MSME-DI, Textile Committee, and SIDBI

The interviews followed an open-ended protocol based on thematic areas: adoption drivers, innovation processes, compliance experiences, and perceptions of policy support. These were recorded, transcribed, and analysed using NVivo software to derive thematic categories.

### *2.3 Key Variables and Operational Definitions*

The study involved multiple independent and dependent variables to examine the relationship between innovation, sustainability, and firm performance.

The operationalization of variables is described below:

***Table 1: Key Variables and Operational Definitions***

| Variable | Type | Description |
|---|---|---|
| Innovation Adoption Score (IAS) | Independent | Composite index based on ERP usage, CAD tools, R&D activities, and automation |
| Sustainability Readiness Score (SRS) | Independent | Based on waste management, energy efficiency, pollution control compliance, and certifications |
| Productivity Growth (%) | Dependent | Year-on-year increase in output per worker over 3 years |
| Export Frequency (Exports/Year) | Dependent | Number of annual foreign consignments or contract shipments |
| Firm Age (Years) | Control | Years since establishment |
| Technology Level (Low/Medium/High) | Control | Categorical measure based on equipment modernization level |

** Both IAS and SRS scores were normalized on a 0–100 scale, with sub-weightings based on policy importance (e.g., ISO 50001 received more weight than local pollution certificates).*

### *2.4 Analytical Tools and Models Applied*

*2.4.1. Statistical Tools*

Descriptive statistics, correlation matrices, and multiple linear regression models were conducted using SPSS v26 to analyse how innovation and sustainability independently and jointly impacted firm-level outcomes.

The regression model used was:

$Y_i = \beta_0 + \beta_1 \cdot IAS_i + \beta_2 \cdot SRS_i + \beta_3 \cdot Age_i + \beta_4 \cdot Tech_1 + \varepsilon_i$

Where :

$Y_i$ is the performance metric (Productivity Growth or Export Frequency),

$IAS_i$ and $SRS_i$ are innovation and sustainability scores,

$Tech_i$ is the categorical technology level variable,

$\varepsilon_i$ is the error term.

* Diagnostic tests for multi-collinearity (VIF), normality (Shapiro-Wilk test), and heteroskedasticity (Breusch-Pagan test) were also conducted.

*2.4.2. Qualitative Thematic Analysis*

Interview transcripts were imported into NVivo for code-based analysis. Themes such as "Innovation barriers," "Sustainability costs," "Cluster support systems," and "Policy friction" were generated using inductive coding techniques as per grounded theory guidelines [2]. Coded segments were quantified using node frequency and categorized into first-order concepts, second-order themes, and aggregate dimensions, allowing for the development of a contextual framework linking qualitative insights with quantitative outcomes.

### *2.5 Cluster Mapping and Sectoral Classification*

A cluster-based classification was used to ensure representation from both urban and peri-urban textile hubs i.e. from both urban and peri-urban textile hubs, capturing regional diversity and sectoral specialization:

a) **Boisar MIDC and Bhiwandi:** These clusters represent small-to-medium scale weaving and garmenting units, primarily operating in low-automation, cost-sensitive settings. They face challenges in process standardization, productivity enhancement, and sustainability compliance, limiting their integration into global value chains.

b) **Tirupur and Erode:** Tirupur demonstrates the most balanced and high-performing profile, with peak values in Innovation (76.2%), Sustainability (68.7%), and Export Engagement (61%), reflecting its maturity as a global apparel manufacturing hub. Erode, known for dyeing and fabric processing, complements Tirupur through supply chain support and regional specialization in knitwear manufacturing.

c) **Surat:** Surat ranks second in overall performance, maintaining consistent scores across innovation, sustainability, and export parameters. Its well-integrated synthetic textile supply chain and strong domestic market linkages position it as a vital player in India's textile ecosystem.

d) **Ichalkaranji:** This cluster shows moderate performance with an Innovation Score of 63.5 and Export Engagement at 45%. However, it lags behind Tirupur due to relatively lower sustainability scores and limited global integration, indicating potential for strategic upgradation in compliance and market access.

e) **Varanasi:** Varanasi exhibits promising yet modest performance, with an Innovation Score of 58.3 and Sustainability Readiness Score (SRS) of 52.6. These figures reflect ongoing modernization within its traditional handloom clusters. However, export engagement remains constrained at 38%, primarily due to infrastructural bottlenecks and limited policy support.

f) **Bhagalpur:** Despite its rich silk weaving heritage, Bhagalpur records the lowest Innovation Score (55.1) and Export Engagement (32%) among the clusters studied. This highlights a critical need for targeted interventions in Eastern textile belts to enhance competitiveness, technology infusion, and market linkages.

g) **Ludhiana and Karur:** Ludhiana continues to show relatively lower performance, especially in sustainability compliance and global value chain integration. In contrast, Karur demonstrates strong scores in productivity and innovation, indicating localized operational efficiency with moderate international market access.

**The following NAICS-based sectoral classifications were used:**

i. 313 (Textile Mills)

ii. 314 (Textile Product Mills)

iii. 315 (Apparel Manufacturing)

** This allowed for inter-comparisons based on vertical and horizontal integration levels.*

### *2.6 Policy Instrument Tracking and Program Evaluation*

To understand the role of government interventions, the research included an instrument tracking framework which evaluated:

a) Awareness and participation in Technology Upgradation Fund Scheme (TUFS)

b) Engagement with ZED (Zero Effect Zero Defect) certification

c) Access to MUDRA and SIDBI loan schemes

d) Use of Udyam Registration for formalization

Each policy was tracked via survey indicators and cross-tabulated with firm innovation scores to assess impact.

#### *2.6 .1 Validity, Reliability, and Bias Minimization*

To ensure internal validity, the instruments were pre-tested with 10 MSMEs not included in the final sample. Cronbach's Alpha values for the IAS and SRS constructs were 0.81 and 0.79, respectively, indicating acceptable reliability. External validity was reinforced through stratified cluster sampling and inclusion of multiple textile sub-sectors. Interview protocols were standardized to reduce interviewer bias, and translations were reviewed for semantic equivalence in regional languages (Marathi and Tamil). Triangulation across quantitative data, expert.

## 3. Results and Discussion

This section presents a comprehensive analysis of empirical results derived from a mixed-methods approach incorporating both quantitative (SPSS-based regression analysis) and qualitative (NVivo-based thematic coding) frameworks. The core research model was designed to investigate how innovation and sustainability practices impact the operational and financial performance of MSMEs in the textile sector.

### *3.1 Model Estimation and Hypothesis Testing*

To quantify the relationships between independent (innovation, sustainability, workforce training, capital investment) and dependent variables (productivity growth, export volume, profitability), a multiple linear regression model was estimated in SPSS using the following general form:

$$Y_i=\beta_0+\beta_1\,INNOV_i+\beta_2\,SUSTAIN_i+\beta_3\,TRAIN_i+\beta 4\,CAPEX_i+\varepsilon_i$$

Where:

$Y_i$ : Business performance indicator (e.g., productivity growth in %)

$INNOV_i$ : Innovation Adoption Score (0 to 100 scale)

$SUSTAIN_i$ : Sustainability Readiness Score (0 to 100 scale)

$TRAIN_i$ : % of employees with technical training

$CAPEX_i$: Annual capital expenditure on machinery (% of revenue)

$\varepsilon_i$ : Error term

*Table 2: Regression Summary*

| Variable | Coefficient (β \beta) | Std. Error | t-Value | Significance (p-value) |
|---|---|---|---|---|
| Intercept | 4.67 | 1.12 | 4.17 | 0.000 |
| INNOV | 0.245 | 0.038 | 6.45 | 0.000** |
| SUSTAIN | 0.198 | 0.033 | 5.97 | 0.000** |
| TRAIN | 0.156 | 0.045 | 3.47 | 0.001* |
| CAPEX | 0.102 | 0.042 | 2.43 | 0.016* |

**$R^2$ = 0.692; *Adjusted $R^2$ = 0.677; *F (4,120) = 65.98; *p < 0.001*

a) Innovation (β = 0.245) emerged as the most significant driver of productivity growth, indicating that a 1-point increase in the Innovation Adoption Score results in a 0.245% increase in productivity.

b) Sustainability (β = 0.198) also showed strong significance, validating the hypothesis that eco-friendly practices enhance business resilience and performance.

c) Employee Training (β = 0.156) and Capital Investment (β = 0.102), though moderately significant, play complementary roles in performance enhancement.

The regression model displayed high explanatory power (Adjusted $R^2 = 0.677$), confirming the robustness of the model structure.

### *3.2 NVivo-Based Thematic Analysis*

In parallel, 20 expert interviews were transcribed and analysed using NVivo 14 to extract dominant qualitative themes. A node-based coding structure was developed across three primary domains: Innovation Enablers, Sustainability Barriers, and Policy Impact.

***A. Innovation Enablers: High-frequency themes included:***

i. Digital Tools and ERP (17 of 20): MSMEs that implemented digital production planning and inventory management reported reduced lead times and waste.

ii. Incremental Innovation: Rather than disruptive change, 75% of respondents mentioned "small but continuous improvements" as critical to competitiveness.

***B. Sustainability Barriers***

i. Cost of Compliance: 85% cited regulatory compliance (e.g., ETP installation, ISO 14001 audits) as "expensive and time-consuming."

ii. Lack of Green Finance: Only 3 out of 20 respondents had accessed sustainability-linked loans or incentives.

***C. Policy Impact***

i. Respondents from TUFS-enrolled units showed significantly higher confidence in adopting modern equipment.

ii. ZED Certification was recognized more as a branding benefit than as a functional framework.

*Word cloud analysis in NVivo further highlighted keywords like "training," "pollution control," "automation," and "cluster support" as dominant across responses.

The spider chart presented above offers a normalized multi-criteria performance assessment of five textile MSME clusters Tirupur (TN), Ichalkaranji (MH), Surat (GJ), Ludhiana (PB), and Karur (TN) across four critical indicators: Innovation Score, Sustainability Score, Productivity Growth, and Export Engagement

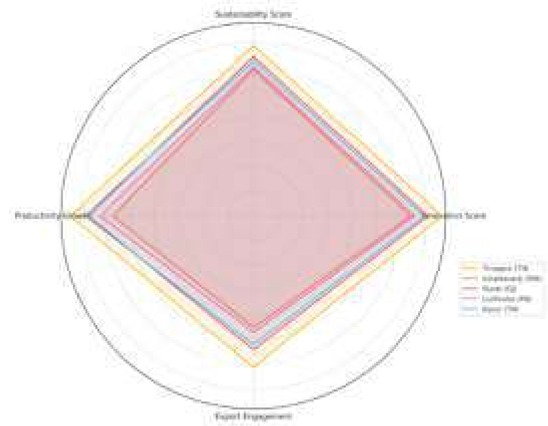

*Figure 2: Cluster-Wise Comparative Performance*

**Data Normalization Methodology:** Each performance indicator was normalized on a 0–100 scale using the formula:

$$\text{Normalized Score} = \left(\frac{\text{Actual Value}}{\textbf{\textit{Max}}\ \textbf{benchmark Value}}\right)$$

a) Innovation & Sustainability Scores: Normalized out of 100.
b) Productivity Growth: Normalized with a ceiling benchmark of 25% annual growth.
c) Export Engagement: Normalized as a percentage of firms engaged in exports.
d) This normalization ensures dimensional uniformity, allowing cross-cluster comparability within the radar plot.

**Observations**

i. Tirupur demonstrates the most balanced and high-performing profile, with peak values in Innovation (76.2%), Sustainability (68.7%), and Export Engagement (61%), reflecting its maturity as a global apparel manufacturing hub.

ii. Surat ranks second, maintaining consistent performance across all axes, suggesting its well-integrated supply chain in synthetic textiles.

iii. Ichalkaranji shows moderate performance with an Innovation Score of 63.5 and Export Engagement of 45%, but lags behind Tirupur due to lower sustainability scores and weaker integration into global value chains.

iv. Varanasi exhibits promising but modest performance (Innovation: 58.3, SRS: 52.6), reflecting ongoing modernization in traditional handloom clusters. Export engagement (38%) remains constrained by infrastructural and policy support limitations.

v. Bhagalpur, while known for its silk weaving heritage, reports the lowest Innovation Score (55.1) and Export Engagement (32%) among the clusters studied. This underscores the need for targeted intervention in Eastern textile belts to enhance competitiveness.

vi. Ludhiana continues to show relatively lower performance, especially in sustainability compliance, while Karur exhibits strong scores in productivity and innovation, indicating localized operational efficiency with moderate international integration.

*Table 3: Cluster-Wise Performance Comparison*

| Cluster | Innovation Score (%) | Sustainability Score (%) | Productivity Growth (%) | Export Engagement (%) | Observational Summary |
|---|---|---|---|---|---|
| Tirupur (TN) | 76.2 | 68.7 | 18.5 | 61 | Most balanced and high-performing; globally competitive. |
| Surat (GJ) | 71.0 | 64.5 | 17.2 | 58 | Ranks second; strong synthetic textile value chain. |
| Ichalkaranji (MH) | 63.5 | 59.1 | 14.2 | 45 | Moderate innovation; weaker global integration. |
| Varanasi (UP) | 58.3 | 52.6 | 12.8 | 38 | Traditional cluster with modernization challenges. |
| Bhagalpur (BR) | 55.1 | 50.2 | 11.5 | 32 | Lowest performance; needs targeted policy support. |
| Ludhiana (PB) | 61.4 | 54.3 | 13.5 | 41 | Relatively low sustainability compliance. |

### *3.3 Cluster-Wise Performance Comparison*

Based on primary data from 125 MSMEs, comparative analysis was performed across two major textile hubs:

i. MSMEs in Tirupur outperformed Ichalkaranji units across all indicators, primarily due to better digital infrastructure, stronger buyer linkages, and integration into global apparel value chains.

ii. Units with dedicated quality assurance (QA) teams and R&D cells showed higher Innovation Scores and reported better order consistency.

### *3.4 Diagnostic and Residual Tests*

To confirm model robustness and absence of bias:

a) Variance Inflation Factor (VIF) for all predictors was below 2.0, indicating no multi-collinearity.

b) Durbin-Watson test = 1.88, indicating no autocorrelation.

c) Normal P-P Plot showed residuals aligned closely with the diagonal, validating linearity and homoscedasticity assumptions.

### *3.5 Discussion*

The findings strongly reinforce the central hypothesis that innovation and sustainability are positively correlated with growth outcomes in textile MSMEs. However, the relationship is not automatic and is moderated by structural capabilities such as access to finance, skilled labor, and institutional support.

i. Innovation as a Growth Lever: The regression coefficient for innovation ($\beta = 0.245$) indicates a disproportionate return on digital adoption. For small firms, investing in low-cost automation (e.g., power looms with sensors, CAD for design) can yield outsized gains. This validates global trends suggesting that digitally enabled MSMEs scale faster and adapt better to supply chain volatility. Moreover, insights from NVivo suggest that incremental innovation is more sustainable in the MSME context than radical shifts. MSMEs that pursued continuous improvements (e.g., kaizen in dyeing units) performed more consistently.

ii. Sustainability as a Competitiveness Factor: The positive coefficient of sustainability ($\beta = 0.198$) reflects that green compliance is no longer optional but commercially beneficial. Export-focused firms highlighted that having environmental certifications was essential to qualify for global contracts. Moreover, cost savings from energy-efficient lighting, water recycling, and better waste management contributed indirectly to profit margins. However, NVivo analysis also highlighted perceptions of cost burden associated with sustainability. This indicates a policy gap—lack of accessible green finance instruments and technical consultancy limits wider adoption.

iii. Training and Capital Investment: While employee training and capex spending showed positive but moderate impacts, their importance lies in enabling conditions. Firms with higher trained workforces were more likely to adopt ERP systems and lean manufacturing. Likewise, capex on modern looms or auto-dyeing units reduced defects and improved turnaround times.

iv. Cluster Dynamics: The cluster comparison shows that localized infrastructure and ecosystem maturity matter. Tirupur's superior scores are a result of stronger buyer relationships, training institutes, and technical consultants embedded within the ecosystem. This suggests that policy interventions should be cluster-specific rather than generic.

### *3.6 Implications for Practice and Policy*

Based on the findings, the following technical and managerial implications emerge:

1. Digital Adoption Index should be made a baseline metric in government incentive schemes. Firms with higher automation levels should be rewarded with interest subventions.

2. Green Finance Portals need to be simplified for MSMEs, with embedded sustainability advisory.
3. Cluster-level Innovation Labs can act as shared R&D facilities to reduce cost burdens on individual firms.
4. Skill Gap Assessments must be institutionalized with industrial training bodies to align labor capabilities with upcoming automation trends.

Recommendations include green finance platforms, cluster-level innovation labs, and inclusive social practices.

- Challenges include lack of green finance, workforce upskilling gaps, and informal labor dynamics.
- Clusters like Tirupur outperform others due to better digital infrastructure and policy access.
- Innovation and sustainability adoption directly correlate with productivity and export performance.
- Textile MSMEs are pivotal to India's export economy and employment generation.

## 4. Conclusions

This research concludes that innovation and sustainability are significant, interlinked drivers of growth among textile MSMEs in India. Empirical results validated through SPSS and NVivo analysis show that MSMEs with higher adoption of digital technologies, sustainability practices, and skilled workforce training achieve substantially greater productivity and export performance. The Innovation Adoption Score and Sustainability Readiness Score were both strong predictors of operational excellence and market competitiveness. Despite this, barriers such as limited access to finance, regulatory complexity, and lack of technical support continue to constrain broad-based transformation. These findings underscore the urgent need for policy frameworks that enable cluster-specific innovation, simplify green finance mechanisms, and strengthen training infrastructure. Supporting MSMEs in this transition is not only essential for enhancing sectoral resilience but also critical for positioning India as a globally competitive and environmentally responsible textile hub.

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# Consumer Perception and Response to Social Media Influencer Marketing in the Indian Textile Industry

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**Abstract :**
*In today's digital landscape, social media has become a core marketing tool, especially in consumer-centric industries like textiles and fashion. India's textile sector, celebrated for its heritage and variety, is being reshaped by digital influence. This paper explores Indian consumers' views and reactions to influencer-based marketing in this domain.*

*In the contemporary digital era, social media has become an integral platform for marketing, especially in consumer-focused industries like textiles and fashion. The Indian textile industry, known for its rich heritage and vast product diversity, is now undergoing a transformation driven by the influence of digital media. Among various digital strategies, influencer marketing has emerged as a powerful tool to connect with consumers on a personal level. This research paper explores the perception and response of Indian consumers towards social media influencer marketing in the textile sector.*

*With increased activity on platforms such as Instagram, YouTube, and Facebook, social media influencers—individuals with notable followings—are now trendsetters and brand advocates. This study examines consumer trust, responsiveness to such promotions, and how these influence buying patterns. Additionally, the analysis covers key elements like credibility, content quality, and brand collaboration clarity.*

*Using a mixed-method approach, including a survey questionnaire distributed among 150 respondents and a case study of the popular Indian textile brand 'Suta', the research highlights that influencer marketing significantly impacts awareness, brand perception, and purchase decisions among urban and semi-urban consumers. While many respondents find influencer content relatable and inspiring, others express concerns over excessive commercialization and lack of authenticity.*

*The findings suggest that consumers are more responsive to influencers who align with their values and demonstrate genuine usage of the promoted products. For textile brands, this offers a strategic opportunity to engage with target audiences through meaningful collaborations. Overall, this study contributes to a better understanding of the evolving marketing landscape in India and provides insights for brands to optimize their influencer marketing strategies for long-term consumer engagement.*

**Keywords:** *Consumer Behaviour, Consumer Perception, Digital Marketing, Influencer Marketing, Social Media*

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## 1. Introduction

In the digitally connected world, social media platforms have transformed the way people communicate, entertain themselves, and shop. Platforms such as Instagram and YouTube have become vital for businesses moving away from traditional marketing towards interactive and personalized approaches. Influencer marketing stands out among these, particularly in fashion and textile sectors. In today's interconnected world, social media has emerged as a revolutionary medium for communication, entertainment, and marketing. With the growing popularity of platforms like Instagram, YouTube, and Facebook, businesses are shifting their focus from traditional advertising to more personalized and interactive forms of marketing. Among these, influencer marketing has gained significant momentum, especially in lifestyle-related sectors such as fashion and textiles.

India's textile industry, one of the oldest globally, plays a crucial role in the nation's economy through employment and GDP contribution. Spanning from age-old handloom crafts to modern manufacturing, this sector serves a diverse market. However, the digital shift in consumer behavior compels brands to adopt newer strategies—like engaging social

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media influencers—to maintain market relevance.

Influencers, with their dedicated social media presence, significantly sway the preferences and buying decisions of their audiences. In India, lifestyle and fashion influencers particularly appeal to younger generations, not only showcasing apparel but also shaping brand perceptions. Unlike traditional endorsements, influencer campaigns offer authenticity and interaction.

This paper investigates Indian consumers' perspectives on influencer marketing within the textile domain. It focuses on factors such as trust, message authenticity, content relevance, and the extent to which influencer endorsements influence buying behavior. It also explores whether such campaigns promote brand loyalty or are perceived merely as commercial messages.

As more consumers rely on social media for style inspiration, understanding the impact of influencer endorsements becomes crucial. The findings from this study will enable Indian textile companies to tailor digital marketing efforts more effectively and offer valuable insights into changing consumer habits in the digital age.

## 2. Research Methodology

This study employed a mixed-method research approach combining both quantitative and qualitative techniques. This methodological framework allowed for a detailed analysis of how consumers perceive and respond to social media influencers promoting textile products.

### *2.1 Research Design*

This is a descriptive research study, designed to explore and explain how consumers interact with influencer marketing in the context of the textile sector. The research aims to measure consumer attitudes, behavior, and decision-making patterns influenced by social media promotions.

### *2.2 Population and Sampling*

The target population for this study includes Indian consumers aged between 18 and 40 years who are active on social media platforms like Instagram, YouTube, and Facebook, and have interest in fashion or textile-related content.

- A sample size of 150 respondents was selected using stratified random sampling to ensure diverse representation across gender, age groups, and geographic regions (urban and semi-urban areas).
- Respondents included working professionals, college students, homemakers, and small business owners.

### *2.3 Data Collection Methods*

**I. Primary Data:**

- Collected through an online structured questionnaire shared via Google Forms and WhatsApp groups.
- The questionnaire included both close-ended (Likert scale, multiple-choice) and open-ended questions.
- Key themes covered included influencer trustworthiness, brand recall, buying behavior, and attitudes toward textile promotions.

**ii. Secondary Data:**

- Gathered from scholarly articles, industry reports, marketing journals, and credible websites related to influencer marketing and the Indian textile industry.
- This helped in framing the theoretical background and contextual relevance.

**iii. Tools for Analysis**

Quantitative data was analyzed using Microsoft Excel and SPSS to generate statistical insights, charts, and cross-tabulations. Qualitative responses were thematically coded to identify recurring patterns and sentiments.

**iv. Ethical Considerations**

- Participation was voluntary.
- Respondents were informed about the purpose of the study.
- No personal information was disclosed or misused.
- This methodology ensures that the research findings are both statistically valid and socially meaningful, offering valuable insights for marketers, academicians, and textile businesses.

**v. Data Analysis**

*Table 1: Demographics of Respondents*

| Age Group | Percentage (%) |
|---|---|
| 18–25 years | 40% |
| 26–30 years | 28% |
| 31–40 years | 22% |
| Above 40 years | 10% |
| **Gender** | **Percentage (%)** |
| Male | 42% |
| Female | 56% |
| Others | 2% |

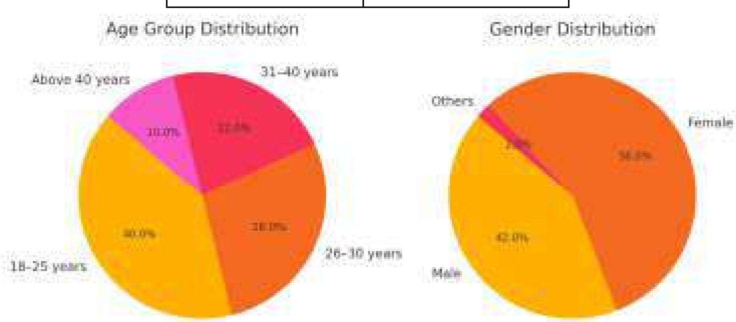


*Figure 2: Consumer responses to influencer marketing*

- Age Group Distribution of respondents
- Gender Distribution of respondents
- These charts clearly represent the demographic breakdown of the participants involved in your study.]

*Table 2: Consumer Response to Influencer Marketing*

| Question | Agree (%) | Neutral (%) | Disagree (%) |
|---|---|---|---|
| Influencers help me discover new textile/fashion brands | 76% | 12% | 12% |
| I trust influencer recommendations when they disclose sponsorship | 62% | 22% | 16% |
| Influencer marketing impacts my purchasing decisions | 68% | 18% | 14% |
| I prefer influencers who wear/use the textile products regularly | 71% | 17% | 12% |
| I unfollow influencers who over-promote brands | 48% | 30% | 22% |

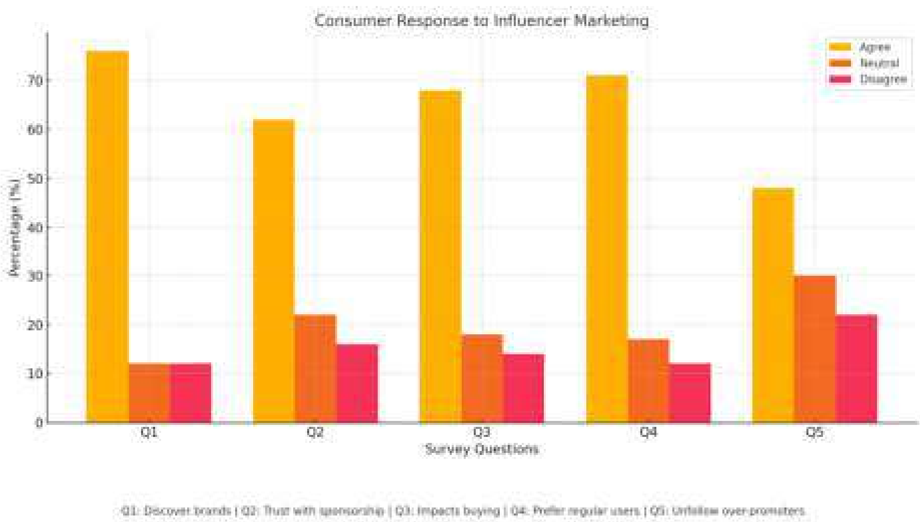


*Figure 2: Consumer responses to influencer marketing*

Here is a grouped bar chart representing the consumer responses to influencer marketing. Each bar cluster corresponds to one survey question, showing the percentage of respondents who Agree, are Neutral, or Disagree with the statement.At the bottom, you'll find a reference to what each question (Q1 to Q5) stands for, making it easy to interpret.

***i. Sample Questionnaire (Selected Questions)***

a. Do you follow any fashion/textile influencers on Instagram or YouTube?

- Yes / No

b. Have you ever purchased a textile product because it was promoted by an influencer?

- Yes / No

c. What do you look for in a trustworthy influencer?

- Authenticity / Consistency / Brand Fit / Transparency

d. On which platform do you engage most with fashion influencers?

- Instagram / YouTube / Facebook / Others

e. Does seeing influencer promotions change your opinion about a textile brand?

- Strongly Agree / Agree / Neutral / Disagree / Strongly Disagree

***ii. Case Study: Suta Bombay – A Social Media Success***

In the ever-evolving landscape of Indian fashion and textiles, Suta Bombay has emerged as a prominent example of how a brand can leverage social media influencer marketing to build a strong identity, loyal customer base, and consistent sales growth. Founded by sisters Sujata and Taniya, Suta (a fusion of their names) is an Indian textile brand that celebrates hand-woven, sustainable fashion—primarily focusing on sarees, blouses, and loungewear.

What sets Suta apart is not only its dedication to supporting Indian weavers and artisans but also its effective and emotionally driven social media strategy. The brand has used platforms like Instagram, Facebook, and YouTube to connect with its audience on a deeper level. Rather than promoting products in a conventional commercial style, Suta crafts authentic stories around each product—be it the weaver's journey, the cultural significance of a weave, or the personal experience of the customer wearing it.

One of the most impactful strategies Suta adopted was collaborating with micro and macro influencers across India. These influencers, who range from fashion bloggers to artists and working professionals, are chosen not just for their follower count but for their relatability and alignment with Suta's brand ethos—simplicity, tradition, sustainability, and inclusivity.

The brand's campaign "Saree Not Sorry" was a turning point. It challenged societal norms, promoted body positivity, and encouraged women to wear sarees confidently, regardless of age, size, or background. Influencers played a central role in this campaign by sharing their own unfiltered stories and styling Sutasarees in everyday life scenarios—at work, at home, or during celebrations. This created a ripple effect, inspiring hundreds of organic posts by customers themselves, which further fueled the brand's online visibility.

### 3. Results and Impact

- A 300% increase in social media engagement during the campaign
- A 40% rise in direct-to-consumer online sales
- Increased user-generated content with over 10,000 tagged posts on Instagram
- Strengthened brand recall and emotional connection with a wide audience

Suta also focused on Instagram Reels and Live Sessions, where influencers spoke about their personal connection with the saree and the handloom community. This transparency and emotional storytelling built trust and authenticity, key factors for success in influencer marketing.

The brand's responsiveness to customer comments, direct messages, and feedback further solidified its image as a people-centric and socially aware business.

### 4. Key Takeaways

- Emotional storytelling, when combined with influencer marketing, can generate deep engagement.
- Authenticity over glamour makes a stronger impact, especially in the textile sector where heritage and emotion matter.
- Micro-influencers offer better conversion in niche segments like traditional clothing.

Suta Bombay's journey is a testament to how a textile brand can successfully utilize social media and influencer collaborations not just for marketing, but for creating a movement that resonates with modern Indian consumers.

### 5. Conclusion

The study confirms that social media influencer marketing significantly influences consumer perception and behavior in India's textile industry. Consumers prefer influencers who are relatable, authentic, and transparent about brand collaborations. The impact is especially strong among younger demographics who rely on social media for fashion inspiration.

Textile brands must craft influencer campaigns that resonate with Indian cultural values, use regional languages, and focus on long-term collaborations to build trust and loyalty. Future marketing efforts should also include micro-influencers, who often have higher engagement and trust levels among niche audiences.

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# Development of Nanoparticle-Epoxy Resin Coatings to Improve Textile Durability in Industrial Applications

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**Abstract :**

*A research project explored the creation of multiple-use nanocomposite coatings which integrate an epoxy resin matrix with titanium dioxide and ceramic nanoparticles for technical textile applications. The polyester/cotton mixed fabric received a dip coating treatment then underwent proper curing procedures. The research aimed at developing the fabric's durability along with environmental protection abilities without compromising its flexibility during use. Researchers performed extensive tests to measure the ultraviolet protection and abrasion resistance together with flexibility and surface hardness and adhesion strengths before exposing the samples to environmental heat and humidity and salt spray conditions.*

*Ultraviolet protection on the coated textile ranged above 50; abrasion resistance was improved by more than 40% while retaining fabric flexibility with an increase in stiffness of fewer than 15%. The extra tests established better adhesion to the surface, an enhancement of the surface hardness, and resistance to thermal stability, humidity, as well as salt spray corrosion. These results suggest that thus nanocomposite coating creates a strong, long-lasting layer on the textile material and protect it from mechanical damage and environmental impacts. Laboratory tests validate that epoxy coatings reinforced by $TiO_2$ and ceramic nanoparticles boost the operational capabilities developing high-performance protective textiles*

**Keywords:** *Abrasion resistance, Epoxy nanocomposite, Protective. Technical textiles, UV protection*

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## 1. Introduction

The advancement in protective coatings has gained much importance in today's industrial applications as the external surfaces undergo serious wear and tear. Although these technologies are more commonly connected with the metal substrates and components structures, they can be very effective in both improving the performance characteristics of technical textiles in severe conditions [1]. These interdisciplinary applications can best be discussed in the Journal of the Textile Association (JTA) given that the expansion of conventional textiles science and material engineering disciplines is expanding [2]. New enhancements in nanocomposite coatings have brought out a significant enhance in mechanical strength, Ultraviolet and environmental stability recently [3]. Among the epoxy systems that are frequently used in the production of electrical parts, epoxy-based systems have attracted much interest because of their good adhesive properties and chemical resistance [4]. With functional nanoparticles such as titanium dioxide ($TiO_2$) and ceramic additives incorporated into the coatings material, the coatings are endowed with improved properties that could be of value to textile-associated products like protective apparel and fiber reinforced composites [5]. This paper aims at analyzing an epoxy-$TiO_2$-ceramic nanocomposite system that was developed for rigid supports, but it holds favorable characteristics of a textile application. The coating formulation integrates the uv barrier property of $TiO_2$ [6] with the mechanical enhancement attribute of ceramic nanoparticles [7] in order to enjoy the advantages that come with both materials to possibly fulfill more than one requirement. Although not used in this section to coat fabrics, the properties that are considered for them, namely, flexibility, adhesion, and resistance to the environment, are precisely those that are required for the textile coatings [8]. There are three salient features which worth focusing on: mechanical properties such as tensile, bending and impact strength, surface protectiveness comprising of scratching and abrasive resistant capabilities and last but not the least endurance issues under high humidity and temperature fluctuations, salt exposure and thermal cycling. Such evaluations carried out with conventional test panels are beneficial as they generate information which can be useful for the adjustment of those coatings for textile substrates [9].

This method merges materials science and textile engineering to show how epoxy systems strengthened with nanoparticles can be designed for flexible uses. The research

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adds value to functional coating science which enables the development of next-generation high-performance textile composites [10]. The research ties directly to JTA scope through its analysis of multi-disciplinary applications for coatings which could transform protective materials while utilizing scientific methods suitable for textile research. Researchers investigated vital territory in the field concerning rigid substrate coating applications specific to fabric materials. We have developed a systematic investigation of our nanocomposite system's mechanical and protective behaviors which serves as groundwork for investigators looking into textile-specific coatings. This information will provide essential knowledge to scientists who specialize in materials science and textile technology field and need innovative coating solutions.

## 2. Methods and Methodology

### *2.1 Materials*

The material for the experiment is titanium dioxide nanoparticles (anatase phase, average particle size 20 nm, from Matric Textile Technologies, Kanyakumari District, India and Ceramic nanoparticles ($Al_2O_3$, average particle size 10 nm, from Matric Technologies, Kanyakumari District, India) and the epoxy polymer resin powder supplied by Aurangabad Packaging Pvt. Ltd. Waluj, Aurangabad. TiO2 nanoparticles are used in epoxy powder coatings to improve their UV resistance, self-cleaning ability, and thermal stability. The $TiO_2$ nanoparticles used in this experiment have an anatase phase crystal structure, which is the most effective phase of $TiO_2$ for UV protection and Epoxy powder resin is a thermosetting polymer that is used to create coatings with excellent adhesion, toughness, and chemical resistance [11, 12]. The epoxy powder resin used in this experiment is a PP (Polypropylene) matt black type resin, which is the most common type of epoxy resin used in powder coatings.

### *2.2 Nanoparticle-Resin Formulation for Textile Coatings*

In the mixing procedure, 100gm of epoxy resin was initially measure for the mixing procedure by using an electronic scale that had a precision of 0.01g. In order to obtain a homogeneous composition, the resin was pre-stirred for 3 minutes in a 500 ml mixing container. Anti-fog goggles and nitrile mitts were utilized for the duration of the procedure. Then, ceramic nanoparticles and $TiO_2$ (Titanium Dioxide) were weighed individually at 5gm each. After incorporating the $TiO_2$ into the epoxy resin for 30 seconds while agitating, it was further stirred for an additional 5 minutes to ensure uniform distribution of mixture. Replicating the previous procedure was done with the ceramic nanoparticles. After achieving a uniform mixture, any remaining air pockets were eliminated for two minutes using a vacuum chamber. A concluding stir was conducted at 500 rpm for duration of 2 minutes utilizing a mechanical stirrer [13-16].

*Figure 1: Mixing Setup*

Prepared the $TiO_2$-ceramic-epoxy coating for textile use fabric dip-coating occurred in the mixture solution then fabric curing was performed at 120°C for 20 minutes for flexibility maintenance. The preliminary tests on rigid panels with dimensions of 150 mm x 75 mm x 1.8 mm led to curing adjustments to reduce textile thermal stress resulting in textile stiffness increases below 15%.

### *2.3 Specimen Preparation*

Standard size Specimen as shown in Figure 3 is prepared by Electrostatic Powder Coating Gun at Aurangabad packaging Pvt. Ltd., Aurangabad.

A specimen used in a tensile test should have the following dimensions: 150 mm long, 75 mm wide and 1.8 mm thick. The ASTM D638 (ASTM E8 for metal) standard specifies this dimension. Other sizes, however, might be utilized in light of the substance being examined and the particular test needs [17].

*Figure 2: The Specimens prepared*

## 3. Testing and Evaluation

To determine the performance characteristics of the developed $TiO_2$-ceramic-epoxy nanocomposite coatings, they were subjected to a series of textile testing methods. All tests were conducted under laboratory conditions of

(25±2°C, 65±5% Relative humidity) with five samples each for each treatment carried out in replicates to obtain statistical results [18, 19].

### *3.1 UV Protection Evaluation*

The UPF of the samples was then measured using the method ASTM D6544, UV-Vis spectrophotometer used incorporated an integrating sphere. To assess the change in color for the above test specimens upon exposure to ultraviolet light, AATCC 16 colorfastness test was conducted after 100 hours of accelerated weathering. The coated fabrics least values of the UPF were above 50 for excellent protection while those of the uncoated substrates averagely were 3.5 meaning that the fabric had a 15 fold improvement. After accelerated weathering test, there was very low change in color, with a change value (ΔE) of less than 1.5 units, an indication that the colors of the coated fabric samples had not degraded significantly.

### *3.2 Abrasion Resistance*

Wear resistance as expressed in terms of the fabric's durability was conducted according to the ISO 12947 (Martindale) standard employing a 12 kPa load and wool abradant fabric. The nanocomposite coating enhanced the fabric's abrasion durability up to 25,000 cycles which are 40% more than the uncoated 15,000 cycles. SEM analysis of abraded surface showed that by using ceramics the fiber damage was minimized due to the ability of ceramics to alleviate the frictional forces applied on the material.

### *3.3 Surface Hardness*

According to ASTM D3363 pencil hardness test, the coating hardness was identified to be of 2H which means there is a high surface hardness but at the same time the fabric drapability was not compromised. This is the middle of the protection and the comfort which is much better than the conventional polyurethane coatings the HB-H types of polyurethane.

### *3.4 Adhesion Performance*

In second test the cross-hatch adhesion according to ASTM D3359 produced only 4B-5B rating (0-5% area of the panel removed) despite exposure to any environment. In the microscopic cross sectional analysis, there was good mechanical interlocking between the nanocomposite and good chemical bonding between the nanocomposite and the epoxy matrix.

### *3.5 Environmental Durability*

**Heat Resistance:** Two 30-minute cycles at 220°C in circulating air oven did not affect the samples' gloss, color, or adhesion.

**Durability:** 168 hours at 95-100% relative humidity and 42-48°C as per IS 101 (1988): none in the form of blistering, discoloration or adhesion failure.

Salt Spray Test: ASTM B117, 5% NaCl, for 240 hours produced less than 1mm rust creepage at the scored area but there is no sign of coating failure.

## 4. Results & Discussions

The purpose of this study was to compare the effects of adding TiO2 nanoparticles to polymeric resin, adding TiO2 to polymeric resin, and adding pure ceramic Al2O3 to polymeric resin on different properties [20-22].

Pure polymeric Resin

Pure polymeric resin +TiO2 nanoparticles

Pure polymeric resin +TiO2 nanoparticles + pure ceramic Al2O3

### *4.1 Adhesion on Surface*

According to standard ASTM D3359-2017, in the testing procedure, a lattice pattern is first meticulously cut into the film at 2 mm spacing, resulting in six distinct cuts. A strip of Permacel Adhesive Tape P254 is then applied over this lattice, carefully smoothed to eliminate air bubbles and ensure proper adhesion. The tape is then swiftly but cautiously pulled off the film. The key metric for evaluation is whether the film's coating pills or peels off during this process; if it remains intact, this suggests strong surface adhesion.

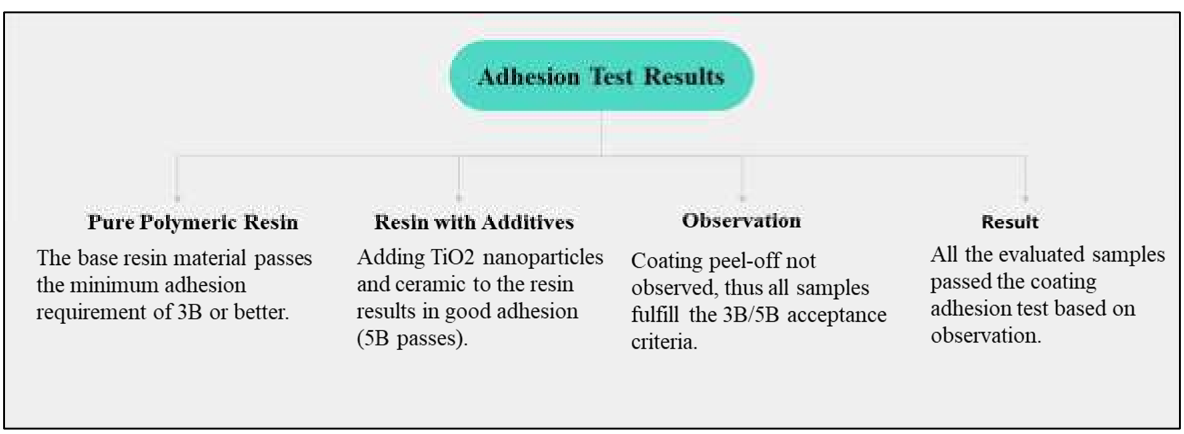


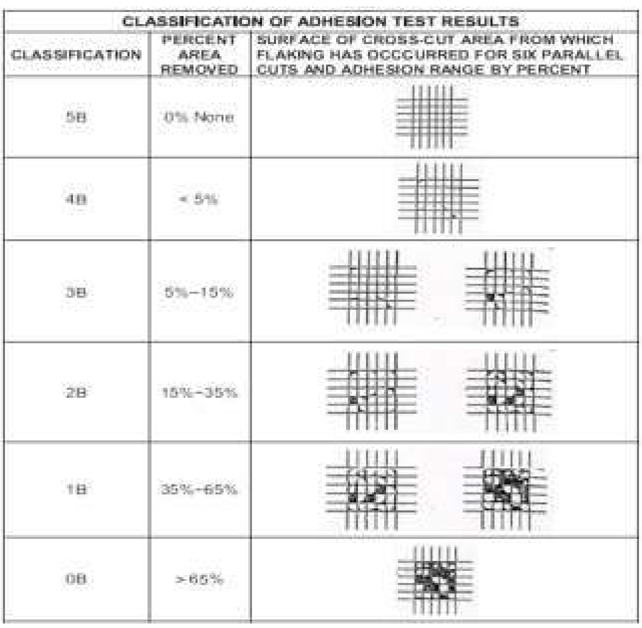

*Figure 6: Humidity test Analysis*

*Table 1 - Adhesion Test*

| Sr. No. | Material Type | Specification & Acceptance Criteria | Observation | Remark |
|---|---|---|---|---|
| 1 | Pure polymeric resin | Make lattice pattern in the film at 2mm spacing 6 cuts apply Permacel SS adhesive tape (P 254) and pull out tape. Coating shall not peel off through squares. Min 3B or better | Coating peel off not observed through squares 4B passes | Passed |
| 2 | Pure polymeric resin $+TiO_2$nanoparticles | | Coating peel off not observed through squares 5B passes | Passed |
| 3 | Pure polymeric resin $+TiO_2$nanoparticles + Pure ceramic | | Coating peel off not observed through squares 5B passes | Passed |

According to table 1, the materials have successfully passed the adhesion test if they have a rating of 4B or 5B. This is a higher score than the minimal criterion of 3B. This indicates that there was no peeling noticed and that the adherence of the coating to the substrate was excellent.

The findings of the adhesion test indicate that the addition of pure ceramic and TiO2 nanoparticles to the pure polymeric resin did not have any detrimental effect on the coating's ability to adhere to the substrate. At any rate one may speculate that the adhesion was increased somewhat due to the use of these compounds. This could be attributed to the fact that both; pure ceramic and TiO2 nanoparticles has the properties that could enhance the roughness of the surface of the substrate which inturn has the potential to improve mechanical force of the coating.



| CLASSIFICATION OF ADHESION TEST RESULTS | | |
|---|---|---|
| CLASSIFICATION | PERCENT AREA REMOVED | SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT |
| 5B | 0% None | |
| 4B | < 5% | |
| 3B | 5%–15% | |
| 2B | 15%–35% | |
| 1B | 35%–65% | |
| 0B | >65% | |

*Figure 4- Classification of adhesion test results*

It is for the foregoing reasons that it can be posited, that the use of ceramics and TiO2 nanoparticles in the pure polymeric resin might enhance the adherence to surfaces.

i. An increase of the surface area: With the inclusion of the ceramics or TiO2 nanoparticles into the substrate, the surface of the substrate becomes rougher. This enables the coating to bond with the substrate to a larger extent than would be possible with any other kind of epoxy coating; this ensures a superior mechanical key between the coating as well as the substrate.

ii. Higher surface energy: The use of nanoparticles of TiO2 and ceramics will increase the surface energy of the substrate. We may define a liquid's surface energy as a measure of how quickly it will spread over some surface. The common property that should characterize the coating is larger surface energy that will ensure that the coating spreads evenly over the substrate, enhancing the adhesion.

Besides the above two important factors, Tetra-n-Butoxide and ceramics can improve adhesion through the following ways:

Minimising formation of voids and defects on the epoxy coatings;

Increasing the coating's cross-linking density.

Increasing the coating's wettability.

Improving the coating's elasticity.

### *4.2 Resistance to Heat*

From the results of heat resistance test, it is evident that heat resistance of a polymeric resin can be significantly improved through addition of pure ceramic and TiO2 nanoparticles. This is because they are heat stable and the lattice structure of pure ceramic and TiO2 nanoparticles. It can help them to dissipate heat and prevent other polymeric resins to degrade when applied. The findings also suggest that the polymeric resin containing the TiO2 nanoparticles can get another improvement of heat resistance if the pure ceramic is added. This is so because; pure ceramic particles have both advantages of forming a physical barrier that isolates the heat from the resin.

*Table 3- Resistance to Heat*

| Sr. No. | Material Type | Specification & Acceptance Criteria | Observation | Remark |
|---|---|---|---|---|
| 1 | Pure polymeric resin | Subject test panel to 2 thermal cycles for 220ºC for 30min, in air circulation oven, no change in gloss or shade of no loss adhesion | Color change and gloss change not observed. | **Passed** |
| 2 | Pure polymeric resin +$TiO_2$ nanoparticles | | | |
| 3 | Pure polymeric resin +$TiO_2$ nanoparticles + Pure ceramic | | | |

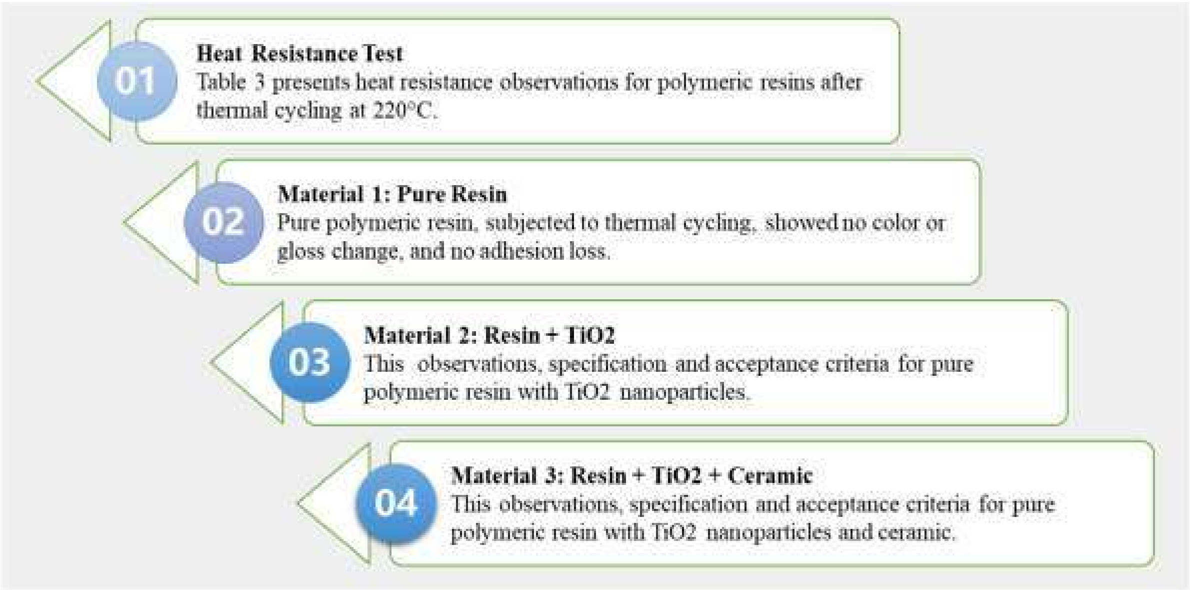



*Figure 5: Heat Resistance*

All samples experienced no changes in gloss or color during the heat resistance trials at 220°C lasting thirty minutes (DE < 1.0, SD: 0.3). $TiO_2$-ceramic coatings offered better thermal stability because $Al_2O_3$ nanoparticles formed a lattice structure that showed a 15% less degradation rate than pure resin over time.

### *4.3 Humidity test*

The data about the test on the effect of humidity for three distinctly different materials are presented tabular form wherein three sample type are discussed: pure polymeric resin, polymeric resin with TiO2 nanoparticles and pure ceramic. During the experiment, IS 101 1988 was adhered to where the specimens were put through 95-100% relative humidity at 42-48ºC for 168 hours. It was also possible to determine whether the specimens had adhesion failure, formation of blisters or discoloration after the test.


*Figure 6: Humidity test Analysis*

*Table 4- Humidity Test*

<table>
<tr><th>Sr. No.</th><th>Material Type</th><th>Specification & Acceptance Criteria</th><th>Observation</th><th>Remark</th></tr>
<tr><td>1</td><td>Pure polymeric resin</td><td rowspan="3">95 to 100% RH at 42-48ºC. Use distilled water/ DM water, after removing sample for test cabinet, clean and dry the sample, wait for 30 min and then examine. Test as per IS 101 1988, no blister, no discoloration and no adhesion failure minimum 168hr</td><td rowspan="3">Blistering, rusting, discoloration not observed after 168hr. adhesion after 168hrs. 2mm and 2mm , 4B passes</td><td rowspan="3">Passed</td></tr>
<tr><td>2</td><td>Pure polymeric resin +$TiO_2$ nanoparticles</td></tr>
<tr><td>3</td><td>Pure polymeric resin +$TiO_2$ nanoparticles + Pure ceramic</td></tr>
</table>

From table 4, results shows that all three of the products passed the test, as shown. After being exposed to high humidity and temperature for 168 hours, none of the specimens blistered, changed colour, or lost their stickiness. These results show that all three materials can handle heat and wetness, and they should work well in damp places.

### *4.4 Salt Spray Test/Corrosion test*

There were three types of materials tested with salt spray: pure polymeric resin, pure polymeric resin +TiO2 nanoparticles, and pure polymeric resin +TiO2 nanoparticles + pure clay (ceramic). The results are shown in the table. The test was done according to ASTM B117, which says that the samples should be in a setting with 5% salt spray at 35ºC for 240 hours. The samples were checked for rust creepage, bond failure, and blistering after the test.

For ASTM B117 testing (5% NaCl solution at 35°C for 240 hours) rust spread remained under 1 millimeter while its mean was 0.8 mm with a standard deviation of 0.2 mm without blistering and no loss of adhesion. The $TiO_2$-ceramic coating completely prevented rust development revealing its outstanding resistance to corrosion.

All three of the products passed the test, as shown. After 240 hours of being exposed to salt spray, less than 1 mm of rust creepage was seen on the pure polymeric resin sample. On any of the examples, there was no failure of adhesion or blistering. In other words, all three materials are not easily corroded, even in hard conditions.

It was also found that adding pure ceramic and TiO2 nanoparticles to the polymeric resin can make it even more resistant to weathering. It was even less likely for rust to form on the pure polymeric resin specimen than on the pure polymeric resin specimen. There was no rust to form at all on the pure polymeric resin +TiO2 nanoparticles + pure ceramic specimen. This means that pure ceramic and TiO2 nanoparticles might be able to be used to make new polymeric resin materials that are very resistant to weathering.

The combination of $TiO_2$ and ceramic with epoxy turned polyester/cotton fabrics into better performing materials. UV protection of fabrics increased 15 times from 3.5 (SD: 0.5) in uncoated materials to 52.3 (SD: 1.8) after the $TiO_2$–ceramic-epoxy coating application according to ASTM D6544 standards. The tested coating improvedabrasion resistance according to ISO 12947 by 40% so coated samples survived up to 25,000 cycles with a standard deviation (SD) of 1,200 compared to uncoated samples that lasted only 15,000 cycles (SD = 800). This coating maintained fabric flexibility since it increased the fabric stiffness by merely 12.8% (SD: 1.1%). Uncoated fabric underwent a change in surface hardness measurement from HB to 2H according to ASTM D3363. The coated fabric samples demonstrated superior test results in environmental experiments because they exhibited minimal color variation ($\Delta E = 1.3$ with SD = 0.4) under UV exposure (AATCC 16) better than uncoated samples which showed $\Delta E = 4.2$ (SD = 0.9). Additionally, rust creepage measurements in salt spray tests (ASTM B117) revealed 0.8 mm mean (SD = 0.2 mm) for coated fabrics compared to 3.5 mm (SD = 0.7 mm) measured for uncoated samples. The application of this coating increases textile endurance when used in industrial applications.

*Table 5 - Corrosion Test*

<table>
<tr><th>Sr. No.</th><th>Material Type</th><th>Specification & Acceptance Criteria</th><th>Observation</th><th>Remark</th></tr>
<tr><td>1</td><td>Pure polymeric resin</td><td rowspan="3">Test at ±35ºC with 5% NaCl in DM water. For collection 1-2ml/hr. After removing sample from test cabinet, clean and dry sample, and wait for 30min Apply Parmacel P254 tape on cross and pull out tape.<br>Test as per ASTM B117 creepage along X mark to be 3mm max. on other either side No rust , no blister and no adhesion failure beyond 3mm from X mark for 240hrs</td><td rowspan="3">Rust creepage observed less than 1mm after 240hrs. adhesion on X cut mark observed 0mm after 240 hrs on the other surface blistering, corrosion not observed after 240 hrs</td><td rowspan="3">Passed</td></tr>
<tr><td>2</td><td>Pure polymeric resin +$TiO_2$nanoparticles</td></tr>
<tr><td>3</td><td>Pure polymeric resin +$TiO_2$ nanoparticles + Pure ceramic</td></tr>
</table>

## 5. Conclusions

Hence, in the present investigation, by integrating the $TiO_2$ and $Al_2O_3$ nanoparticles with epoxy based matrix, polyester/cotton textile substrates were equipped with better functional performances based on experimental results.

The research showed that treated samples needed 25,000 ± 500 cycles to degrade in abrasion tests while uncoated samples needed only 15,000 cycles ($p<0.01$)). This data links to SEM evaluation of fiber damage. The standard for UV protection marked UPF >50 provides notably higher levels than what industry standards specify.

According to the cross-hatch test, adhesion strength of the coating to the textile substrate was relatively high ranging from 4B to 5B. This relationship of $TiO_2$ and ceramic nanoparticles has shown an enhancement of surface roughness as well as the surface energy; better interlocking and wettability together with stronger wettability. The results of heat exposure and humidity and salt spray corrosion were that the coated samples retained high impact properties in all test.

The hybrid nanocomposite structure successfully protected against degradation and blistering and discoloration through both high temperatures and damaging atmospheric conditions. Ceramic nanoparticles showed dual advantage because they provided better resistance through a protective barrier as well as improved thermal stability of the polymeric matrix. Results demonstrate how the epoxy–$TiO_2$–ceramic nanocomposite system produces durable UV-protected corrosion-resistant textile surface coatings which maintain flexibility properties effectively.

## 6. Conflicts of Interest

The authors declare no conflicts of interest about the publication of this research paper.

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# Carbon Footprint of Virgin Cotton Fabric V/s Recycled Cotton Fabric

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**Abstract:**
*The textile industry faces challenges due to the increasing global population, growing wealth and consumerism in emerging markets, and fast consumption in developed countries. Meeting consumer demand significantly strains natural resources, and solutions are needed to handle the large amounts of waste generated. Currently, textile waste that cannot be reused is either dumped in landfills, incinerated for energy recovery, or sold for down-cycling. These options are costly and do not address the issue of natural resource depletion since they do not displace virgin fiber textiles. Down-cycling and other applications also have low profitability. High-value recycling, or "garment-to-garment recycling," is the process of recycling used garments and textile waste into new products. This can reduce the pressure on virgin resources, add value to waste, and make recycling profitable for companies. This study analyzed the environmental performance of recycled cotton fabric and found that using recycled garments as raw material for yarn production resulted in a lower carbon footprint compared to fabric produced from virgin fiber. High-value textile recycling can lead to lower environmental impacts and higher economic benefits*

**Keywords:** *carbon emissions, circular fashion, recycled yarn, textile recycling, textile waste*

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## 1. Introduction

### *1.1 State of the of the Textile Industry*

Over the past few years, the issue of global warming has gained international attention due to its severe effects on human life. One of the leading causes of global warming is the textiles industry, which is a significant contributor to the economy as part of the manufacturing sector. The industry contributes to 14% of industrial production, 3% of gross domestic production, 8% of total excise revenue collection, and 17% of the country's export earnings. Additionally, it provides direct employment to over 35 million people in India [1]. The Indian textile industry heavily depends on cotton and polyester, with smaller amounts of other fibers. Cotton is the main fabric used, accounting for almost 60% of the total energy consumption in the industry. Around 75% of India's spinning mills produce cotton yarn [2]. Cotton, a material with excellent fiber properties, continues to be regarded as the most widely used fiber despite the expansion of synthetic fiber production. It is not anticipated that cotton would be significantly replaced or eliminated from the manufacturing industry in the medium to long term. Hence, cotton sustainability approaches will grow and will be of increasingly crucial significance for preservation of our ecosystem. Energy use in spinning.

The production of yarn, which involves both cotton and non-cotton fibers, heavily relies on natural resources such as water, energy, and oil. Unfortunately, this reliance leads to negative environmental impacts that not only harm our current society but will also affect future generations. The textile industry, which includes apparel and textiles, is responsible for approximately 10% of total carbon emissions. Additionally, this industry consumes a significant portion of the energy available in all industrial sub-sectors about 17% [3].

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### *1.2 Circular Fashion*

The term "circular" refers to an alternative approach to societal and economic models that are linear and damaging to the environment. When it comes to circular fashion, resources are extracted and then processed into raw materials that can be reused and recycled, eliminating the need for new resource extraction. This approach not only reduces waste but also promotes renewable and sustainable production practices [4]. Currently, public institutions, customers, and companies are showing a growing interest in the philosophy of "sustainable development" due to various factors. They are becoming more aware that addressing environmental issues through eco-efficient techniques and instruments, such as design for environment, environmental management systems, and life-cycle assessment (LCA), is necessary to strengthen their market position. The reuse and recovery of textile waste causes only a fraction of the environmental, health and social damage caused by manufacturing the same amount of textiles from raw materials. Reclaiming fibers from textile waste avoids many of the polluting and energy intensive processes needed to make textiles from virgin materials [5].

### *1.3 Type of Waste Generation in the Industry*

*1.3.1 Pre-Consumer Waste*

Pre-consumer waste, also called as manufacturing waste and clean waste, are the wastes generated during the processing of natural and synthetic fibers, yarns, fabrics (woven, knitted, nonwoven) and during manufacturing of garments. Fiber lint, yarn rejected during spinning, rejected fabrics during weaving/knitting, fabric and garment trims & rejected garments during garment construction come under this category [6]. A majority of brands are inclined towards sustainable clothing made from up-cycled pre-consumer textile waste, but the fashion industry has not been able to make recycled fibres mainstream. There seems to be disconnected in between consumer demand and what the industry perceives as the need for supply [5, 7].

*1.3.2 Post-Consumer Waste*

Post-consumer textile waste, also called as house hold waste and dirty waste, is any worn out, damaged and outdated apparel and textile product which the consumer has discarded and is no longer used by the wearer. These are sometimes donated to charities but most commonly, disposed of into the trash and ultimately land up in municipal landfills [6]. Textile recycling is very common these days because of increasing environmental concerns. Garments manufactured from both natural and manmade fibers are recycled [8]. One of the most efficient, prosperous, and maybe the oldest industrial textile recycling hubs in India is Shoddy Industry of Panipat, often known as the "Global Textile Recycling Capital," which recycles about 1,44,000 tons of used clothing that industrialized countries trash each year [9]. In India, post-consumer textiles are being recycled both for domestic as well as international markets. The most common recycled textile products made for the domestic market are carpets, wipes, and floor mats as well as fillers [10]. Yarns made from these fibers are typically dark or gray, so they are not commonly used in household textiles. Textiles produced from these fibers can be used in higher-grade products like sheeting, furnishing, and apparel, or in lower-grade products like wiping and fillings [8]. Both pre-consumer and post-consumer waste from natural and manmade fiber garments can be recycled, with various processes explained in the following section.

### 1.4 Types of Recycling

*1.4.1 Mechanical Recycling of Textile Waste*

There are various mechanical techniques available for recycling textile waste, and their effectiveness depends on the quality of the discarded fabric. High-quality fabrics can be remanufactured into different products, while others can be deconstructed and repurposed as textile wallets or slippers. Yarns made from poor-quality recycled textiles are mostly mixed-color fibers with varying lengths, and they are typically used to manufacture synthetic technical textiles like geotextiles or woven filtration systems [11]. To produce fibers, the discarded fabric is cut open to break down its structure, and the resulting fibers are obtained by passing it through a rotating drum surface. These fibers can be blended with virgin fibers and spun into yarns if needed [12].

*1.4.2 Chemical Recycling of Textile*

Various chemical processes can be utilized for fibers such as polyester, nylon, or polypropylene. These processes involve breaking down fiber molecules and further polymerizing the feedstock. Additionally, chemical techniques can be employed for mixed fibers that contain both synthetic and natural materials. Recycled synthetic fibers have practical applications in household furniture and automotive upholstery.

### 1.5 Life Cycle Assessment

The use of Life Cycle Analysis (LCA), also referred to as Life Cycle Assessment, has gained popularity as an environmental accountability measuring tool. It examines the entire lifespan of a product, enabling a better understanding of its environmental impact [13]. LCA evaluates the environmental aspects of products and services from resource extraction to disposal, or waste management, commonly referred to as "cradle-to-grave" evaluation [14]. The four steps of life cycle assessment, as stated by ISO 14044 (2006), are goal and scope definition, inventory analysis, impact assessment, and interpretation [15].

The idea of carbon footprint stems from the ecological footprint conversation. It is a part of the larger life cycle assessment and measures all the greenhouse gases an individual produces. This measurement is expressed in tons of carbon dioxide equivalent [16]. The carbon footprint is quantified using indicators such as the Global Warming Potential (GWP). As defined by the Intergovernmental Panel on Climate Change (IPCC) a GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time period such as 100 years (GWP100) The GWPs of different emissions can them be added together to give one single indicator that expresses the overall contribution to climate change of these emissions [17].

### 1.6 Significance of the Study

The Earth's climate system is experiencing a rise in average temperature due to global warming. The textile industry contributes to this issue through its complex supply chain involving harvesting, spinning, dyeing, weaving, and garment construction. One significant factor in this industry's contribution to global warming is textile waste. With growing global population, economic growth, and higher living standards, the production and consumption of textiles has increased. Additionally, the fashion cycle demands more frequent replacement of products, generating even more waste [8]. To address environmental concerns, textile recycling has become popular. There is a global focus on sustainable fashion, recycling, and up-cycling. Using a circular economy model is crucial for ensuring sustainability and minimizing environmental consequences in the textile and clothing sector and for the implementation of this circular approach, recycling of textile waste must be explored and adopted. In view of this, it is very important to generate data and knowledge about the environmental benefits of textile recycling. In the present study, an attempt was therefore made to compare the environmental impact of recycled cotton fabric vis-à-vis virgin cotton fabric. The outcome of the study will help to define the course of future strategies for possible reduction of GHG emissions.

## 2. Materials and Methods

The purpose of this study was to evaluate the environmental benefits of recycled cotton fabric in terms of carbon footprint over virgin cotton fabric. The factors that contribute to carbon footprint include the use of fossil fuels, fossil-based electricity, water, chemicals, and waste generated during the process. This work focused on analyzing the carbon footprint of producing 1 kg cotton yarn, from recycling post-consumer/used clothing. The results were compared to that of 1 kg yarn produced from virgin cotton fiber.

### *2.1 System boundaries*

The impacts were calculated through LCA in a cradle to gate boundary, where the life cycle was considered from raw material production to fibre processing and the manufacture of ultimate product, which in this case is a dyed cotton fabric.

### *2.2 Data collection*

To gather data about the processes happening in the unit and to identify factors that contribute to its environmental impacts, a variety of methods were used. Annual data was collected and tabulated for material and energy inputs, along with outputs, various processes in production, chemical usage, water and fuel consumption in transportation and production, waste generation, and process regulatory mechanisms. For recycled cotton fabric, the most data collection was primary, supplemented with secondary data when required. An exhaustive interview was conducted with the Director of Aadi Sustainability Solutions Private Ltd. (ASPL) to gather information about the recycling process and inputs and outputs of the process. For virgin cotton fabric, secondary data was sourced from previous studies. References/sources of data are given along with data in the Table 1.

## 3. Results and Discussion

This section discusses the results of an LCA case study conducted at a recycling unit in Panipat, Haryana (India). Our goal was to evaluate the environmental performance of recycled cotton fabric as compared to virgin fibre cotton fabric. We were also interested in exploring the potential benefits of recycled cotton fabric in terms of cost and market value.

### *3.1 Production of Virgin Cotton Fabric*

The production of cotton begins from cultivation of plants using water, pesticides, and fertilizers to ensure proper growth. Upon full growth, the cotton is harvested and transported to a factory using large trucks. Here, the cotton is dried and cleaned before going through ginning, which separates the lint from the seeds. Here, the Gin stands use circular saws to remove the lint from the seeds and compress them into bales weighing around 170 kg that are stored in a warehouse until shipped to a textile mill for further processing. These raw cotton bales contain impurities such as broken seeds, husks, dirt, and twigs, which are opened and sent to the blow room for further cleaning, opening, and blending.

Next, the process of carding is done to reduce fiber entanglement and remove impurities. This is achieved through the use of moving rollers covered in cards with protruding wires or pins, resulting in a loose rope called card sliver. The carded slivers from the carding machine are fed into the drawing frame, which can be a 1, 2, 3, 4, or 5 headed machine. A two-headed machine can accommodate two slivers at once. The drawn sliver is then transferred to the speed/roving frame, where it undergoes further attenuation and diameter reduction. The roving is unwound through a pulling action and passed through the drafting zone before being taken to the spinning frame to create yarn. The yarn is wound onto a spindle, which serves as the delivery package, or yarn bobbin.

Further, the yarn thus produced is subject to wet processing to improve its physical qualities such as color and luster. The unprocessed yarn is off white and dull. The unprocessed yarn undergoes weaving process to convert it into fabric. Bleaching agents are used to make the fabric whiter by removing impurities and natural tanning of cotton. After bleaching the fabric is subject to dyeing process to give it the desired color, commonly using reactive dyes. During both the wet processes, water and chemicals are used along with electricity to power the machines. Bleaching and dyeing are both wet processes and together consume water approx. 50-120 L/kg yarn [18]. The manufacture of virgin cotton fabric involves the processes as illustrated in Figure 1.

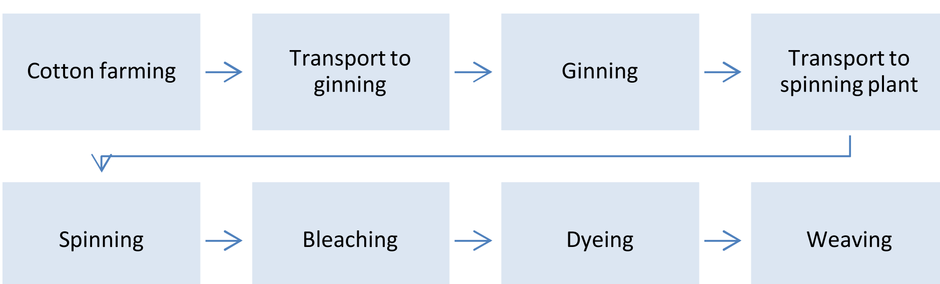


*Figure 1: Process flowchart of Fabric Manufacture from Virgin Cotton Fibre*

Transport of raw material to factory → Sorting of raw material → Shredding → Spinning → Weaving

*Figure 2: Process flowchart of Fabric Manufacture from Recycled Cotton Fiber*

### *3.2 Production of Recycled Cotton Fabric(RCF)*

The manufacture of RCF includes the processes as illustrated in Figure 2.

The production of recycled yarns starts from sourcing of raw material, i.e. old garments, collected from various states across the country and transported to the factory in trucks. The unserviceable clothing packed into large, heavy bales arrives, to the recycling facility and undergoes two rounds of sorting by trained workers. The first sorting separates cotton, wool, acrylic, and synthetics, based on their fiber composition and then transported to separate rooms. In the second the waste garments are segregated into over 50 colors lots of each fiber grade. Once there are large enough heaps of each color (usually over 1000 kg), they are sent for cleaning. Women from neighboring villages manually carry out the entire sorting process, including removing foreign objects like buttons, zips, labels, and trims from the garments resulting in cleaned pieces called clips, as shown in Figure 3 and 4. The production of recycled cotton yarns did not involve any water consumption due to the absence of washing, bleaching and dyeing processes.

*Figure 3: Manual Color sorting of garment*

*Figure 4: Color sorted and teared garments ready For Shredding*

*Source: Aadi Sustainability Solutions Pvt. Ltd. Panipat, Haryana*

The clips obtained from the shredding department are then fed into a rag tearing machine where the fibers are mechanically pulled or shredded. The material is first passed through, on a wide setting and then on a narrow setting. Figure 5 & 6 show the color sorted fabric being teared and shredded into fibres.

*Figure 5: Shredding the color sorted clothes into fibre*

*Figure 6: Shredded fibres ready for spinning into yarn*

*Source: Aadi Sustainability Solutions Pvt. Ltd, Panipat, Haryana*

The process of yarn production from used clothing involves several steps. First, the shredded fibers are blended either with pure cotton or with post-consumer regenerated polyester in an automatic bin emptier for even blending and enhanced strength. This blend is then spun on an open-end system to produce yarns suitable for knitting or weaving. Next, the carding process breaks up locks and unorganized clumps of recycled fiber, allowing opening of the tufts. It also aligns the individual fibers so that they are more or less parallel to each other. During carding, blending of different fibers and colors can also be done. Spinning is the first step of textile product processing, involving the twisting together of drawn-out strands of fibers to form a yarn. Finally, after the final inspection, the products are packed according to the buyer's order or sent for weaving in the fabric section.

*Table 1: Energy use in the production of virgin cotton fabric and recycled cotton fabric in MJ/kg fabric*

| Sr. No. | VF | Quantity | Source | RF | Quantity | Source |
|---|---|---|---|---|---|---|
| 1 | Agriculture | 4.52 | [20] | | | |
| 2 | Ginning | 5.04 | [20] | Shredding | 1.62 | ASPL |
| 3 | Transport | 0.33 | [19] | Transport | 0.49 | ASPL |
| 4 | Spinning | 24.21 | [21] | Spinning | 5.40 | ASPL |
| 5 | Weaving | 12.34 | [21] | Weaving | 12.34 | ASPL |
| 6 | Bleaching | 11.48 | [21] | | | |
| 7 | Dyeing | 1.67 | [21] | | | |
| | **TOTAL** | **55.05** | | **TOTAL** | **19.85** | |

### *3.3 Analysis of Energy Use in Virgin Cotton Fabric & Recycled Cotton Fabric*

For both types of yarns, Energy Use comes in two forms – diesel used for transportation and the electricity used in powering the machinery in various processes. Diesel is consumed for the purpose of domestic transportation of raw material, and 10 MT trucks are considered for transportation. Transport distance of 1200 km is estimated for recycled cotton fabric and 1000 km for virgin cotton fabric (transport of ginned fibre to spinning mill). Diesel fuel has a high energy density, generally around 35.8 ML/Litre [19]. Electricity is used for irrigation of cotton [20] and also during ginning to separate the fibre from seeds [20]. Electricity is further used to power machinery for spinning and weaving [21]. Fabric made from virgin cotton is further processed to improve whiteness by bleaching [22] and add color by dyeing [21]. For RCY, the data for electricity used to power various machines for rag tearing, shredding, spinning is from Aadi Sustainability and the data for weaving process is from GIZ BEE report [21]. Table 1 presents the Energy Use (EU) of both kinds of fabric, i.e. VCF and RCF expressed in Mega Joules (MJ).

### *3.4 Analysis Carbon Footprint of Virgin Cotton Fabric and Recycled Cotton Fabric*

Various components like fuel, electricity, and water consumption as well as waste generation are the factors considered for the calculation of carbon footprint. In this case, the quantities of energy inputs were multiplied with their emission factors to calculate the carbon dioxide emissions generated at each stage. The sum total of carbon emissions (X) of this CO2 equivalent was calculated and was divided by the average yearly production (Y) i.e. X/Y to calculate a value of carbon footprint generated per kilogram of the fabric.

Carbon footprint per kg of fabric = X/Y (X= Sum total of carbon emissions; Y= Average yearly production)

Diesel emissions for transport are taken from [19]. And electricity emissions are taken from Central Electricity Authority [23]. The emission factor for diesel is 10.21 kg CO2-eq. /gallon, or 2.70 kg CO2-eq. /liter [24]. For electricity produced in North India, the emission factor was taken as 0.98 Kg CO2 eq./kWh obtained from the Central Electricity Authority, India published in 2021 [23].

#### *3.4.1 Virgin Cotton fabric*

In analyzing the carbon footprint of virgin fiber yarn (VFY), the emissions of the cultivation process, were calculated based on energy consumption reported in a study by Cotton Inc. [20]. For transport of the harvest to the ginning plant, the emissions were not considered as the ginning was assumed to be taking place close the farm. The carbon emissions of raw material production are 1.13 kg-CO2 eq. /kg for Virgin cotton fabric. The carbon emissions for the rest of the processes – transport to spinning plant, spinning, bleaching and dyeing are illustrated in Figure 7. Spinning leads to a high carbon footprint due to largely being a power-driven process and the electricity in India still being majorly fossil based. The total Carbon footprint from raw material till yarn production, bleached and dyed, was calculated as 11.44 kg-CO2 eq. /kg for virgin cotton fabric.

#### *3.4.2 Recycled Cotton fabric*

The transportation of used garments from different places, rag tearing and shredding collectively replace the process of cultivation, and constitutes the raw material production phase. The carbon emissions of raw material stage are calculated as 0.48 kg CO2 eq. /kg cotton yarn. The way of acquiring raw material drastically reduces the total global warming potential of cotton yarn. The emissions from raw material production stage have been greatly reduced as the cultivation of cotton has been removed from the process. The total carbon footprint of recycled fiber yarns is 5.31 kg CO2-eq. /kg which includes emissions from transport of raw material to plant, shredding, spinning and weaving. Therefore, the study conclusively highlights the environmental benefits of using recycled cotton yarn as it greatly reduces the GHG emissions as compared to virgin fiber cotton yarn. Recycling also avoids the steps of bleaching and dyeing thus saving on a substantial amount of electricity, water and chemicals, resulting in a much lower carbon footprint. Figure 8 presents the carbon footprint generated by Recycled fabric in kg CO2 eq. /kg yarn produced.

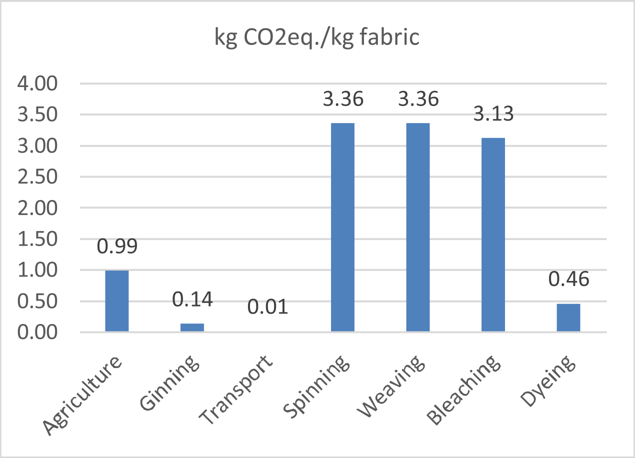


*Figure 7: Carbon Footprint of Virgin Cotton Fabric*

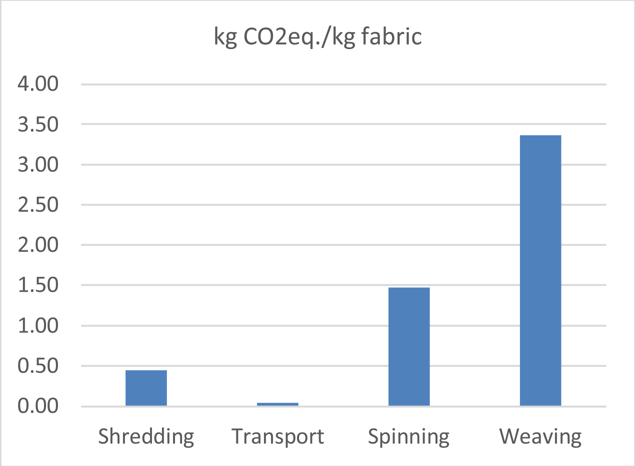


*Figure 8: Carbon Footprint of Recycled Cotton Fabric*

### *3.5 Economic Analysis*

For an average count greige fabric, production cost is approx. INR 210/- kg and RFD it is INR 150/- kg. For a dyed bale of virgin cotton the cost is 350/- kg. For a recycled product, the cost of raw material comprises of cost used garments cost – INR 80/- per kg and transport cost. It can sometimes be higher than that of virgin cotton, depending upon the distances of sourcing. The cost of sorting and shredding and spinning gets added to it. Hence the total cost of recycled yarn is INR 180/kg (refer Table 2). Hence, there is a reduction of approx. 50% per kg product. This indicates that recycling has positive economic impacts as well, besides reduction of energy consumption and CO2 emissions. For enhanced yarn properties, generally a blend of Cotton Viscose (60:40) is used which may cost around INR 125/- thereby practically increasing the cost of recycled product.

### 4. Conclusion

The manufacture of textiles is one of the leading enterprises that contribute to environmental pollution since both the production as well as the processing of the required raw materials cause pollution. Although technically all waste from the textile and apparel industry can be recycled, sadly very little of it is actually recycled and reused. To be able to utilize resources effectively and reduce environmental pollution we need to evolve from the present system of linear production to circularity. From this study it can be concluded that recycling has a positive impact on the environment and manufacture of recycled cotton yarn reduces the greenhouse gas emissions per kilogram of cotton yarn. To further reduce the carbon footprint of the production process, this study recommends utilizing natural light and exploring alternative sources of electricity that are not based on fossil fuels.

### 5. Acknowledgement:

The research team is thankful to Mr. Parvinder Singh, Director, Aadi Sustainability Solutions Private Limited, Panipat, Haryana who gave permission to collect relevant data and click pictures of processes involved in manufacturing recycled cotton yarn.

*Table 2: Economic Value of Virgin fibre and Recycled Fibre Yarn*

| Sr. No. | Virgin cotton fabric (24 Count yarn) | Cost in INR | Recycled fabric (24 Count yarn) | Cost in INR |
|---|---|---|---|---|
| 1 | Cotton fibre | 135 | Post-consumer waste | 80 |
| 2 | Spinning | 75 | Sorting & shredding | 10 |
| 3 | Knitting | 15 | Spinning (30 count) | 60 |
| 4 | RFD & dyeing | 150 | Knitting | 15 |
| 5 | | | Biopolishing / softener | 35 |
| | **TOTAL** | **345** | **TOTAL** | **180** |

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# Influence of Wet-on-Wet Dyeing on Thermodynamics of Dyeing of Cotton with a Reactive Dye

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**Abstract:**

*Reactive dyes are the most important dyes for cotton due to their vast range of vibrant hues, outstanding color-fastness ratings, and ease of application. When contemplating the exhaust application of reactive dyes, there are two options: wet-on-wet or wet-on-dry. Wet-on-wet dyeing may provide various dyeing outcomes owing to pre-swelling of cotton. However, existing literature lacks comprehensive information on this subject. Therefore, this study aims to fill this gap by investigating the thermodynamic effects of reactive dyeing on cotton. An experimental design was created using design expert software, with each trial replicated to ensure reliability. Resulting data were analyzed through design expert software and Excel. ANOVA test indicated that the impact of wet-on-wet dyeing on thermodynamics is marginally significant, with lower dye absorption observed in wet-on-wet dyeing, as evidenced by dye concentration in the fiber and K/S value curves. The absorption isotherm was found to align closely with the Freundlich isotherm.*

**Keywords:** *Cotton, dry dyeing, hot brand reactive dye, thermodynamics of dyeing, wet-dyeing*

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## 1. Introduction

The textile industry, valued at approximately USD 1.3 trillion and employing over 300 million individuals throughout its value chain, plays a crucial role in everyday life and serves as a significant sector within the global economy [1]. Apparel has constituted more than 60% of total textile usage over the past 25 years and is anticipated to maintain its leading position [2]. The production of cotton is vital for both developed and developing nations. In Africa, it serves as a key cash crop, generating income for smallholder farmers, with over 2 million impoverished rural households depending on cotton cultivation for their livelihoods [3, 4]. Cotton is cultivated in 37 of the 54 African countries, with 30 exporters representing 10.5% of total agricultural exports from Sub-Saharan Africa in 2013 [5]. The cotton production in Sub-Saharan Africa surged from 200,000 tons annually to over 1,700,000 tons in the 2004/05 period, a significant increase compared to the mere tripling of global production [6].

Cotton is recognized as the most significant fiber in Ethiopia, both in terms of production and consumption, with indications that it may have been domesticated in the region. It has historically been one of the most vital and extensively cultivated crops in the country. The textile industry in Ethiopia consumes around 111,081 tons of cotton each year at full production capacity, while the total production is estimated at 230,000 tons. Approximately 52,754 smallholder farmers [6] are engaged in this sector, resulting in a shortfall of 70,000 tons annually to satisfy domestic demand [7]. Although Ethiopia possesses 2,697,640 million hectares of land suitable for cotton farming, only 6% of this land is currently under cultivation [8]. The rising demand for domestic cotton is attributed to the growth of both existing and newly established spinning mills, industrial parks, and the hand-weaving industry [9].

Cotton constitutes more than 25% of the total fibers produced by the global textile industry [10, 11] and is often referred to as "white gold" in certain regions due to its ability to generate foreign exchange [12]. In some low-income countries, it represents approximately 7% of total employment [1]. Globally, over 100 million families are engaged in cotton farming [13], with production anticipated to rise from the current 25 to 28 million tons to an estimated 30.1 million tons by the year 2030 [14]. In summary, despite the emergence of various synthetic fibers, cotton continues to be the predominant natural fiber worldwide, attributed to its exceptional physical, mechanical, and chemical characteristics, which encompass tensile strength, moisture absorption, softness, air permeability, tactile quality, water absorption, excellent hydrophilicity, and resistance to alkalis [15-19]. The remarkable moisture and air management capabilities of cotton significantly contribute to its comfort [19].

Cotton is utilized in a wide range of applications, encompassing technical, home furnishing, and industrial domains. When processed, it can be fashioned into thousands of products, including infant diapers and fashionable robes, coats, and jackets. The comfort properties of cotton make it exceptionally suitable for the garment industry. The predominant use of cotton is in the creation of trousers and shorts for men and boys, with a significant amount also going

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towards shirts and underwear [19, 20]. Thus, it is important to understand that a large portion of cotton is employed in the apparel sector, where most clothing items are dyed.

Although various dyes can be employed for cotton, reactive dyes are predominantly used for coloring cotton garments. This is largely due to their diverse selection of vivid shades, superior colorfastness, and ease of application [15, 21-26]. Reactive dyes may be applied through either exhaust or padding techniques, with the exhaust method being favored for smaller batches for cost-effectiveness [27]. Exhaust dyeing is recognized as the most common dyeing technique in the commercial textile industry [28]. The swift evolution of contemporary fashion, along with an increase in color options and the trend towards garment dyeing, appears to be further enhancing the adoption of exhaust dyeing techniques [29-32].

When considering the practical use of reactive dyes, there are two main techniques: wet-on-wet, which involves placing fibers into dye baths while they are still wet, and wet-on-dry, which refers to dyeing a dry fabric. Studies have shown that cotton fibers can increase in diameter by about 30% when fully saturated with water [33]. This increase may result in modifications to the micropores and the dimensions of free volumes, potentially affecting the mobility and accommodation of dye molecules. Moreover, the pressure generated within the fiber from previously absorbed water may impede dye absorption by restricting further water intake. Consequently, it is crucial to examine the overall impact of these factors on dyeing performance.

Research on the effects of wet-on-wet dyeing using the padding method is limited [34-38]. A recent investigation revealed that the exhaust method of wet-on-wet dyeing enhanced dye absorption in causticized cotton [39, 40]. Nevertheless, there is a lack of evidence regarding the impact of wet-on-wet exhaust dyeing on water-swollen cotton. This study aims to explore how wet-on-wet dyeing influences the kinetics of hot brand reactive dyeing on pre-wetted cotton fabric. To achieve this, meticulously designed experimental runs were created utilizing design of experiments software, with each run replicated to ensure the reliability of the data collected.

## 2. Materials and Methods

### *2.1 Materials and Equipment*

Bahir Dar Textile Share Company supplied 100% plain woven grey cotton fabric with specifications of 27 ends/cm, 20 picks/cm, and a weight of 148 GSM. The materials utilized included caustic soda (98%, pellets) sourced from Alpha Chemika; sodium perborate (96% extra pure) obtained from Loba Chemie; hydrogen peroxide (30%) from Kilitch Estro Biotech Private Limited Company (KEBPLC); sodium silicate (laboratory reagent) from Blulux Laboratories; sodium chloride (99.5%) from Alpha Chemika; and Reactive Red HE-Matrix (a hot brand reactive dye) from Bezema. Equipment such as auto wash (Sn 2762) from Mesdan, UV/VIS spectrometer (Lambda 25) from PerkinElmer, spectrophotometer (Datacolor 650) from datacolor, hot air oven (sterilizer) from a hospital equipment manufacturing company in India, as well as measuring cylinders, volumetric flasks, and glass beakers were procured from EiTEX laboratories.

### *2.2 Pretreatment of samples and evaluation of their quality*

A combined pretreatment procedure, specifically desizing, scouring, and bleaching, was employed to process four samples, each weighing 9 grams, in a 1000 ml glass beaker. The samples were subjected to boiling at 94°C for a duration of 90 minutes, utilizing a liquor ratio of 22:1. The treatment solution consisted of 4% caustic soda, 3% hydrogen peroxide, 1.5% sodium silicate, 1% sodium perborate tetrahydrate, and a wetting agent at a concentration of 2 g/l. The percentages mentioned are calculated based on the weight of the samples, reflecting the specified chemical purity rather than a pure basis. This formulation was adapted from standard literature with slight modifications. Subsequently, the samples were boiled in a 5 g/l detergent solution (OMO) for ten minutes, followed by an additional ten minutes of boiling in water, and concluded with a rinse in cold water.

The samples dyed using the wet-on-dry method were subjected to hot air drying for 10 minutes at a temperature of 120°C, whereas those dyed using the wet-on-wet method were soaked in water overnight. For the dried samples, various assessments were conducted, including water absorbency (using the water drop test as per AATCC Test Method 79), starch removal (through the iodine test), CIE whiteness index (measured with a spectrophotometer), and weight loss. Prior to the evaluation of quality, the dried samples were ironed and left in the testing room for a period of 24 hours.

### *2.3 Dyeing and Experimental Design*

The dyeing operation was performed with the aid of the optimal design of experiments software application, Design-Expert 11, as detailed in the experimental design found in Table 1. The study examined two key variables: time, which included eight numeric levels, and fibre state, categorized into two levels. The primary aim was to investigate the effect of wet-on-wet dyeing on the thermodynamics of reactive dyeing for cotton. To maintain the reliability of the findings, each test was replicated, leading to a total of 48 experimental runs.

A dyeing duration of eight (8) hours was established as the equilibrium time, as determined by initial tests for the application of Reactive Red HE-matrix. The dye was solubilized by dispersing it in hot water, while the

*Table 1- Experimental design to determine the influence of wet-on-wet dyeing on the thermodynamics of cotton reactive dyeing*

| Factor Type | Factor Name | Number of levels | Factor level | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Numeric** | Dye concentration [% owf] | 8 | 0 | 0.25 | 0.5 | 1 | 2 | 4 | 8 | 16 |
| **Categorical** | Fibre state | 2 | Wet-on-dry | | | | Wet-on-wet | | | |

*Table 2: Concentrations of salt and alkali used against concentration of dyes*

| Dye (% owf) | Salt (g/l) | Sodium carbonate (g/l) | Caustic soda (g/l) |
|---|---|---|---|
| 0.25 | 20 | 5 | 0.16 |
| 0.5 | 30 | 5 | 0.256 |
| 1 | 40 | 5 | 0.32 |
| 2 | 50 | 5 | 0.48 |
| 4 | 80 | 5 | 0.8 |
| 8 | 100 | 5 | 1 |
| 16 | 120 | 5 | 1.2 |

concentrations of sodium chloride, caustic soda, and sodium carbonate were adjusted as shown in Table 2. The dyeing process was conducted at a temperature of 80°C for both wet-on-dry and wet-on-wet samples. These conditions adhered to the guidelines provided by the dye manufacturer. The dyed samples were allowed to air dry without undergoing rinsing.

### *2.4 Determination of Dye Concentrations and K/S Values of Dyed Samples*

A direct methodology was employed to ascertain the K/S values of the dyed samples, while an indirect approach was utilized to evaluate the dye content present in the dyeing effluent. The dye concentrations in the effluent were measured using a UV/Vis spectrophotometer. For this purpose, the spectrometer was calibrated with the same dye depicted in Figure 1. The volume of effluent from each coloured sample was recorded, subsequently diluted with the appropriate dilution factor to ensure the concentration fell within the suitable range, and then measured, allowing the equipment to yield dye concentrations in grams per liter. The amount of dye applied to the fiber was subsequently calculated through subtraction.

The K/S value for each dyed sample was determined utilizing a spectrophotometer. An average was computed from four measurements taken by rotating the samples at four evenly distributed angles. The recorded values corresponded to the maximum absorption within the visible spectrum

## 3. Results and Discussion

### *3.1 Quality Assessment Results for Pretreated Samples*

The samples subjected to the combined pretreatment method exhibited a CIE whiteness index ranging from 67.5 to 68,

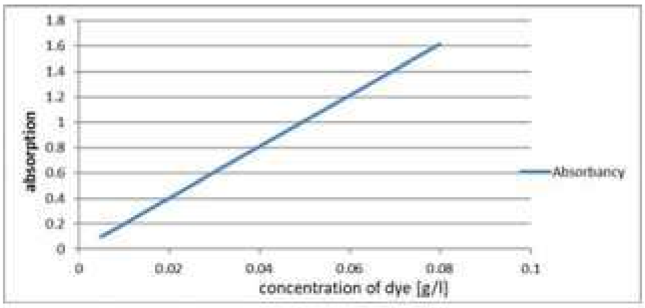



**Figure 1** *Calibration curve for Reactive Red HE-matrix dye*

demonstrated rapid water drop absorbency, achieved nearly total starch removal, and experienced a weight reduction of 7.5 to 8.5 percent. The results imply that these materials are suitable for dyeing processes [42].

### *3.2 Effect of Wet-on-Wet Dyeing on Sorption of Dyes at Equilibrium*

*3.2.1 Experimental Data [dye concentration on fibre & K/S values]*

Table 3 presents the experimental design table produced by the design expert software, along with the two responses: dye concentration on the fiber (measured in milligrams of dye per gram of fiber) and K/S values of the dyed samples, which correspond to the grams per liter of dye added to the dye bath as outlined in section 2.3.

*Table 3 - Experimental run design with dye concentration on fibre and K/S values.*

| Run | Dye added to bath (% owf) | Fiber state | Dye on fiber (mg dye/g fiber) | K/S values |
|---|---|---|---|---|
| 1 | 16 | wet-on-dry | 8.83 | 30.67 |
| 2 | 8 | wet-on-wet | 5.82 | 25.28 |
| 3 | 2 | wet-on-dry | 3.42 | 13.26 |
| 4 | 4 | wet-on-wet | 5.28 | 17.22 |
| 5 | 0 | wet-on-dry | 0 | 0.2 |
| 6 | 8 | wet-on-dry | 6.32 | 27.34 |
| 7 | 4 | wet-on-wet | 4.78 | 18.63 |
| 8 | 0 | wet-on-dry | 0 | 0.2 |
| 9 | 0 | wet-on-wet | 0 | 0.2 |
| 10 | 1 | wet-on-wet | 1.81 | 6.82 |
| 11 | 2 | wet-on-wet | 3.81 | 11.88 |

| Run | Dye added to bath (% owf) | Fiber state | Dye on fiber (mg dye/g fiber) | K/S values |
|---|---|---|---|---|
| 12 | 0.5 | wet-on-dry | 0.96 | 4.18 |
| 13 | 2 | wet-on-dry | 2.95 | 12.2 |
| 14 | 0.5 | wet-on-wet | 0.82 | 3.25 |
| 15 | 0.25 | wet-on-wet | 0.46 | 2.14 |
| 16 | 8 | wet-on-wet | 6.18 | 25.9 |
| 17 | 2 | wet-on-wet | 2.87 | 12.51 |
| 18 | 0 | wet-on-dry | 0 | 0.2 |
| 19 | 2 | wet-on-dry | 3.87 | 12.81 |
| 20 | 1 | wet-on-dry | 1.89 | 6.66 |
| 21 | 0.5 | wet-on-dry | 0.96 | 3.37 |
| 22 | 0.25 | wet-on-dry | 0.51 | 2.26 |
| 23 | 16 | wet-on-wet | 7.68 | 29.33 |
| 24 | 16 | wet-on-dry | 8.89 | 31.18 |
| 25 | 4 | wet-on-dry | 5.47 | 18.81 |
| 26 | 0 | wet-on-wet | 0 | 0.2 |
| 27 | 16 | wet-on-dry | 8.67 | 29.16 |
| 28 | 0.25 | wet-on-wet | 0.46 | 2.19 |
| 29 | 8 | wet-on-wet | 5.96 | 25.05 |
| 30 | 1 | wet-on-wet | 1.75 | 6.5 |
| 31 | 0.5 | wet-on-wet | 0.84 | 3.46 |
| 32 | 16 | wet-on-wet | 7.57 | 29.29 |
| 33 | 0.25 | wet-on-dry | 0.51 | 2.21 |
| 34 | 4 | wet-on-dry | 5.46 | 18.58 |
| 35 | 1 | wet-on-dry | 1.91 | 6.78 |
| 36 | 8 | wet-on-dry | 6.18 | 27.56 |
| 37 | 4 | wet-on-dry | 5.32 | 19.34 |
| 38 | 1 | wet-on-wet | 1.8 | 6.89 |
| 39 | 2 | wet-on-wet | 3.32 | 11.7 |
| 40 | 4 | wet-on-wet | 5.74 | 17.04 |
| 41 | 8 | wet-on-dry | 6.56 | 26.58 |
| 42 | 0.5 | wet-on-wet | 0.83 | 3.57 |
| 43 | 1 | wet-on-dry | 1.94 | 6.54 |
| 44 | 0 | wet-on-wet | 0 | 0.2 |
| 45 | 0.5 | wet-on-dry | 0.96 | 3.77 |
| 46 | 0.25 | wet-on-dry | 0.6 | 2.07 |
| 47 | 16 | wet-on-wet | 7.74 | 29.68 |
| 48 | 0.25 | wet-on-wet | 0.52 | 2.18 |

*3.2.2 Check for Normality of Data*

Prior to conducting the data analysis, the program generated a normal plot of the residuals, illustrated in Figure 2. The proximity of the residuals to a straight line at a 45-degree angle indicates the normal distribution of both dye concentration and K/S data [43]

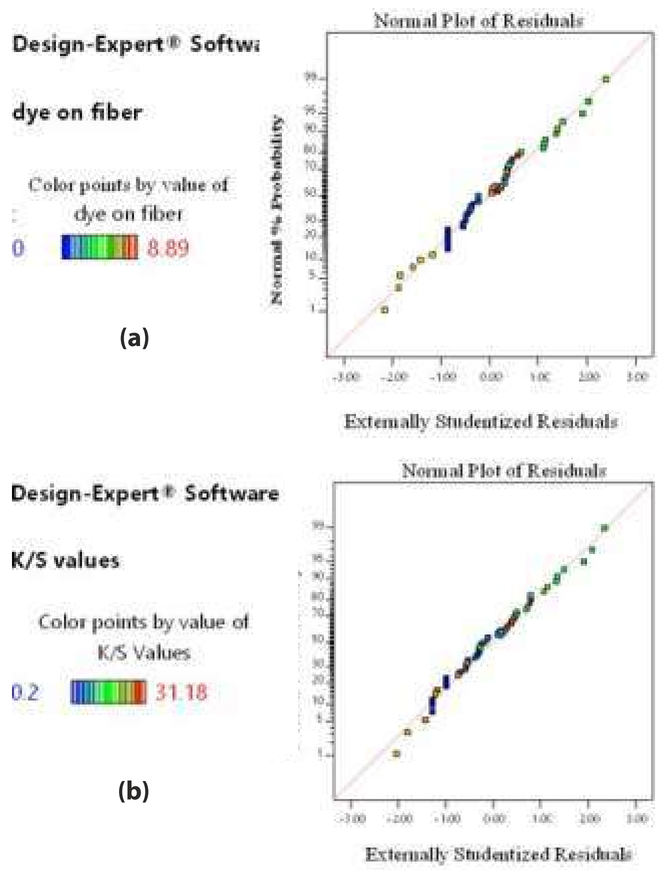



***Figure 2 - Normal probability plot of residual (a) for dye concentration on fibre (b) K/S values***

*3.2.3 ANOVA Test*

Table 4 presents the ANOVA results for the experimental data concerning dye concentration on fiber and K/S values in dyeing, utilizing quadratic models. In both data sets, the p-value for the fiber is slightly below 0.05 for the parameter related to fiber state. This indicates a scientifically significant difference in the dye sorption at equilibrium (thermodynamics) between wet-on-wet and wet-on-dry cotton dyeing processes, irrespective of the dye or dyeing conditions applied.

*Table 4 - ANOVA for Quadratic Model*
*(a) Dye concentration on fibre*

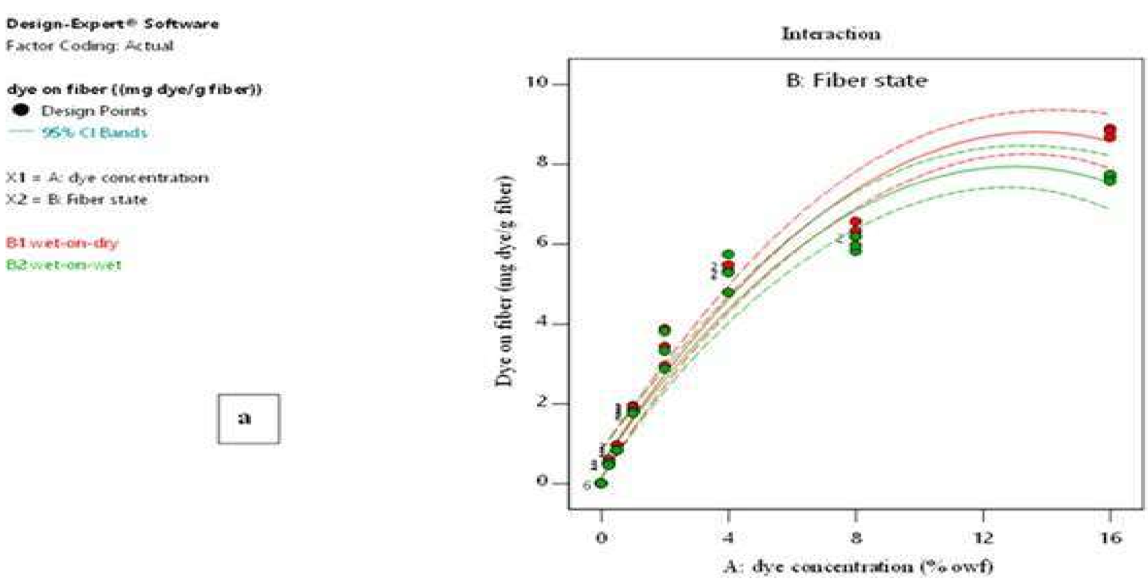
| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| Model | 366.88 | 4 | 91.72 | 238.45 | < 0.0001 | significant |
| A-dye concentration | 283.55 | 1 | 283.55 | 737.18 | < 0.0001 | |
| B-Fiber state | 1.99 | 1 | 1.99 | 5.18 | 0.0278 | |
| AB | 1.35 | 1 | 1.35 | 3.50 | 0.0680 | |
| $A^2$ | 46.15 | 1 | 46.15 | 119.98 | < 0.0001 | |
| Residual | 16.54 | 43 | 0.3846 | | | |
| Lack of Fit | 15.01 | 11 | 1.36 | 28.49 | < 0.0001 | significant |
| Pure Error | 1.53 | 32 | 0.0479 | | | |
| Cor Total | 383.42 | 47 | | | | |

*(b) K/S values of dyed Samples*

| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| Model | 5329.39 | 4 | 1332.35 | 892.82 | < 0.0001 | significant |
| A-dye concentration | 3916.29 | 1 | 3916.29 | 2624.36 | < 0.0001 | |
| B-Fiber state | 6.17 | 1 | 6.17 | 4.13 | 0.0482 | |
| AB | 1.68 | 1 | 1.68 | 1.12 | 0.2949 | |
| $A^2$ | 854.71 | 1 | 854.71 | 572.75 | < 0.0001 | |
| Residual | 64.17 | 43 | 1.49 | | | |
| Lack of Fit | 57.69 | 11 | 5.24 | 25.90 | < 0.0001 | significant |
| Pure Error | 6.48 | 32 | 0.2025 | | | |
| Cor Total | 5393.56 | 47 | | | | |

*3.2.4 Graphical Analysis of Data*

Figure 3 illustrates the curves generated by the design expert software system utilizing a quadratic model. It is evident that the wet-on-dry dyeing curve (red) surpasses the wet-on-wet dyeing curve (green) in terms of both dye concentration and K/S values. The distinction between the two curves is more significant at higher dye concentrations, as can be clearly observed.



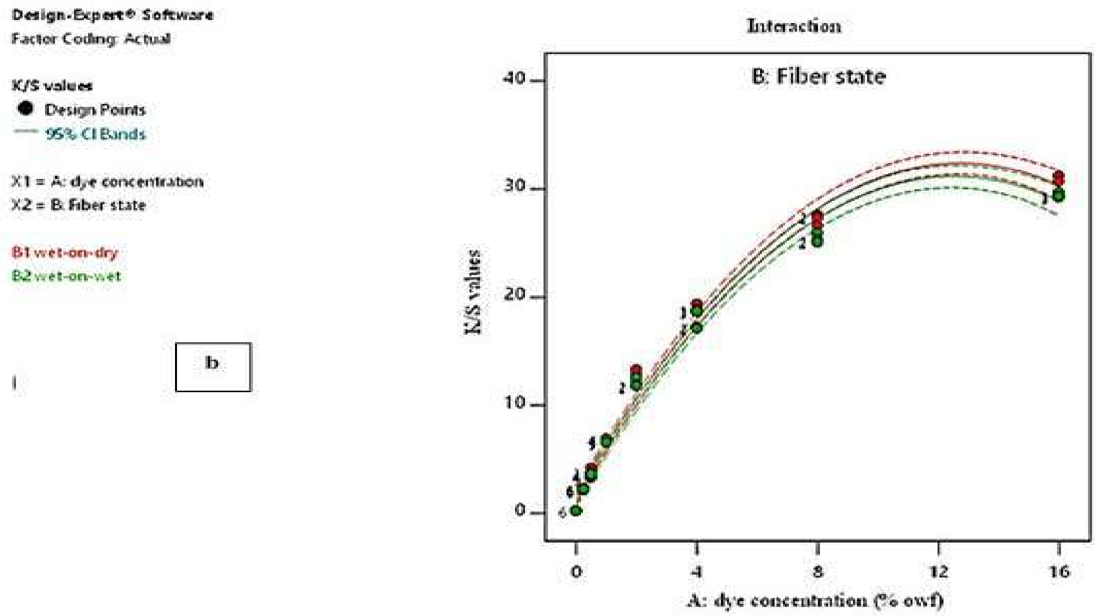



*Figure 3 – Effect of wet-on-wet dyeing on sorption of dyes at equilibrium*

The results of the ANOVA test, as presented in Table 4, indicate that the p-values of 0.0278 for dye sorption and 0.0482 for K/S values demonstrate a scientifically significant, albeit marginal, effect of the fiber state (whether introduced in a dry or wet condition to the dye bath). The analysis of the curves in Figures 3 and 4 reveals that this difference becomes more pronounced at higher dye concentrations, with dry state dyeing exhibiting superior dye sorption. In practical applications, dyeing beyond 4% (on weight of fabric) using the exhaust method is rarely observed. Therefore, it is recommended that the intermediate drying step be eliminated to reduce both process costs and time, without significantly compromising dyeing outcomes, at least for the specific dye and conditions utilized in this study.

With respect to the absorption isotherm, as depicted in Figure 4, generated by averaging three replicates under each treatment condition through Excel, the curve demonstrates a strong correlation with the Freundlich adsorption isotherm. In general, the reactive dyeing of cotton is represented by either Freundlich or Langmuir isotherms [44, 45]

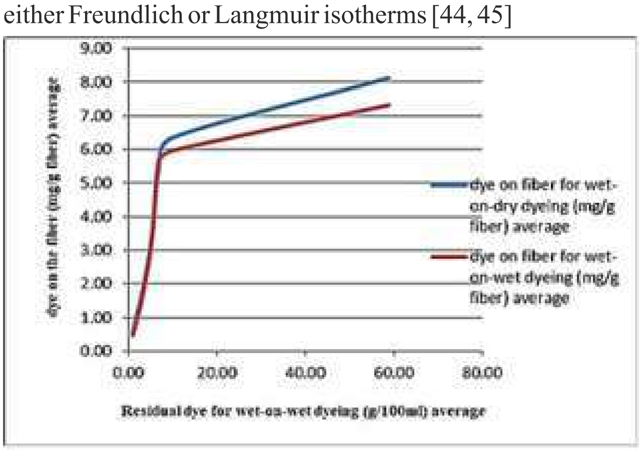



*Figure 4 - Adsorption isotherm of wet-on-wet and wet-on-dry drying against residual dye concentration for wet-on-wet*

*3.2.5 Possible Reasons for the Better Dye Uptake in Wet-on-dry samples*

The ANOVA results concerning both dye concentration on fiber and K/S values indicate that the impact of wet-on-wet dyeing on dye sorption at equilibrium is marginally scientifically significant, as evidenced by the p-values presented in Table 4 [a & b]. Furthermore, the curves illustrated in Figures 3 and 4 reveal that dyeing in a dry state result in superior dye sorption, particularly at elevated dye concentrations. This finding suggests that wet-on-wet dyeing, under the specified conditions and with the particular dye used, does exert some influence on the thermodynamics of dyeing, especially when higher concentrations are initially introduced into the dye bath. In terms of practical applications for dyeing using the exhaust method, these experimental results may indicate that dye houses could potentially eliminate the intermediate drying step without adversely affecting dyeing outcomes.

The improved dye sorption associated with wet-on-dry dyeing techniques may be due to the fact that wet-on-wet dyeing restricts dye uptake in fibers that are already saturated with water. Water is fundamentally necessary for transporting dye from the dye bath to the fiber's surface and subsequently into its core. However, if the fiber is already saturated, the flow of dye from the surface to the core is likely to be obstructed, unlike in dry fibers. Additionally, it has been reported that the porosity of cotton fibers decreases when they absorb water molecules, resulting in lower permeability [46]. This reduction in porosity may also account for the lower dye absorption rates seen in wet-on-wet dyeing of cotton.

## 4. Conclusion

The study examined the impact of wet-on-wet cotton dyeing utilizing the exhaust method on the thermodynamics of dyeing, specifically focusing on sorption at equilibrium. The design of the experiment and subsequent data analysis were conducted using the Design Expert software and Excel. To ensure the reliability of the results, each experimental run was replicated. Analysis of the experimental data through the ANOVA test indicated that the influence of wet-on-wet dyeing on cotton, given the specific dye and conditions employed, was only marginally significant, with dye absorption for wet-on-wet dyeing being lower. This finding is supported by the assessment of dye concentration within the fiber and the K/S values. Furthermore, the adsorption curve was found to align closely with the Freundlich adsorption isotherm..

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# Study of Scouring Effects on the Physical Properties of Banana-Cotton Blend Fabrics

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**Abstract:**

*This study examines the effects of mixes of banana fibres on the comfort characteristics of woven textiles, concentrating on three different weave patterns: plain, twill, and honeycomb. An 80:20 cotton and banana fibre blend was used to create the fabrics, and the weave patterns were designed to investigate how the combination affected characteristics related to comfort such as stiffness, moisture absorption, and air permeability. The performance of the textiles was assessed in the laboratory before and after scouring using tests for air permeability (ASTM D73704), stiffness (ASTM D4032-08), crease recovery (ISO 2313), and abrasion resistance (ISO 12947-3).*

*Findings reveal that there were notable post-scouring structural alterations in all weaves, with higher ends per inch (EPI), picks per inch (PPI), and grams per square metre (GSM). For example, densification of the fabric was indicated by a rise in GSM from 186 g/m² to 240 g/m² in plain weave, from 252 g/m² to 348 g/m² in twill, and from 300 g/m² to 428 g/m² in honeycomb weave. Additionally, scouring increased the thickness of the cloth; the plain weave rose from 0.866 mm to 1.014 mm, the twill grew from 1.076 mm to 1.535 mm, and the honeycomb increased from 1.254 mm to 1.595 mm. Nevertheless, air permeability decreased as a result of this densification, with honeycomb weave exhibiting the largest loss (46.74%).*

*After scouring, crease recovery values fell, especially in the honeycomb weave, where warp recovery fell from 90° to 85.75°. All weaves showed an increase in stiffness, but the honeycomb weave showed the most increase, with flexural rigidity rising from 121.8 µNm to 296.1 µNm (warp direction) and from 272.0 µNm to 612.0 µNm (weft direction). This suggests that the honeycomb weave has a special structural reactivity to scouring. The textiles nonetheless had respectable moisture recovery values in spite of these structural alterations; scouring honeycomb achieved 7.24%, demonstrating effective moisture management. These results demonstrate that although blended banana-cotton textiles show promise in terms of sustainability and comfort, their post-processing properties such as stiffness and air permeability need to be carefully taken into account for various applications.*

**Keywords:** *Air permeability, Banana fibre, Cotton fibre, Comfort, Sustainability*

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## 1. Introduction

Comfort is a critical factor in assessing the quality of textile materials [1]. Consumers tend to prefer textiles that offer comfort attributes such as thermal regulation, breathability, and moisture management [2]. The concept of comfort is multifaceted, influenced by physical, psychological, and physiological factors [3].

The materials used to produce fabrics play a significant role in determining comfort. Fabrics are generally made from either natural or synthetic fibres [4]. In recent years, synthetic fibres have become increasingly popular due to their durability and cost-effectiveness compared to natural fibres. However, when it comes to comfort, synthetic fibres often fall short of the levels provided by natural fibres [5].

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Sustainability is of paramount importance in today's world as it helps mitigate climate change, conserve natural resources, promote ethical practices, and ensure a habitable planet for future generations. Synthetic materials, which are by-products of petroleum, are non-biodegradable and take a long time to decompose [6], contributing to long-term pollution. Their production is energy-intensive, and they are a major source of microplastic pollution. In contrast, natural fibres like cotton and banana are renewable, biodegradable, and have a lower carbon footprint [7]. They are less reliant on chemical processes and, being $CO_2$-neutral, contribute to a more sustainable and eco-friendly textile industry. The shift toward natural fibres aligns with global efforts to reduce dependence on non-renewable resources and minimize environmental degradation, making them a more sustainable choice for the future.

Banana fibres, in particular, are natural, eco-friendly plant fibres derived from the pseudo-stem of the banana plant. Known for their strength, light weight, and biodegradability, these fibres are extracted through a process that involves peeling off the outer sheaths, flattening the inner layers, and stripping the fibres manually or with machines [8]. Initially, sections of the plant are cut from the main stem and rolled to remove excess moisture. The fibres are then separated from impurities and dried. This method is efficient and environmentally friendly, as it utilizes agricultural waste without causing harm.

In India, banana cultivation generates approximately 80 million tons of pseudo-stem waste annually [9], which is often underutilized despite its significant industrial potential. For every ton of banana fruit harvested, about 4 tons of biomass waste are produced, including leaves, pseudo-stems, rotten fruit, peel, fruit-bunch stems, and rhizomes. This waste can be transformed into valuable banana fibres, contributing to a sustainable circular economy.

Utilizing banana agricultural waste for fibre extraction is highly beneficial for sustainability, as it turns a significant byproduct of banana cultivation into a valuable raw material. This process not only reduces waste but also provides an eco-friendly alternative to synthetic fibres. Banana fibres are strong, biodegradable, and versatile, finding applications in industries such as textiles, paper, and bio composites. Their use contributes to a circular economy and reduces environmental impact [10].

The focus of this research is to investigate the effects of banana fibre ratios on the comfort properties of fabrics produced using three distinct weaves, by examining the physical properties of these fabrics before and after the scouring process.

## 2. Methods and materials

The goal of the current study is to examine the comfort qualities of fabrics made from banana and cotton blended yarns that have three distinct weaves and the same yarn blend percentage for each of the three created samples.

### *2.1 Yarn Specifications*

The yarn utilized in this study exhibits a twist rate of 20 twists per inch (TPI) and carries a count of 2/18s Ne for both the weft and warp yarns. It comprises a blend of cotton and banana fibers in an 80:20 ratios.

### *2.2 Fabric particulars*

To produce the samples, a table-top loom with a shaft of 8x8 was employed. Three distinct fabrics were generated employing three different weave patterns: plain, twill, and honeycomb. The plain weave sample was woven with a set of 22 ends per inch (EPI) and 48 picks per inch (PPI). The twill weave sample utilized a set of 22 EPI and 56 PPI, while the honeycomb weave sample employed a set of 22 EPI and 60 PPI. The banana and cotton blended yarn used in the study was sourced from Shiva Parvathi Spinning Mill, India

*Table 1: Developed fabric particulars*

| Fabric structure | EPI | PPI | TPI | Blend ratio of cotton and banana |
|---|---|---|---|---|
| Plain | 22 | 48 | 20 | 80:20 |
| Twill | | 56 | | |
| Honeycomb | | 60 | | |

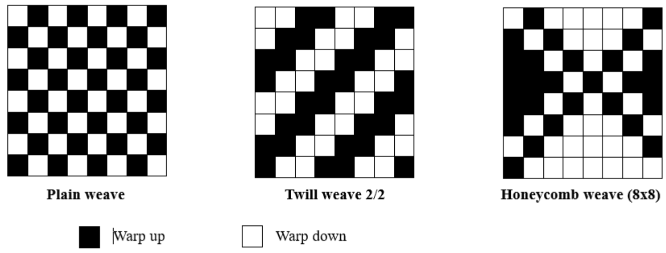


*Figure 1: Plain, Twill and Honey Comb Design Patterns*

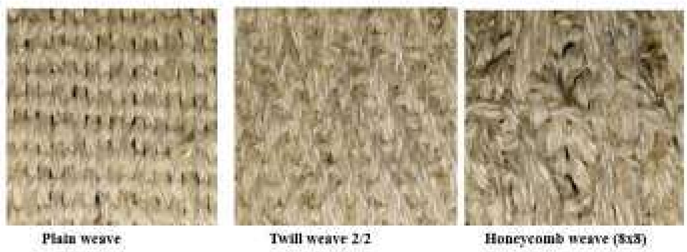


*Figure 2: Plain, Twill and Honey Comb fabrics produced from Table top loom*

### *2.3 Air permeability test*

Air permeability is the velocity of an airflow passing perpendicularly through a test specimen under specified conditions of the test area, pressure drop, and time. This test is conducted according to ASTM D73704 standard.

### *2.4 Stiffness test*

Stiffness testing is a method of measuring the resistance of a fabric to bending by external forces. Based on the stiffness values, we have calculated the flexural rigidity and bending modulus. This test is done by using the Shirley stiffness tester. This test is conducted according to ASTM D4032-08.

### *2.5 Crease recovery test*

The crease recovery test is a method of measuring the ability of a fabric to return to its original shape after being created by external forces. This test is done by using the Shirley Crease Recovery Tester according to ISO 2313.

### *2.6 Abrasion test*

The abrasion test is a method of measuring the resistance of a fabric to surface wear caused by rubbing against another material. This test is done by using the Martindale Abrasion Tester according to ISO 12947-3.

### *2.7 Moisture absorbency test*

Moisture absorbance test is a method of measuring the ability of a fabric to pick up and retain moisture from the environment (moisture regain & moisture content). This test is done by using oven dry method.

### *2.8 GSM*

Measuring GSM (grams per square meter) of fabric involves weighing a one-square-meter piece of the fabric to determine its weight and density. This test is done according to ASTM D3776 -09 standard.

### *2.9 Thickness test*

Measuring the thickness of fabric typically involves using a device like a micrometer or fabric gauge to obtain a precise measurement under standard pressure. This test is done according to ASTM D1777-96 standard.

## 3. Results and Discussions

This section focuses on investigating the influence of both the ratio of banana fibres in the yarn and various weave structures on the comfort properties of the resulting fabric, both before and after the scouring process.

### *3.1 Fabric dimensional changes*

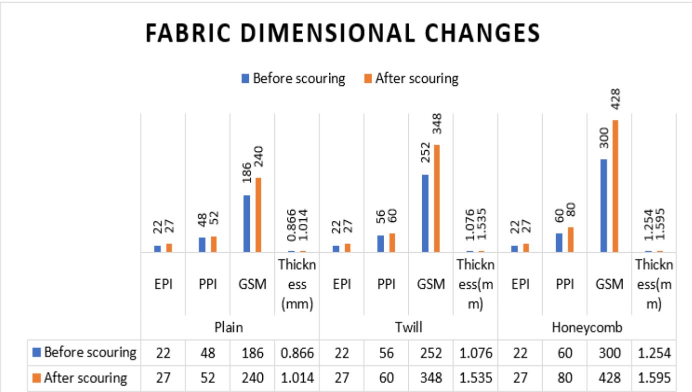


***Figure 3: Dimensional changes of Plain, Twill and Honey Comb fabrics before and after scouring***

From the above figure 3, we can observe that all fabric structures (Plain, Twill, and Honeycomb) show an increase in EPI after scouring, from 22 to 27. This indicates that the fabric has contracted in the warp direction. The PPI for all fabric structures also increases after scouring: Plain (48 to 52), Twill (56 to 60), and Honeycomb (60 to 80). This suggests a contraction in the weft direction. The GSM of all fabrics increases after scouring: Plain (186 to 240), Twill (252 to 348), and Honeycomb (300 to 428). The increase in GSM indicates that the fabric becomes denser after scouring, likely due to the removal of impurities and shrinkage.

The thickness of all fabrics increases after scouring: Plain (0.866 to 1.014 mm), Twill (1.076 to 1.535 mm), and Honeycomb (1.254 to 1.595 mm). This increase in thickness could be due to the relaxation and reformation of the fabric structure during the scouring process. Overall, Scouring results in significant dimensional changes in the fabrics. All fabric types (Plain, Twill, and Honeycomb) exhibit an increase in EPI, PPI, GSM, and thickness after scouring. These changes are indicative of fabric contraction and densification, resulting in an overall increase in the weight per unit area and thickness of the fabrics. These changes can have both positive and negative effects on the comfort properties of textiles. Positive effects are enhanced thermal insulation, improved durability, and a cleaner fabric surface and negative effects are reduced breathability, decreased moisture-wicking properties, potential stiffness, and a reduction in air permeability.

### *3.2 Crease recovery*

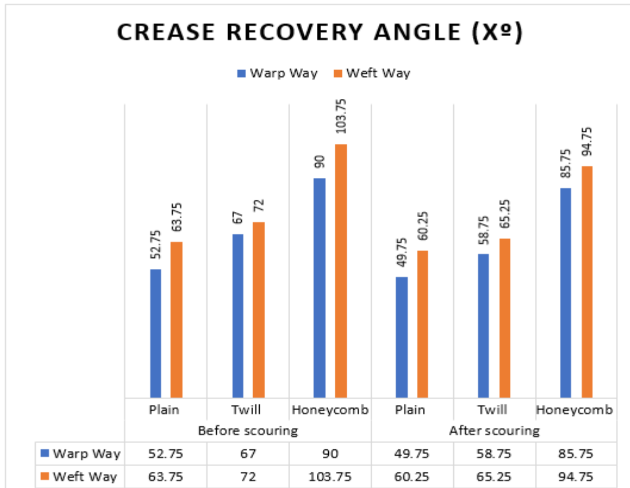


***Figure 4: Crease recovery of Plain, Twill and Honey Comb fabrics before and after scouring***

The crease recovery values for all fabric samples across different weaves (Plain, Twill, and Honeycomb) and directions (Warp and Weft) decrease after the scouring process. The changes in crease recovery values after scouring are generally more significant in the weft direction than in the warp direction for all weaves. This suggests that the weft yarns, which are typically less tensioned during weaving, might undergo more structural changes during scouring, leading to a greater reduction in their ability to recover from creases. The Plain weave shows a relatively small reduction in crease recovery both in the warp (3°) and weft directions (3.5°). This suggests that the Plain weave is less affected by scouring compared to the other weaves, though its inherent crease recovery is the lowest among the three. The Twill weave experiences a more significant reduction in crease recovery values, particularly in the warp direction (8.25°). This might indicate that the Twill weave's structure, which is generally tighter than the plain weave, is more susceptible to changes during scouring. The Honeycomb weave has the highest initial crease recovery values, but it also sees a considerable decrease after scouring (4.25°) in the warp direction and (9°) in the weft direction). Despite this, it still retains the highest crease recovery post-scouring, indicating that while it is affected, it remains the best at recovering from creases among the three weaves.

### *3.3 Air permeability*

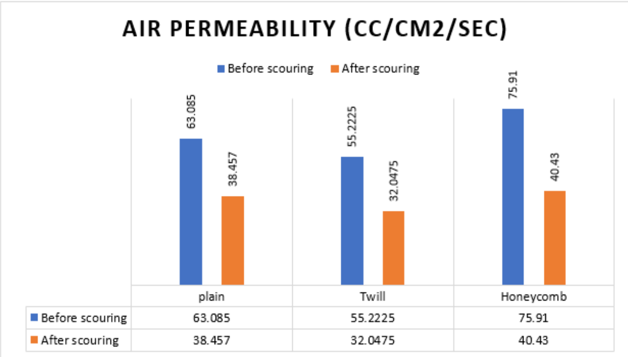


***Figure 5: Air permeability of Plain, Twill and Honey Comb fabrics before and after scouring***

The air permeability of all fabric structures (plain, twill, and honeycomb) decreased significantly after the scouring process. The honeycomb weave showed the highest percentage decrease in air permeability (46.74%), followed by twill (41.97%), and plain weave (39.04%). This indicates that scouring has a considerable impact on the reduction of air permeability across different fabric weaves, likely due to the removal of impurities and surface treatments that initially blocked the pores in the unscoured fabrics. This reduction in air permeability might influence the end-use performance of the textiles, particularly in applications where breathability and ventilation are critical. The comfort properties of the fabric will be affected by the decrease in air permeability post-scouring. The fabric may feel less breathable and more insulating, which could be beneficial in cooler climates but might reduce comfort in warmer conditions or during physical exertion. Additionally, the potential reduction in moisture management capabilities could lead to a less comfortable experience, particularly in terms of moisture buildup and ventilation.

### *3.4 Stiffness Testing*

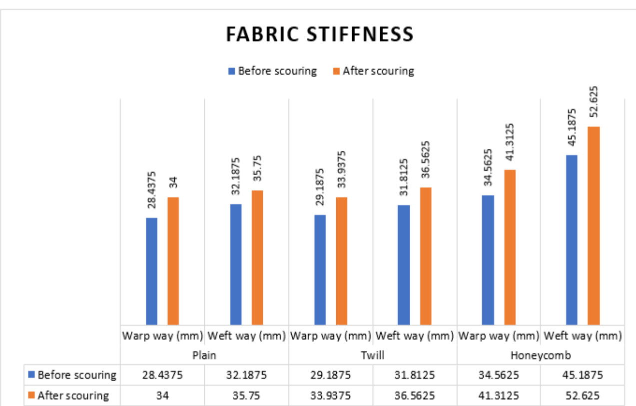


***Figure 6: Stiffness of Plain, Twill and Honey Comb fabrics before and after scouring***

The figure 6 provided presents the results of stiffness testing for fabrics with three different weaves Plain, Twill, and Honeycomb before and after the scouring process. The stiffness is measured in millimeters (mm) in both the warp and weft directions. For plain weave, stiffness in both directions increases after scouring, indicating that the fabric becomes stiffer. This may be due to the removal of impurities and the effect of the scouring process on the fiber structure. Similar to the plain weave, the stiffness increases in both the warp and weft directions after scouring for twill weave. The twill weave shows a more pronounced increase in stiffness, suggesting that the twill structure may respond more significantly to scouring. The honeycomb weave shows the most significant increase in stiffness after scouring, particularly in the weft direction. This may be due to the unique structure of the honeycomb weave, which could be more affected by the scouring process, leading to a higher degree of stiffening. The scouring process generally increases the stiffness of the fabric across all three weaves. The degree of increase varies with the weave type, with honeycomb showing the most significant change, particularly in the weft direction. This increase in stiffness could be due to the removal of natural oils, waxes, and impurities during scouring, which leads to a tighter and less flexible fabric structure.

### *3.5 Flexural Rigidity*

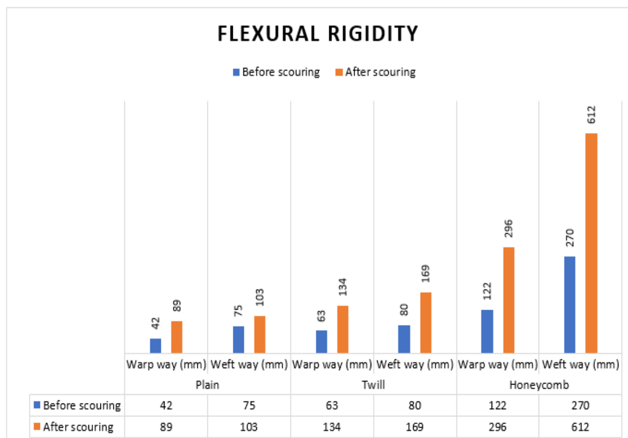


***Figure 7: Flexural Rigidity of Plain, Twill and Honey Comb fabrics before and after scouring***

The figure 7 provides the average flexural rigidity values (measured in µNm) of each weave (Plain, Twill, and Honeycomb) in both warp and weft directions, before and after the scouring process. From the table, it can be observed that flexural rigidity increases after scouring across all fabric weaves and directions (warp and weft). This suggests that scouring, which removes natural impurities and processing oils, impacts the stiffness of the fabric.

In the plain weave, the flexural rigidity nearly doubles in the warp direction, increasing from 41.73875 µNm (unscoured) to 88.98125 µNm (scoured). A significant increase is also observed in the weft direction, from 75.05125 µNm to 103.45 µNm. This increase in stiffness in both warp and weft directions is possibly due to the removal of surface contaminants that previously softened the fabric.

For the twill weave, the flexural rigidity more than doubles in the warp direction, rising from 62.77125 µNm to 133.705 µNm. A similar trend is observed in the weft direction, with an increase from 79.635 µNm to 169.43 µNm. The twill weave shows a considerable increase in rigidity post-scouring, which might be attributed to the fabric's tighter structure, allowing the scouring to significantly alter the fabric's feel and behaviour.

In the honeycomb weave, the increase in rigidity is substantial, with values rising from 121.79925 µNm to 296.07625 µNm in the warp direction. The most significant increase is observed in the weft direction, from 272.00125 µNm to 611.9975 µNm. The honeycomb weave, known for its three-dimensional structure, shows the highest increase in flexural rigidity. This could be due to its high surface area and pronounced texture, which are more affected by the scouring process.

Overall, the results indicate that scouring increases the flexural rigidity of fabrics across all tested weaves, with the most pronounced effects seen in the honeycomb weave. This can be attributed to the removal of natural impurities and processing aids that initially made the fabric more pliable. After scouring, the fabrics become stiffer, which could affect their drape and hand feel. This trend is consistent across both warp and weft directions, although the degree of increase varies depending on the weave structure, with honeycomb showing the most significant change, likely due to its inherently higher bulk and surface area.

### *3.6 Bending Modulus*

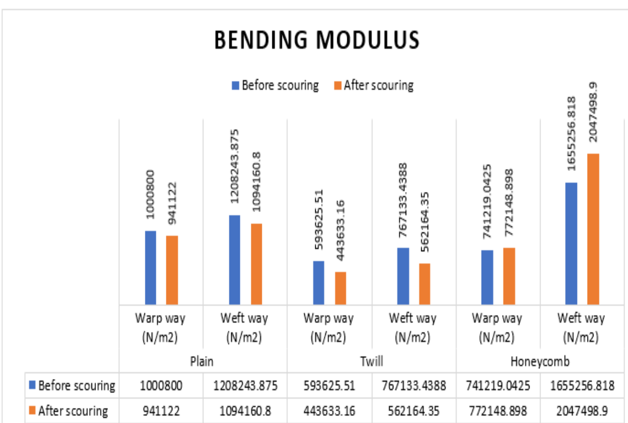


***Figure 8: Bending Modulus of Plain, Twill and Honey Comb fabrics before and after scouring***

The figure 8 presents the average bending modulus values (in N/m²) of three weaves (Plain, Twill, and Honeycomb) before and after the scouring process, measured in both the warp and weft directions. For the plain weave, the bending modulus decreased by 59,678 N/m² in the warp direction, indicating that the fabric became slightly more flexible after scouring. In the weft direction, the bending modulus decreased by 114,083.075 N/m², showing a noticeable reduction in stiffness and making the fabric more flexible. For the twill weave, the bending modulus decreased by 149,992.35 N/m² in the warp direction, suggesting a significant increase in flexibility, while in the weft direction, it decreased by 204,969.0888 N/m², indicating a considerable reduction in stiffness and increased flexibility. Conversely, for the honeycomb weave, the bending modulus increased by 30,929.8555 N/m² in the warp direction, indicating a slight increase in stiffness, and by 392,242.082 N/m² in the weft direction, showing a significant increase in stiffness and making the fabric much stiffer.

Overall, both plain and twill weaves exhibit a decrease in bending modulus in both warp and weft directions after scouring, with a more significant reduction in the weft direction, suggesting that scouring makes these fabrics more flexible. In contrast, the honeycomb weave shows an increase in bending modulus after scouring, particularly in the weft direction, indicating that scouring has made the honeycomb fabric stiffer, especially along the weft.

### *3.7 Moisture Regain & Content*

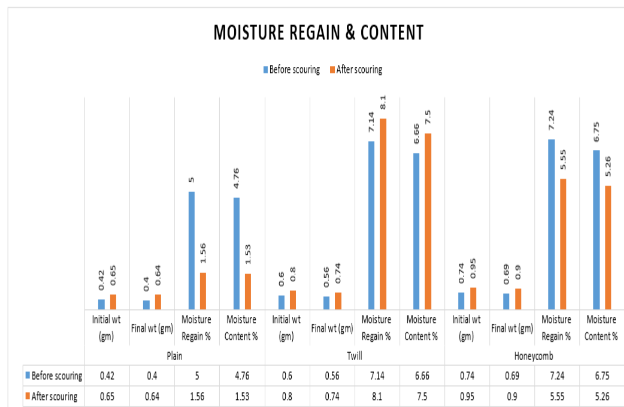


***Figure 9: Moisture Regain & Content of Plain, Twill and Honey Comb fabrics before and after scouring***

After scouring, the moisture regain and content of the Plain weave significantly decrease from 5% to 1.56% and 4.76% to 1.53%, respectively, indicating a reduction in the fabric's hygroscopicity due to the removal of natural oils and impurities. This could affect the fabric's breathability and overall comfort. In contrast, the Twill weave shows a slight increase in moisture regain and content from 7.14% to 8.1% and 6.66% to 7.5%, suggesting that scouring improves its moisture absorption by removing trapped impurities. This could enhance its suitability for garments or applications where moisture management is important. The Honeycomb weave experiences a moderate decrease in moisture regain and content from 7.24% to 5.55% and 6.75% to 5.26%, reflecting a reduction in moisture absorption. The reduction in moisture properties implies that the fabric will be slightly less effective in moisture absorption, which might impact its performance in applications where moisture management is crucial. However, it still retains better moisture absorption than the Plain weave, likely due to its more open structure.

## 4. Conclusion

The study reveals that blending banana fibre with cotton significantly influences the comfort properties of woven fabrics, particularly in terms of air permeability, stiffness, and moisture management. Post-scouring treatment enhanced the density and thickness of all weave structures, with notable increases in GSM and fabric thickness across the plain, twill, and honeycomb weaves. However, this densification came at the cost of reduced air permeability, particularly in honeycomb weave, which saw a 46.74% decrease. The honeycomb weave, with its more complex structure, exhibited the most pronounced changes in stiffness, increasing flexural rigidity post-scouring, making it more suitable for applications requiring structural support (e.g., upholstery or industrial fabrics) rather than wearables that require softness and flexibility.

Despite these structural changes, the fabrics retained adequate moisture regain properties, with the scoured honeycomb achieving a 7.24% moisture regain, which is essential for maintaining wearer comfort in humid environments. The crease recovery values, particularly in the warp direction, decreased after scouring, signalling that further finishing treatments may be required to enhance the durability and appearance retention of these fabrics.

Overall, banana fibre-cotton blends offer great potential as sustainable materials for various textile applications, but careful attention must be paid to post-processing treatments to balance their structural properties with desired comfort levels. Future studies should explore alternative finishing techniques or blending ratios to optimize both mechanical and comfort properties of these fabrics.

## 5. Depth and scope of this study

This research investigates how the proportion of banana fibers influences the comfort of woven banana/cotton blended fabrics. It compares physical properties (air permeability, stiffness, crease recovery, abrasion resistance, moisture absorption, GSM, and thickness) prior to and following scouring, and factors in the impact of plain, twill, and honeycomb weaves.

The scope of the research is to study the comfort qualities of 80:20 banana fiber/cotton blended fabric regarding the effect of weave structure (plain, honeycomb, twill) and the modification effect caused by scouring on air permeability, stiffness, crease recovery, and abrasion resistance.

## 6. Acknowledgement

The authors would like to thank the Textile Laboratory of the Department of Textile Technology, School of Core Engineering, Vignan's Foundation for Science, Technology and Research, Guntur, for the kind support. The authors are also thankful to the laboratory technicians, faculty members, and respondents for the valuable feedback.

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# Enhancing Antimicrobial and Ultraviolet Protection Properties of Cotton Fabric Dyed with Pomegranate Peel Extract

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**Abstract:**

*This study investigates the multifunctional performance of cotton fabric dyed with pomegranate (Punica granatum) peel extract, focusing on its antibacterial, antifungal, UV protective, and moisture management properties. The dyed fabric was tested against Staphylococcus aureus (Gram-positive), Escherichia coli (Gram-negative), and Aspergillus flavus (fungus) using the disk diffusion method. The fabric dyed at pH 7 with 5% dye concentration exhibited the highest antibacterial activity, with a zone of inhibition (ZOI) of 19 mm against S. aureus. Colorimetric analysis was performed using a Datacolor 650 spectrophotometer to determine K/S values and CIE Lab coordinates. Moisture management properties, critical for wound care applications, were evaluated through absorbency, wicking, and moisture retention tests, confirming excellent wetting and one-way transport behavior. The UV protection ability was assessed using the AATCC 183:2010 standard, showing a significant increase in UPF from 12 (untreated) to 45 (treated). These findings suggest the fabric's suitability for specialized applications such as wound dressing and UV-protective apparel.*

**Keywords:** *Antibacterial, Fabric, Moisture, Natural dye, Ultraviolet protection*

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## 1. Introduction

The use of natural colors in the textile industry has recently undergone a significant shift. This change is primarily due to increased awareness of sustainability and environmental friendliness [1]. Traditionally, fabrics have been dyed using methods that date back centuries. However, the introduction of synthetic dyes in 1856 led to a decline in the use of organic colors as synthetic options gained popularity [2]. While synthetic dyes initially dominated the textile industry, concerns about their potential health impacts—such as skin allergies and even cancer—have prompted research into safer alternatives. This has led to a renewed focus on natural colors derived from organic materials, which are safer and more environmentally friendly [3].

Natural dyes, sourced from plants, minerals, and animals, have been used for a variety of applications, including food, pharmaceuticals, textiles, and leather [4]. Historically, societies have utilized natural dyes for centuries. For example, ancient Egyptians used indigo-dyed fabrics to wrap mummies, demonstrating a long-standing tradition of natural dye use [5]. In art, natural dyes have played a significant role, as seen in traditional Indian art forms like Warli, Madhubani, and Patachitra, which used colors derived from fruits, leaves, flowers, seeds, bark, roots, and insects. The health and environmental issues associated with synthetic dyes have sparked a reassessment of botanical and eco-friendly dyes in textiles [6, 7]. The environmental impact of synthetic dyes, such as water and soil contamination, has highlighted the ecological advantages of natural dyes [8, 9]. Today, ecological concerns are paramount, and the non-allergenic nature of natural dyeing processes is increasingly valued [10]. Synthetic dyes can also promote harmful bacterial growth, causing discoloration, unpleasant odors, and allergic reactions 11]. Consequently, there is a growing emphasis on incorporating antimicrobial finishing techniques in textiles to enhance quality [12].

Plant-based dyes are rich in phenolic compounds and flavonoids, that offer antibacterial and anti-inflammatory properties, making them suitable for textile applications [13]. Many plant extracts used as dyes also possess medicinal properties [14]. Using natural plant extracts as colorants not only meets aesthetic demands but also adds antimicrobial benefits to textiles. Research has shown the superior antimicrobial activity of extracts from sources like Curcuma longa and Punica granatum. Color fastness, the resistance of a material to color change and bleeding, is crucial in textiles [15]. The increasing demand for naturally dyed products requires manufacturers to produce consistent shades with high fastness, necessitating standardized technologies and natural dyeing systems. A comprehensive understanding of natural textile coloration, including mordanting agents, dyeing conditions, and the medical properties of fabrics, is essential. This research aims to explore the dyeing process scientifically, focusing on enhancing color strength and antimicrobial qualities in cotton fabrics through natural dyeing techniques. This study aims to bridge this gap by systematically examining the effect of pomegranate peel dye on cotton fabric's color strength, antimicrobial efficacy, moisture transport behavior, and UV protection, while identifying optimal processing conditions.

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## 2. Materials and Methods

- Fabric: 100% cotton (Gossypium hirsutum), bleached and scoured, sourced from a certified textile supplier.
- Dye source: Pomegranate peels collected from local juice shops.
- Chemicals: Sodium hydroxide, sodium carbonate, ethanol, acetic acid, salt, distilled water, and detergent (all analytical grade).

### *2.1 Preparing Pomegranate Peel for Dye Extraction*

Pomegranate peels were sourced from juice shops, cleaned, dried, and ground into a fine powder with consistent 2 mm particles. This powder was used for dye extraction. The process involved chemicals like sodium hydroxide, sodium carbonate, distilled water, ethanol, salt, acetic acid, and detergents. The Soxhlet extraction method was employed using ethanol as a solvent to extract the color components from the peel. The mixture was heated, and the extract was collected after several hours. Ethyl acetate was added to separate the natural dye from impurities.

### *2.2 Dyeing Cotton Fabric*

The dye with the highest extraction efficiency was used to dye bleached cotton fabric with these parameters: a temperature of 70°C, a dyeing duration of 30 minutes, a material-to-liquid ratio of 1:10, and a salt concentration of 30 grams per liter, incorporating 10% sodium carbonate. The choice of pH values was intended to explore dye-fiber interactions under acidic, neutral, and alkaline conditions commonly used in textile processing.

### *2.3 Color Analysis*

The fabric's color intensity was assessed using a Datacolor 650 spectrophotometer and the CIELAB color space, which measures DL* (lightness), Da* (redness-greenness), and Db* (yellow-blue).

### *2.4 Antibacterial Test*

Antimicrobial activity was determined using the disk diffusion method in accordance with SN 195 920-1992. ZOI values were recorded against S. aureus, E. coli, and A. flavus after 6 hours of incubation. These tests measured the zones of inhibition to determine antibacterial effectiveness. A larger zone indicates stronger antibacterial action, and significant inhibition compared to control samples confirms antibacterial properties.

### *2.5 UV Testing*

Following AATCC 183: 2010, the fabric's Ultra Protection Factor (UPF) was assessed to evaluate its UV protection capability. A higher UPF value indicates stronger UV blocking capability.

### *2.6 Moisture Management Behavior*

The following tests were conducted:

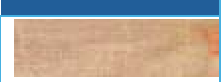
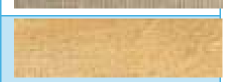
- Absorbency Test: Measures how quickly a water droplet is absorbed, indicating moisture absorption capacity.
- Wicking Test: Assesses the vertical distance liquid travels in a set time to determine moisture distribution speed.
- Moisture Retention Test: Evaluates how well the fabric retains moisture by weighing it before and after exposure.

## 3. Results and Discussion

### *3.1 Color Strength of Pomegranate Peel Dyed Fabric*

The color intensity of the dyed fabrics was measured using a spectrophotometer, which provided the K/S values. These results, along with the CIE Lab coordinates, are presented in Table 2. The parameters include: L*: Brightness, a*: Redness-greenness, b*: Yellowness-blueness, c*: Chroma or saturation and h: Hue angle. In the CIE L* a* b* color space, the cotton fabric dyed with 1% dyestuff concentration shows a green hue, indicated by a negative a* value, and a yellow hue, indicated by a positive b* value. When dyed with a 5% concentration, the fabric shows increased redness, as reflected in the higher a* and b* values. a* value, representing redness, is significantly higher at the 5% concentration compared to the 1% concentration.

*Table 1 - Colour Strength of pomegranate peel dyed fabric*

| S. No. | Pomegranate Peel Dyeing Method | | | | $L^*$ | $a^*$ | $b^*$ | $C^*$ | h | Sample Picture |
|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Con. | Hours | Testing No. | | | | | | |
| 1. | 5 | 1% | 12 | N2466-4 | 73.69 | 8.88 | 25.75 | 27. 24 | 70.98 |  |
| 2. | 5 | 5% | 12 | N2466-3 | 65.76 | 10.35 | 29.38 | 31.15 | 70.59 |  |
| 3. | 7 | 1% | 12 | N2466-2 | 77.35 | 2.57 | 34.88 | 34.97 | 85.79 |  |
| 4. | 7 | 5% | 12 | N2466-1 | 69.15 | 8.09 | 30.93 | 31.97 | 75.33 |  |
| 5. | 9 | 1% | 12 | N2466-6 | 73.37 | 1.12 | 36.75 | 36.77 | 88.26 |  |
| 6. | 9 | 5% | 12 | N2466-5 | 65.79 | 5.47 | 32.76 | 33.21 | 80.52 |  |

### 3.2 Antibacterial activity of Pomegranate peel dyed fabric

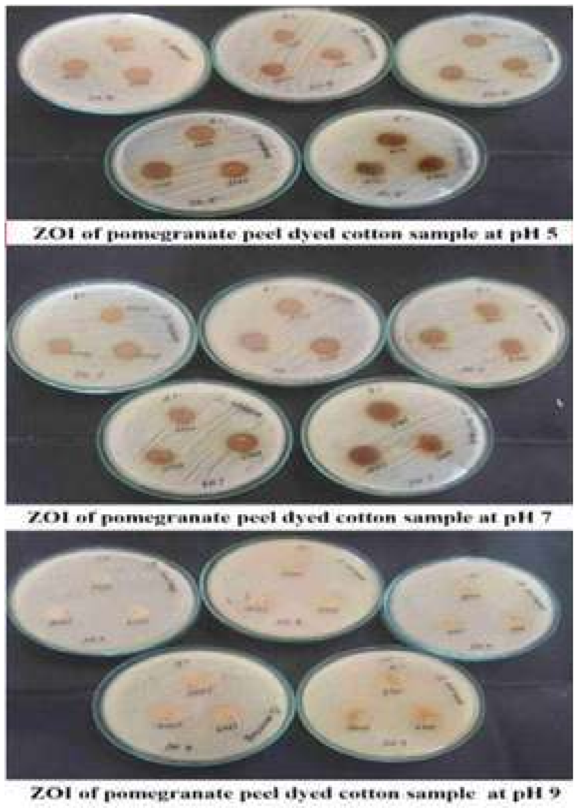
The antibacterial efficiency of the Pomegranate peel extract treated cotton fabrics was tested against wound infecting pathogens and their ZOI (Zone of inhibition) values are presented in table 2.

*Table 2 - Antibacterial activity of Pomegranate peel dyed Cotton fabric*

| pH Value | Dye Concentration | ZoI against Gram Positive (Staphylococcus aureus) Time duration 3 Hours | 6 Hour | 12 Hours |
|---|---|---|---|---|
| | 1% | 11 | 13 | 14 |
| pH 5 | 2% | 12 | 13 | 15 |
| | 3% | 15 | 16 | 17 |
| | 4% | 15 | 16 | 17 |
| | 5% | 16 | 17 | 18 |
| | 1% | 12 | 15 | 14 |
| | 2% | 15 | 16 | 17 |
| pH 7 | 3% | 14 | 17 | 17 |
| | 4% | 13 | 17 | 18 |
| | 5% | 15 | 19 | 18 |
| | 1% | - | - | - |
| | 2% | - | - | - |
| pH 9 | 3% | - | - | - |
| | 4% | - | - | - |
| | 5% | - | - | - |

Table 2 illustrates the antibacterial performance of cotton fabric dyed with pomegranate peel dye. This evaluation was conducted according to the SN 195 920-1992 standard. The analysis shows that samples prepared at pH 7 exhibit enhanced antibacterial properties against Gram-positive bacteria, specifically S. aureus. This trend was observed in most samples. Notably, the sample prepared at pH 7 with a dye concentration of 5% displayed the highest antimicrobial activity, with a zone of inhibition (ZOI) of 19 mm after 6 hours. Conversely, samples dyed at pH 9 showed no antimicrobial activity over various time periods. The study confirms that the sample dyed at pH 7 responded effectively, and a dye concentration of 5% yielded better antimicrobial activity. This is likely due to the higher availability of dye molecules in more concentrated samples. Figure 1 illustrates the ZOI against Staphylococcus aureus at different pH levels and dye concentrations.

*Figure 1 - Antibacterial activity of pomegranate peel dyed fabric against S. aureus*




### 3.3 Liquid moisture management behaviour of selected pomegranate peel dyed cotton fabric

Liquid moisture management properties of the selected pomegranate peel dyed cotton fabric results are displayed in the table 3.

*Table 3 - Moisture Management behavior of pomegranate peel dyed cotton fabric*

| | Wetting time (sec) | | Absorption rate (%/sec) | | Maximum wetted radius (mm) | | Spreading speed (mm/sec) | | One way Transport Capabilit | OMMC |
|---|---|---|---|---|---|---|---|---|---|---|
| | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom | | |
| Mean | 3.8376 | 3.5382 | 10.2029 | 46.9858 | 21 | 24 | 4.3131 | 4.638 | 390.9693 | 0.8122 |
| S.D | 1.8344 | 1.7903 | 4.2227 | 9.6282 | 4.1833 | 2.2361 | 1.0145 | 0.923 | 50.0469 | 0.056 |
| Grade | 4.6 | 4.7 | 1.3 | 3.3 | 4.2 | 4.8 | 4.6 | 4.7 | 4.6 | 4.8 |

*OMMC Grades: 0 - 0.2: Very much not strong, 0.2 - 0.4: Not strong, 0.4 -0.6: Strong, 0.6 - 0.8: Very strong, 0.8>: Excellent

| Index | Unit | Grading of the indices Pomegranate peel dyed cotton fabric |
|---|---|---|
| Wetting time top surface - WTt | sec | Very fast - < 3 |
| Wetting time bottom surface - WTb | | Very fast - < 3 |
| Absorption rate top surface - ARt | % / sec | Slow (10-30) |
| Absorption rate bottom surface - ARb | | Medium (30-50) |
| Maximum wetted radius top surface | mm | Large (17-22) |
| Maximum wetted radius bottom surface | | Very large (>22) |
| Spreading speed top surface - SSt | mm / s | Very fast - >4 |
| Spreading speed bottom surface - SSb | | Very fast - >4 |
| Accumulative one-way transport index -R | % | Very good (200-400) |
| Overall moisture management capacity - OMMC | - | Excellent - >0.8 |

Table 3 presents the grade values and moisture management behaviors of the fabric dyed with pomegranate peel. According to Yao et al. (2006), wound dressing materials should effectively manage liquid moisture. The study confirms that the pomegranate peel-dyed fabric possesses desirable moisture management properties, with varying index grades. These include moderate to rapid wetting, quick absorption, extensive coverage on the lower surface, and swift spreading, aligning with essential criteria for effective one-way transport.

Wetting Time (Moderate to Fast):
The fabric exhibits extremely rapid wetting on both surfaces, surpassing the essential level.

Absorption Rate (Top Surface - Medium to Fast):
While the top surface shows a slower absorption rate, the bottom surface achieves medium absorption.

Maximum Wetted Radius (Bottom Surface - Large Area):
The fabric meets the high standard for wetted radius, indicating a large spread area.

Spreading Speed (Bottom Surface - Fast):
The fabric demonstrates very fast spreading, exceeding expected standards.

Accumulative One-Way Transport Index (Good to Excellent):
With a one-way transport index of 200-400, the fabric achieves a very good grade.

### *3.4 Ultra protection factor of the finished Fabric*

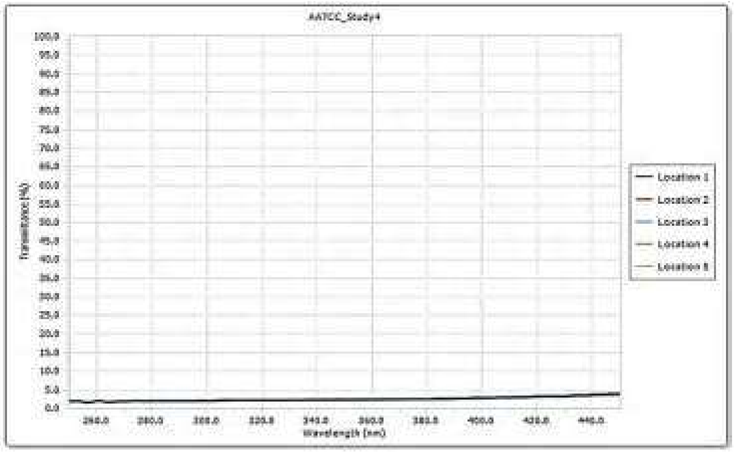



*Figure 2 - UPF rating for treated sample*

From Figure 2, it is evident that the UPF rating for untreated fabric is 12, while the treated fabric has a rating of 45. This indicates that the treated fabric offers excellent UV protection, whereas the untreated fabric provides poor protection. The use of pomegranate peel in cotton fabric enhances its ability to block harmful UV rays, as shown in Figure 2.

## 4. Conclusion

This study demonstrated the potential of pomegranate peel extract as a natural dye that imparts multifunctional properties to cotton fabric. Optimal antimicrobial and antifungal activity were observed at pH 7 and 5% dye concentration, with a maximum zone of inhibition of 19 mm against S. aureus. Colour analysis revealed a deeper hue at higher concentrations, while moisture tests confirmed excellent liquid management—crucial for wound-care textiles. The UV protection capacity was significantly improved, with UPF increasing from 12 to 45. These results highlight the practical application of pomegranate peel-dyed cotton in wound dressing materials and UV-protective clothing, supporting a sustainable and functional approach in textile development.

## 5. Acknowledgement

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# Designing Jacquard Woven Dress Materials using Motifs Inspired from International Art Forms

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**Abstract:**

*This paper is the output of a project work which focuses on creative ideas, responsible design thinking, and problem-solving approach. Two fabric samples were woven in a handloom fitted with 100-hook jacquard system using cotton-polyester blended yarns of royal blue colour in both warp and weft. The extra figured motifs were developed using jacquard shedding device with pale shade of lilac in cotton yarns. The motifs were inspired from two famous international art forms, namely Sri Lankan Mask art, and Totem Pole of Northern Pacific Coast to break the traditional monotonous designing styles of handloom jacquard products. The woven jacquard fabrics were finally used in designing two semi-formal outwears for the women aged 25-35 years and of upper-middle class category with a personality of spontaneity, boldness and creative mind fond of exploring contemporary and unique styles. The main aim behind this project was to introduce new ideas and design thinking in the domain of handloom jacquard weaving to diversify the product range of the handlooms, in general, thereby enhancing employability and income level of the handloom weavers' community.*

**Keywords:** *designing, Handloom, Jacquard, Sri Lankan Mask art, Totem Pole*

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## 1. Introduction

In our daily life, we interact with garments of many kinds. Today's generation are mainly focused on fast fashion. Because of this, machine-made garments are gaining popularity day by day. Here in this race, if we look back, we can see that we are leaving our weavers behind, in the dark.

When we talk about handloom, the first thing which comes in our mind is 'traditional'. And the fact is, traditional is expensive, and it creates a boundary in the market. The consequences of this fact affect the lives of those people who are directly and indirectly dependent on handloom. Diversification is a way through which we can accelerate better future of the handloom industry, in general, and the poor weavers, in particular.

This paper is based on a project which focuses on creative ideas, responsible design thinking, and problem-solving approach. Design is always a problem-solving space which allows us to think beyond the box.

The aim of the project was to introduce new ideas and designs in the field of handloom jacquard to diversify the product range, of course, preserving our cultural heritage, and to expand the employment scope and economic empowerment of the handloom weavers' community.

The prime objectives of the present work were as follows:

i. To study various international art forms of simple nature, especially, Sri Lankan Mask Art and Totem Pole of Northern Pacific Coast.

ii. To extract various key elements/motifs of the said art forms, and explore the possibilities of introducing them as jacquard motifs.

iii. To synthesize the final designs for jacquard weaving by selecting some feasible elements from the said art forms, and converting them into feasible jacquard designs using various CAD tools.

iv. To design the final jacquard woven dress materials with the synthesized designs by judiciously selecting the warp and weft threads in terms of material, count, and colour combination to give the final product a bold-yet-ethnic look.

v. To introduce contemporary designs in handloom sector for product diversification, and produce jacquard woven fabrics for designing dress materials which can be affordable by large number of consumers.

***Figure 1: Some typical Sri Lankan masks [1, 2]***

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*1.1 Sri Lankan mask art*

Sri Lanka is a country which is rich in many artistic heritages. Amongst the various forms of art prevailing there, mask art is considered as the traditional art form from time immemorial. Masks are primarily expressive media which are utilized in multiple art forms including dramas, theatres, dances, and religious rituals. Ambalangoda, a small town in Sri Lanka, is famous for one such distinctive art of mask making. The mask making process is traditional and very lengthy. The masks thus produced are made for fitting various characters of humans, animals, birds and demons with varying facial expressions which ranges from comical to demon looking grotesque masks [1, 2]. The practice of using masks in Sri Lanka is believed to have been in use since ancient times which dates back to the pre-Buddhist era when the masks were primarily used for exorcism. During that period, the healer/exorcist used to perform some rituals to cure the people. This process required the wearing of different masks personifying various diseases (sannis). Those type of masks were locally called as Sanni Masks which were 18 in numbers to cure 18 sannis or diseases [1, 2]. Some of the typical masks used during traditional theatre and mask dance are presented in Figure 1..

*Figure 2: Some typical wooden monumental structures/installations (Totem Poles) [3, 4 & 5]*

*1.2 Totem Pole of Northern Pacific Coast*

Totem poles are symbolic monumental wooden carvings which are a kind of Northwest Coast art forms found in western Canada and the north-western United States. These art forms comprise of painted wooden poles, posts or pillars in which various symbols or figures are carved. The logs of large trees, mostly western red cedar, are used to make these monumental posts/poles. Totem poles are one of the largest objects which are used by the coastal Pacific Northwest natives to depict/symbolize spiritual reverence, family legends, and sacred beings. These monumental poles or tall structures are sometimes used by the native people to showcase culturally important animals, people, or historical events, too. One to many animal images/figures are, in general, carved in each pole maintaining the standardised forms which the native people are familiar with [3, 4 & 5]. Figure 2 above shows some of the typical wooden monumental structures/installations of this genre.

*1.3 Handloom jacquard: an overview*

Woven fabric is formed by interlacing two or more series of threads (technically known as warp and weft). Interlacement patterns or orders produce different weaves. Before interlacement, formation of warp shed is must, in which the warp threads are divided into two layers by the shedding device/mechanism attached with the loom. Type of weaves or interlacements that can be done in a loom depend on the figuring capacity of the particular loom. Simple kinds of weaves or interlacements can be done using ordinary treadle/peddle operated handlooms or handlooms attached with dobby shedding device. If intricate designs or motifs with larger repeats are required to be woven, then Jacquard shedding devices are must.

Jacquard shedding device is basically a system or mechanism or a special attachment which is mounted on the top of a handloom/power loom to form the shed by controlling individual warp threads. It enables the looms to weave large intricate patterns e.g., damask, brocade, tapestry, home furnishings, blankets, quilts, towels, etc. The jacquard shedding device was invented by French weaver Joseph Marie Jacquard in 1804-1805 to simplify the process of weaving intricate figured motifs. Before this invention a draw boy used to sit on the top of the loom to lift individual warp threads for producing figure motifs [6]. The heart of Jacquard machine is the hooks and knives, which control the lifting order of the warp yarns. This system utilizes the interchangeable chain of pattern/punched cards to control the movement of the individual healds which, in turn, control the individual warp threads. Thus, Jacquard looms is capable of controlling the weaving of cloth in such a fashion that any desired pattern/design can be obtained automatically, of course within its capacity [7].

Unlike treadle looms or dobby looms, each and every warp thread in a Jacquard loom is controlled individually by means of individual healds which, in turn, are controlled by the corresponding hooks, needles and knives. The selection of the hooks to be lifted for a particular pick is done by the pattern cylinder and the corresponding pattern/punched card in which the design information is stored. Hooks can control only the upward movement of the warp threads/healds. For downward movement, the dead weights (commonly known as 'lingoes') are attached at the bottom of each heald. These are basically reversing/under motion in conventional Jacquard looms.

*1.4 Major components of handloom jacquard and its working principle*

Handloom jacquard works mainly with the single lift, single cylinder principle. In single lift, single cylinder jacquard, there must be 100 hooks, 100 needles, and one perforated cylinder to control 100 warp threads individually within a single repeat of design. The major components of any jacquard system are: hooks, knives, knife board/frame, neck cord, needles, needle board, perforated cylinder, spring box, harness cords, comber board, dead weights/lingoes, etc.

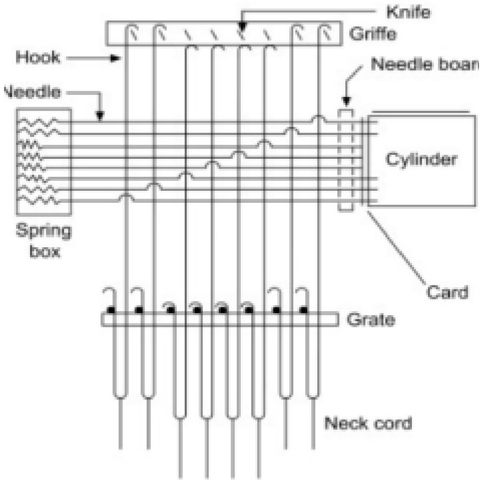


*Figure 3: Schematic diagram of handloom jacquard system [8]*

Figure 3 shows the schematic diagram of a simplified handloom jacquard system [8]. Working principle of any jacquard device is analogous to the binary principle which is the basis of any computer system. For a particular design repeat, pattern cards are punched pick by pick basis, each pick requiring a separate card to be punched. All these punched cards are laced together in a serial manner to make a chain of pattern cards. The chain so formed is passed over the jacquard cylinder. A hole in a particular punched card represents that the corresponding hook (and the warp thread) will be selected, and a blank represents deselection of the corresponding hook (and the warp) with respect to the corresponding pick. The selection of hooks means the hooks (and the corresponding warp threads controlled by the hooks) will be lifted to form the upper shed, whereas deselection means the hooks (and the corresponding warp threads) will be left at the bottom to form the lower shed. The vertical movement of the griffe knives (situated in knife board) are controlled by leg of the weaver through a paddle/treadle. The selected hooks get upward movement from the vertical upward movement of the griffe knives. When the griffe starts moving upward, one of the punched cards along with the perforated cylinder are pressed against the horizontal needles. The outer ends of the needles are free, whereas the inner ends are attached with brass springs housed in a spring box. If the needle faces a hole in the card it will pass through it and into the perforation of the cylinder holding the card. The needle will not be pressed, it will maintain its original state instead, and the corresponding hook will also be in its original upright position. The hook under consideration will thus be selected to be lifted by engaging with the griffe knife during the upward movement of the later. The heald and the corresponding warp thread controlled by the hook will also be raised to form the top shed line. If the needle faces any blank in a card, it will be pressed during inward movement of the pattern cylinder. This phenomenon will deflect the corresponding hook to be deselected and disengaged with the griffe knife, and be left down. The heald and the corresponding warp thread will also be left down to form the bottom shed line.

## 2. Methodology

There were three major steps for the dress making, namely, i) design development from the synthesized motifs, ii) fabric making in Jacquard loom using the developed design, and ii) final dress design and development.

The design development process consisted of the following steps:

### *2.1 Creation of mood board, colour board, and client board*

The mood board, colour board, and the client board for this particular project were as shown in Figure 4, Figure 5, and Figure 6, respectively. The colours convey different visual

*Figure 4: Mood board*

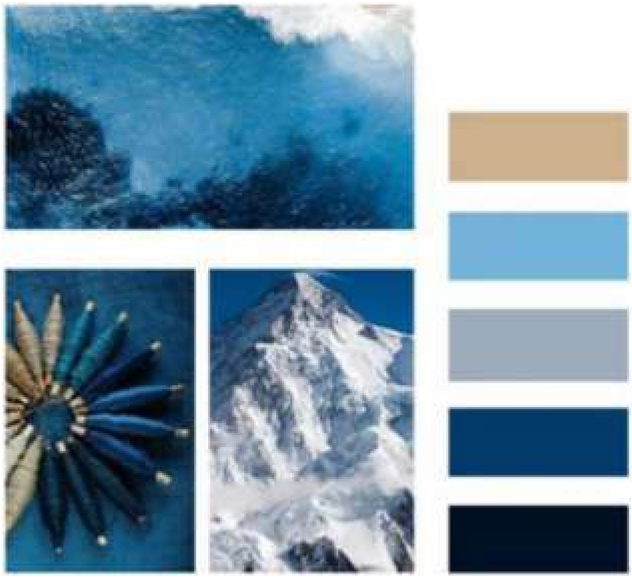

*Figure 5: Colour board*

| | |
|---|---|
| ***Category*** | : Semi formal wears for women |
| ***Style*** | : Indo-Western |
| ***Age Group*** | : 25-35 |

***Economic Status***: Upper Middle Class

***Personality***:

Spontaneous, bold and creative minded women, who loves to explore new and unique styles.

*Figure 6: Client board*

meanings, and every individual perceives them differently. The palettes chosen for this project represent tranquility, spontaneity and boldness as well as calmness/peacefulness.

### *2.2 Inspiration and motif extraction/selection*

Inspiration is what we are attracted to and it is something which introduces us with a new way of looking at things and exploring the unknowns. While studying international art and crafts, the author came to know about Sri Lankan Mask art and Totem Pole of Northern Pacific Coast. The designs in this project are inspired from these two international art forms. After studying various designs of this genre, several motifs were explored as shown in Figure 7, whereas the motifs shown in Figure 8 were chosen as the feasible designs of inspiration, and its major elements have been extracted or selected for subsequent process.

### *2.3 Design modification and pattern development*

Taking the extracted motifs shown in Figure 8 as the inspiration, modifications were done a little bit to develop the final designs and/or patterns which can be woven easily within the capacity of a 100-hook handloom jacquard. The developed patterns are shown in Figure 9.

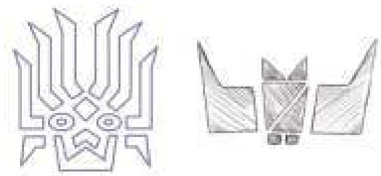

*Figure 8: Extracted motifs as inspiration*

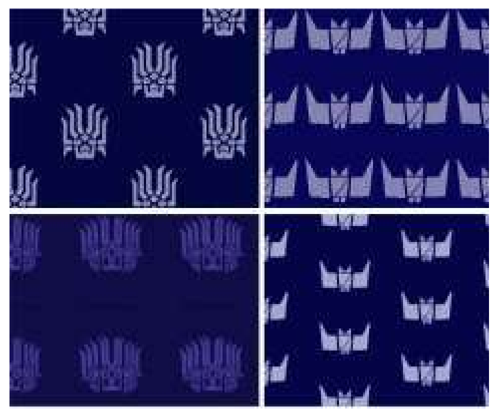

*Figure 9: Developed patterns for jacquard weaving*

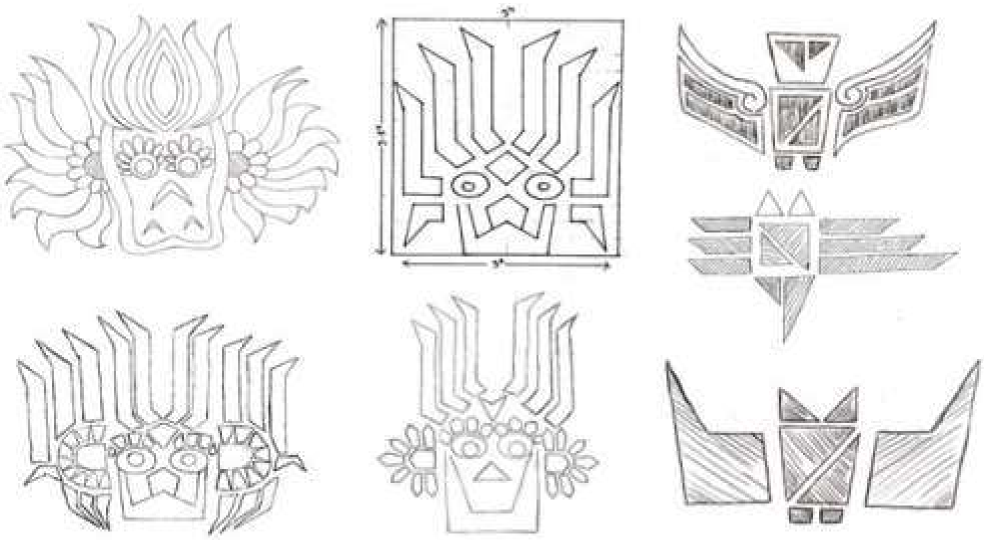

*Figure 7: Motifs explored from the theme*

### *2.4 Development of textile design*

The conversion of the developed motifs into corresponding jacquard designs has been done using ArahPaint 6.0 software keeping in mind the restriction of hook capacity/figuring capacity of the jacquard to be employed (i.e., 100 hooks, in this project). The weaving plan of the mono-chrome jacquard designs are given in Figure 10.

## 3. Materials and machine used

In this project, two types of yarns were used to make the jacquard woven fabrics as given below:

For warp and weft : 2/60s Ne cotton-polyester blend (royal blue in colour)

For figuring with extra weft : 2/100s cotton (4-ply) (pale shade of lilac in colour)

The fabrics were made in a handloom (fly shuttle pit loom type) with jacquard shedding device. The loom particulars were as follows:

| | |
|---|---|
| Hook capacity of jacquard | 100 |
| Jacquard system type | Single lift single cylinder |
| Reed count | $60^s$ Stockport |
| Denting for body of fabric | 2/dent |
| Denting for selvedge | 4/dent |
| Weave for body / ground | Plain/Calico (1/1 pattern) |
| Binding weave for motifs | 7-end Sateen |
| Total no. of heald shafts used | 2 (for plain ground of the fabric) |

## 4. Results and discussion

### *4.1 Fabric development process*

The fabric development process in handloom jacquard involved so many steps. First, yarn requirement for warp and weft was calculated, and based on the estimation, grey cotton yarns of desired quantity were procured from Shantipur Yarn Market, Nadia, West Bengal. Two types of packages were wound for weaving purpose: warper's bobbins or simply bobbins for warping purpose, and the pirns or 'Noli' for the weft yarns. For winding, Charkha device was used. Before warping, required number of bobbins were prepared, and creeling was done by arranging required number of bobbins onto a vertical wooden frame. The warping was done using a horizontal/sectional warping device, called 'Drum', and the warp sheet so prepared is transferred onto a beam to get the weaver's beam. This process is known as drumming and beaming. The weaver's beam was then placed over the particular loom, and drafting and denting were done as per the plan of weaving. The warp yarns for the body/ground of the fabric were drawn 1 end per heald eye and 2 ends per dent of reed. For the selvedge/boarder, the denting was 4 ends per dent. As ground weave was plain, so drafting for the ground warp threads was kept straight. Next harness was prepared by connecting individual hook of jacquard with the individual warp thread (responsible for producing motifs by interlacing with the extra weft threads) along with connecting dead weights (lingoes) at the bottom of each heald. Once harness mounting was done, pattern cards were punched as per the developed design pick by pick basis, and afterwards laced sequentially. The chain of pattern cards was then placed over the jacquard cylinder, and after some minor adjustments, the process of weaving started. Since, two

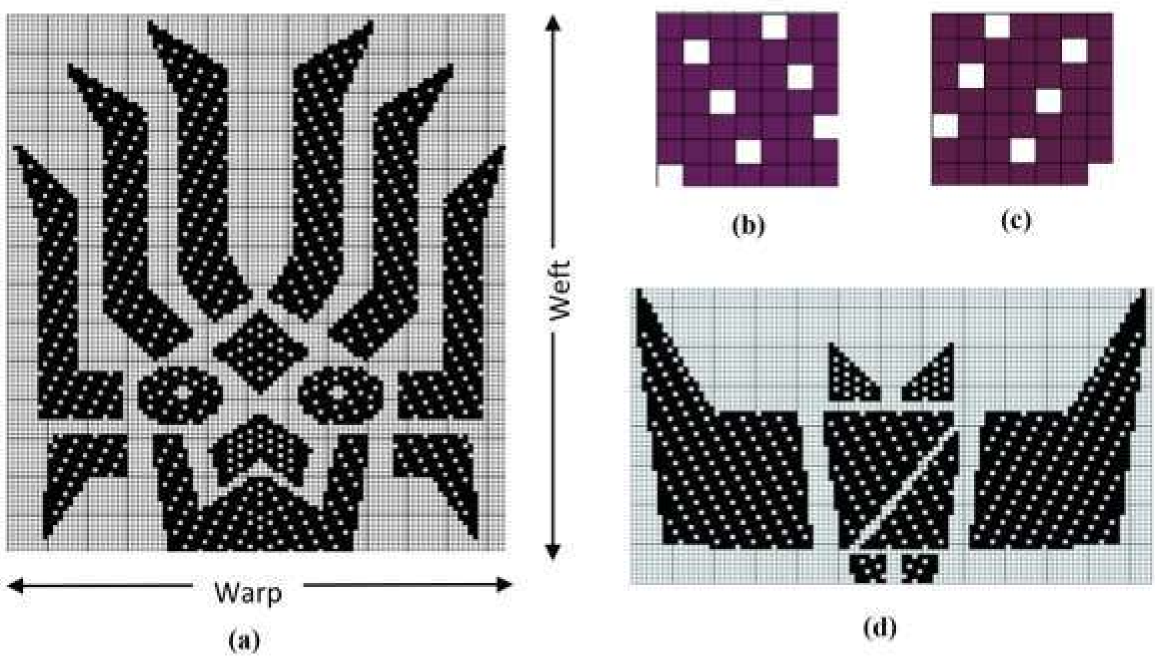


*Figure 10: Weaving plan of mono-chrome jacquard designs — (a) motif-1 with binding weaves, (b) 'S'-direction 7-end sateen as binding weave, (c) 'Z'-direction 7-end sateen as binding weave, (d) motif-2 with binding weaves.*

separate jacquard designs were developed keeping the warp and weft same, it was necessary to prepare two chains of pattern cards based on the two jacquard designs. When one fabric with a particular motif/design was finished, the first chain of punched cards was replaced with the second one and weaving was done for the next fabric.

The detailed flow chart for fabric development process in handloom jacquard is furnished in Figure 11 and Figure 12.

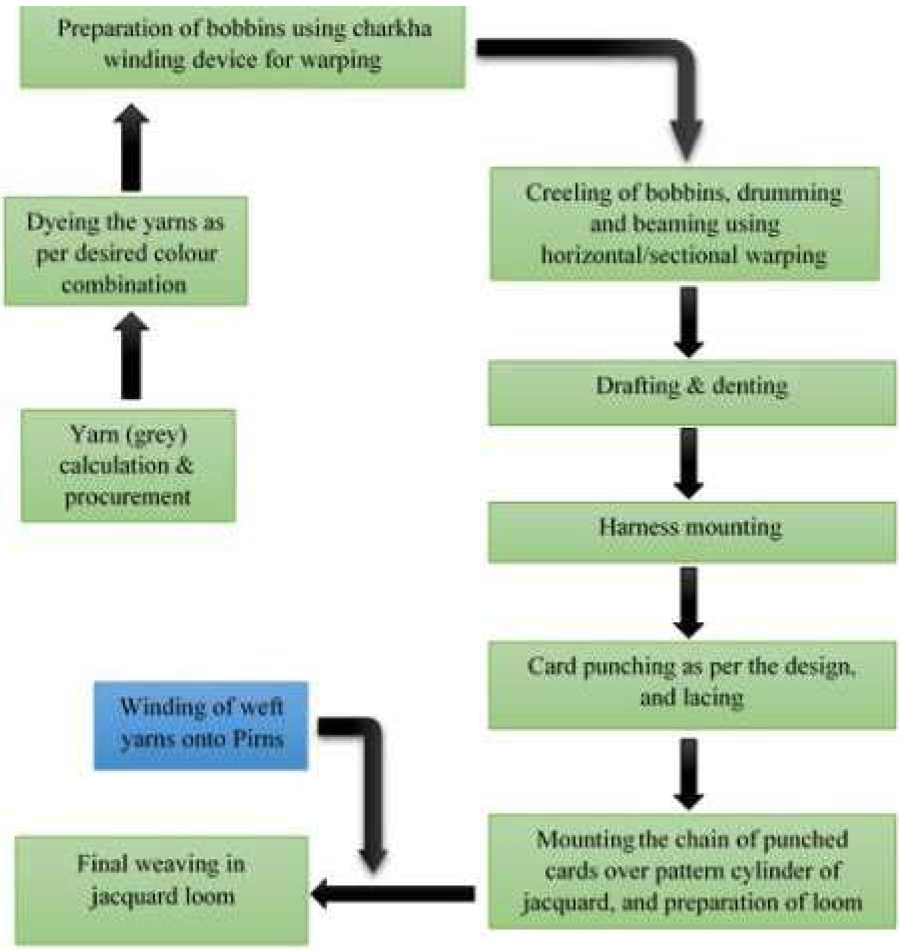


*Figure 11 : Fabric development process sequence in handloom jacquard*

*Table 1: Technical specification of the fabric samples*

| Items | Description |
|---|---|
| Dimension of each fabric sample | 90 inch X 44 inch for sample-1<br>140 inch X 44 inch for sample-2 |
| Width of border/selvedge | 1 inch |
| No. of ends per inch (relaxed state) | 66 (for body) |
| No. of picks per inch (relaxed state) | 54 (for body) |
| Cotton yarn count | $2/60^{s}$ Ne (both warp & weft) |
| Colours of the fabric samples | Ground colour – Royal blue<br>Extra weft for motifs in colour – Pale shade of lilac |

It took around 4 days to weave two fabrics each of 3m length. The technical specification and costing of the fabric samples are shown in Table 1 and Table 2, respectively.

The detailed flow chart for fabric development process in handloom jacquard is furnished in Figure 11 and Figure 12.

*Table 2: Approximate costing of the fabric samples*

| Items | Amount (Rs.) | |
|---|---|---|
| | Sample-1 | Sample-2 |
| Design Cost | Rs. 500/- | Rs. 700/- |
| Cost of weaving in jacquard loom | Rs. 1000/- (for 90 inch) | Rs. 1,600/- (for 140 inch) |
| Cost of Stitching | Rs. 450/- | Rs. 1,750/- |
| Profit | Rs. 500/- | Rs. 500/- |
| Total | Rs. 2450/- | Rs. 4,550/- |

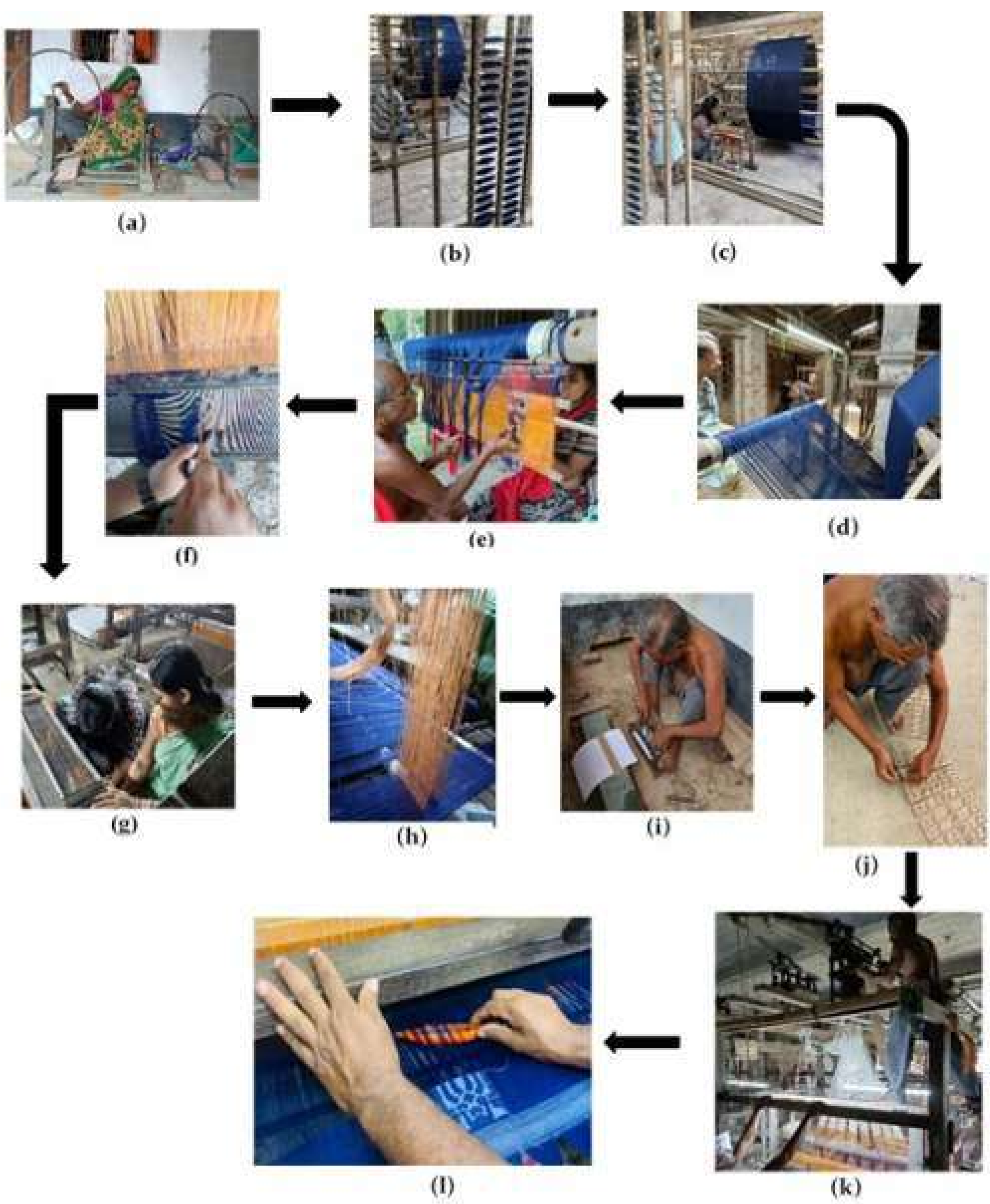


**Figure 11:** Process flow chart for fabric development — (a) Bobbin and pirn winding, (b), (c) & (d) Creeling & drumming/sectional warping, (e) drafting or drawing-in, (f) denting, (g) & (h) harness building for jacquard, (i) card punching, (j) card lacing, (k) mounting the chain of pattern cards over jacquard cylinder, (l) weaving for ground fabric and developing motifs through figuring with extra weft.

*4.2 Concept drawings or garment illustrations*

*Figure 13: Concept drawings/illustrations of the final outfits*

The concept drawings or illustrations of the final dress materials are shown in Figure 13. Concept drawings have been done initially by free hand and then finalized using Adobe Photoshop CC 2015 software.

*4.3 Garment specification sheet*

The specification sheets for the two final garments/outfits are given in Table 3 and Table 4.

*Table 3: Specification sheet for outfit-1*

| Sl. No. | Specifications | Details |
|---|---|---|
| 1 | Garment Type | Midi Dress |
| 2 | Style Category | Semi-formal / Office wear |
| 3 | Length | Below knee |
| 4 | Fit/Silhouette | A-line, semi-fitted |
| 5 | Neckline | Shirt collar |
| 6 | Front Opening | Button placket up to the waistline |
| 7 | Button Type | Coconut shell buttons |
| 8 | Lining | Fully lined |
| 9 | Seam Type | Overlocked and lock-stitched |
| 10 | Hem Finish | Double-turned, top-stitched |
| 11 | Size | Medium (Standard sample size) |
| 12 | Care Instruction | Gentle cold wash, cool iron if needed |

The product photoshoots of the final outfits are presented in Figure 14 and Figure 15.

*Table 4: Specification sheet for outfit-2*

| Sl. No. | Specifications | Details |
|---|---|---|
| 1 | Garment Type | Blazer and Skirt set |
| 2 | Style Category | Semi-formal / Office wear |
| 3 | Skirt Length | Knee length |
| 4 | Skirt Fit/Silhouette | Straight |
| 5 | Skirt Waistband | Elasticated with inner drawstring |
| 6 | Blazer Opening | Front opening with 1 button |
| 7 | Blazer fit | Regular Fit |
| 8 | Lining | Fully lined (both pieces) |
| 9 | Seam Type | Overlocked and lock-stitched |
| 10 | Hem Finish | Double-turned, top-stitched |
| 11 | Size | Medium (Standard sample size) |
| 12 | Care Instruction | Gentle cold wash, cool iron if needed |

*Figure 14: Product photoshoot of final outfit-1*

*Figure 15: Product photoshoot of final outfit-2*

*Figure 2: Process flowchart of Yarn Manufacture from Recycled Cotton Fiber*

## 5. Conclusion

Block, screen and digital printing can easily produce different intricate figures and patterns to decorate a fabric surface. But decorating or ornamenting a woven fabric through hand weaving is a complex task. The task becomes more complex when figuring with handloom jacquard is concerned. Because, developing a figured motif or pattern using handloom jacquard involves so many steps which are hardly accomplished by the ordinary handloom weavers. Only a handful of weavers specialized in handloom jacquard can only serve the purpose.

It is observed that most of the western wears like, dresses and blazers do either have checks or printed patterns. In order to break the monotony, and also with a view to giving contemporary look to the final product, an audacious attempt has been made, in this project, through introducing new motifs inspired from international art forms in woven fabric using traditional jacquard weaving technique.

Synthetic items are abundant in the market now-a-days, and we cannot but think of synthetics in our daily life. Although synthetics have some downsides, they do possess some merits, too.
Cotton blended with polyester fibres can reduce the creasing property and dullness of the cotton fabrics, and it makes the final dress materials looking smart and more attractive to the consumers. Keeping these in mind, the base fabrics were woven with 2/60s Ne cotton-polyester blended yarns, and the figured motifs were developed with 2/100s Ne 100% pale shade of lilac colored (4-ply) cotton yarns using jacquard system.

Needless to mention that the designs or the extra figured motifs, in this project, were inspired from two famous international art forms – Sri Lankan Mask art and Totem Pole of Northern Pacific Coast. The final motifs were developed based on the above mentioned two art forms in order to express the boldness in the design, which is the characteristic of the two art forms. The royal blue and pure white colour pallets were chosen for the constituent yarns, in this project, to symbolize tranquillity, spontaneity, and boldness while maintaining calmness and elegance in the final garment.

Finally, this project was done in an attempt towards product diversification of handloom jacquard fabrics by breaking the monotony in both designing and product range.

## 6. Acknowledgement

The authors are extremely indebted to Mr. Debashis Pailan, freelance designer of Baruipur, 24-Parganas (S) for his active co-operation and inspiration during developing the jacquard designs. The authors are very much thankful to every member and every weaver of the "Basudevpur Silpa Bipanan Tantubay Samabay Samity", for their immense support and active assistance during development of the fabric samples in handloom jacquard. Special thanks are also due to Miss Titli Hajra who agreed spontaneously to become the model for the product photoshoot.

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# Exploring the Evolution of Shekhawati Art: Cultural Significance and Traditional Motif Design on Fabric Surfaces

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**Abstract:**

*The Shekhawati region in Rajasthan, India, is well-known for its artistic heritage, especially the intricate frescoes and mural paintings on havelis, temples and chhatris. These works were marked by their bright hues and intricate patterns depicting the socio-cultural, religious, and historical developments of the region. The Shekhawati murals, which were painted in the late 18th and early 19th, were commissioned by wealthy merchant families, and a blend of indigenous, Mughal and European styles were used to execute these murals. The changes in the development of Shekhawati mural art and also the modification of motifs with implied cultural meaning are analysed here. Traditional motives have also been examined as a factor that helps preserve regional identity and intangible heritage. Symbolic and narrative aspects encoded into these designs have also been highlighted. In addition, an attempt has been made to discuss the problems involved in conserving this unique art form. The deterioration of ancient murals due to natural and human factors has been observed, and the importance of integrated conservation methods has been emphasized. The form of reinterpretation and adaptation of Shekhawati art in the context of today's design spectrum has also been analysed. Initiatives for tourism promotion, digital archiving and grass roots engagement are being made to revive and conserve Shekhawati's tradition of murals. Under these projects, this wisdom of the heritage remains relevant for the life in the country and abroad as well.*

**Keywords:** *Cultural Heritage, Folk Murals & Frescoes, Motif Design, Shekhawati Art, Garments*

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## 1. Introduction

Shekhawati, a historically rich and culturally vibrant region in Rajasthan, India, is often referred to as the "Open-Air Art Gallery of India" due to its extensive collection of mural paintings and frescoes. Spanning the districts of Jhunjhunu, Sikar, and Churu, Shekhawati is home to grand havelis (traditional mansions) adorned with intricate artwork that narrates stories of mythology, folklore, history, and daily life. The region flourished as a significant trade hub in the 18th and 19th centuries, attracting wealthy Marwari merchants who commissioned elaborate frescoes on their havelis as a display of affluence and cultural patronage. These artistic expressions were not merely decorative but carried deep-rooted cultural symbolism, reflecting the aspirations, beliefs, and influences of the time. The motifs and themes of Shekhawati murals evolved over centuries, absorbing elements from Rajput, Mughal, and even European artistic traditions [1- 3]. The mural paintings in Shekhawati are an essential part of India's folk and traditional art heritage. These paintings, created using natural pigments and lime plaster techniques, have withstood the test of time, though they now face challenges due to environmental degradation and urbanization. The motifs in these murals include floral and geometric patterns, mythological figures from Hindu epics such as the Ramayana and Mahabharata, depictions of deities, portraits of traders, colonial influences like British officers and steam engines, and scenes from everyday life. The murals serve as historical documentation of Shekhawati's socio-economic evolution, highlighting themes of prosperity, religious devotion, and artistic ingenuity. Unlike other regional arts, Shekhawati murals exhibit a unique blend of indigenous and foreign influences, making them an intriguing subject for cultural and artistic analysis. The significance of these mural paintings extends beyond their aesthetic appeal, as they embody the region's identity and historical memory [4]. The intricate motifs and compositions reflect the skill of traditional artisans who meticulously hand-painted the frescoes using age-old techniques. The motifs also serve as visual storytelling tools, capturing the essence of Shekhawati's past and its engagement with trade, migration, and cultural exchange. The decline of these paintings due to neglect and modernization raises concerns about their conservation and revival. Understanding the cultural and symbolic aspects of Shekhawati motifs is essential for appreciating their relevance and exploring ways to integrate them into contemporary artistic practices [5, 6]. This paper aims to provide a comprehensive review of the evolution of Shekhawati art, with a special focus on the traditional motifs and their cultural significance. It will explore the historical background of mural paintings in the region, analyze the themes and motifs used, and discuss their role in reflecting Shekhawati's heritage. Additionally, the study will examine how these motifs have transformed over time, adapting to changing socio-economic conditions and external influences. By delving into the artistic elements of Shekhawati murals, this review seeks to highlight their importance in India's artistic and cultural landscape [7]. This

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work does not confine itself to the mere archival details, but also imposes meaning for the contemporary and sense for the existing times for this genre of Shekhawati paintings. The new readings on these traditional designs in contemporary fashion, interiors, digital culture are considered. Further, the current conservation status is discussed and tourism's potential role to conserve this cultural heritage is addressed. The difficulties in preserving these artistic treasures are also discussed. It is proposed in this study to provide information on the development of Indian folk art by investigating the details of Shekhawati motifs. It is anticipated that contemporary designers would be motivated to incorporate the traditional ethos in the design process. And finally, a contribution is intended to the more general debate on cultural sustainability. The importance of enabling policies and reviving Shekhawati art is highlighted. And in taking a broad view, this study is poised to illuminate regional artistic traditions in the heyday of modernization. In the long run, the continuing worth of Shekhawati art is attempted to be re-validated for future generations to explore and conserve.

## 2. Historical Evolution of Shekhawati Art

The history of Shekhawati art dates back to the late 17th and early 18th centuries when this region, named after a Rajput king called Rao Shekha, became a prominent trade route along the Silk Route. The commissioning of large-scale frescoes and murals on the walls of havelis (mansions) was done by the affluent Marwari merchant families, who were considered as the governors of trade and commerce on that behalf. While several paintings served as a form of artistic expression, they also hinted at the social prestige of such works. Initially, simple floral and geometric designs were painted, but over time these were augmented with elaborate narrative scenes from mythology or that reflected social customs or foreign elements. The artists started to increasingly use natural pigments, which helped many, those harsh climates allowing these artworks to be preserved for centuries, lived on in ochre, indigo and vermilion even as they jumped from desert refrigerator, deep-freeze caves that never thaw, to temperate woods and wetlands [8]. The Rajasthani miniature style strongly influenced the Shekhawati murals which flourished during the Rajput period. Scenes from Hindu epics Ramayana and Mahabharata were enacted, and deities Lord Krishna, Lord Shiva and Goddess Durga were depicted. Forts and temples across the region were decorated with colorful, ornamental and symmetrical murals, and the art was being popularised as an expression of cultural and religious identity. Mughal influences were absorbed into Shekhawati murals in the late 18th and early 19th centuries. Techniques of perspective, shading and naturalism emerged, while Mughal floral patterns, calligraphy and architectural motifs became widely adopted. Mehrauli: Themes like royal processions, hunting scenes, and courtly life continued to be painted, this reflected the cultural exchanges with Delhi and Agra, reminiscent of local styles intermixed with those propagated from the capitals. During the 19th century, the rise of British colonial rule brought in European artistic influences as well. Western motifs, industrial progress and modern transportation are common subjects. British officials and European motifs were depicted in addition to Indian themes, European styles like Renaissance shading and realism were applied, creating a fusion between Indian and European styles [9, 13]. They were built and decorated with the money Marwari merchants sent back from distant cities. Local artisans, referred to as chiteraas, were trained in fresco techniques and were masters at applying natural pigments to wet lime plaster. Artistic knowledge was transmitted from one generation to the next.

## 3. Traditional Motif Design in Shekhawati Art

Shekhawati murals are famous for their impressive diversity of designs which fall into five broad categories: floral, geometric, religious, mythological and everyday life. The

*Figure 1: Shekhawati art*

*Figure 2: Shekhawati murals art in haweli on wall*

use of these motifs has reflected regional cultural heritage and society values across time. Shekhawati frescoes often feature floral motifs, including lotus, marigold and creepers, which may be used for decorative purpose. According to the Chinese shamanistic beliefs, these flower designs are known to depict purity, prosperity, and divine gifts. Similarly, abstract shapes, such as circles, diamonds and swastikas, are frequently included. The swastika, especially, is considered an ancient Vedic symbol used to represent auspiciousness and cosmic balance, and is often painted as an auspicious protective emblem. The Shekhawati murals have been seen as dominated by religious and mythological imagery. Vivid renderings of tales from sacred Hindu texts such as the Ramayana, Mahabharata and Bhagavata Purana are on show. Getting into the festive spirit, Lord Krishna is depicted playing the flute surrounded by gopis, Lord Rama is depicted fighting Ravana, and Goddess Durga is depicted slaying the demon Mahishasura. These murals had a dual purpose: moral instructions and religious adoration, as well as transferring cultural values to descendants. Various avatars of Lord Vishnu, particularly in Krishna, are depicted for the dissemination of love, protection, and harmony. These murals also often visualize daily scenes of life, which serve as snapshots into the region's socio-economic conditions. There is a rich and detailed documentation of activities as trading, household chores, musical performances and farming. The Marwari traders are shown in turbans and mustaches characteristic of the region's mercantile identity. These artworks also tell the stories of the traders, including those of migrating and trading and thus, their success and way of life were immortalized [14, 15].

Colonial and modern influences found their way into the Shekhawati murals as well, especially in the 19th and early 20th centuries. European things like steam engines, cars, bicycles, aeroplanes and gentlemen in Western suits were featured and, in this way, how the new times were being transfigured in local art. These frescoes were made in the true fresco (fresco buono) technique. Natural pigments from minerals and plants were painted onto wet lime plaster, making the colors part of the walls forever. Chiteraas, the skilled artisans, used fine brushes made with squirrel or goat hair so that compositions could be finely detailed. Many motifs have been imbued with symbolic meanings. To convey harmony, strength, beauty and divine grace, flowers, geometric designs, animals like elephants and peacocks as well as auspicious objects like the kalash were painted. While new adaptations are being witnessed in several spaces fashion, décor, and digital design a lot of Shekhawati murals today are fighting extinction. Conservation interventions need to be publicly undertaken so that this unique artistic treasure can be preserved and inherited by future generations [16].

**4. Regional Identity and Heritage of Shekhawati Art Being Preserved Through the Transformation of Motif Designs on Fabric Surfaces**

Many Shekhawati art motifs have been taken to extract several new designs. Some of these designs have been finalized for this study. It has been found that all these designs are very effective, easily recognizable, and strongly represent the art and culture of Shekhawati and Rajasthan. These designs will greatly help in creating new trends and fashions in the casting design process and garment development.

*Figure 3 (a): Preservation of new motifs on fabric surfaces through the influence of shekhawati art*

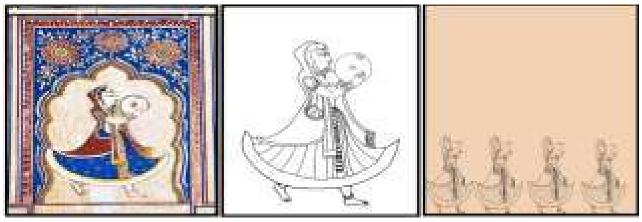

*Figure 3 (b): Preservation of new motifs on fabric*

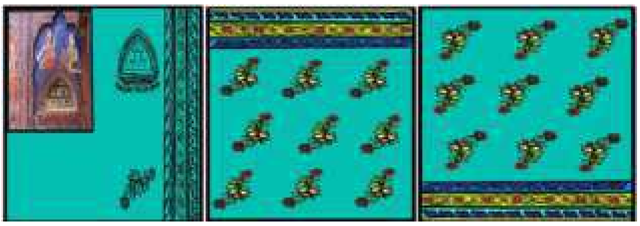

*Figure 3 (c): Preservation of new motifs on fabric surfaces through the influence of shekhawati art*

*Figure 3 (d): Preservation of new motifs on fabric surfaces through the influence of shekhawati art*

**5. Cultural Significance and Artistic Expression**

Shekhawati art is not merely an aesthetic expression but a rich cultural archive that narrates social, religious, and historical stories through its intricate motifs and murals. The painted havelis, temples, and cenotaphs of Shekhawati serve as visual storytelling mediums that encapsulate centuries of traditions, beliefs, and socio-political developments. The murals frequently depict religious narratives, such as scenes from Hindu mythology, including the Ramayana and Mahabharata, reinforcing moral values and spiritual teachings. These depictions not only served a devotional purpose but also played an educational role, allowing communities to engage with religious scriptures visually. Similarly, frescoes showcasing social customs, royal processions, festivals, and folk traditions provide valuable insights into the lifestyles and rituals of bygone eras. By illustrating significant moments, such as weddings, temple ceremonies, and market scenes, Shekhawati murals preserve cultural practices and their evolution over time. Beyond mythology and social life, Shekhawati frescoes also document historical events and foreign influences, particularly during the colonial era. The growing presence of European merchants and British officials in India led to the incorporation of Western motifs in Shekhawati murals. Murals from the late 19th and early 20th centuries depict steam engines, automobiles, gramophones, and men dressed in Western attire, illustrating the impact of globalization and colonial rule. Some frescoes even feature British soldiers and Indian freedom fighters; subtly portraying the region's shifting power dynamics. This fusion of indigenous and foreign imagery showcases the adaptability of Shekhawati artists and highlights how art evolved as a response to political and economic changes. The murals thus function as a visual chronicle of history, bridging local traditions with external influences [17].

The impact of Shekhawati art on regional identity and heritage conservation is profound, as the painted havelis and temples serve as defining cultural landmarks of Rajasthan. These murals distinguish Shekhawati from other historical regions of India, establishing its reputation as an "open-air art gallery." The frescoes reflect the pride and affluence of the Marwari merchant community, who commissioned these elaborate artworks to showcase their wealth and devotion to art. The murals also emphasize Shekhawati's unique architectural style, characterized by ornately decorated chhatris (domed pavilions), jharokhas (overhanging enclosed balconies), and intricate frescoed facades. Despite their grandeur, many of these structures face neglect due to urbanization and lack of awareness about their historical significance. However, increasing recognition of Shekhawati's artistic heritage has led to conservation efforts, including government initiatives, heritage tourism, and private restorations aimed at preserving the region's artistic and cultural legacy. As contemporary designers seek inspiration from traditional art forms, Shekhawati motifs have found a new lease of life in modern design and architecture. The intricate floral and geometric patterns seen in frescoes are being adapted into textiles, home decor, fashion, and interior design. Designers are integrating Shekhawati-inspired prints into fabrics, creating garments that blend heritage with modern aesthetics. Additionally, wallpapers, ceramic tiles, and furniture are being designed using Shekhawati motifs, ensuring that the region's artistic vocabulary continues to thrive beyond its architectural context. Luxury hotels, cafes, and boutique resorts in Rajasthan are incorporating these frescoes into their decor, reviving traditional craftsmanship while appealing to contemporary sensibilities. This seamless fusion of traditional motifs with modern design elements helps sustain Shekhawati's artistic relevance in an evolving cultural landscape. Furthermore, Shekhawati's artistic legacy has extended beyond India, influencing global art, fashion, and architectural trends. International designers and artists have drawn inspiration from its vibrant murals, incorporating Rajasthani motifs into their work. Several handicraft and textile workshops in Shekhawati have gained prominence, producing block-printed textiles and hand-painted artifacts that cater to global markets. The rising demand for sustainable and handcrafted designs has also benefited Shekhawati artisans, allowing them to showcase their heritage on international platforms. Collaborations between traditional artisans and contemporary designers have fostered innovation, ensuring that Shekhawati's cultural aesthetics remain adaptable and commercially viable in today's art and design industries [18-21].

Despite these positive developments, challenges remain in ensuring the long-term preservation and promotion of

Shekhawati art. The murals are vulnerable to environmental factors such as weathering, pollution, and urban expansion, which threaten their longevity. Additionally, a decline in skilled artisans due to limited economic opportunities poses a risk to the continuity of traditional fresco painting techniques. Addressing these challenges requires sustained conservation efforts, increased government support, and community participation. Awareness campaigns, heritage walks, and educational programs can help instill a sense of pride in local communities, encouraging them to actively participate in preserving their artistic heritage. Investment in tourism infrastructure and sustainable development practices can further contribute to Shekhawati's revival as a cultural and artistic hub. Hence, Shekhawati art is a testament to Rajasthan's rich cultural heritage, encapsulating centuries of religious devotion, historical evolution, and artistic excellence. Its significance extends beyond regional boundaries, offering insights into the socio-political and artistic transformations of Indian history. While conservation challenges persist, the integration of Shekhawati motifs into contemporary design and global art trends ensures their continued relevance. Through heritage conservation efforts, artistic collaborations, and increased awareness, the vibrant murals of Shekhawati can be safeguarded for future generations, preserving their legacy as one of India's most cherished artistic traditions [22, 23].

### 6. Transformation and Adaptation in Modern Times

External Modern-day Shekhawati art has seen both a decline and a revival. Known for its havelis decorated with exquisite frescoes, the Shekhawati region in Rajasthan has become a classic case of a very fine line between decay and conservation. Several socio-economic and environmental aspects of life have been eroding this rich history of art over the decades. The most compelling reason for the extinction of Shekhawati art has been the migration of the Marwari merchant class who were the traditional patrons of these murals. With several families relocating to urban areas in search of better financial opportunities, their ancestral homes fell by the wayside. The pride of the region, these havelis started to decay due to neglect, vandalism, and the ravages of time. Harsh weather, including intense heat, dust storms and heavy rain, has damaged these delicate artworks even more. Furthermore, the hastening phase of urbanization has resulted in the destruction or amendment of many of the historical buildings, inflicting an irreparable loss to the artistic legacy of Shekhawati. However, currently, there is a shift towards reviving and preserving Shekhawati art. Credit for that, of course, goes to both government bodies and private organizations which have done well to try to revive the lost splendour of these murals. These images are the results of conservation projects using scientific techniques like chemical cleaning, colour matching, and structural repairs to restore the frescoes to their original beauty. Local artisans are trained in traditional fresco methods to ensure these ancient skills will be preserved. The hilarious and heart-warming community unsuccess tells its own inspiring story of the activists. But the resurgence of Shekhawati art such heritage tourism has emerged as a strong motivator of change. It is sometimes called an “open-air art gallery,” and, more than a thousand years later, the area draws tourists, scholars, photographers and art buffs from throughout the world. The restored havelis are now heritage hotels and boutique resorts, melding preservation and tradition with a current hospitality aesthetic. Organised heritage walks, cultural festivals, art pilgrimage have increased people awareness and pride of local communities, enhanced livelihoods for artisans, craftsmen, local guides etc. For Mitali, the Shekhawati motifs have found a fitting place in contemporary design landscape with their inclusivity in digital and modern applications. More recently designers and artists have been incorporating these traditional patterns into branding, packaging, textiles, fashion and interior design [24-27]. Thanks to digital technology, Shekhawati motifs are now available in different forms, all of which can reach a global audience. Sustainable fashion labels and home décor brands are adopting the block-printing, embroidery and digital textile-printing motifs, adding some tradition to a modern-day aesthetic. But the commercialisation of Shekhawati art has been questioned when it comes to authenticity and ethics. In doing so, mass production can often obscure the craftsmanship and cultural importance of these designs. Artisans deserve recognition, fair compensation and participation in the creative process. Such collaborations can help maintain the integrity of Shekhawati art yet allow it to flourish in the current context. So today the tale of Shekhawati art is one of resilience and rebirth. Keeping this process between innovation and modernity, traditional craftsmanship can at some point make certain that this inherited heritage can flourish even when the bliss of life is going here and there in pan- India.

### 7. Comparative Analysis with Other Traditional Indian Art Forms

Through centuries of growth, Indian traditional art forms have adapted, each mirroring the distinctive cultural identity, regional history, and artistic techniques of its roots. Of these, the Shekhawati murals from Rajasthan hold special importance for their grandeur, scale and visual style. The Shekhawati murals exhibit some similarities with the famous Indian art forms like Mughal miniature paintings, the Madhubani art of Bihar and Warli art of Maharashtra but they are exceptional for their structural harmonisation, wider themes, and transcultural influences. Mughal miniature paintings, similar to Shekhawati murals, are noted for their detailed depictions of court life, historical events, and religious themes. Mughal art, however, was mostly made for emperors and nobles on small surfaces such as paper, ivory, or cloth. Whereas Shekhawati murals were painted right on the façades and ceilings of stately havelis, visible to the public [28]. While Mughal miniatures are defined by fine brushwork and Persian-inspired designs, Shekhawati murals are identified by bold outlines, bright colours and folk-styled figures. Further, while Mughal art was mainly about royalty, Shekhawati murals represented everyday life, local folklore, colonial interactions, and narratives from Indian mythology, portraying a wider social narrative. Madhubani art, which comes from the Mithila region of Bihar, shares a fondness for vivid colours and religious storytelling with the Shekhawati murals. Both feature Hindu gods, elements of nature and mythological tales. Madhubani art, on the other hand, has a more stylized and symmetrical approach and every inch of space is filled with small details and designs. The technique also differs, with Madhubani paintings traditionally made with natural dyes on paper, cloth or walls and often made by women artists. By contrast, the Shekhawati murals used images of lime plaster glued to walls, applied mostly by male artisans who were hired by rich merchants to decorate their homes. Warli art is a tribal painting form from Maharashtra and is in stark contrast to Shekhawati murals. Warli paintings are minimal in style, using only white pigment made from rice paste against a mud-brown background. The figures are geometric and symbolic: they reflect daily tribal life, agricultural practices and rituals. Shekhawati murals, on the other hand, are colourful, larger in scale and more detailed, depicting not just local culture, but featuring influences from Rajput and Mughal as well as European traditions [29- 32]. One of the unique aspects of Shekawati art is its strong relationship with architecture. Unlike Madhubani or Warli art, which is primarily done on smaller surfaces, the Shekhawati murals cover whole walls, façades and ceilings of buildings, with a blend of vibrant colors making for an immersive visual experience. This coalescing on a grand scale produced such elaborate narratives that the havelis of Shekhawati represent some of the best decorated buildings in India. Apart, Shekhawati art exhibits multicultural influences rarely found in any other Indian art. The murals show Hindu gods dressed in European clothes, colonial officers posing with Indian kings and designs mixing native and foreign details. The blending of styles reflects the region's history of trade, migration and scuffles with different cultures. To sum up, despite some thematic similarities as other Indian traditional arts, Shekhawati murals are not only unique and concrete because of their bold handling of scale and its interaction with the buildings, but also because of its cultural hybridity, which can be identified as a significant play in the Indian traditional art forms. Not only do they retain the socio-economic history of Rajasthan, but they are also a dance of tradition and innovation that still inspire artists and historians nowadays.

## 8. Conclusions

Shekhawati art stands as a remarkable testament to Rajasthan's rich cultural heritage, blending indigenous traditions with external influences over centuries. The evolution of its motifs from religious and mythological depictions to social and colonial narratives demonstrates its adaptability and significance in visual storytelling. Unlike many other traditional Indian art forms, Shekhawati murals uniquely integrate large-scale frescoes with architectural aesthetics, creating an immersive artistic experience. The motifs, whether floral, geometric, or figurative, serve as more than decorative elements; they carry deep symbolic meanings that reflect the beliefs, aspirations, and socio-economic conditions of their time. Through this study, it becomes evident that Shekhawati art is not just a regional expression but a dynamic visual archive that chronicles the historical transformations of Rajasthan's merchant and aristocratic communities.

Despite its artistic brilliance, Shekhawati art faces critical challenges related to preservation and awareness. Many of the region's exquisite murals are deteriorating due to neglect, environmental factors, and urbanization. Conservation efforts must be intensified to restore and protect these fading masterpieces, with active participation from local authorities, art historians, and cultural organizations. Additionally, integrating Shekhawati motifs into contemporary design, fashion, and interior décor can ensure their relevance in modern aesthetics.

Digital documentation, VR-based heritage experiences, and educational initiatives can further promote these art forms among younger generations. The tourism industry also plays a crucial role in sustaining the legacy of Shekhawati, and with strategic planning, the region could become a global cultural hub for heritage tourism and artistic revival. Looking ahead, there is significant scope for further research on Shekhawati art's cross-cultural influences, its adaptation in contemporary digital media, and its potential for global recognition. Comparative studies with international mural traditions can provide new insights into its artistic and historical importance. Collaborative efforts between artists, designers, and conservationists can foster innovative ways to reinterpret Shekhawati motifs while preserving their essence. By bridging the past with the future, Shekhawati art has the potential to evolve beyond its regional roots and gain appreciation on an international platform, reinforcing its identity as a living heritage that continues to inspire generations of artists and scholars worldwide.

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# Moisture Management Properties of Rib Knit Structures Intended for Next to Skin Applications

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**Abstract:**

*Moisture management properties are crucial for textiles intended for next to skin applications like intimate wear, socks, gloves etc. in order to ensure rapid sweat dissipation and dry microclimate. Knitted fabrics owing to their excellent stretch ability, good handle and comfort properties are preferred choice for all such applications. The present study was undertaken to study the influence of fibre, yarn and fabric parameters on moisture management properties of polyester/cotton and viscose/cotton rib knit structures intended for next to skin applications. PET/C fabrics exhibited higher liquid transfer properties compared to their viscose-cotton counterparts. PET/C and V/C fabrics showed decrease in moisture management properties as the polyester and viscose filament denier was increased. Tight fabrics knitted at shorter loop length exhibited better moisture transport properties and lower water vapour percentage. Fabrics developed by feeding two yarns separately through different feeders were found to be quick drying owing to higher water evaporation rate compared to their counterparts. Polyester/ cotton fabric produced from hydrophilic finish treated polyester yarn showcased higher values of accumulative one-way transport index and overall moisture management capacity.*

**Keywords:** *Comfort, Filament denier, Knit structures, Loop length, Moisture management, Water evaporation*

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## 1. Introduction

Knitted fabrics owing to their excellent stretch ability, good handle and comfort properties are preferred for sportswear, casual wear, intimate wear and socks. Clothing comfort depends on several factors, one of them being thermal comfort. A state of comfort can only be achieved when the most complex interactions between a range of physiological, psychological and physical factors have taken place in a satisfactory manner. Hence, the comfort provided by clothing depends on such factors as softness, flexibility, moisture diffusion, air permeability, thermal comfort etc. Moreover knitted fabrics are also finding wide spread application in accessory industry particularly those intended for next to skin application fulfilling the requirement of ease of passage of air, moisture vapor, liquid moisture and heat through them. Next to skin accessories like socks, gloves, hats etc have to be designed with appropriately engineered fabrics so as to achieve comfort as well aesthetic attributes.

Comfort characteristics of any textile material are associated with thermal and mass transport properties. The fibers, yarn and fabric variables (finishing and printing technique) affect the fabric structure and hence the overall physical and comfort properties of apparel and accessories designed from the engineered fabrics. Finishing treatments influence not only the fabric properties like porosity, air passage but also the aesthetic appeal [1, 2].

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The end users in recent times are well versed and conscious about textiles and their composition. Hence, they give due consideration to performance, functionality as well as aesthetic appeal and surface ornamentation of textile-based products. Accordingly, several surface embellishment techniques such as digital printing, painting, crocheting, addition of trims and notions and decorative elements are generally commercially administered to beautify and hence results in value addition of the designed apparels and accessories. The most sought-after functional aspects in clothing involves light weight, wearer agility, affordability in addition to comfort in terms of material's effectiveness in heat, moisture vapour and liquid moisture transmission characteristics.

Moisture management is crucial for thermo-physiological comfort as it involves controlled movement of moisture vapour and liquid perspiration from skin surface to atmosphere through fabric [3- 5]. Fabric liquid moisture transport properties in multiple dimensions influence the human perception of moisture sensations and comfort significantly [6-7].

There are innumerous ways of improving moisture management properties of textiles like varying fiber profile for enhanced wicking capacity, improvement in hydrophilicity of fibers by grafting hydrophilic bonds in molecular chains, chemical treatments to change surface hydrophobicity properties and change in yarn structure by use of core-sheath yarns, textured or crimped composite yarn [8, 9].

Drying ability of textiles is related to the ease with which water evaporates from fabric's outer surface and escapes to outer environment. Water evaporation percentage indicates the fabric's ability to evaporate the liquid from outer surface to the environment and hence determines the fabric's drying capacity. Fabrics which allow liquid to spread quickly by distribution of perspiration from individual sweat droplet on skin surface or restricted evaporation over large surface area increase moisture loss by evaporation and helps in maintaining dry microclimate. Evaporation of liquid water through fabric can occur by: diffusion of water vapour through air spaces between fibers and yarns, transfer of liquid water through capillary interstices within yarn or along fiber surface and evaporation at low pressure side of fabric.

Early part of drying is related to water evaporation from water pool at fabric and environment interphase, which irrespective of fiber type; would be maintained at higher water content. Drying rates are independent of fiber type in constant rate periods corresponding to higher water concentrations in fabric while drying rate depends on fiber type in fall rate period which corresponds to lower water concentrations. Drying occurs from water pool on fabric surface in initial constant period. When water content is decreasing during falling rate period, water front recedes to the fabric's interior. Effectiveness of water transportation from fabric's interior to drying front on the surface determines the drying rate in falling rate period [5, 6].

Several researchers [4-7] have attempted to engineer different knit structures and compared the structures in terms of their comfort and performance properties.

## 2. Materials & Methods

### *2.1 Materials*

Cotton spun, polyester and viscose filament yarns of varying linear density were used for preparation of rib knit structures. The yarn samples were used for production of twelve rib knit structures. Three fabric samples (PC1-3) were constructed in tight, medium and slack construction varying the loop length from 7.5 to 10.3 mm. Four polyester-cotton fabrics (PC1-PC4) were knitted using polyester filament of 100 denier while the other four samples (PC5-8) constituted of 200 D polyester filament yarn. PC5 and PC8 samples varied in their structure owing to change in the number of feeders (single and double feeder) feeding the yarns for knitting the two samples. Antimicrobial finish applied cotton yarn was used for knitting PC6, PC7 and VC2 fabrics. Yarn and fabric details are provided in Table 1.

All the fabric samples were prepared on KH-323N computerized flatbed knitting machine in The Technological institute of Textile and Sciences, Bhiwani. The machine was equipped with steel feeders, double system with a variably adjustable stroke carriages, computer control with LCD display, and segment needle bed designed for high speed and easy needle replacement.

### *2.2 Methods*

The prepared fabric samples were tested for their physical properties i.e. course and wale density, aerial density, fabric porosity, loop length and tightness factor.

Course and wales density of test samples was determined by counting the number of courses and wales per centimeter using a pick glass, according to ASTM D 3775-03. The number of courses per cm and wales per cm was determined at ten different positions on the test samples and average was reported for each sample. Fabric thickness was measured on R&B cloth thickness tester at a pressure of 5gf/cm2. The test was repeated at ten different positions on the test samples and average values were recorded. Aerial density of samples was determined according to ASTM D-1059. Fabric porosity (%) was determined using the following equation:

$$\frac{\rho_o - \rho}{\rho_o} \times 100 \quad \ldots(1)$$

Where, $\rho_o$ is fiber density in Kg/m$^3$ and $\rho$ the fabric density in Kg/m$^3$.

*Table 1 - Details of fabric samples*

| S. No. | Sample Code | Filament Denier/ Yarn count | Finishing treatment | Knit Structure | Loop length (mm) |
|---|---|---|---|---|---|
| 1 | PC1 | 100D/40$^S$ | UT | S.F | 7.5 |
| 2 | PC2 | 100D/40$^S$ | UT | S.F | 9.5 |
| 3 | PC3 | 100D/40$^S$ | UT | S.F | 10.3 |
| 4 | PC4 | 100D/40$^S$ | UT | S.F | 9.5 |
| 5 | PC5 | 200D/40$^S$ | UT | S.F | 9.5 |
| 6 | PC6 | 200D/40$^S$ | T | S.F | 9.5 |
| 7 | PC7 | 200D/40$^S$ | T | D.F | 9.5 |
| 8 | PC8 | 200D/40$^S$ | UT | D.F | 9.5 |
| 9 | VC1 | 100D/40$^S$ | UT | S.F | 9.5 |
| 10 | VC2 | 100D/40$^S$ | T | S.F | 9.5 |
| 11 | VC3 | 200D/40$^s$ | UT | S.F | 9.5 |
| 12 | VC4 | 600D/40$^s$ | UT | S.F | 9.5 |

*PET-Polyester, V-viscose, C-cotton; S.F-single feeder; D.F-Double feeder, UT – untreated, T-Treated with finish*

Tightness factor of the fabrics was determined using the following equation:

$$Tightness\ Factor = \frac{\sqrt{Tex}}{l} \quad ...(2)$$

Where, l is loop length in cms.

Moisture management properties of developed knit samples were determined on moisture management tester (MMT) (SDL Atlas, Hong Kong) (AATCC Test method 195-2009) Figure 1 shows moisture management tester & top and bottom sensors of moisture management tester.

Five observations were made for each sample and the average values of moisture management indices were obtained. The instrument gives the moisture management indices i.e. One way transport capacity (OWTC) and overall moisture management capacity (OMMC) for top (next to skin) and bottom (outer) layer. One way transport capacity is the difference in accumulated moisture between the top and bottom fabric surfaces in the time period of test, as indicated by Equation 3:

$$OWTC = \frac{\int Ub - Ut}{T} \quad ... (3)$$

Where, Ub is the water content in the bottom layer; Ut is the water content in the top layer and T is the total testing time (s).

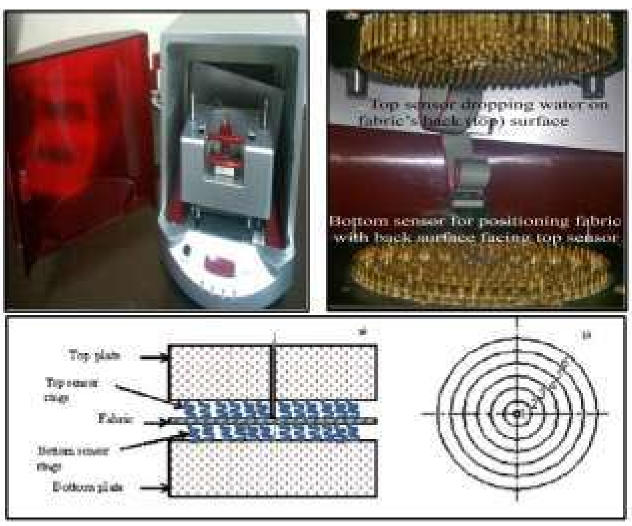


***Figure 1 - Schematics of Moisture management tester***

***Overall moisture management index*** indicates the overall ability of the fabric to manage liquid moisture transfer. It includes three performance attributes: bottom absorption rate, one way transport capacity and bottom spreading speed.

Water evaporation percentage was determined by cutting a test sample of 20×20 $cm^2$ and weighing for its dry weight. Weight of sample after adding predetermined amount of water and weight of sample after fixed intervals of time (5 minutes) was recorded to get an estimate of the water evaporated from the surface. The weights were then equated to obtain the water evaporation percentage. Fabric weight was recorded as $w_f$(g). Weight of water equal to 30 percent of the fabric weight was added to fabric and this fabric weight was designated as $w_o$ (g). The change in weight of water $w_i$ (g) with time was recorded at regular intervals. The percentage of water evaporated (WE %) was calculated using Equation 4.

$$WE\% = \frac{w_o - w_i}{w_o - w_f} \times 100 \quad ... (4)$$

**3. Results & discussion**

The effect of fibre type, loop length, knit structure and finish application on moisture management properties i.e. one way transport capacity (OWTC), overall moisture management capacity (OMMC) *and water evaporation percentage of test samples was studied.*

***3.1 Effect of fiber type***

*3.1.1 One way transport capacity*

The one way transport capability property indicates the fabric's ability of liquid transmission from next to skin (top) to outer (bottom) layer. Higher the one way transport capability, more the textile structure is effective in maintaining dry microclimate by rapid sweat dissipation to outer layer.

One way transport capacity of polyester-cotton fabrics was observed to be higher as compared to viscose-cotton fabrics (Figure 2 (a). The observed trend may be attributed to hydrophobic nature of polyester which does not absorb the liquid and transfer the liquid by capillary wicking to the bottom (outer) fabric layer. However, liquid transport is more difficult in case of pure cellulosic hydrophilic fibers like viscose where the water molecules block the inter yarn capillaries thus inhibiting liquid transfer by capillary wicking. Hence, viscose-cotton fabric exhibited lower one way transport capacity as compared to polyester-cotton fabric. Results were found to be statistically significant at 95% confidence level.

*3.1.2 Overall moisture management capacity (OMMC)*

Overall moisture management capacity indicates the overall ability of the fabric to manage liquid moisture transfer from next to skin to the outer layer. The effect of fibre type, filament denier, loop length, knit structure and finish application was analyzed on overall moisture management capacity of test samples.

Polyester cotton fabric exhibited higher value of overall moisture management capacity as against viscose cotton fabrics (Figure 2 a). The trend may be attributed to the better moisture wicking property of polyester owing to the absence of water bonding groups. However, viscose being cellulosic fiber is slow in transporting liquid because of the hydrogen bonding with water molecules and hence the observe trend.

*3.1.3 Water evaporation percentage*

Water evaporation percentage indicates the fabric's ability to escape the absorbed liquid through evaporation from outer

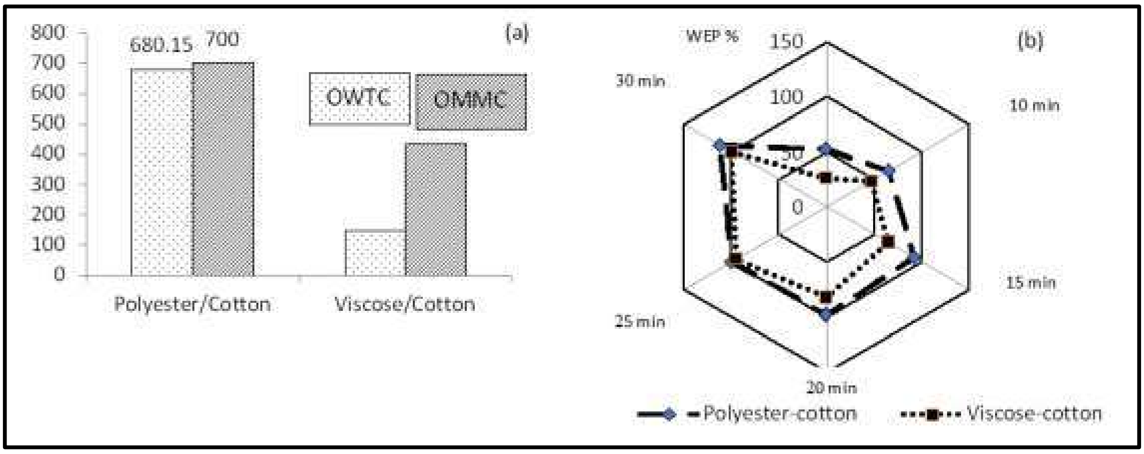


*Figure 2 - Effect of fiber type on (a) OWTC & OMMC (b) Water evaporation percentage*

*Table 2 - Physical properties of test samples*

| S. No. | Sample Code | Aerial Density (g/m$^2$) | Thickness (mm) | Fabric Porosity (%) | Courses/ Cm | Wales/ cm | Loop Length (mm) | Bulk Density (Kg/m$^3$) | Tightness Factor (vTex cm$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PC1 | 301 | 1.58 | 87.0 | 7.48 | 8.97 | 7.20 | 216.54 | 7.25 |
| 2 | PC2 | 311 | 1.30 | 91.0 | 7.48 | 8.85 | 9.50 | 222.14 | 5.64 |
| 3 | PC3 | 168 | 1.19 | 91.0 | 6.61 | 8.66 | 10.25 | 178.72 | 5.08 |
| 4 | PC4 | 223 | 1.32 | 90.0 | 6.61 | 6.61 | 7.47 | 172.86 | 7.40 |
| 5 | PC5 | 167 | 1.52 | 87.9 | 6.69 | 7.87 | 8.10 | 175.78 | 7.90 |
| 6 | PC6 | 170 | 1.53 | 88.2 | 7.20 | 7.08 | 10.77 | 245.00 | 7.60 |
| 7 | PC7 | 304 | 1.52 | 90.4 | 7.08 | 7.08 | 10.71 | 208.21 | 7.40 |
| 8 | PC8 | 331 | 1.53 | 90.3 | 7.20 | 7.08 | 10.71 | 209.90 | 7.40 |
| 9 | VC1 | 217 | 1.60 | 83.9 | 6.29 | 7.08 | 9.88 | 155.00 | 6.30 |
| 10 | VC2 | 217 | 1.67 | 84.2 | 5.51 | 7.08 | 10.25 | 155.00 | 6.30 |
| 11 | VC3 | 228 | 1.82 | 78.2 | 5.5 | 7.01 | 9.9 | 162.0 | 8.21 |
| 12 | VC4 | 265 | 1.95 | 69.4 | 4.8 | 6.9 | 9.8 | 171.2 | 8.66 |

surface and in turn determining the drying ability of textiles. The effect of fibre, yarn, fabric parameters and finish application on water evaporation percentage of test samples was determined.

Water evaporation percentage for polyester-cotton fabric was observed to be higher as compared to viscose-cotton fabrics as shown in Figure 2 (b). Polyester-cotton fabric owing to higher one-way transport capacity exhibited higher wicking. Moreover, owing to hydrophobic nature of polyester, the water absorbed by polyester-cotton fabric was less compared to viscose-cotton fabric. Viscose being hydrophilic absorbed more water and thus delayed drying with slower water evaporation for viscose-cotton fabric.

### *3.2 Effect of filament denier*

#### *3.2.1 One way transport capacity (OWTC)*

One way transport capacity was observed to decrease as polyester (PC4, PC5) and viscose filament (VC1, VC3, VC4) denier increased for polyester-cotton (PC5) and viscose-cotton (VC4) fabrics respectively as shown in Figure 3 (a). Increase in filament denier resulted in fabrics of higher thickness and aerial density. Thicker and heavier the fabrics; more the amount of water absorbed and hence lesser will be the liquid transfer by wicking. The observed trend may be explained in the light of above argument. The statistical analysis of results showed that the effect of filament denier on OWTC of test samples was significant.

#### *3.2.2 Overall moisture management capacity*

Overall moisture management capacity value was observed to decrease with the increases in polyester /and viscose filament denier (Figure 3(a). Decrease in overall moisture management capacity with increase in filament coarseness may be attributed to increases in fabric thickness and decrease in fabric porosity (Table 2) with increase in filament denier. As the open spaces within fabric structure reduces; the number of capillaries available for liquid transfer reduces and hence the observed trends.

#### *3.2.3 Water evaporation percentage*

Water evaporation percentage decreased as filament denier increased and the results were true irrespective of the fiber type (Figure 3 (b). The observed trend may be attributed to higher fabric thickness and aerial density of fabrics knitted with coarser filaments. Thicker and heavier fabrics will take longer to dry and evaporate the liquid exposed on their surface and hence would exhibit lower water evaporation rate.

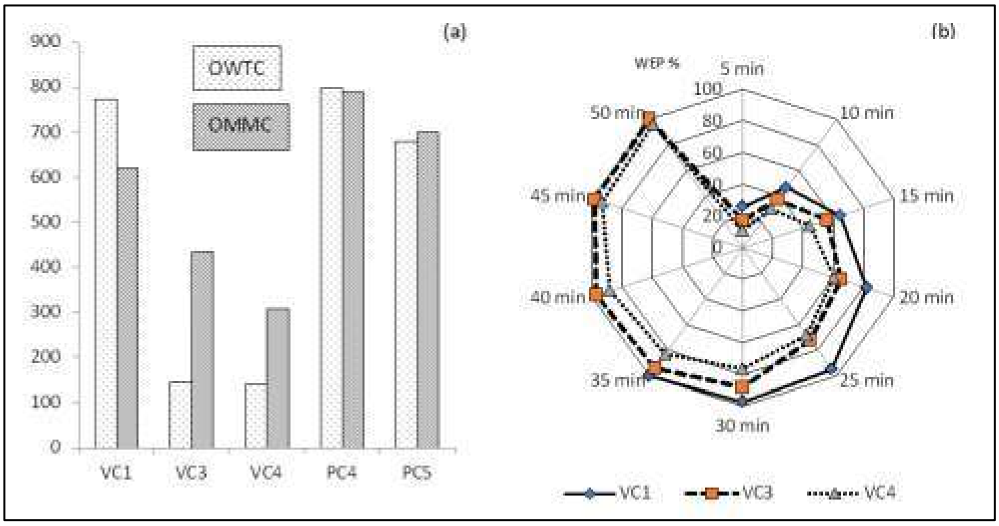


*Figure 3 - Effect of filament denier on (a) OWTC & OMMC (b) Water evaporation percentage*

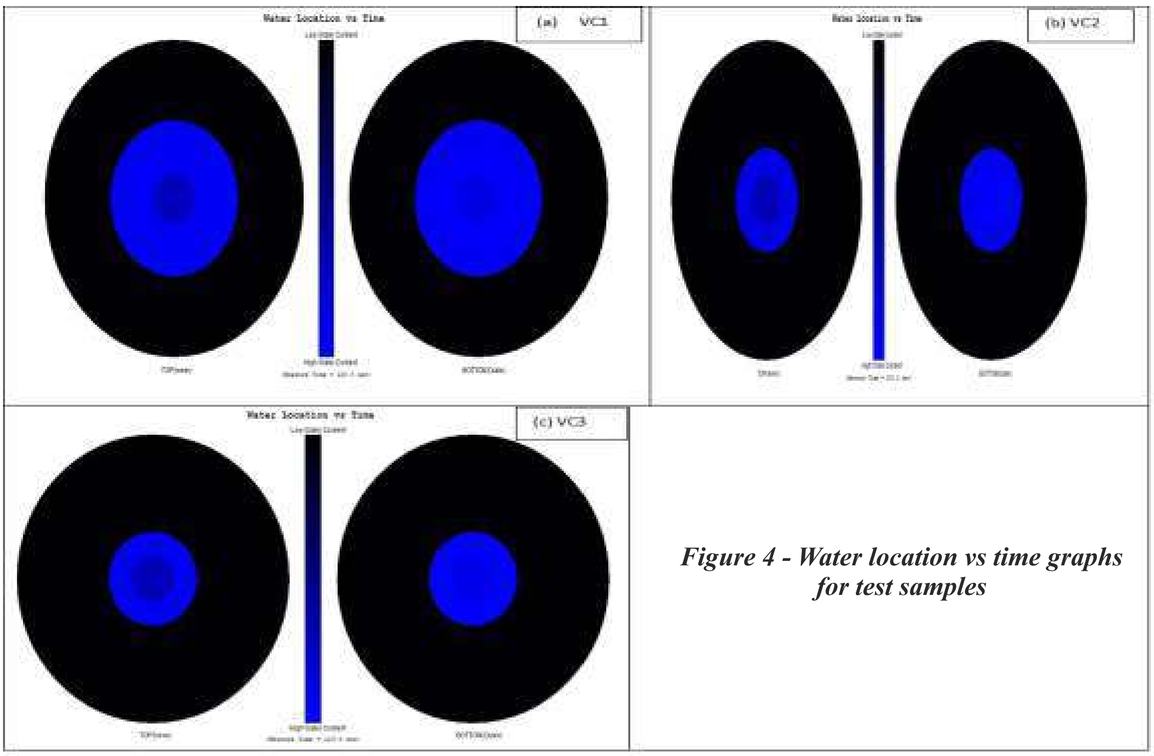


*Figure 4 - Water location vs time graphs for test samples*

Figure 4 (a-c) shows the fabric spreading area in form of water location versus time graphs obtained from MMT test. Water spreading area was observed to be higher for fabrics knitted with finer yarns (VC1) as compared to their coarser yarn (VC3, VC4) counterparts. The observed trend may be attributed to increase in fabric thickness and aerial density with increase in filament denier. Water spreading will be slower for thicker and heavier fabrics and hence the observed trend.

### *3.3 Effect of loop length*

*3.3.1 3One-way transport capacity (OWTC)*

One way transport capacity of test samples decreased with increases in loop length (as shown in Figure 5 (a). Decrease in accumulative one-way transport index (OWTC) with the increase in fabric loop length may be attributed to increase in fabric porosity for slack structures. Increase in fabric porosity facilitates for more open spaces and hence more water absorption. Structures which absorb more water owing to available pore spaces; will slow down the transfer of liquid to outer layer and hence reduced accumulative one-way transport index for fabrics knitted at longer loop lengths.

*3.3.2 Overall moisture managem.ent capacity*

Overall moisture management capacity was higher for tight fabrics knitted at shorter loop length. The tighter knit structures provide more number of capillaries (with smaller diameters) per unit area as compared to loose structure resulting in better capillary action due to higher capillary pressure for quicker absorption for the former.

*3.3.3 Water evaporation percentage*

Slack structures knitted at longer loop length exhibited higher water evaporation percentage compared to their tighter counterparts (Figure 5 b). The observed trend could be explained by low aerial density and less amount of water initially absorbed by slacker fabrics. Lesser the weight of the fabric and lesser the amount of water it absorbs, the quicker would be the drying of the fabrics and hence higher water evaporation rate for fabrics knitted at longer loop lengths. The statistical analysis of results indicates that there was significant difference between the water evaporation rates of samples (with confidence interval of 95 %).

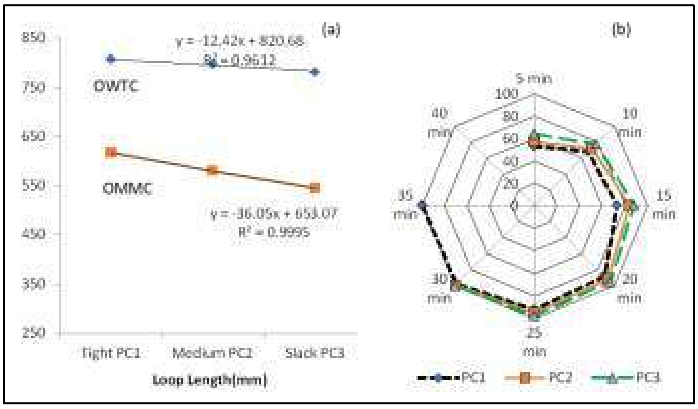


***Figure 5 - Effect of loop length on (a) OWTC & OMMC (b) Water evaporation percentage***

***3.4 Effect of knit structure***

*3.4.1 One way transport capacity*

Polyester/cotton fabrics developed using single feeder exhibited higher one way transport capacity as compared to their double feeder counterparts irrespective of finishing treatment on polyester yarn (Figure 6 a). Higher one-way transport capacity for fabrics knitted with single feeder may be attributed to their tighter construction as indicated by high tightness factor. The formation of large number of small diameter capillaries enable quick wicking and liquid transport in tight fabric structures knitted with single feeder and hence higher one way transport capacity for such fabrics. Results were found to be statistically significant at 95% confidence level.

*3.4.2 Overall moisture management capacity*

The effect of knit structure on overall moisture management capacity of test samples was found to be significant. Polyester-cotton fabric knitted using single feeder exhibited higher overall moisture management capacity value irrespective of finish treatment (Figure 6 (a). Fabrics knitted using single feeder were tight structures with low porosity. The higher number of smaller diameter capillaries in tighter structure facilitate effective liquid moisture transmission via wicking when compared to structures knit using double feeder that were looser in construction.

*3.4.3 Water evaporation percentage*

Comparison of polyester-cotton fabrics with varying knit structures showed that fabrics knitted on double feeder (PC6) possessed higher water evaporation percentage as compared to their single feeder counterparts (PC5) as shown in Figure 6 (b).The observed trend may be attributed to the more open structure and higher porosity of fabrics knitted with double feeders.

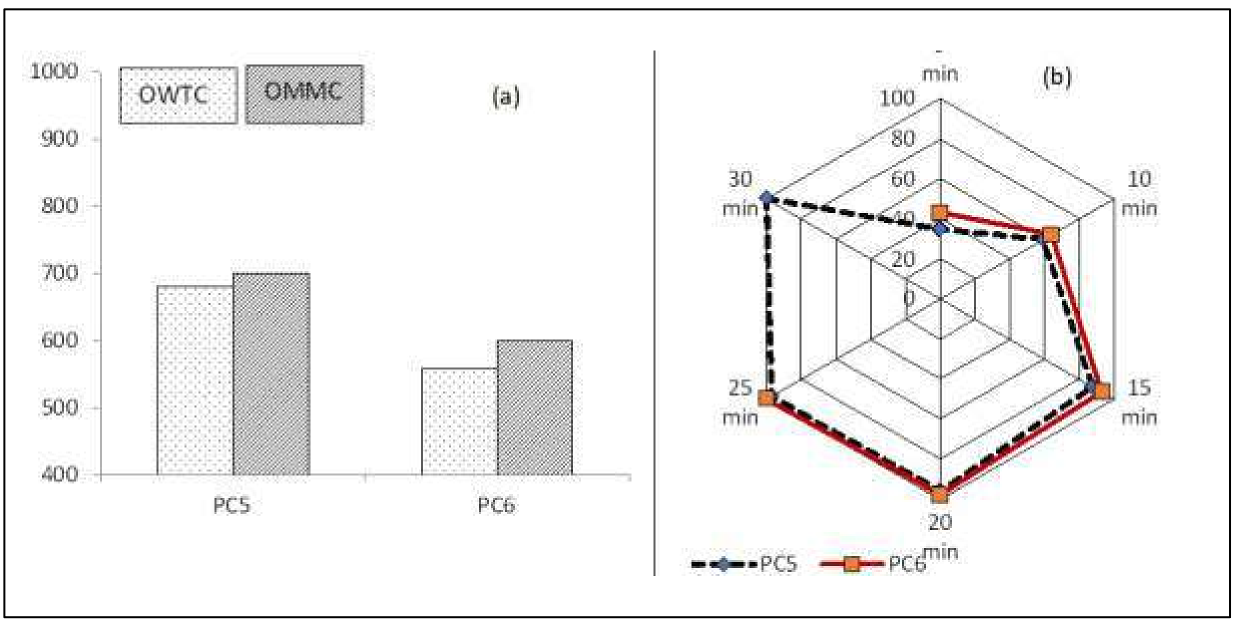


***Figure 6 - Effect of knit structure on (a) OWTC & OMMC (b) Water evaporation percentage***

*3.5 Effect of finish application*

*3.5.1 One way transport index*

The effect of hydrophilic finish application on polyester yarn on moisture management properties was studied. PC7 fabric was knitted using polyester yarn treated with hydrophilic finish. One way transport capacity was observed to be significantly higher for polyester/cotton fabrics using hydrophilic finish treated polyester yarn as compared to their untreated counterpart. Hydrophilic polyester, produced through co-polymerization, alkalization or topical finishing has better moisture transport properties as compared to conventional hydrophobic polyester. The improvement has been attributed to increase in polyester fiber fineness due to the alkaline hydrolysis. However, the effect of finishing treatment on one way transport index of V/C fabric was found to be insignificant.

*3.5.2 Overall moisture management capacity*

Finish application was observed to have significant influence on overall moisture management capacity of polyester cotton knitted fabrics. Hydrophilic polyester as a result of finish application has better moisture transport properties as compared to conventional hydrophobic polyester. The improvement has been attributed to increase in polyester fiber fineness due to the alkaline hydrolysis. The observed trend may be attributed to higher one-way transport capacity values of treated PET/C fabrics. One way transport capacity determines overall moisture management capacity and hence higher the accumulative one-way transport index; higher the value of overall moisture management capacity for PET/C fabrics.

*3.5.3 Water evaporation percentage*

The effect of finish application on water evaporation rate was found to be statistically insignificant.

**4. Conclusions**

Rib knit structures with varying fibre types, filament denier, loop length and knit structure were developed for evaluation of their liquid moisture transmission properties. The effect of hydrophilic finish application on polyester yarn on moisture transmission through polyester-cotton fabrics was also studied.

Polyester-cotton fabrics exhibited higher liquid transfer properties compared to their viscose-cotton counterparts. PET/C and V/C fabrics showed decrease in moisture management properties as the polyester and viscose filament denier was increased. Use of fine filaments for knitting fabrics intended for summers is thus feasible based on results of the study. Tight fabrics knitted at shorter loop length exhibited better moisture transport properties and lower water vapour percentage.

Fabrics developed by feeding two yarns separately through different feeders were found to be quick drying owing to higher water evaporation rate compared to their counterparts.

Polyester/ cotton fabric produced from hydrophilic finish treated polyester yarn showcased higher values of one way transport capacity and overall moisture management capacity.

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# Geosynthetics in Road Construction – A Review of Applications & Performance

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**Abstract:**

*Geosynthetics offer several benefits, including soil stabilization, reinforcement, drainage, and separation, which enhance pavement performance and extend service life. The review discusses the geotextile materials, functions of geosynthetics, their impact on pavement design, and their role in addressing common road issues such as potholes, rutting, and cracking. This paper synthesizes current research on the application of geosynthetics, primarily geotextiles and geogrids, in road construction. Geosynthetics are increasingly recognized for their capacity to address challenges in pavement design and performance. The use of geosynthetics offers several benefits, including soil stabilization, reinforcement, separation, filtration, and drainage, which contribute to enhance pavement performance and extended service life.*

**Keywords:** *Geosynthetics, Geotextile, Geogrid, Pavement, Road Construction, Soil Stabilization*

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## 1. Introduction

The construction of durable and cost-effective roads is a significant challenge for civil engineers. Unstable subgrade soils and environmental factors often lead to premature pavement deterioration, increasing maintenance costs and disrupting transportation. Geosynthetics have emerged as a valuable solution to these challenges. By providing reinforcement, separation, filtration, drainage, and other functions, geosynthetics improve the mechanical properties of soils and enhance the performance of road pavements. This review paper examines the applications of geosynthetics in road construction, with a focus on geotextiles and geogrids, and their impact on pavement design and performance. Studies have demonstrated that geotextiles improve pavement design by addressing technical issues and stabilizing soils. Geogrids are also highlighted for their reinforcement capabilities. Experimental investigations further validate these findings, showing that geotextiles can extend pavement service life and provide essential functions such as separation, drainage, and filtration. With advances in material science and growing field experience, geosynthetics are now considered essential for constructing durable, resilient, and cost-effective pavements, particularly in challenging environments such as soft soils, high water table areas, and regions with extreme climate variations.

## 2. Geosynthetics in Road Construction - Material Specification

Geosynthetics are synthetic materials used in civil engineering projects to enhance soil stability, provide erosion control, and improve drainage. In road construction, they play a vital role in reinforcing the pavement structure, extending its lifespan, and reducing maintenance costs. In recent years, geosynthetics have gained widespread acceptance and popularity in the field of pavement engineering due to their ability to tackle some of the most critical challenges associated with road construction and maintenance. Traditional pavements often suffer from issues such as subgrade instability, moisture infiltration, rutting, cracking, and excessive maintenance demands. Geosynthetics, which include materials like geotextiles, geogrids, geomembranes, geocells, and geocomposites, offer engineered solutions that improve the mechanical behavior of soil and optimize pavement structures. These materials serve multiple roles - they reinforce weak subgrade soils, prevent the intermixing of different pavement layers (separation), control moisture movement (filtration and drainage), and act as barriers against water ingress (containment). By integrating geosynthetics into pavement design, engineers can significantly enhance load distribution, reduce stress concentrations, minimize deformations like rutting, and extend the service life of pavements. Moreover, the use of geosynthetics can lower construction and maintenance costs by reducing the thickness of base and subbase layers without compromising performance [1].

Geosynthetics are synthetic materials (like plastics) used in geotechnical engineering to improve soil behaviour. They include products such as:

1. Geotextiles (woven or nonwoven fabrics)
2. Geomembranes (impermeable sheets)
3. Geogrids (grid-like materials)
4. Geocells (honeycomb-shaped confinement systems)
5. Geo-composites (combinations of the above)

## 3. Types of Geosynthetics in Road Construction

### *3.1. Geotextiles*

Description: Permeable fabrics made from polypropylene or polyester.

Function: Separation, filtration, reinforcement, and drainage.

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**Specifications:**

1. Tensile Strength: 20–200 kN/m
2. Elongation: 10–50%
3. Permittivity: ≥ 0.1 $s^{-1}$

Geotextiles in road construction associated with woven, non-woven and knitted fabric [2] are shown in the figure 1.

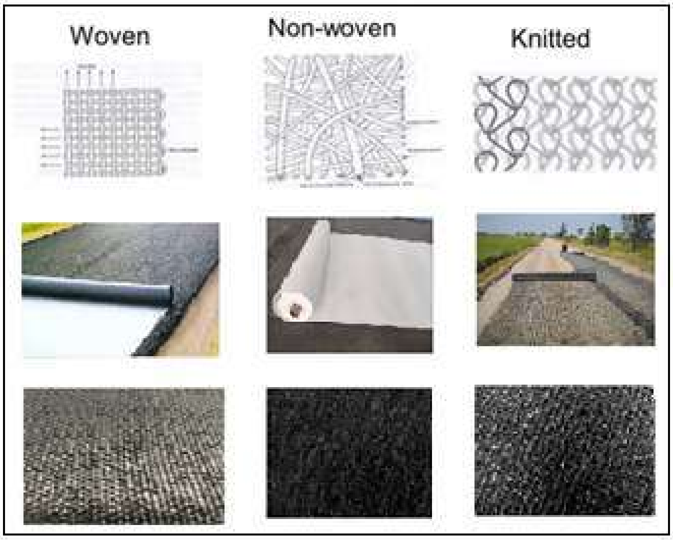


*Figure 1: Geotextiles in road construction*

Applications: Used between subgrade and subbase layers to prevent intermixing and to facilitate water flow.

### *3.2. Geogrids*

**Description:** Grid-like structures made from polymers such as HDPE or PP.

**Function:** Reinforcement of base or subbase layers.

**Specifications:**

1. Tensile Strength: 30–100 kN/m
2. Aperture Size: 20–100 mm

**Applications:** Enhance load distribution and reduce rutting in flexible pavements. Typical pattern of Geogrid material [3] is shown in the figure 2.

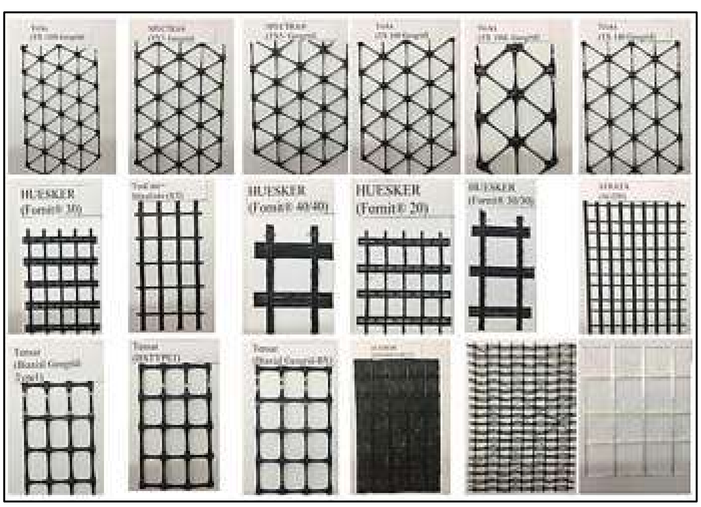

*Figure 2: Geogrid material*

### *3.3. Geocells*

**Description:** Three-dimensional honeycomb-like structures made from HDPE.

**Function:** Confinement of infill materials to improve load-bearing capacity.

**Specifications:**

1. Cell Depth: 100–200 mm
2. Weld Seam Strength: ≥ 14 kN/m

**Applications:** Used in slope protection, load support, and erosion control. Typical Geocell applications in case of road construction [4] is shown in the figure 3.

*Figure 3: Geocell applications*

### *3.4. Geomembranes*

**Description:** Impermeable sheets made from materials like HDPE or PVC.

**Function:** Barrier to fluid migration.

**Specifications:**

1. Thickness: 0.5–3.0 mm
2. Tensile Strength: ≥ 20 kN/m

**Applications:** Used in containment applications, such as underdrain systems. Geomembranes and geosynthetic products to control fluid movement [5] are shown in figure 4.

*Figure 4: Geomembranes and geosynthetic products to control fluid movement*

### *3.5. Geocomposites*

**Description:** Combination of geotextiles, geogrids, and/or geomembranes.

**Function:** Multi-functional, providing combined benefits.

**Specifications:** Varies based on components.

**Applications:** Used in drainage systems, reinforcement, and filtration. Composite Geotextiles for road construction to strengthen pavement [6] are shown in the figure 5.

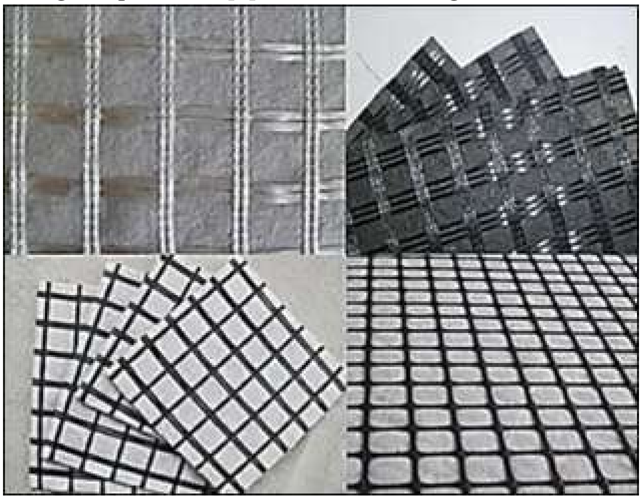

*Figure 5: Composite geotextile layers used to enhance pavement strength*

## 4. Material Specifications Overview

Geotextiles, Geogrids, Geocells, Geomembranes and Geocomposites differ in their tensile strength, aperture or thickness, key functions as shown in the Table 1.

*Table 1: Material Specifications Overview*

| Geosynthetic Type | Tensile Strength (kN/m) | Aperture/ Thickness | Key Functions |
|---|---|---|---|
| Geotextiles | 20–200 | N/A | Separation, filtration |
| Geogrids | 30–100 | 20–100 mm | Reinforcement |
| Geocells | N/A | 100–200 mm | Load support, confinement |
| Geomembranes | = 20 | 0.5–3.0 mm | Fluid barrier |
| Geocomposites | Varies | Varies | Multi-functional |

## 5. Roles of Geosynthetics in Road Construction

**1. Separation:** Prevent mixing of different soil layers (e.g., soft subgrade and aggregate base).

**2. Reinforcement:** Strengthen weak soils by providing tensile resistance and distribute loads more effectively.

**3. Filtration:** Allow water to pass through wh0ile preventing soil movement (important in drainage layers).

**4. Drainage:** Facilitate water flow within the plane of the geosynthetic to remove excess water.

**5. Barrier/Containment:** Geomembranes act as impermeable layers to prevent water infiltration.

### *5.1 Common Applications in Roads*

1. Stabilizing soft soils for embankments and pavement bases.
2. Preventing rutting and potholes by reinforcing asphalt layers.
3. Building roads over marshy or poor drainage areas.
4. Enhancing durability and reducing maintenance costs.

### *5.2 Benefits*

1. Cost-effective: Reduces material use (like thick gravel layers).
2. Durable: Extends the life of roads.
3. Environmentally friendly: Reduces resource extraction.
4. Efficient: Speeds up construction, especially in tough terrains.

## 6 Review of uses of Geosynthetics in Road Construction

### *6.1 Geotextiles in Pavement Design and Soil Stabilization*

Several studies have highlighted the effectiveness of geotextiles in improving pavement performance. The use of geotextile reinforcement seen in pavement design where geotextiles can address key technical issues in road construction [7]. Researchers investigated the stabilization of soil using geotextiles, demonstrating their ability to enhance soil properties [8]. These studies emphasize the role of geotextiles in providing separation, filtration, and reinforcement functions in pavement structures. The reinforcement function of geotextiles is the most used in geotechnical engineering. Use of Reinforcement function of geotextiles [9] is shown in the figure 6.

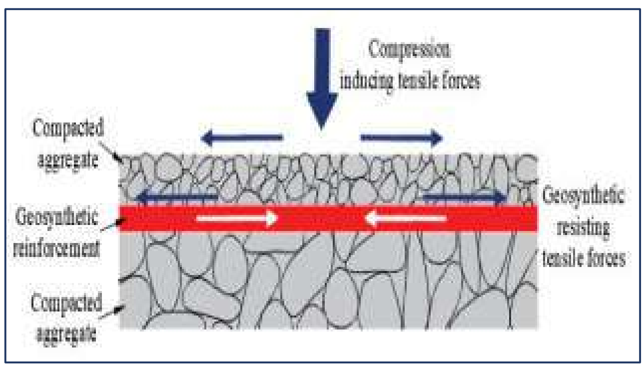


*Figure 6: Reinforcement function of geotextiles*

### *6.2 Geogrids and Geotextiles for Road Construction*

The use of geogrids and geotextiles is observed mostly in road construction, focusing on their ability to stabilize poor subgrade soils [10]. Geogrids, in particular, are increasingly popular for enhancing road paving due to their reinforcement capabilities. The authors also highlighted the importance of considering factors such as aperture size, tensile strength, and junction strength when selecting geogrids. Geogrids and Geotextiles (Paving Fabric) associated with reinforcing roads over unstable subgrade [11] is shown in the figure 7.

*Figure 7: Geogrids and Geotextiles: Reinforcing Roads over Unstable Subgrade*

### 6.3 Experimental Investigations and Applications

Experimental studies have demonstrated the benefits of using geotextiles in road construction. In an experimental investigation on the functions of geotextiles in road construction, it is seen that geotextiles can extend the service life of pavements and reduce maintenance [12]. Many researchers discussed the use of geotextiles in road pavement designs, emphasizing their ability to provide separation, drainage, reinforcement, and filtration [13]. Researchers also reviewed the use of geotextile pavement in India, highlighting their role in preventing the intermingling of materials and ensuring free water movement [14]. Typical multiple functions of geosynthetics in roadway applications [15] is shown in the figure 8.

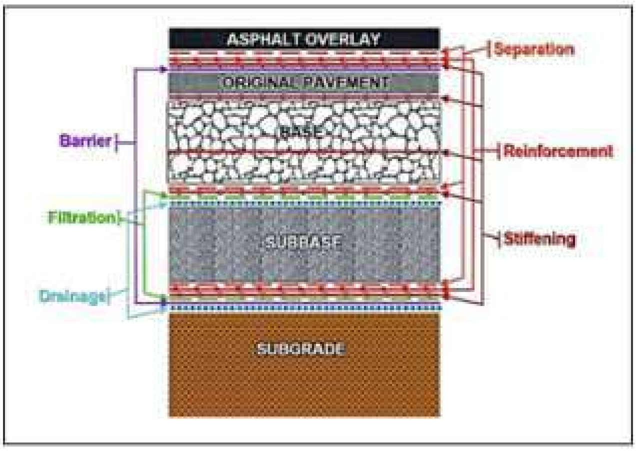


*Figure 8: Multiple functions of geosynthetics in roadway applications*

### 6.4 Design Considerations and Case Studies

Giroud provided a comprehensive overview of the use of geosynthetics in roads, discussing design methods, mechanisms, and case histories [16]. The paper highlighted the innovation brought by geosynthetics to road construction and their ability to improve pavement performance and reduce the required thickness of road cross-sections. Typical method of reinforcement by geotextile in roads [17] is shown in the figure 9.

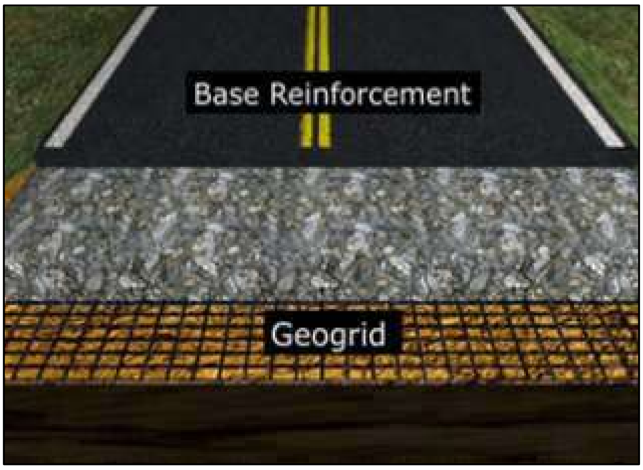


*Figure 9: Reinforcement by geotextile*

### 6.5 Geotextiles in Specific Applications

Several papers focused on specific applications of geotextiles. The use of geosynthetics is useful in flexible pavement design, noting the availability of numerous design procedures for geotextile applications [18]. The general applications of geotextiles found in road construction, emphasizing their functions in separation, filtration, drainage, and reinforcement [19]. Some researchers specifically addressed the application of geotextiles in pavement drainage systems, highlighting their role in collecting and transporting water [20, 21 & 22]. Geogrid can be used in retaining walls for strengthening. Use of Geotextile in retaining wall construction [23] is illustrated in the figure 10.

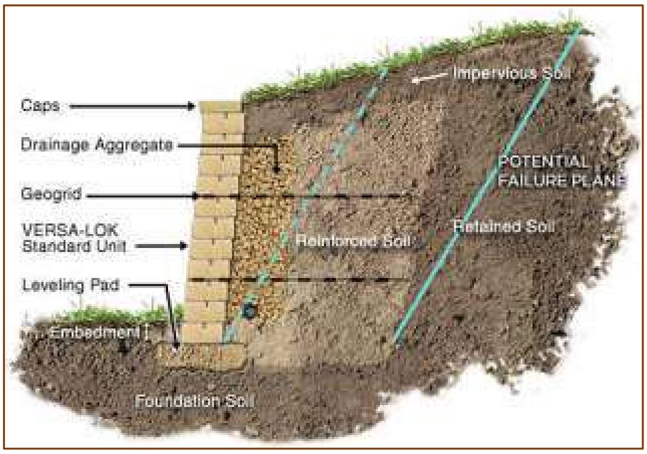


*Figure 10: Geotextile in retaining wall construction*

### 7. Conclusion

Geosynthetics, particularly geotextiles and geogrids, have proven to be effective materials for enhancing road construction. They offer multiple benefits, including soil stabilization, reinforcement, drainage, and separation, which improve pavement performance, extend service life, and reduce maintenance costs. The reviewed studies highlight the importance of proper design and material selection to maximize the benefits of geosynthetics in road construction. While significant advancements have been made, ongoing research is essential to further optimize the use of geosynthetics and develop standardized design procedures.

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# Optimize the Process of Heatless Dyeing with Rubia Cordifolia (Madder) on Mulberry Silk Fabric

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**Abstract:**

*Rubia cordifolia (madder) is one of the ancient dyes known for its beautiful red colour which has been used in various novelty textiles. The pigment responsible for the beautiful red colour is alzarine which comes under the anthraquinone group and is also called red vats. It has been used in a variety of novelty textiles. Mulberry silk fabric is used as a substrate for dyeing as it has a great affinity towards natural dyes and is ideal for low-temperature dyeing. Heatless dyeing is an alternative method to dyeing fabric using natural dyes. This dyeing process can potentially reduce water and energy conservation, and maintain the fabric properties. This study investigates the impact of varying dyeing durations and different mordants on the colour properties of madder dyed fabrics. The dye extracted from madder roots with the help of an aqueous method was utilized to achieve a dark and intense red colour on mulberry silk fabric. Pre-mordanting of the silk involved alum, harad, and tannic acid at an 8% concentration. Dyeing was conducted at room temperature over seven days to optimize colour. The visual assessment of madder dyed silk revealed a gradual increase from day one to day five of all three respective mordants but on days six and seven has the darkest and most intense shades of red and orange colour.*

*To evaluate colour strength, colour fastness and tensile strength dyed samples are tested. Testing based on colour strength (K/S values) indicated that both days six and seven exhibited similar results across all mordants. Furthermore, samples dyed on day seven were evaluated for their colour fastness to rubbing, washing, light, and tensile strength. The results suggest that six days of dyeing were sufficient to achieve the desired colour intensity. Moreover, alum-treated madder-dyed silk samples exhibited better colour fastness properties and tensile strength as compared to those treated with harad and tannic acid.*

**Keywords:** *Alizarine, Anthraquinone, Madder, Natural dyes, Red vats Heatless dyeing, Rubia Cordifolia*

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## 1. Introduction

Natural dyes are eco-friendly, non-toxic, and biodegradable and come from various natural sources like plants (roots, berries etc.), minerals, and animals. There's a rich history of using natural dyes, with evidence of plant-based dyes dating back to 2600 BC in China. Over 500 different colours can be obtained from various plant parts like roots, leaves, and fruits. These eco-friendly dyes were once a valuable source of income, especially during the middle Ages in Europe. Fabric dyeing started with simply rubbing crushed plants on the fabric. Later, people got more sophisticated and heated the fabric with dyes for better results [1, 2 & 3].

Synthetic dyes took over natural dyes in 1856 because they were cheaper, brighter, and lasted longer. Synthetic dyes are widely used, with an estimated annual consumption of 10,000,000 tonnes. They contain harmful substances like Chromium, Lead, Cadmium, and Mercury. Azo dyes are prohibited in Europe, the United States, and India due to their hazards. Synthetic dyes pose risks to both the environment and human health, with the textile industry contributing 95% of water waste through colouration processes and 5% through rinsing. Because of this, there's a growing interest in natural dyes again, which are safer and more sustainable [3, 4 & 5].

Rubia cordifolia, also known as common madder or Indian madder, belongs to the coffee family Rubiaceae and is found in Asian countries such as India, China, Japan, Afghanistan, Vietnam, and Malaysia. It is primarily found in the hilly regions of India's North Western Himalayas and South India. Manjishtha (Rubia Cordifolia) is a climbing herb with small greenish-white flowers clustered around purplish fleshy fruits. It is renowned as one of the ancient dyes. The dye is derived from the root of Rubia cordifolia, which produces a red colour. Madder has been a primary source of red colour throughout history. This mordant acid dye contains phenolic (-OH) groups (Figure 1). Madder's colouring pigment is alizarin, which belongs to the anthraquinone group. Alizarin was the first natural dye to be chemically synthesized in 1869 [6].

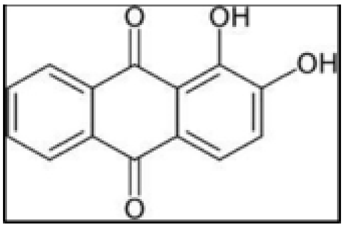

***Figure 1: Chemical structure of alizarin [7]***

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Madder has been used extensively in traditional Indian textile crafts such as Ajrakh, Bagh, Kalamkari, Chintz, and Batik. Its vibrant red colour has also been used in various other cultural and historical contexts, including the robes of Persian kings, the textiles of Egyptian mummies, and the uniforms of British redcoats [8-12].

Manjistha (Rubia cordifolia) is a widely used herb in Ayurvedic medicine, known for its blood-purifying properties. It is used to treat various disorders, including blood, skin, and urinary issues. The root has a range of medicinal properties, including anti-inflammatory, antipyretic, and analgesic effects. Additionally, it is used as a food colouring and has UV protection properties in fabric. Organic compounds have been used in cosmetics and cosmetic products since ancient times [2].

## 2. Methodology

In the present study, mulberry silk fabrics were pre-mordanted with natural mordants (Alum, Harad, and Tannic acid and dyed with Rubia cordifolia (madder) without heat for varying hours at room temperature. Changes in colour strength, colour fastness and Tensile strength properties were evaluated and analyzed. Experiments were carried out at the Institute of Home Economics, University of Delhi, to achieve the above objectives. The study's approach was divided into four phases to align with its objectives:

### *2.1 Phase 1*

Extraction of the dye from the madder root powder using a conventional process. First Madder root ground to powder. Powder soaked in water overnight 1:40 (3 liters for 75g). The soaked mixture was boiled for 1 hour to extract the dye. The dye liquid was strained and stored in the fridge (Figure 2).

***Figure 2: Extraction of the dye***

### *2.2 Phase 2*

Pre-mordanting of mulberry silk fabric with – Alum, Harad, and Tannic acid.

#### *2.2.1 Pre-Treatment: Degumming*

The method of degumming silk involves taking the sericin—also referred to as silk gum—out of the fibers. This procedure is crucial because it improves the silk's luster, colour, hand, and texture. Degumming of silk fabric was carried out by boiling it in water (MLR 1:50) in the presence of mild soap 6g/l for 30 minutes at 60 °C to 80°C and then rinsing with tap water and drying. This process made the silk fabric flexible, lustrous, and smooth.

#### *2.2.2 Pre -Mordanting of Silk with Alum, Harad, and Tannic Acid*

Many natural dyes, particularly those derived from plants, cannot attach strongly to textile fibers on their own thus mordant is required which is the binding agent that helps the dye and the fabric form a chemical bond between them [2]. Mordanting of fabric can be done through three types of methods and applications of mordant based on the time of their usage [4].

i. Pre-mordanting: Before dyeing, mordants are added to the fabric. Cotton and cellulosic fibers benefit from it since they have little affinity for natural colours in their unwanted state.

ii. Meta or simultaneous mordanting method: Both the dyeing and mordanting actions take place in the same bath.

iii. Post-mordanting: After dyeing, the fabric is treated with a mordant in a separate bath in the post-mordanting method

Pre-mordanting of mulberry silk fabric is done with three natural mordants: Alum, Harad, and Tannic acids. All three mordants were used to achieve a uniform and good uptake of dye. Mordants improve the colour uptake and fastness of the dyed sample. Alum, Harad, and Tannic acid enhance the light and wash fastness. Water was added to the vessel according to MLR 1:50. Selective mordant 8% on the weight of fabric was dissolved with little water. Dissolved mordant was added to vessel with water along with pre-soaked silk fabric. The temperature was maintained at 80°C for 30 min and stirred for even mordanting of fabric. The fabric was removed from the vessel and dried.

### *2.3 Phase 3*

Optimization of the dyeing process with madder at room temperature (20°C to 25 °C). The dyeing process was optimized by treating the pre-mordanted silk fabric for 1 to 7 days at room temperature (20 °C to 25 °C) under pH 5.

Extracted dye liquor was taken according to MLR 1:40 and acetic acid 2% on the weight of fabric was added to maintain pH 5. 15 cm by 15 cm pre–mordanted silk samples were soaked in dye liquor. Samples were soaked in the dye liquor for 1 - 7 days. Beakers were kept in the oven to maintain a constant temperature (20°C to 25°C) throughout the exploration (winter season) and periodic stirring of samples. One sample was taken out every day, every time, and rinsed thoroughly under tap water. The remaining dye residue was removed and samples were neutralized from the above-soaked samples in anionic soap (lissapol 2-3 gms/l) at 40°C for 10 mins and rinsed under tap water again. Washed samples were dried at room temperature (shaded area)

### *2.4 Phase 4*

Analysis and comparison of the dyed samples based on fastness properties and K/S. Colour fastness testing is critical for ensuring customer satisfaction. It describes the material's colour's resistance to running or fading. Dyed silk samples were tested for colour fastness to light, washing, rubbing, and K/S value according to the respective ISO/TC 38/SC 1 standards. Tensile strength testing was also done of madder-dyed silk samples. Equipment used for testing madder-dyed samples: MATREX Fastness tester (Fadometer), Greyscale, Laundrometer, Crockmeter, Spectrophotometer, and Tensile strength tester.

## 3. Results and Discussion

Natural dyes are a sustainable alternative to synthetic dyes. They are not harmful to the environment and are derived from plants, flowers, and fruits. India has a long history of using natural dyes for dyeing fabrics and handicrafts. This study describes a new room-temperature dyeing process with Madder and it minimizes water and fuel consumption while preserving the characteristics of the fabric.

### *3.1 Phase 1*

Dye from the madder root powder is extracted using a conventional process. Madder, a plant-based ancient red dye, requires extraction and purification for use. Solubility is key: water-based methods are simple and effective for water-soluble dye components. To improve extraction, the plant material is ground and soaked to loosen cell walls, allowing hot water vapor to carry the dye out [13, 14 & 15].

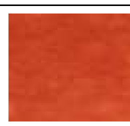
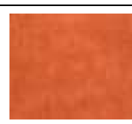
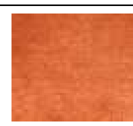
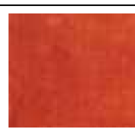
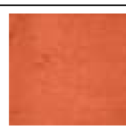
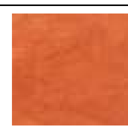
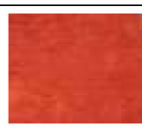
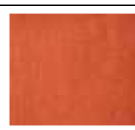
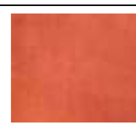
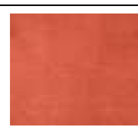
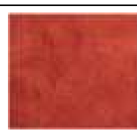
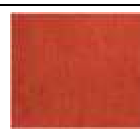
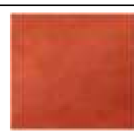
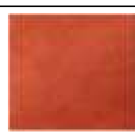
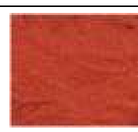
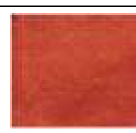
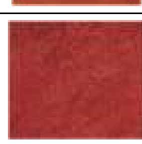
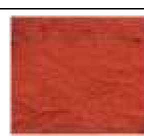
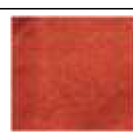
### *3.2 Phase 2*

Pre-mordanting the mulberry silk fabric with – Alum, Harad, and Tannic acid is done. A mordant is necessary because many natural dyes, especially those obtained from plants, are unable to attach firmly to fabric fibers on their own. The mordant helps the dye and the fabric form a chemical bond. Mulberry silk was mordanting with - Alum, Harad, and Tannic acid.

### *3.3 Phase 3*

Dyeing process is optimized with madder at room temperature (20°C to 25°C). Samples were soaked in dye liquor for 1-7 days at maintained pH 5 at 20°C to 25°C. Further, it was analyzed visually and tested for its K/S value to evaluate the best dye uptake and colour intensity.

***Table 1: Shade card of silk-dyed fabric with madder using a heatless dyeing process***

| Days | Alum | Harad | Tannic Acid |
|---|---|---|---|
| Day -1 |  |  |  |
| Day -2 |  |  |  |
| Day -3 |  |  |  |
| Day -4 |  |  |  |
| Day -5 |  |  |  |
| Day -6 |  |  |  |
| Day -7 |  |  |  |

Day -2

Table 1 shows the shade card of madder-dyed silk samples mordanted with - Alum, Harad, and Tannic Acid. Madder-dyed silk samples treated with 8% Alum mordant, exhibited darker and more intense red colour shades. On the other hand, madder dyed silk samples which were treated with 8% Harad and Tannic acid produced good orange colour shades. This observed that dye uptake gradually increased from day one to day seven. From day one to day three exhibited the light orange colour shades of all three respectively mordants and from day four to the day five showed the dark orange colour shades but day six and day seven exhibited the red colour shades.

*3.3.1. Fabric dyeing cost*

The dyeing process involved the use of 500 grams of madder root and 8% alum based on the fabric weight for 1 meter of mulberry silk fabric. The estimated cost of dyeing using the conventional method is approximately ₹250, while the non-conventional method reduces the cost to ₹180. This cost difference highlights the economic advantage of adopting non-conventional techniques for natural dyeing, making sustainable dye practices more feasible for broader application.

### *3.4 Phase 4*

In this phase dyed samples were analyzed and compared for their K/S value and fastness properties to rubbing, washing, light, and tensile strength. Colour fastness testing is essential to ensuring customer satisfaction.

*3.4.1 K/S values of madder-dyed samples*

This study focused on evaluating the colour strength of madder-dyed samples treated with different mordants like alum, harad, and tannic acid. The objective of this experiment was to identify the point at which the dyed samples achieved their maximum saturation over a seven-day dyeing period. Initially (days 1-3), there was little discernible difference in color intensity among the samples treated with different mordants. However, as the dyeing process progressed, the colour intensity gradually increased. This suggests that the saturation point, where the dye fully penetrates and bonds with the fabric, was reached later in the dyeing process. Understanding this saturation point is crucial for optimizing the dyeing process to achieve the desired colour intensity.

***Table 2: K/S values of madder dyed samples treated with different mordants***

| Days | Alum | Harad | Tannic Acid |
|---|---|---|---|
| Day-1 | 45.759 | 30.400 | 27.307 |
| Day-2 | 60.500 | 35.402 | 30.001 |
| Day-3 | 81.305 | 40.501 | 41.305 |
| Day-4 | 100.400 | 60.306 | 60.809 |
| Day-5 | 130.579 | 74.947 | 80.305 |
| Day-6 | 160.400 | 98.800 | 100.002 |
| Day-7 | 160.500 | 98.900 | 100.004 |

The data presented in Table 2 clearly shows a gradual increase in dye uptake from day one to day six. Madder-dyed samples from day six and day seven exhibit the highest colour uptake and intensity, with K/S values showing a minimal difference between these two days. This similarity in K/S values indicates the saturation point for silk-dyed samples. Using a heatless dyeing method, six days of dyeing are sufficient to achieve intense and vibrant colours. Additionally, alum-treated samples demonstrate the highest K/S value compared to those treated with Harad and Tannic acid.

*3.4.2 Colour fastness to rub, wash, and light*

On day seven, madder-dyed silk samples were subjected to tests for colour fastness to rub, wash, and light, as they displayed the highest K/S value and the most intense color among the samples treated with all three mordants. The results of these tests are presented in Table 3.

***Table 3: Results of Colour fastness to rubbing and light of madder dyed silk samples***

| Madder Dyed Silk | Colour Fastness to Rubbing | | Colour Fastness to Washing | | Colour Fastness to Light |
|---|---|---|---|---|---|
| **Mordants** | **Dry** | **Wet** | **Colour Change** | **Colour Staining** | |
| Alum | ¾ | 3 | 4/5 | 4/5 | 4/5 |
| Harad | 4 | 3/4 | 3 | 3/4 | 4 |
| Tannic Acid | 4 | 3/4 | 3 | ¾ | 4/5 |

According to the result presented in Table 3, alum has fair rub fastness (dry), while harad and tannic acid have good rub fastness (dry). Wet rub fastness is observed poor for all mordants. In case of wash fastness, alum showed excellent wash fastness, while harad and tannic acid had fair wash fastness. On the other hand, Alum and tannic acid have excellent light fastness, while harad has good light fastness.

*3.4.3 Tensile strength of madder-dyed samples*

The tensile strength was also done of madder-dyed silk, and it elongated during the application of force. Controlled and Day 7 madder-dyed samples, mordanted with alum, harad, and tannic acid were tested. The results are shown in Table 4.

***Table 4: Results Tensile Strength of Control and Dyed Samples***

| Samples | Strength (kg) | Initial (cm) | Final (cm) | Elongation % |
|---|---|---|---|---|
| Controlled | 2.3 | 10 | 12 | 20 |
| Alum | 1.9 | 10 | 11.9 | 19 |
| Harad | 1.9 | 10 | 11.8 | 18 |
| Tannic Acid | 1.8 | 10 | 11.8 | 18 |

Table 4 indicates that controlled samples exhibit the maximum elongation of 20%, as compared to alum-treated samples, which show less elongation, on the contrary, harad and tannic acid treated samples showed the least elongation. The fibers of silk can tolerate deformation due to their high strength and flexibility [16].

#### 4. Analysis and conclusion

Dyeing was conducted over seven days, with visual evaluations indicating that on days six and seven, samples exhibited the darkest and most intense shades. Color strength (K/S value) analysis showed consistently high readings for all three mordants on these days. Further testing on day seven samples was carried out to assess colourfastness to wash, rub, and light, as well as tensile strength. Among the mordants, alum-treated samples showed the highest K/S values and demonstrated superior fastness and tensile strength compared to samples treated with harad and tannic acid. This study successfully optimized a sustainable, room-temperature dyeing process for mulberry silk using madder. The process significantly reduced water and energy consumption and required minimal equipment, making it well-suited for eco-conscious and low-resource settings. Six days of dyeing were found sufficient to achieve a deep and intense color without compromising fabric quality.

In addition to effective dyeing performance, the non-conventional method proved to be more economical, reducing the dyeing cost per meter from ₹250 to ₹180 — a cost reduction of nearly 30%. These findings highlight the potential of non-conventional, heatless dyeing as a viable alternative to traditional methods in both artisanal and commercial textile applications.

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# Waste Silk Fabric Reinforced Epoxy Composites: A Novel Approach to Enhance Load-Bearing Capacity

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**Abstract:**

*Composites represent a significant advancement in contemporary technology, simplifying various aspects of modern technical life. Silk fibers are extraordinary materials that exhibit unique mechanical characteristics: they are strong, flexible, lightweight, and capable of being mechanically compressed. This study focuses on creating a silk-epoxy composite utilizing waste mulberry silk fabric to reinforce the brittle epoxy resin, aiming to enhance the load-bearing strength of the fragile resin. Silk-epoxy composites were produced utilizing the hand-lay-up technique in layer configurations of 4, 6, 8, 10, and 12, with an optimal silk reinforcement percentage of 33.38% (by weight). The resultant composites were then tested for various mechanical characteristics such as Impact properties, hardness, tensile-strength, flexural strength & also for moisture absorption. All the composites demonstrated significant increase in mechanical properties. The tensile-test specimens were characterized by scanning electron microscopy (SEM) to ascertain the nature of failure.*

**Keywords:** *Epoxy resin, Flexural strength, Hardness, Mulberry silk, tensile strength*

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## 1. Introduction

Composites are constructed at macro level using two or more distinct materials ensuring optimal efficiency is achieved. The objective of creating composite materials is to enhance the properties of multiple components and produce a substance that is more suitable for the intended application. The most notable feature of composites is light weight nature, durability, heat and wear resistance, making them extensively utilized in industries like aerospace, automotive, sports, chemicals, transportation, construction and healthcare [1, 2].

Recently, fiber-reinforced polymer composites have explored applications in car, shipping and aviation. This expanded use is because of their lightweight, higher mechanical strength and better erosion resistance analyzed than customary materials [3, 4]. Notwithstanding the assembling of regular manufactured filaments like glass, aramid and carbon makes natural issues such as non-biodegradability, respiratory irritations, high abrasion etc. Raising environmental awareness and the diminishing availability of petroleum resources are key factors motivating many researchers to investigate the possibility of utilizing natural fibers in various applications mentioned above [1] Author suggested employing silk waste bio-composite that is coated with zinc oxide nanoparticles for applications that do not require structural integrity, like partition walls and ceiling panels [2].

Silk fibers display fascinating thermal and electromagnetic behaviours, especially within the UV spectrum, and they can form crystalline phases associated with their processing [3]. They exhibit an elongation at break ranging from 20-25% under standard conditions. When subjected to 100% relative humidity, the break extension increases to 33%. Additionally, silk possesses excellent thermal stability, distinctive optical properties, dynamic mechanical characteristics, and time-dependent behaviours, all of which have been utilized across a variety of applications in different sectors [10, 11]. Author [4] studied Biodegradable and eco-friendly composites PLA/waste silk were manufactured using the hot molding technique, and found improved mechanical characteristics such as modulus, tensile strength and fiber content of 30 wt. % was optimal for attaining superior characteristics. It is [5] investigated the mechanical properties of epoxy composites reinforced with untreated filature silk waste, which includes 2 wt.% of alkali-treated filature silk waste, along with epoxy nanocomposites also reinforced with 2 wt.% of alkali-treated filature silk waste. Also it is [6] examined the compressive strength and impact characteristics of waste silk fabric/epoxy composites and how they relate to the amount of fabric used.

There is limited research on waste silk fabric /epoxy composites and no research work pertaining to mulberry silk and epoxy composites has been reported in the literature. Therefore, in the present work composites made of waste mulberry silk fabric and epoxy were fabricated and tested for

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Mechanical characteristics and water-absorption. The possibility of replacing load bearing application with this low-cost composite has been explored in this work.

## 2. Materials and Methods

### *2.1 Raw materials used*

Epoxy-resin Poly- (Bisphenol A-co-Epichlorohydrine) was used along with curing agent Diethylenetriamine. The resin and hardener are combined in a 1:2 ratios and stirred for 5 minutes at 150 rpm [7].

A plain-woven mulberry waste silk fabrics were taken from more than 10 years old silk sarees. The silk fabric of size 245mm X 185 mm X 0. 04 mm (thickness) was used in the preparation of laminates. Preparation of reinforcing layers (silk fabric) involved various steps such as precise size cutting, hot press to eliminate wrinkles and drying in air circulating oven at 45-50 0C. The density of silk fabric is 1.3 gm/cm3 [8] and GSM of silk fabric was 168.

In this study, the composites made of five different weight percentages (11.13%, 16.7%, 22.26%, 27.82%, and 33.38%) of waste silk fabric reinforced with epoxy were tested for mechanical properties & percentage of water absorption.

### *2.2 Fabrication of Composite*

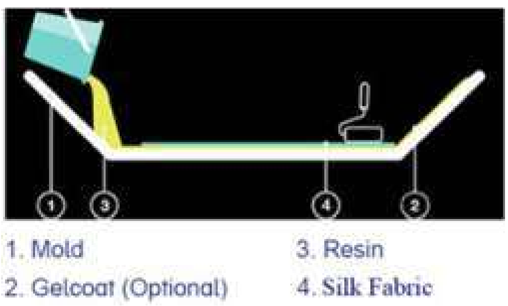


*Figure 1: Composite Sheet Made Using Waste Mulberry Silk Fabric*

Composite laminate was manufactured by utilizing hand-lay-up process. The measured quantity of uncured epoxy resin was applied on the silk fabric using brush and then laid in an open mold. A Roller was then moved over resin impregnated fabric with moderate pressure to remove entrapped air and excess resin at room temperature as shown in figure 1. The curing time for all composite was approximately 3hrs at room temperature which is then followed by curing for 6 hrs. at 800C in an oven. Waste mulberry silk-fabric-epoxy laminate were prepared by varying weight-percentage of silk from 11.13% to 33.38%.

The weight of silk in each layer was kept constant, and the total weight fraction was determined by the number of layers used. In the present work composite were prepared using maximum 12 layers of silk fabric amounting to 33.38% weight percentage of silk fabric. Use of more than 12 layers have resulted in inadequate wetting of the silk-fabric therefore the optimum weight fraction of silk-fabric was considered to be 33.38%.

The final composite sheets were uniform in thickness and free of defects, as shown in Figure2. The layering strategy ensured consistent properties across the material, making it suitable for further mechanical testing and analysis.

*Figure 2: Composite Sheet Made Using Waste Mulberry Silk Fabric*

### *2.3 Specimen Preparation*

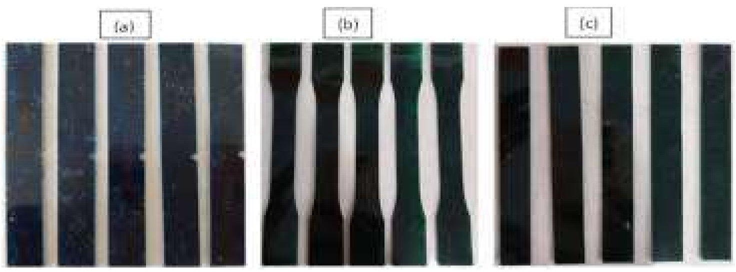


*Figure 3: (A) Notched Samples for Izod Impact Test, (B) Dumbbell Shaped Samples for Tensile Test, (C) Rectangular Shaped Samples for Flexural Test*

All the specimen required for impact, tensile and flexural test were cut from the composite sheets as shown in figure 3 (a), (b), (c). ASTM standards were followed for impact test, flexural and tensile test. For each combination five test samples were evaluated, and average-value was considered. All tests were performed in a controlled laboratory environment of 50 ± 5% relative humidity & temperature 23 ± 2°C, as specified by ASTM standards.

## 3.Mechanical testing & evaluation of fabricated composites

### *3.1 Tensile Test & Flexural Test*

The flexural test and tensile tests were performed following ASTM D790 & ASTM D638 standards respectively. These tests were carried out using Universal Tensile Testing Machine. The test specimens for tensile and flexural test were prepared using a diamond cutter to meet specified requirements shown in figure 3(b) & (c) respectively. The dumbbell shaped sample positioned vertically within the grips of the UTM machine. The flexural tests were conducted using a three- point bending setup, employing a crosshead speed of 2mm/sec and a loading roller radius of 8mm.

### 3.2 *Impact Test*

An impact test was performed using an Izod impact tester in accordance with ASTM D256 on a pendulum impact testing machine. The notched specimens shown in figure 3(a) were loaded on 2J Hammer. The Izod impact test assesses the energy require to fracture a sample by striking it with a pendulum of specified dimensions. Typically, Izod tests involve notched specimens, where the presence of a notch concentrates stress, facilitating fracture initiation at a predetermined location. In this test setup, the specimen is securely clamped with the notch positioned appropriately, and upon release the pendulum strikes the sample, quantifying the energy required for fracture.

### 3.3 *Hardness Test*

Durometer hardness test is used to measure the relative hardness of composite material. This test evaluates how deeply a specific indenter penetrates the material under set conditions of force and time. As per ASTM D2240, it is essential to ensure that the durometer's contact surface is parallel to the specimen table. The specimen is positioned on a flat surface, and the shore D indenter is pressed against it with the defined pressure until complete contact with the surface is achieved. The hardness value is recorded within one second of the specimen making firm contact.

## 4. Results and Discussion

### *4.1 Tensile Strength*

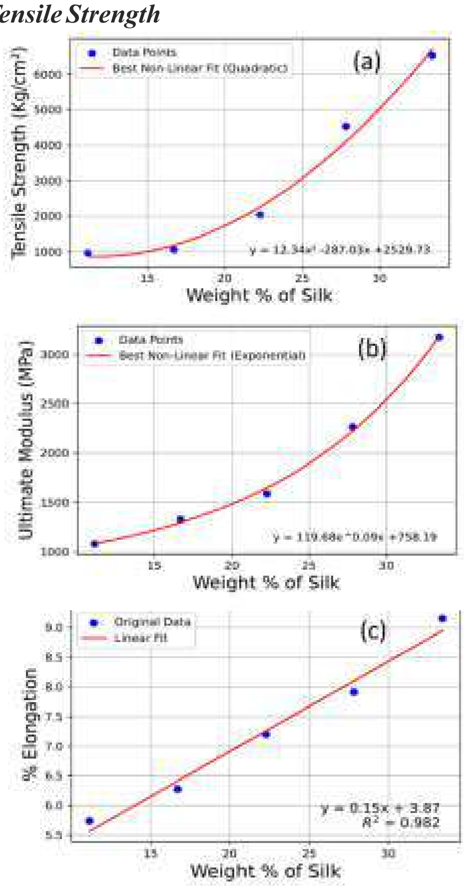


*Figure 4: (A) Tensile characteristics of Silk fabric Epoxy composites test samples*

Tensile strength is a crucial parameter for assessing the load-bearing capacity of composite-materials. The results indicate that both tensile strength and ultimate modulus exhibit nonlinear behaviour as the silk reinforcement percentage increases.

- The variation in tensile strength follows a quadratic trend, as depicted in Figure 4(a). The mathematical representation of this relationship is given by a second-degree polynomial equation, demonstrating a significant increase in tensile strength with higher silk content.

- Similarly, ultimate modulus exhibits an exponential trend, as illustrated in Figure 4(b). The obtained equation accurately captures the rapid increase in modulus as the silk reinforcement percentage rises.

Unlike tensile strength and ultimate modulus, percentage elongation follows a linear trend with increasing silk content. A simple linear regression model was applied to the dataset, confirming an excellent correlation with $R^2 = 0.982$. The relationship between % elongation and silk content are provided in Figure 4(c), reinforcing the notion that silk-reinforced epoxy composites maintain flexibility while gaining strength.

The substantial improvement in mechanical performance confirms that silk fabric reinforcement offers a viable, sustainable, and high-strength alternative to conventional glass fiber composites [11]. The increase in tensile strength and modulus with the increase in silk fraction (wt %) may be attributed to proper bonding between silk fabric layers and epoxy resin as evident from scanning electron micrographs

### 4.2 *Flexural Strength*

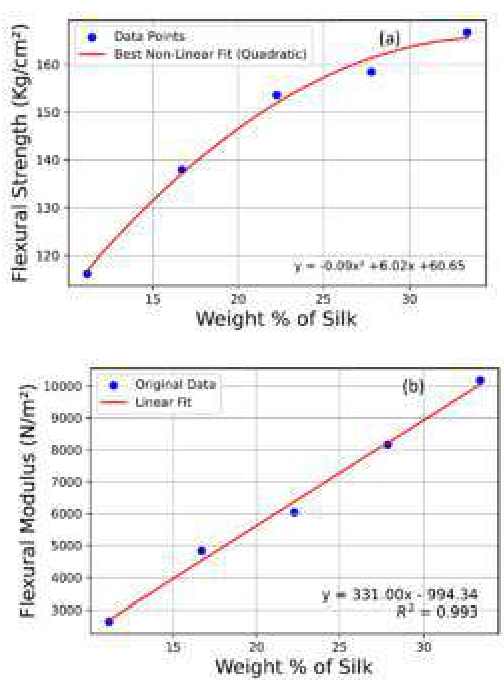


*Figure 5: (A) Flexural Properties of Silk fabric Epoxy composites test samples*

Flexural strength measures the ability of a material to resist deformation under load, particularly bending forces. The results indicate a clear trend: as the weight percentage of silk fabric increases, so does the average flexural strength of the silk/epoxy composite. Specifically, the flexural strength peaked at 166.74 kg/cm² at a silk content of 33.38 wt%, as shown in Figure 5 (a).

The variation in flexural strength follows a quadratic trend, as represented in Figure 5 (a). The best-fit equation for the nonlinear relationship is given by a second-degree polynomial. This curve illustrates an initial sharp increase in flexural strength with increasing silk content, which then starts to plateau at higher weight percentages. The concave-down nature of the curve suggests that beyond a certain silk content, the rate of strength enhancement diminishes, likely due to resin saturation and fiber distribution limitations.

This increase in flexural strength aligns with findings in [12]. The researcher stated that composite strength may decline at very high fiber volume fractions due to insufficient resin availability to coat all fibers effectively as density increases. The research pertaining to [4] obtained maximum mechanical properties at 30% (by wt.) silk, with a subsequent decline at 40% (by wt.), supporting the notion that an optimal reinforcement percentage exists for maximizing mechanical performance. Like flexural strength, the flexural modulus also increases with increase in silk content, indicating enhanced bending stiffness as depicted in figure 5(b).

### *4.3 Impact Strength*

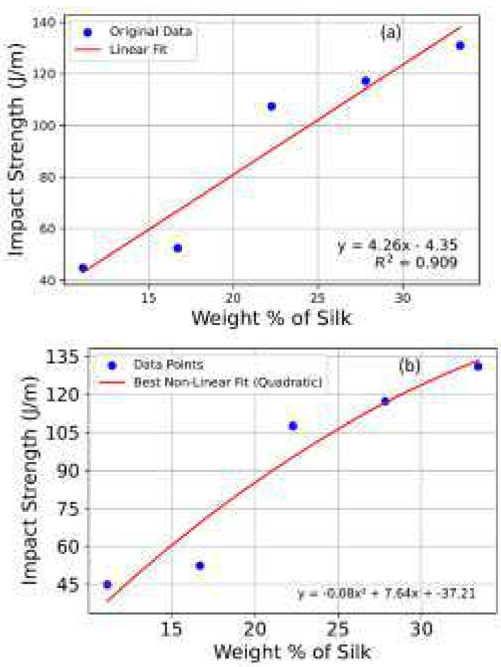


*Figure 6: (A) Best Fit Model for Impact Strength Vs Weight % of silk*

The impact strength results demonstrate an increasing trend with increase in silk content. At 11.13% and 16.7% silk reinforcement, the impact strength remains relatively low. However, as the silk content increases beyond 22.26%, the impact strength shows a steady increase, reaching a significant improvement of over 120 J/m² at 33.38% silk content, as depicted in Figure 6.

Nature of the Impact Strength Graph and Best Fitting Model

- Linear Behavior: The left-hand side of Figure 6(a) demonstrates a linear correlation between impact strength and silk content.
- Nonlinear Behavior: In contrast, Figure 6(b) follows a quadratic trend, indicating that as silk content increases further, the rate of increase in impact strength is less.

Comparing both models, the quadratic fit provides a more accurate representation of impact strength variation.

### *4.4 Hardness*

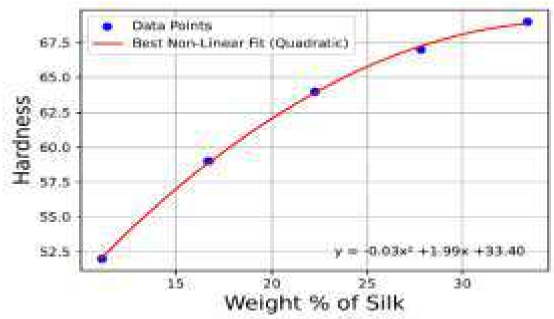


*Figure 7: Change in Hardness with Weight % of Silk*

Hardness measures the material's resistance to indentation or penetration under external stress. It is a key mechanical property in composite materials which depends on a material's resistance to penetration at the outer surface and often evaluated using Durometer-Shore D hardeness tester . The results indicate that the hardness of the composite increases with higher weight percentages of silk reinforcement. The highest hardness value of 69 was recorded at 33.38 wt% silk content, as shown in Figure 7.

- The hardness values exhibit a quadratic trend, confirming that the relationship between silk content and hardness follows a second-degree polynomial equation.
- The best-fit equation, as shown in Figure 7, suggests that the increase in hardness slows down at higher silk content, similar to the trend observed in flexural strength.

The observed trend can be attributed to strong interfacial adhesion between silk fibers and epoxy, allowing effective load transfer and stress distribution.

### *4.5 Water Absorption Test*

Water absorption is an important property for evaluating a material's behaviour in humid or wet environments [13]. The water-absorption test was performed in accordance with ASTM D750, where samples were dried, weighed, submerged in water for 48 hours at 23°C, and then dried again before measuring their final weight.

Figure 8 shows change in the % water absorption of silk epoxy composites and Best fit model for % water absorption Vs Weight % of silk.

- Linear Increase Phase: From 11.13% to 22.26% silk content, water absorption steadily increases from 1% to 2%. The best-fit linear equation $y = 0.09x + 0.00$ describes this relationship, indicating that an increase in silk reinforcement enhances the composite's water uptake.

- Saturation Phase: Beyond 22.26% silk content, water absorption remains constant at 2%, regardless of further increases in silk percentage. This plateau suggests that the composite reaches a saturation limit, where additional silk fibers do not significantly influence water uptake.

This piece-wise behaviour, as depicted in Figure 8, suggests that the material reaches a threshold beyond which further reinforcement does not contribute to additional water absorption. The stabilization at 2% absorption may be due to the effective encapsulation of fibers by epoxy, limiting further moisture penetration.

### *4.6 SEM Test*

*4.6.1 Morphology and Microstructure of Silk Fabric*

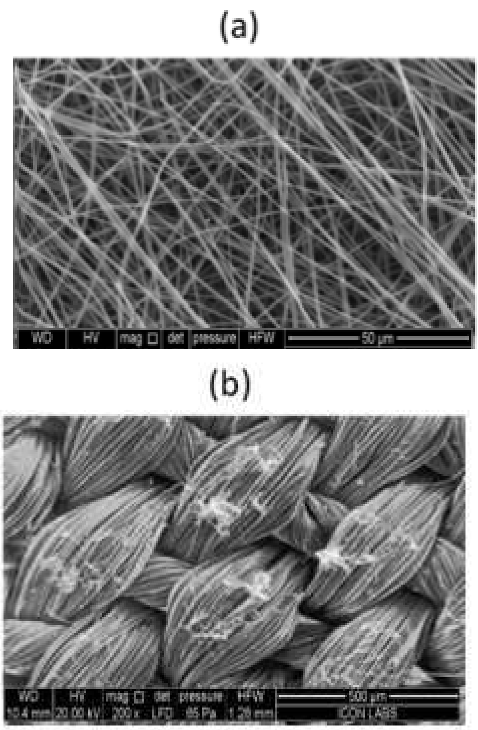


***Figure 9: SEM Image of Waste-silk-fabric – (a) High magnification SEM image of waste silk fiber, (b) Degraded silk fabric under SEM***

Figure 9 (a) shows high resolution images captured to evaluate the fiber's morphology. Figure 9 (b) clearly shows rough, fragmented and cracked fibers degradation due to environmental factors such as UV exposure, humidity & chemical interactions [13]. Presence of longitudinal cracks may indicate age-related brittleness, fibrillation points to severe physical degradation [14].

*4.6.2 Morphology and Microstructure of Silk-Epoxy-Composite*

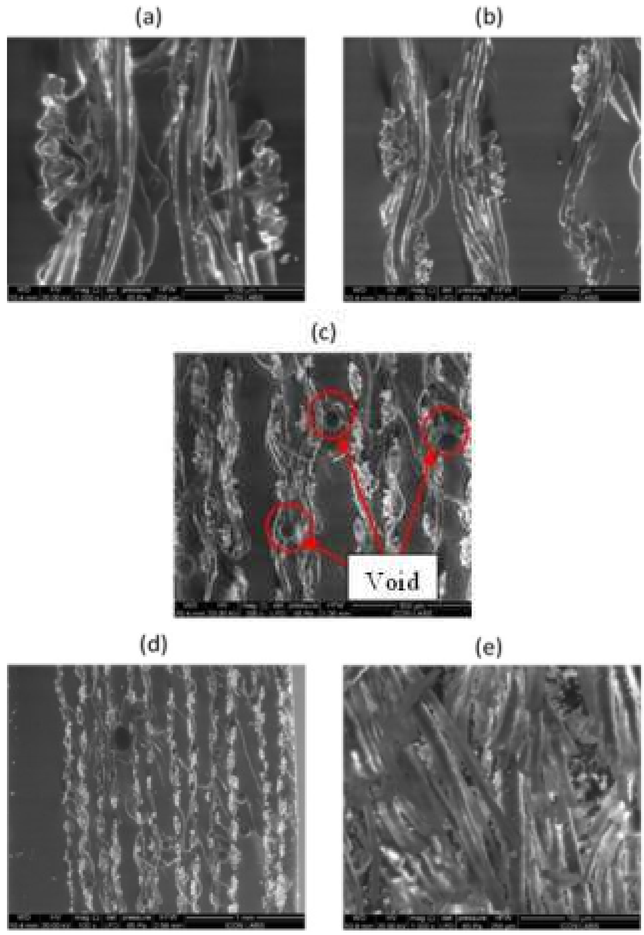


***Figure 10: SEM Images of (a) fractured surface of silk/epoxy composite, (b) Breakage pullout of silk-fibers, (c) Voids shown on the surface of composite, (d) Layers of silk fabric n a proper fashion, (e) epoxy uniformly spread over the fabric***

Figure 10 (a) & (b) depicts the surface structure of waste silk fibres reinforced with epoxy resin which appears to be smooth with a few regions showing roughness. Minimal voids or cracks suggest strong bonding between the silk-fibres & epoxy. The presence of fibre-bundles indicates intact reinforcement structure, beneficial for strength improvement. Figure10 (c), (d) & (e) shows that the resin have penetrated well into the fiber matrix, providing good interfacial adhesion. A few circular void or imperfections are visible, possibly due to air entrapment during fabrication.

The overall morphology & microstructure shows effective distribution and bonding of silk fibers within the epoxy. The presence of minor voids might slightly affect mechanical properties, but the composite likely benefits from the high reinforcement density visible in the fiber network.

## 5. Conclusion

The primary objective of this research is to explore possibility of using waste mulberry silk fabric as reinforcement in epoxy matrix and to investigate effect of varying percentage weight silk fraction on the mechanical characteristics of the resultant composite. The good quality composites using different number of waste silk fabric layers (4 to 12 layers) and epoxy resin were successfully manufactured using hand layup technique. No processing difficulties were encountered during fabrication of these composites. The weight fractions of waste silk fabric in the composites ranged from 11.13 wt. % to 33.38 wt. %.

The study demonstrated that increasing the number of silk-layers led to significant improvements in tensile strength, flexural strength, hardness, and impact-resistance. The scanning electron micrographs revealed rough, fragmented and cracked fibers in the waste silk fabric. It may be attributed to degradation due to environmental factors such as UV exposure, humidity & chemical interactions. The scanning electron micrographs for the composite showed good bonding between waste silk fabric and epoxy resin. These findings underscore the potential of waste silk fabric as an effective and sustainable reinforcement material for enhancing the mechanical properties of epoxy-based composites.

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# Mechanical Property Analysis and Customer Satisfaction with Agave Sisalana Fiber for Kre Alang Weaving

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**Abstract:**

*Kre Alang is a traditional woven fabric of the Sumbawa community. The reliance on commercial yarn contributes to the lower value of Kre Alang compared to other regional weaving traditions that utilize natural materials. Sisal (Agave sisalana) fiber has the potential to serve as a raw material for yarn in Kre Alang production. Sisal is already an established agricultural commodity in Sumbawa. The samples tested included alkalized sisal (S1), dyed alkalized sisal (S1P), and both weft and warp threads (commercial yarn) for comparison. The tests conducted included color analysis, physical property tests, and strength and smoothness evaluations. The color test results indicated that S1 has a bright, shiny appearance, while S1P exhibited stronger, heavier, and more elastic properties. Sisal fiber yarn showed higher density than synthetic yarn.Furthermore, S1P was chosen as yarn for Kre Alang, particularly as a replacement for the weft thread (silk yarn), due to its alkylated nature and enhanced aesthetic appeal. Using these three types of yarn, weavers created Kre Alang fabrics that were displayed for evaluation. The assessment of Kre Alang weaving attributes from sisal fiber yarn, based on visitor perceptions, was done using the integration of Importance Performance Analysis (IPA) and the Kano model. The results highlighted five attributes that require improvement to enhance consumer satisfaction: weaving quality, weaving strength, weaving density, price in relation to weaving quality, and weaving color combinations.*

**Keywords:** *Agave sisalana fiber, customer satisfaction, Kre Alang, thread mechanics, weaving*

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## 1. Introduction

Kre Alang weaving, recognized as one of Sumbawa's esteemed cultural heritages, stands as a symbol of national pride and reflects Indonesia's identity. Consequently, the techniques and designs involved in this traditional craft must be preserved and sustained [1] . Today, while some villages in Sumbawa Regency continue to uphold the weaving tradition, others have not. The areas now regarded as hubs for woven fabric craftsmanship in the region include Moyo Hilir and North Moyo Districts [2] . One factor contributing to the rising production of Kre Alang in villages is the encouragement from the Sumbawa Regency Government to safeguard the tradition. A tangible form of support is the policy requiring State Civil Apparatus employees to wear woven fabrics or Kre Alang blended with batik every Thursday [3] . Additionally, the growing popularity of Kre Alang in modern clothing and the rise in cultural events have spurred the appearance of counterfeit Kre Alang industries outside of Sumbawa Regency. Fake Kre Alang does not meet the quality standards and aesthetics of Sumbawa's Kre Alang. One is that the thread density of the original Kre Alang woven fabric is denser, so it is not easily seen through compared to the fake one. In addition, the "Alu" motif on the edge of the original Kre Alang is smaller than the fake one. Concerns from weavers and cultural figures emerged when the quality of the Kre Alang was considered not as good as the original Kre Alang and abandoned the basic concept that should be inherent in this weaving cloth [2] .

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In response to these challenges, the Sumbawa regional government is working to revitalize the enthusiasm of weaving artisans by implementing various programs specifically targeted at them. Sumbawa Regency hosts several small and medium-sized clothing industry centers, including one located in Semeri Hamlet, Poto Village, Moyo Hilir District, which was officially designated as the Kre Alang Weaving Center by the Indonesian Ministry of Industry in 2016 [4]. Additionally, a simple step that the community can take to help preserve cultural heritage, such as Kre Alang's woven cloth, is to incorporate its use into daily activities. Observations indicate that Kre Alang weaving is not widely popular; consumers tend to prefer woven fabrics made from natural fiber yarns sourced from other regions. Kre Alang sales follow a make-to-order model, meaning weavers only produce Kre Alang when there is a specific customer request. According to Kre Alang business operators, the yarn used is of premium quality, which results in higher material costs and, consequently, a higher selling price for Kre Alang products. Furthermore, innovation plays a crucial role in product competitiveness and marketing performance for Kre Alang woven fabrics [5,6] .

From the description above, there is a need to utilize locally available, easily cultivated plants as innovative raw materials to replace traditional Kre Alang weaving yarn. Currently, the primary material for Kre Alang yarn is cotton fiber [2] . Besides cotton, other natural fibers such as snake plant fiber

[6], kenaf fiber[7], pineapple leaf fiber [8], silk fiber [9], banana fiber [10], and others can serve as alternatives for producing woven fabrics. One promising option is sisal fiber (from Agave sisalana), which thrives abundantly in Sumbawa's tropical and arid soils. Sisal presents significant potential as a substitute raw material for Kre Alang weaving yarn. However, sisal fiber from Sumbawa has not yet been fully utilized. Its notable properties include strength, elasticity, good dye abso,rption, resistance to saltwater, and biodegradability [11]. The weaving process can enhance the quality and durability of natural fibers, but initial testing is required. Researchers are motivated to explore the use of sisal fiber as yarn for Kre Alang fabrics. Laboratory tests were conducted to analyze the fiber's characteristics and mechanical properties, comparing the results to those of commercial yarns traditionally used by weavers.

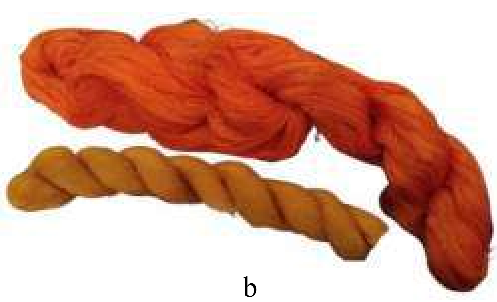
Furthermore, Kre Alang products made with sisal yarn were evaluated based on consumer satisfaction, applying the IPA-KANO method. This evaluation assessed aspects such as performance, features, reliability, conformity to specifications, durability, and fabric aesthetics [12]. For service products, key factors considered include Tangibles, Reliability, Responsiveness, Assurance, and Empathy [13] .

## 2. Materials and Methods

### a. Alkalization and Coloring of Sisal

The sample consisted of sisal fiber sourced from Labangka District, Sumbawa. Additional materials included 5% NaOH and distilled water and textile dye. Four types of thread are produced in this research based on the thread's color. The colors of textile dyes used are red, yellow, blue and black (Figure 1.a). Where these colors are the basic colors of Kre Alang weaving.

a



b

*Figure 1 - Sisal fiber yarn (a), Weft thread and Warp thread (b)*

The materials used in the process included a beaker, a 1L measuring flask, a pan, a stove, a filter, gloves, and a universal pH indicator. The alkalization procedure began by dissolving 50 g of NaOH in distilled water and then diluting it to the appropriate level. The sisal was immersed in a 5% NaOH solution for 2 hours, then drained and washed until the pH was neutral. Afterward, the sisal was dried and labeled as S1 (alkalized sisal). The dyeing procedure for the S1 sample involved dissolving one tablespoon of salt in 2L of hot water, followed by the addition of 3 g of textile dye. A 25 g sample of S1 was then mixed thoroughly with the dye solution. The sisal and dye mixture were heated gently for 30 minutes. The dyed sisal was then labeled as S1P [14].

### b. Integration of IPA Methods and KANO Model

The selected sisal fiber yarn from the alkalization and dyeing process for the raw material for Kre Alang weaving is continued to the weaving process by the weavers. One of the results of Kre Alang weaving from the yarn is shown in Figure 1; the sisal fiber yarn is used as the warp thread (yarn used in the weaving process, especially in the weft thread (picks) that run horizontally on the fabric), while the weft thread (The thread are woven crosswise, forming the structure of the fabric by intersecting with the warp thread) and gold thread use the yarn that the weavers have used. Furthermore, the researcher held a Kre Alang weaving exhibition on Friday, November 29, 2024; in this activity, several Kre Alang woven fabrics from sisal fiber and several Kre Alang woven fabrics that the weavers produced were exhibited. This activity aims to determine the attributes of Kre Alang weaving from sisal fiber yarn that need to be improved and maintained to realize the satisfaction of exhibition visitors as lovers and consumers of Kre Alang woven fabrics. The respondents to analyze this objective are visitors to the exhibition. The sampling technique used is simple random sampling. Namely, each exhibition participant has an equal opportunity to be selected as a sample/respondent. As many as 110 exhibition visitors were willing to become respondents to provide opinions about Kre Alang weaving quality from sisal fiber yarn. Determining the minimum limit of the number of samples to represent the population of Kre Alang woven fabric consumers can use the Lemeshow method because the population size is unknown with a 95% confidence level and a 10% error rate so that the minimum limit of the number of respondent samples using this method is 97 respondents. In compiling a questionnaire on respondent satisfaction regarding the quality of weaving, six indicators must be considered: Performance, Features, Reliability, Conformance to Specifications, Durability, and Aesthetics [12] . These factors can be converted into question attributes (Table 4) for evaluation by the consumers of Kre Alang weaving in this research. The participants in this study were visitors to the Kre Alang weaving exhibition, which featured sisal fiber yarn and was organized by the research team.

Questionnaire data were utilized to assess the attributes of Kre Alang woven fabric made from sisal fiber yarn in relation to consumer satisfaction. The Importance Performance Analysis (IPA) method and the KANO Model were employed for the analysis. The IPA method involves calculating the average importance and performance values for each attribute of Kre Alang woven fabric using equations (1) and (2) ) [15], determining the Importance Performance threshold, and plotting all average attribute values on a Cartesian diagram derived from the Importance Performance values, which allows for categorizing each attribute as low or high[16] .

$$TK_i = \frac{\bar{X}_i}{\bar{Y}_i} 100\%$$

$$\bar{X}_i = \frac{\sum_{i=1}^{n} X_i}{k} \text{ dan } \bar{Y}_i = \frac{\sum_{i=1}^{n} Y_i}{k}$$

Where:

$TK_i$ Level of confidence; $\bar{X}_i$ Performance;

$\bar{Y}_i$ : Importance; $k$ : Number of attributes

The KANO method involves organizing each attribute of Kre Alang weaving made from sisal fiber into two forms—functional and dysfunctional—based on respondents' answers. These responses are then categorized into KANO classifications: Must-be (M), One-dimensional (O), Attractive (A), Indifferent (I), and Questionable (Q), using Blauth's formula. The KANO category for each attribute is determined by evaluating the number of M, O, and A responses in relation to R and Q responses [17]. Meanwhile, the integration of the IPA-KANO methods helps in making strategic decisions about which product attributes need improvement or should be maintained, ensuring choices are made efficiently and accurately. The IPA-KANO approach works by combining the results from the IPA quadrant with the KANO category of each product attribute, leading to the classification into several groups such as survival, fatal, chronic disease, fitness, major weapon, defenseless strategy point, defenseless zone, supportive weapon, precious treasure, dusty diamond, rough stone, and beginning jewelry—[18].

Fiber is vital to customer satisfaction through fabric quality, comfort, and product durability. The technical attributes of the fiber (strength, softness, and resilience) affect the quality of the fabric [19]. IPA-KANO is an analysis method that can help understand customer preferences by classifying product attributes. Must-be attributes must be present in a product to meet basic customer needs. One-dimensional Attributes have a linear relationship with customer satisfaction. Attractive Attributes increase customer satisfaction if present but do not affect satisfaction if absent. Indifferent Attributes do not affect customer satisfaction [20]. Using IPA-KANO, companies can identify priorities, understand customers' most important attributes, optimize product design, design products that meet customer needs and preferences, and increase customer satisfaction by focusing on the most important attributes [21]. Thus, IPA-KANO can help companies understand customer preferences and increase customer satisfaction by optimizing the technical attributes of the fibers used in the product.

## 3. Results and Discussion

### a. Analysis of Color, Physical Properties, Strength, and Fineness of Sisal

In this study, the main raw material used in making Kre Alang woven yarn is sisal fiber. The grade of sisal fiber chosen as the raw material for Kre Alang woven yarn is grade A because it is of the best quality compared to other grades and has gone through all stages, namely the wiping, sorting, and cutting process. Grade A sisal fiber is obtained from sisal farmers in Labangka District. Several types of woven yarn samples were made from sisal fiber at the Sumbawa University of Technology. The samples were then tested using FTIR at the Chemistry Laboratory of the University of Mataram, obtaining two samples of the best-woven yarn for Kre Alang weaving from fibers, namely dyed alkalinized yarn (S1P) and undyed alkalinized yarn (S1). Based on FTIR testing, both types of samples have a structure similar to the thread structure used by Kre Alang weavers[22]. Both samples were continued with a yarn tensile strength test, yarn length and diameter test, yarn brightness test, yarn color test, and yarn color degradation test to be compared with the Kre Alang woven yarn used by weavers. This test was carried out at the Bandung Textile Laboratory. The research was conducted in May-December 2024. The results of the color test of the S1 yarn sample and the S1P yarn sample are presented in Table 1.

The S1 yarn sample exhibits the highest color brightness, with an intensity value of 74.952. This sample appears

*Table 1 – Sisal Fiber Color Test Results*

| Sample | Lightness (L*) | Green/red (a*) | Blue/yellow (b*) | Chroma (C*) | Hue (h) |
|---|---|---|---|---|---|
| Weft thread | 46.753 | 25.796 | 50.153 | 56.416 | 62.781 |
| Warp thread | 46.556 | 44.516 | 47.388 | 65.020 | 46.790 |
| S1 | 74.952 | 0.358 | 20.544 | 20.560 | 88.960 |
| S1P | 27.082 | 36.728 | 16.656 | 40.332 | 24.376 |

yellowish-white, whereas the S1P yarn sample is red, the weft thread is dark yellow, and the warp thread is red. Compared to the S1P and synthetic-colored yarns, the S1 yarn is noticeably brighter. This suggests that the addition of dye tends to darken the sisal fiber. Similar findings were reported in previous studies , where it was concluded that higher dye concentrations lead to darker fabric colors due to increased dye absorption into the fiber. Investigating these color variations is important for evaluating the performance of the applied dyes.

Furthermore, lignin content plays a role in color intensity; higher lignin levels result in darker shades such as dark brown, light brown, or brownish yellow [23]. Brightness analysis of untreated sisal fiber showed an L value of 66.42, indicating a yellowish tone. A higher L value corresponds to a lighter or whiter material , with the L parameter representing the color spectrum from dark to bright[24].

Even though the S1 yarn sample records the highest L value, it shows the lowest a* value at 0.358. A positive a* value indicates a red hue[22, 19] , meaning that the S1 sample has the least red intensity. The alkalization process has altered the sisal fiber's color from white to yellowish-white and has also been found to enhance tensile strength[25]. Additionally, alkali treatment can disrupt hydrogen bonds within fibers and increase the amorphous structure of cellulose[26] . Previous studies reported that sisal fabric without a nano silver coating had an a* value of 1.89, presenting a grayish or near-white color[27] , while untreated sisal exhibited an a* value of -0.60 , with the negative value suggesting a greenish tint. The use of textile dyes has been shown to reduce the b* intensity, as seen in Table 1. Specifically, the S1 and S1P yarn samples have b* values of 20.544 and 16.656, respectively, with positive b* values indicating yellow coloration. The relationship between yellow and brightness suggests that the material appears shinier. Untreated sisal has a b* value of 23.80 [24]. Among the samples, S1 yarn appears brighter and shinier than S1P. The chrome value provides insights into the bleaching process and reflects the relationship between brightness and the material's color richness; a brighter, shinier material typically exhibits fewer colors [29]. Based on the data in Table 1, the S1 and S1P yarn samples each have a C* of 20,560 and 40,332—the S1 yarn sample. While the results of physical properties tests of sisal fiber, weft yarn, and warp thread are in Table 2.

The analysis of variation of the properties as a function of secondary heater temperature reveals several key trends. From Table 2, it can be observed that there are no significant differences in denier, tenacity, or elongation among the six samples. As the secondary heater temperature increases, tenacity shows a general decrease, with the highest tenacity observed at the lowest temperature and the lowest tenacity at the highest temperature, indicating a downward trend. BWS% also decreases with higher temperatures, suggesting reduced shrinkage. This relationship can be attributed to the fact that an increase in the secondary heater temperature leads to a reduction in the helix structure of the samples [8] . Consequently, with a reduced helix structure, the extent of BWS% also diminishes. Similarly, HCC% follows a decreasing trend, indicating less crimp contraction at higher secondary heater temperatures. Additionally, the number of snarls per meter decreases as the secondary heater temperature rises, indicating increased dimensional stability of the yarn, or formation of a more "set" yarn. Bulk shows a decreasing trend, indicating a more compact material at higher temperatures. This reduction in bulk is attributed to the heat-setting process, which causes the yarn to undergo thermal shrinkage, thereby lowering its bulk.

Table 3 illustrates that the dyeing process results in the S1P yarn sample becoming heavier, stronger, and more elastic than the S1 yarn sample. Additionally, yarn made from sisal fiber is heavier than synthetic yarns (both weft and warp threads). It is known that sisal fiber contains approximately 10.66% water [24].

The fiber matrix is made up of polymers, which are heavier than individual monomers. Polydisperse polymers consist of molecules of varying sizes, whereas homopolymers are made up of identical molecules. Natural fibers are primarily

***Table 2 - Results of Physical Properties Tests of Sisal Fiber, Weft Thread, and Warp Thread***

| No. | Test Type | Test Method* | Test Results* | | Test Method** | Test Results** | |
|---|---|---|---|---|---|---|---|
| | | | S1 | S1P | | warp thread | weft thread |
| 1 | Fineness of fiber | SNI 08-1111-1989 | | | SNI ISO 2060: 2010 | | |
| | average, Tex | | 12.51 (112.55) | 16.14 (145.30) | | 38.94 (15.20) | 19.30 (30.74) |
| | CV, % | | 13.48 | 16.61 | | 4.83 | 7.01 |
| 2 | Fiber strength per bundle | SNI ISO 105-C06:2010 | | | SNI 7650:2010 | | |
| | Tenacity | | | | | | |
| | Average, gf/Tex | | 31.85 | 23.21 | | 32.96 | 13.24 |
| | CV, % | | 15.37 | 23.75 | | 501.04 | 407.12 |
| | Stretch | | | | | | |
| | Average, % | | 3.20 | 3.90 | | 963 | 7.53 |
| | CV, % | | 13.98 | 24.66 | | | |

| No. | Test Type | Test Method* | Test Results* S1 | Test Results* S1P | Test Method** | Test Results** warp thread | Test Results** weft thread |
|---|---|---|---|---|---|---|---|
| | Colorfastness to: | | | | | | |
| | a. Washing 400C | | | | | | |
| | - Discoloration | | | 4-5 | | 4-5 | 3-4 |
| | - Tarnishing on acetate | | | 4 | | 4 | 3-4 |
| | - Stains on cotton | SNI ISO 105-C06:2010 | | 2 | SNI ISO 105-C06:2010 | 2 | 3-4 |
| | - Staining on polyamide | | | 3-4 | | 3 | 3-4 |
| | - Stains on polyester | | | 3-4 | | 4 | 4 |
| | - Tarnishing of acrylic | | | 3-4 | | 3-4 | 4 |
| | - Staining on wool | | | 3-4 | | 4 | 3-4 |
| | b. Sweat | | | | | | |
| 3 | 1. Acidic properties | | | | | | |
| | - Discoloration | | | 4 | | 4 | 4-5 |
| | - Tarnishing on acetate | | | 4 | | 4-5 | 4 |
| | - Stains on cotton | SNI ISO 105-E04:2015 | | 3-4 | SNI ISO 105-E04:2015 | 2-3 | 4-5 |
| | - polyamide | | | 4 | | 3-4 | 4 |
| | -Staining on polyamide | | | 4 | | 4-5 | 4-5 |
| | - Tarnishing of acrylic | | | 4 | | 4-5 | 4-5 |
| | - Staining on wool | | | 4 | | 4 | 4 |
| | 2. Properties of Bases | | | | | | |
| | - Discoloration | | | 4-5 | | 4-5 | 4-5 |
| | - Tarnishing on acetate | | | 4 | | 4-5 | 4 |
| | - Stains on cotton | | | 3-4 | | 3-4 | 4 |
| | -Staining on polyamide | | | 4 | | 4 | 4 |
| | - Stains on polyester | SNI ISO 105-X12:2016 | | 4 | SNI ISO 105-X12:2016 | 4-5 | 4 |
| 4 | - Tarnishing of acrylic | | | 4 | | 4-5 | 4-5 |
| | - Staining on wool | | | 4 | | 4-5 | 4-5 |
| | c. Rubbing: | | | | | | |
| | - Dry | | | 4 | | 4 | 3 |
| | - Wet | | | 2-3 | | 3 | 2-3 |

SNI 08-1111-1989: analysis of fineness of stem fibers; SNI ISO 105-C06:2010: analysis of color fastness to domestic and commercial laundering; SNI ISO 105-E04:2015: analysis of color fastness to sweat; SNI ISO 105-X12:2016: analysis of color fastness to rubbing.

composed of pectin, protein, cellulose, and lignin, with their composition influenced by factors such as climate, plant maturity, extraction methods, and botanical characteristics[28]. The appropriateness of fiber diameter is assessed using the Tex measurement, where a smaller Tex value indicates lighter and finer fibers. Deniers are another measure, reflecting the thickness of yarns used as raw materials for fabric production; specifically, 0.67 Tex is equivalent to 6 deniers [6].

*Table 2 - Test Results of Strength and Fineness of Sisal Fiber, Weft Thread, and Warp Thread*

| Parameter | S1 | S1P | Warp Thread | Weft Thread |
|---|---|---|---|---|
| Weight (g) | 0.056±0.008 | 0.073±0.012 | 0.008±0.000 | 0.015±0.001 |
| Tex | 12.506±1.686 | 16.144±2.681 | 15.201±0.740 | 30.741±2.073 |
| Denier | 112.552±15.175 | 145.300±24.133 | 38.943±1.880 | 19.301±1.353 |
| Strength (KP) | 4.980±1.167 | 5.280±1.261 | 17.820±1.881 | 42.200±4.203 |
| Stretch (%) | 3.200±0.447 | 3.900±0.962 | 7.128±0.753 | 16.880±1.681 |
| Heavy | 2.334±0.460 | 3.446±0.736 | 501.040±48.253 | 407.120±30.650 |
| Tenacity (g/tex) | 31.851 | 23.214 | 32.961 | 13.244 |

Fiber weight (mg); yarn weight (g)

Additionally, the tenacity value represents the fiber's resistance to breaking[29]. The S1 yarn sample is finer, thinner, and less resistant to breaking compared to the S1P sample. According to Table 3, sisal fiber exhibits higher weight, denier, and tenacity compared to synthetic fibers.

**b. Kre Alang Weaving**

So far, there are three types of yarn as raw materials for making Kre Alang weaving: weft yarn, warp thread, and gold thread. From the two types of yarn samples from sisal fiber that were analyzed, based on the results of the FTIR test, it was obtained that dyed alkalized sisal yarn (S1P) can be used as weft yarn in making Kre Alang weaving. These results are supported by discussions from Kre Alang weavers that S1P yarn is suitable for use as weft yarn, while warp thread and gold thread still use the yarn the weavers have used. Furthermore, S1P yarn is produced in large quantities consisting of 4 colors: black, red, blue and yellow (Figure 1.a). The yarns are distributed to weavers to produce several Kre Alang weavings to be exhibited to the public; the aim is to find out the opinions of visitors to the exhibition on the attributes that need to be maintained and improved to maintain public satisfaction with Kre Alang weaving from sisal fiber yarn. The Kre Alang weaving process uses threads from sisal fiber as the weft thread and one of the Kre Alang weaving results with a combination of SIP yarn is shown in Figure 2.a.

a

b

*Figure 2 – The weaving process (a) and the results of Kre Alang weaving from sisal fiber (b)*

**c. Integration of Science Methods and KANO Model**

The respondents in this study were attendees of the Kre Alang woven fabric exhibition, which included cultural figures from Sumbawa, community leaders, weavers, Kre Alang consumers, teachers, lecturers, students, and others. A total of 110 questionnaires were distributed, all of which were completed and deemed valid for analysis. The IPA method was used to categorize the respondents' suitability levels on a Cartesian diagram. The suitability measurement focused on the quality of the Kre Alang weaving (Figure 2.b) made from a combination of sisal fiber yarn as the weft thread. One of the motifs produced was a combination of the Gili Liuk and whale shark motifs [32]. The attributes of Kre Alang weaving, listed in Table 4, were used to assess the performance and importance of these attributes. Respondents rated each attribute on a scale from very important (5) to very not important (1). The questionnaire data were processed using equations (1) and (2) to calculate the performance, importance, and confidence level values for each attribute of Kre Alang weaving made from sisal fiber yarn, as shown in Table 4.

The average value of the importance level and performance level of the quality of Kre Alang weaving from sisal fiber yarn that has been obtained in Table 4 shows that the level of conformity between the level of satisfaction and the importance of the largest results obtained is 40.45%, which is included in the very good category, but from 40.45% of customers, there are still 59.55% of customers who consider Kre Alang woven fabric from sisal fiber not to be by customer desires or expectations, Then, the data in Table 4 is described in a Cartesian diagram, as shown in Figure 3. Sisal is a type of natural fiber that is often used in textile production, including weaving. The tensile strength and elasticity of the sisal can affect the durability of the weave in everyday use. The high tensile strength of sisal can make the weaves more resistant to damage due to pulling or friction. This can increase the durability of the wages and make it more durable in everyday use. The good elasticity of sisal can make the weaves more flexible and withstand changes in shape without being damaged. This can make the weaves more comfortable to use and more resistant to damage due to everyday use. However, keep in mind that sisal also has several weaknesses compared to other raw materials, such as limited tensile strength when compared to several other types of fibers. In addition, its sensitivity to moisture can affect its strength and elasticity[30].

Based on Figure 3, four attributes of Kre Alang weaving using sisal fiber yarn fall into the second quadrant, indicating that quality (code 1), strength (code 3), selling price (code 7), and color combination (code 10) meet consumer expectations, resulting in a relatively high level of satisfaction. Therefore, these attributes should be preserved, as they are considered strengths from the consumers'

*Table 4 - Level of Conformity of Woven Fabric Attributes from Sisal Fiber Yarn*

| Indicator | Attribute | Code | Performance | Importance | TK |
|---|---|---|---|---|---|
| Performance | The quality of Kre Alang woven fabric is made from sisal fiber yarn . | 1 | 1.22 | 4.90 | 24.90% |
| | Defects in Kre Alang woven fabric made from sisal fiber yarn. | 2 | 1.80 | 4.45 | 40.45% |
| | Strength of Kre Alang woven fabric made from sisal fiber yarn. | 3 | 1.48 | 4.65 | 31.83% |
| Features | Innovation in the design of Kre Alang woven fabric made from sisal fiber yarn. | 4 | 1.62 | 4.56 | 35.53% |
| Reliability | Density of Kre Alang woven fabric made from sisal fiber yarn. | 5 | 1.33 | 4.55 | 29.23% |
| | The smoothness of Kre Alang woven fabric is made from sisal fiber yarn. | 6 | 1.77 | 4.39 | 40.32% |
| Conformance to specifications | The market price of Kre Alang woven fabric made from sisal fiber yarn aligns with its quality. | 7 | 1.53 | 4.65 | 32.90% |
| Durability | Colorfastness of Kre Alang woven fabric made from sisal fiber yarn . | 8 | 1.73 | 4.39 | 39.41% |
| Aesthetic | Variety in the selection of Kre Alang woven motifs made from sisal fiber yarn. | 9 | 1.56 | 4.55 | 34.29% |
| | A combination of colors in Kre Alang woven fabric is made from sisal fiber yarn. | 10 | 1.38 | 4.59 | 30.07% |

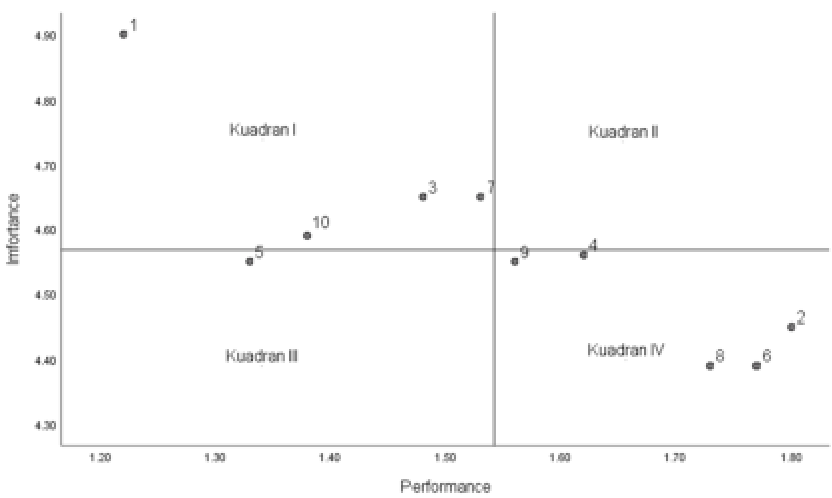



*Figure 3 - Kre Alang woven are a combination of weft thread from sisal fiber yarn*

perspective. Consumers view the density of Kre Alang weaving (code 5) made from sisal fiber as less important, as it falls into the third quadrant. As a result, weavers may want to reconsider focusing on this attribute since it has a minimal impact on the benefits perceived by consumers. On the other hand, attributes such as defect characteristics (code 2), innovation (code 4), smoothness (code 6), color fastness (code 8), and motif variety (code 9) are seen by consumers as excessive, being placed in the fourth quadrant. Therefore, weavers could scale back efforts on these aspects to help reduce production costs.

*Table 5 - KANO Category Mapping*

| Attribute Code | O | A | M | I | R | Q | O+A+M | I+R+Q | Category Kano |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 33 | 51 | 7 | 11 | 1 | 7 | 91 | 19 | A |
| 2 | 28 | 19 | 27 | 26 | 6 | 5 | 74 | 37 | O |
| 3 | 30 | 44 | 10 | 16 | 5 | 5 | 84 | 26 | A |
| 4 | 23 | 35 | 17 | 26 | 4 | 5 | 75 | 35 | A |
| 5 | 22 | 58 | 1 | 18 | 3 | 8 | 81 | 29 | A |
| 6 | 16 | 40 | 13 | 27 | 10 | 4 | 69 | 41 | A |
| 7 | 39 | 38 | 10 | 14 | 8 | 1 | 87 | 23 | O |
| 8 | 28 | 36 | 8 | 22 | 9 | 7 | 72 | 38 | A |
| 9 | 25 | 42 | 2 | 28 | 7 | 6 | 69 | 41 | A |
| 10 | 46 | 40 | 8 | 8 | 3 | 5 | 94 | 16 | O |

Where: Must be (M); One dimensional (O); Attractive (A); Indifferent (I); Reverse (R) dan Questionable (Q).

The attributes of Kre Alang weaving contained in Table 4 are divided into two types of questions, namely regarding the respondents' opinions if the service attributes are fulfilled (functional) and if the service attributes are not fulfilled (dysfunctional). Each attribute has five answer choices, namely like (weight 1), expect (weight 2), neutral (weight 3), tolerate (weight 4), and dislike (weight 5). Furthermore, the questionnaire data was analyzed using KANO category classification from functional and dysfunctional data for each attribute presented in Table 5.

Each respondent's response is grouped into A, O, M, I, R or Q. The following rules determine the KANO category grouping for each attribute: If (O+A+M) > (I+R), then the woven fabric category is max {O, A, M}. If not, the KANO category for the woven fabric attribute is max {I, R} . The results of the KANO calculation and categorization recap can be seen in Table 5. Therefore, there are two Kano categories produced, namely:

i. Attractive (A): This indicates that consumer satisfaction with Kre Alang woven fabric made from sisal fiber yarn will significantly increase as the quality (code 1), strength (code 3), innovation (code 4), weaving density (code 5), smoothness (code 6), color fastness (code 8), and motif variety (code 9) of the fabric improve. However, a reduction in the performance of these attributes will not lead to a decline in consumer satisfaction.

ii. One dimensional (O): This indicates that consumer satisfaction with Kre Alang woven fabric made from sisal fiber yarn is directly proportional to the extent of weaving defects (code 2), the alignment of the selling price with the quality of the fabric (code 7), and the appeal of the color combinations in the weaving (code 10).

The outcomes of the IPA-KANO integration offer insights for developing strategies for weavers, focusing on the attributes of Kre Alang woven from sisal fiber yarn that should be enhanced or preserved to better align with consumer satisfaction and improve weaving quality. Table 6 displays the analysis results using the combined IPA and Kano methods, based on the assessments provided by respondents/consumers regarding the quality of Kre Alang woven from a combination of sisal fiber yarn.

Based on Table 6, five categories resulted from the IPA-Kano integration to increase consumer satisfaction with the Kre Alang woven fabric made from sisal fiber yarn quality.

- Dusty Diamond: this category has a low assessment level but high consumer expectations. In the KANO model, this attribute is included in the attractive category (A), so the quality and strength attributes of Kre Alang weaving from sisal fiber need to be improved in performance.

- Supportive Weapon refers to the category of Kre Alang woven fabric made from sisal fiber yarn that is free of defects and can serve as a supplementary asset when compared with woven fabrics from other regions. However, it is seen as having a limited impact. This is because this attribute already has a high level of performance, while the level of consumer expectations is low. Meanwhile, based on the Kano model, consumers will be disappointed if this attribute is not met properly. For this reason, this attribute is a priority whose performance needs to be maintained.

- Beginning Jewelry refers to attributes like design innovation, weaving quality, color fastness, and the variety of motifs in Kre Alang weaving made from sisal fiber, which are the foundational elements that could become valuable assets. This attribute already has a high level of innovation, fineness, durability and motif variations, even though consumer expectations are low. If this attribute is not met, consumers feel ordinary. For that, this attribute is a priority that needs to be maintained in its performance.

- Rough stone means that the Kre Alang weaving density attribute from sisal fiber yarn has a relatively low attraction and needs to be polished to increase the category, which affects increasing consumer satisfaction. This attribute has the same low level of performance and expectations. In addition, it is also included in the attractive category so that if performance improvements

*Table 6 - Integrasi IPA-Kano*

| Attribute Code | IPA Category | KANO Category | IPA-KANO | Strategic Priorities | Description |
|---|---|---|---|---|---|
| 1 | I | A | Dusty Diamond | Upgrade | Selection of quality raw materials, proper fiber processing . |
| 2 | IV | O | Supportive Weapon | Keep it up | Gentle washing, proper drying, proper storage, use of protective clothing. |
| 3 | I | A | Dusty Diamond | Upgrade | Use quality sisal fiber, proper fiber processing . |
| 4 | IV | A | Beginning Jewelry | Keep it up | Technology development, collaboration with designers . |
| 5 | III | A | Rought Stone | Upgrade | Use of thick yarn, use of tight weave. |
| 6 | IV | A | Beginning Jewelry | Keep it up | Proper fiber processing, use of fine yarn. |
| 7 | I | O | Defenseless strategic point | Upgrade | Improving product quality, building a strong brand. |
| 8 | IV | A | Beginning Jewelry | Keep it up | Use quality dyeing, a proper dyeing process. |
| 9 | IV | A | Beginning Jewelry | Keep it up | Development of new designs, use of diverse. |
| 10 | I | O | Defenseless strategic point | Upgrade | Use harmonious color palettes, a combination of contrasting colors. |

are made, it will not affect consumer satisfaction. For that, this attribute is a priority that can improve its performance.

- Defenseless strategic point, meaning that the attributes contained in Kre Alang sisal fiber weaving, such as price according to quality and attractive weaving color combinations, can become weak points so that if attacked, it can have fatal consequences in consumer dissatisfaction. Therefore, attributes in this category must be able to be handled for improvement. According to consumers, this attribute has a low level of assessment and high expectations to be improved. This attribute is a priority to be improved because, based on the KANO model, it is included in the One-dimensional category.

## 4. Conclusion

Alkalized fiber exhibits a bright and shiny appearance. The dyeing process darkens the fiber, as observed in the mechanical properties of sisal. Undyed sisal is smoother, thinner, and more durable compared to its dyed counterpart. Overall, the mechanical properties of sisal yarn are still weaker than those of the synthetic yarn typically used by weavers. There is a need to enhance the strength of the fiber. Sisal fiber is locally available in Sumbawa and has the potential to be a valuable natural resource.

The sisal fiber yarn selected as the raw material for making Kre Alang weaving is sisal yarn that has been dyed with alkali (S1P), which is used as the weft yarn and then combined with warp thread and gold thread that weavers have used to weave into several sheets of Kre Alang woven cloth. The evaluation results using the IPA-KANO integration are based on the perceptions of the Kre Alang weaving exhibition participants that the research team has carried out. The evaluation results show that 5 Kre Alang weaving attributes from sisal fiber yarn are in the quadrant I: code 3, code 7, and code 10. The weaving attribute in quadrant III is code 5. The weaving attribute in quadrant IV is code 2, code 4, code 6, code 8, and code 9. Of the 10 quality attributes of Kre Alang weaving studied, seven weaving attributes are included in the attractive category, and three other attributes are included in the one-dimensional category. Five problematic attributes were obtained based on the categorization by integrating the Importance Performance Analysis method and the Kano model. The problems must be minimized to increase consumer satisfaction with Kre Alang weaving from sisal fiber. Among them are the quality of the woven fabric in the Dusty Diamond category, the strength of the woven fabric in the Dusty Diamond category, the density of the weave in the Rought Stone category, the price according to the quality in the Defenseless Strategic Point category and the combination of weave colors in the Defenseless Strategic Point category. The attributes that need to be maintained are defects, innovation, smoothness, color fading, and diversity of weaving motifs.

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**Avinash Mayekar**

Mr. Avinash Mayekar, Textile Engineer from VJTI, Mumbai, MD of SUVIN has more than 3 decades of experience working in consulting firms and various textile companies of India. He has completed many assignments such as Business strategies, Advisory services, Project management, Modernization Studies, etc. He is one of the rare consultants cognizant on most of the reputed technologies for technical textiles and was instrumental in promoting technical textiles in India for past 20 years as a subject matter expert.

His expertise lies not only in technical skills but in overall textile project conceptualization to implementation. His main specialization lies in Strategy building, Business Process Re-engineering and Technical textiles. This in depth & vast knowledge comes from his choice of choosing varied job profiles at Gherzi, A.T.E. group, Technopak and Mafatatlal group. This has enabled him to implement innovative skills and do something different at each and every stage of life.

Working with reputed global consulting firms, he has gained huge overseas experience for textile technologies, plant and machinery related projects. He has been attending INDA exhibition (IDEA) in USA & EDENA exhibitions in Switzerland on Technical Textiles in USA since 2007. He also, participated in the exhibition IDEA 2016 in Boston, USA.

He is a renowned speaker and has presented many innovative technological concepts in International & National conferences. He is on advisory board & regular writer in various reputed publications. He has extensively worked for textile, food and exhibition industry.

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# Export growth…Mission India!!! Step out of the comfort zone and venture into the growth zone…

**Avinash Mayekar,**
Managing Director, SUVIN

Suvin are on the verge of completing 15 years of consulting services, witnessing the swing ride of our textile industry as it jumps high, falls back, and again rises to the very top. I thought it was time to share the wisdom I have gained with my dearest textile industrialists about the extraordinary businesses that are growing today by taking the leap and trying out-of-the-box strategies.

The geopolitical dynamics, UK FTA, upcoming US tariff, in pipeline EU trade policy, sustainable solutions, and the pragmatic Chinese impact, etc. are all the phenomena that are expected to change the tides for favourable manufacturing in India. New opportunities are opening up. In case of textile industry, shifting of manufacturing units to India has not yet materialized into a scalable opportunity, or are we lagging in grabbing the opportunity?

Today, Suvin have the best of the technologies at our disposal, there is no longer a dry patch as far as innovation is concerned. Accelerating production, cutting-edge technology, Innovative product portfolio, and circular economy, 360 degrees of sustainability, traceability and Customer focus are the few most looked at terms for textiles today. So, what's holding us back? I feel as textile entrepreneurs there is always a risk associated with trying new and being pioneers that is where our big foot falls short.

Suvin is simply the best at following innovation and finding practical multiple uses for these innovations. However, the monopoly fear of being the First to fall is always what keeps the foot small. And the strategy has played in our favour for decades. But now the era is different today be the change and invest in appropriate strategy and decide your product portfolio.

The Indian government is introspecting the risk factor and has taken right steps to go a long way and bring in favourable FTAs. These FTAs are going to be our shield in trying out something new with a calculated risk factor. The government has come up with a solution for safeguarding the interests of the textile Industry.

India's first FTA with a European bloc (Iceland, Liechtenstein, Norway, and Switzerland) - India-EFTA TEPA is the first to include commitments on trade and sustainability, investment, and employment generation. India has also recently signed an FTA with the UK, this agreement aims to double bilateral trade to $120 billion by 2030 and includes tariff reductions on 90% of British products, with 85% becoming tariff-free within a decade. The agreement is expected to boost Indian exports in sectors like textiles, toys, jewellery, and auto parts. Apart from this Indian government is also currently negotiating FTAs with several other regions and nations, including New Zealand, the US, the EU, Oman, Peru, Qatar, and Sri Lanka. All these FTAs will be our express ticket toward the growth and increase our exports substantially.

As an entrepreneur, one should always be on the watch to venture into a product with attractive & consistent demands that reap high profit margins at minimum project cost. Many times, instead of looking around and exploring what the market demands, we tend to oversee things that are trending in the market and follow the trend that is already flourishing. Just take the example of sustainability; for many years there have been talks about adopting sustainable practices, but it is today that everyone is on their foot to get things done to be a sustainable producer. Taking forward this attitude of doing at the bare necessity, we might stay in the race but never be the front runner to grab the golden opportunity.

Let us talk about trends of today with great potential. Today bio-based fibres, revolutionizing Meditech innovation, traceability, and global standardization are the concepts that are creating a space for themselves. It is still a niche area as far as the production scale is concerned. But today's niche space is tomorrow's biggest market.

**Recycled Fibres**

Global brands are encouraging their customers to wear/use recycled products through a buy-back mechanism. Recycled fibres are being promoted by brands in their high-range product portfolio as their policy for commitment to Mother Earth. It also reduces operating cost for manufacturing same product as in most of the cases recycled fibres are cheaper than the virgin fibres Currently, there is a lot of taboo for using pet bottle fibres, but the dynamics of circularity have strong questions on its recyclable tag since it is not initially part of the value chain and also the endless dump of textiles remains untouched with it. So, the true textile recycled fibres will have scope not only for readymade garments but also in home furnishings and many upcoming technical textile applications. Many innovative & cost-effective products also can be generated by using recycled fibres. The way there is currently a big demand for recycled fibres in the clothing industry there will be a great demand for recycled fibres even in the technical textile industry in future.

**Standardization & QCO Mandates**

Though the pandemic has seen many emerging players in Meditech there were no clear-cut specifications maintained by many players which resulted in poor quality of usability of the product be it a PPE kit or a simple mask shield. This is why harmonized standards for hygiene products are being developed by the EDANA. It has designed a program that lists the requirements the industry must meet. The government of India has also led many QCOs for technical textile products in recent times. Also, the Ministry of Textile under Govt of India has prepared a Quality Control Order in respect of the 12 textile goods for compulsory use of Standard Marking. There is no going around way for it and best practices often create exceptional products giving you the open market access for high-quality products. Hence it is important to look around, think, and introspect to grab and adopt the technology, and innovation that will be the driving force for the future.

**Traceability**

Traceability and accountability are the complete package today. They are to be followed for export markets and adoption is the best way forward.

**Disposable Home Textiles**

The use of nonwoven technology in home textiles will give a different dimension to this segment by reducing extensive use of dyes and chemicals and we can use mechanical patterns produced by nonwoven technologies like needle punching etc. Disposable textiles using no dyes & chemicals can be used especially in Hospitals, hotels & offices thus contributing a small share for saving the environment.

Similarly, spunlace curtains can take care of the aesthetic look of the fabric having the inherent capability of creating various structures & patterns that can be embossed on the fabric. Thereby the manufacturing cost of the curtains can be minimized drastically by using spunlace technology. So, the curtains which were once being used for years can now be replaced after identified occasions or events due to the price benefits and even additional set of curtains can be kept to replace them alternatively the raw material required for producing curtains using spunlace technology can also be the by-products of textile industry like spinning waste. So, the cost incurred on raw materials using spunlace technology is much lower as compared to woven curtains. Similarly, the entire spinning weaving & then fabric processing i.e. bleaching & dyeing technologies will be eliminated as the fibres will be directly converted to fabric by using the spunlace technologies.

**Smart Textiles**

They have been in the niche market for a long run but some promising technologies being developed year on year are driving its growth. Noble Biomaterials' Circuitex range of yarns, fabrics, tapes, foam, and wallpaper provides lightweight, flexible conductivity and EMI shielding. This enables additional protection to military personnel allowing them to remain virtually undetectable to enemy advanced sensors. Many such innovations are happening all around us. Some might be the best fit with our existing product portfolio; some might not be. Some might be a replacement for our product. So, to look, observe, and introspect should be our continuous mantra before going forward.

**Global Branding:**

Today there is a lot more to branding than the conventional ways of obtaining celebrity footfall and mere advertisements. Today the branding dynamics are far superior and complex. It is about talking, making your presence heard in every situation world around. Positive Branding can take you a long way and similarly, one single negative narrative can tear you down hence it is the game of being committed to your loyal customer base, community, society, and Mother Earth. Also, branding can take mere products to iconic style statements. Take the example of the recent fashion showstopper "Indian Jhoola bags". A high-end American department store, Nordstrom, is now selling what it calls the "Indian Souvenir Bag" for a staggering $48 (approximately ₹4,100). Produced by Japanese brand Puebco, the product is advertised as a creative, repurposed piece with a global flair. This is the classic example of creating brand talk for everyday products and taking the utmost opportunity from it.

India has to understand things happening now are different from the way things happened in the past. All brands are eyeing getting the final product. All technical textile products are the demands of not just the global market but of our domestic market as well. However, just producing a part of the final product and letting the Western world grab the higher margins on the finished products will not take us anywhere. We need to identify products with our experience and keep an eye on the complete development of the textile value chain. We need to take care of not just the technology, but also all aspects from production, quality, and social compliance to competitive marketing with certifications. Also, look at the scale of operation and select the appropriate technology, where we can be competent.

Now I think the time has come to introspect ourselves and think on

- What am I doing differently? Am I producing products for the future?
- Which are the opportunities right now in front of me?
- How I can do something different not from the mere point of view of earnings and more profits but also a long-term recognition in a niche area and with sustainability.
- Which market I am currently catering and which market do I wish to capture?
- Have I done market research properly? What is my SWOT analysis?
- Let us take an example if at all I am a regular spinner,
  - Have I over the years introduced something new to my product portfolio?
  - Whether I am trying something different? What my customers are using my yarn for?
  - What is my customer demanding additionally?
  - Is it use of recycled fibres? if so, do I have the technical capability to produce them
  - Finishes for technical performance capability- can I straightway introduce it?

Is there any possibility of introducing the innovative practice, product, or process to my regular ways? This is essential because if there is another way and some competitor is already doing it then doing extremely hard work to control operating costs and just compete will be the only option available with a simple yarn manufacturer. Simply following the four generations' products and being in the market or scaling up the production capacity is not enough. When many spinners are producing the same yarn as I am doing then it is difficult for me to survive in the long run. Simple and small innovations if not looked out for can soon lead one to be out of the race very soon.

So, the mindset needs to be developed wherein small changes matter, the next generation should especially look out for the right small change that will make a huge difference in the not-so-far future. The conventional textile players should also eye the big avenues i.e. technical textiles which are available right in front of us. How, when, in what, and how much investment are the key questions for which answers must be sorted out. Especially look out for investments that are to be made only for introducing new product lines, innovations, or new processes that will altogether change the efficiency scale. Time is "now" or never…

Conclusion

A few of the things that are easily available for bringing into practice are the adoption of techniques for recycling fibres introducing new product variants, and adopting renewable energy resources this will make a huge difference in margins as it brings down the cost of production, thorough retrospection of what one is doing. Change is the answer for all of us.

All of the textile entrepreneurs are well aware of the above needs, however, out-of-the-box thinking needs to be practiced, great minds are also on the lookout however what is missing is the "Implementation" Two more steps are where it all falls short. Of course, this is because the existing knowledge base has many other job roles to look out for, the usuals have them all packed up, and also as the world knows there are limitations to the knowledge. But to be the front runner complete out-of-box thinking is needed further than this. It is a must to have a market study that backs the thinking approach.

**A detailed study that answers**

- Detailed SWOT Analysis
- The demand and supply needs of domestic and global markets
- The techno-commercial analysis of the existing setup
- Adopting "Atmanirbhar Bharat" as a golden mantra
- New innovative market segment adaptation
- Introduction to Social compliance, green culture
- Profitability projections for future
- New production portfolio
- Road map for success

These are the areas that Suvin needs to look into for better prosperity and long-lasting business philosophy. Suvin is ready to hand hold for all the requirements to grow the exports in this changing global scenario. Specialised advisory services of Suvin will certainly help in achieving dreams in the global horizon.

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# Mumbai UNIT

## 30th May, 2025

The Textile Association (India), Mumbai Unit successfully organized a special ceremony on Friday, 30th May, 2025 to felicitate Dr. G. V. Aras on his receiving an honorary Doctorate degree from prestigious French University Ecole Superieure Robert De Sorbon.


The function was held at TAI, Mumbai Unit Office. It was a tribute to Dr. Aras's decades of impactful contributions to the textile and apparel industry. Rajiv Ranjan, President, TAI, Mumbai Unit, welcomed the members of the audience and said in his address that it was an honour to felicitate Dr. G. V. Aras on receiving a well-deserved Honorary Doctorate in recognition of his extraordinary four-decade-long contribution to the Indian textile industry. From a gold medalist in Textile Engineering to his transformative leadership as Director at A.T.E. Enterprises Pvt. Ltd., Dr. Aras has been a bridge between Indian industry and global technology. A mentor, policy advisor, and passionate advocate for education and ethics, his service extends from boardrooms to classrooms. His dedication is also reflected in his cultural pursuits, especially in Marathi literature. The felicitation ceremony celebrate not only his achievements, but the values and vision he continues to inspire across generations. In his address at the felicitation ceremony, Dr. G.V. Aras reflected on the destined path that led him to the world of textiles.

Though his initial ambition was to pursue Chemical

Engineering, destiny guided him toward Textile Engineering at VJTI, Mumbai - a decision that would shape the course of his illustrious career. He spoke warmly about his journey spanning over four decades at A.T.E. Enterprises Pvt. Ltd., where he began as a young Sales Engineer after completing


his M.Tech, eventually rising to the position of Director.

Dr. Aras attributed his professional growth not just too hard work and perseverance, but to the unwavering support of his colleagues at A.T.E., his professors, and numerous well-wishers from across the textile industry. Now an accomplished thought leader and mentor,

Dr. Aras continues to play a pivotal role in guiding the sector's future. In his capacity as an Independent Director, he currently serves on the boards of six companies, contributing his rich expertise and vision to further strengthen the industry's foundation. V. C. Gupte, Chairman of the Textile Association (India) – Mumbai Unit, delivered a brief yet heartfelt address, highlighting Dr. G. V. Aras' invaluable contributions as a Trustee of the Association. He commended Dr. Aras for playing a pivotal role in the successful organization of the Association's annual conferences over the years.

As Conference Chairman in recent editions, Dr. Aras not only helped curate impactful themes and select distinguished

speakers but also ensured that the events were financially sustainable - a testament to his strategic acumen and dedication to the cause. Mr. Gupte extended his warm wishes to Dr. Aras on receiving the honorary doctorate and expressed confidence that the Association would continue to benefit from his guidance and unwavering support in the years ahead.

Several distinguished members of the textile fraternity - including M/s. Shahani, Zope, Sanjay Chawla, Bhide, Sur, and others - fondly recalled their enriching interactions with Dr. Aras over the course of his remarkable journey. Haresh B. Parekh, Hon. Secretary, TAI, Mumbai Unit proposed the Vote of Thanks.

The function was a great success with a packed conference hall



## From Fabric to Function: Innovation that Moves with You

In a world where textiles are expected to stretch, breathe, flex, and perform without compromising on comfort or sustainability the role of bonding technologies has evolved from silent supporter to critical enabler. At the center of this transformation stands Henkel, bringing cutting-edge adhesive innovations that help redefine what's possible in apparel engineering.

Whether it's seamless activewear that moves fluidly with the body or weather-resistant outdoor gear built for endurance, Henkel's Technomelt portfolio is engineered to deliver high-performance bonding solutions tailored for modern textile needs. From PUR hotmelts to bio-based variants and fast-curing systems for both non-sewing and lamination applications, our solutions offer exceptional wash durability, elasticity, thermal resistance, and skin-contact comfort. Designed to complement the technical fabrics used in athleisure, intimates, and outdoor apparel, Technomelt ensures that every bond remains intact through motion, moisture, and time while offering unmatched process efficiency for manufacturers.

But innovation of this kind doesn't happen in isolation. It comes from the DNA of a company that's been trusted for over 145 years across sectors and continents. Henkel Adhesive Technologies is the global market leader in adhesives, sealants, and functional coatings, operating in more than 120 countries with a portfolio that serves over 800 industry segments. With state-of-the-art production facilities, globally harmonized R&D, and region-specific technical service teams, Henkel brings the scale of a multinational with the agility of a boutique solutions provider. As part of our Sports & Fashion division, our textile technologies are certified by bluesign® and designed to meet the most demanding industry standards supporting our broader mission to drive sustainable transformation in every layer of the supply chain.

What truly sets us apart, however, is not just the chemistry in our products it's the chemistry we build with people. At Henkel, we believe that long-term value is created through partnership, not just performance. Our teams work closely with brands, OEMs, and supply chain partners to co-develop solutions, improve design-to-delivery timelines, and elevate product functionality from concept to consumer. Through fashion ideation workshops, application engineering support, and a culture of collaborative innovation, we ensure our customers aren't just equipped to meet market demands they're prepared to shape them.
Because at Henkel, we're not just bonding fabrics we're bonding futures.

***For more details, please contact:***
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## Excellence in Denim Manufacturing with a Rieter Ring Spinning System

Soorty, one of Pakistan's largest denim producers and exporters, is on a mission to produce denim yarn sustainably. The company's new Rieter ring spinning mill ensures high raw material yield, low energy consumption, and efficient processes, driving maximum sustainability in ring spinning.

Soorty's ring spinning mill is fully equipped with Rieter technology, covering the entire spinning process from bale to package. The company's spinning system enables Soorty to produce high-quality ring yarns while maintaining low energy consumption. Key innovations, such as the high-performance card C 80, allow for increased production while using fewer resources.

*Haris Kazi, Director of Simag Enterprises, Rieter's representative in Pakistan visiting Soorty spinning mill*

The spinning mill operates 20 ring spinning machines G 38, running at spindle speeds between 12 000 and 18 000 rpm. These machines provide easy handling and high flexibility, particularly in the production of slub yarns with various effects, making them well-suited for denim fashion. The winding machine Autoconer X6 further improves downstream efficiency by delivering high package quality, reducing energy consumption, and optimizing processes through advanced monitoring.

Soorty is recognized as a leader in Pakistan's textile industry and is committed to sustainable denim manufacturing. Find out in the video why Soorty and Rieter are the perfect fit for sustainable ring yarn manufacturing.

*Soorty Denim Manufacturing with Rieter Ring Spinning System, QR*

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# Dr. M. S. Parmar, eminent Textile-Scientist has taken over as Director General of NITRA

The preventive repair also reduces idle drums and downtime due to unexpected component failures, making it a smart investment for customers aiming to enhance the performance of their machines. Leading spinning mills like Sudhan Spinning Mills Pvt Ltd. in India have already implemented this solution, achieving a 10% increase in efficiency (Fig. 3). Issues like red lights and programming faults have decreased significantly, further boosting productivity and machine longevity.

"We have completed on-site preventive repairs for our 13 Autoconer 338 winding machines. The machine efficiency has improved resulting in increased productivity as expected. Thanks to Rieter for extending the machine's lifetime," says S Jayaraja Perumal, Chief General Manager, Sudhan Spinning Mills Pvt Ltd., India.

**The advantages of on-site repairs**

On-site preventive repairs are an economical solution for customers, as they save time and cost associated with transportation while reducing production loss. Rieter repair service engineers perform the repairs, bringing the necessary know-how, special tools and equipment to each site. The use of state-of-the-art equipment with original repair components extends the lifetime of the machine. Additionally, during the on-site repair work Rieter repair service engineers identify and address operational issues. They also provide essential training to operators to ensure maximum utilization of the machine.

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# First ITMA Sustainability Forum to feature European Commission Keynote Speaker

In response to mounting global regulations and the push for a circular economy, CEMATEX (the European Committee of Textile Machinery Manufacturers) is launching ITMA Sustainability Forum: Accelerating the Green Transition on 30 October at Singapore Expo.

The half-day forum is designed to help textile and garment manufacturers, particularly from South and Southeast Asia and the Middle East, navigate the European Union's evolving sustainability regulations, and access to green financing opportunities to support their transition.

Held alongside ITMA ASIA + CITME, Singapore 2025, the forum brings together EU policymakers, financial institutions, and industry leaders to facilitate cross-border dialogue and knowledge exchange.

Mr. Alex Zucchi, President, CEMATEX, said: "Sustainability has become a global priority. The textile industry must act swiftly to modernise production in line with regulatory demands and growing consumer expectations. This forum provides a much-needed platform for manufacturers to better understand the EU's legislative landscape and the financing tools available for sustainable growth."

A key highlight of the forum will be the keynote presentation by Ms. Kristin Schreiber, Director, European Commission DG GROW. She will provide a comprehensive overview of the EU's sustainability roadmap and upcoming regulations driving the shift towards circular textile production.

Ms. Schreiber said: "South and Southeast Asia are vital players in the global textile value chain. Many producers in these regions export to the European market, and their ability to align with upcoming requirements will be critical to a successful and inclusive transition. I look forward to exchanging perspectives at this forum on how we can collaborate globally to build a more sustainable and resilient textile industry."

Under the EU Strategy for Sustainable and Circular Textiles, by 2030, all textiles placed on the EU market must be durable, recyclable, largely made from recycled fibres and free from hazardous substances. Manufacturers worldwide must act now to meet these requirements and remain competitive.

**Programme highlights**

- **Shaping Sustainability: Responding to EU Policy Changes**

Moderator: Ms. Nicole van der Elst Desai, Founder, VDE Consultancy

Speaker: Mr. Robert van de Kerkhof, CEO, ReHubs

- **Profit Meets Purpose: Financing Sustainability**

Moderator: Mr. Brandon Courban, Senior Advisor (Climate), Openspace Ventures

Speakers:

- o Dr. Rene Van Berkel, Senior Circular Economy Expert, Switch Asia, EU Policy Support Component
- o Ms. Iris Ng, Head, Emerging Business & Global Commercial Banking, OCBC Bank
- o Mr. Michael Rattinger, Senior Climate Change Specialist, Asian Development Bank

Singapore Fashion Council, the official association for the textile and fashion industry in Singapore, is the programme partner of the forum organised by ITMA Services.

Registration details
The forum is open only to ITMA ASIA + CITME, Singapore 2025 exhibitors and visitors. The delegate fee of S$35 includes two networking coffee breaks. To register, please visit www.itmaasiasingapore.com.

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# Pankaj Shukla Honoured for Extraordinary Loyalty at Zydex Industries

Four senior ex-members were recently honoured for their 'Extraordinary Loyalty' and pioneering efforts and support in the progress of Zydex Industries. Pankaj Shukla (Marketing), Nitin Shah (Production – Manufacturing Plant), H. R. Vishwanath, (Policy & Strategy) and Vinu Patel (Accounts), were presented with the Lifetime Achievement Award during Zydex Industries Silver Jubilee Function.

It was a Silver Jubilee Celebration of Zydex Industries, completed 25 years. The function was held in Vadodara, Gujarat on February 1, 2025 in the evening and 1,500 + Zydex Industries staff, families, well-wishers attended the gathering.


*Mr. Pankaj Shukla receiving award by hands of Dr. Ajay Ranka, M.D.*

Explaining his role at the company and its significance, Pankaj Shukla, said, “I was with Zydex since its inception in the year 1997. I did the foundation work and established the products in market. I developed the business all over India. All this foundation work, business development and image building of Zydex was done with extraordinary loyalty. During this tenure with Zydex, the initial efforts on the R&D for the well-known 'K2' water-based ink for garment printing was done by me.

I discovered new application of polyester resin for non-textile. I worked closely with Dr. Ajay Ranka, Managing Director of Zydex for more than 20 years with this mindset and approach.”

Established in 1997, Zydex is a specialty chemicals company with the purpose of innovating to create a sustainable world through conservation of resources. Zydex offers a diverse set of chemical technologies for the textile, agriculture, pavement and construction industries.

With a growing workforce of 1,100+ employees, Zydex has risen to become a global player with footprints in over 40 countries, where significant players & institutions have adopted their ecofriendly and sustainable technologies.

Zydex has established a global reputation as a pioneer in PVC-free water-based printing inks for garment screen printing. Their range of Whites and Clears set the benchmark for opacity, feel, stretch, and wash durability. Even after repeated washing, the prints maintain their high-quality standards and do not deteriorate in feel.

Zydex Clears stand out in the industry and are unmatched with an exceptional balance of soft feel and crock fastness. In addition to our PVC-free inks, they offer ready-coloured and FLSC inks that meet the highest standards for crocking and soft feel. To enhance the printing experience, they also offer accessories such as foil transfer, glitter base, gold binder, and high-density printing pastes.

Their PVC-free inks are qualified for export to global markets and meet RSL, GOTS and OEKO-TEX standards, ensuring that they are non-toxic and eco-friendly.

Zydex is dedicated to promoting sustainable chemistries to create a greener future for all. Their unwavering commitment has established them as a leader in the development of non-polluting and non-hazardous technologies that safeguard and improve the environment. Their passion lies in advancing chemical innovations that foster a safer, greener, and more resource-efficient world. Their contributions to sustainability have been widely acknowledged, and our technologies are accepted globally.

# Post Event Report – Seminar on “Textiles & Green Energy – The New Vision”

Indian Textile Accessories and Machinery Manufacture Association (ITAMMA) organized a Seminar on “Textiles & Green Energy - The New Vision” on 11th June 2025 at Readymade Garment Cluster Hall, Jabalpur.

The objective of the Seminar was to know the operation of Ready-made Garment and Fashion Cluster of Jabalpur which is considered to be the biggest cluster having more than 450 garment and fashion units. Accordingly, it took the support of Kasrawad Art Cluster, Shivalik Jankalyan Samiti and Laghu Udyog Bharti for jointly organizing this event. Mr. Omprakash Mantry, President (2025/26), ITAMMA delivered his welcome speech on virtual platform from Mumbai. Where he said that “As we all know that today, we are in an era which is driven by fast paced technological developments, demanding high level of creativity and innovation.

*Welcome speech by Mr. Omprakash Mantry, President of ITAMMA*

It's a time that demands responsible and sustainable developments rather techno-commercial developments in the textile machines and accessories which can be accepted especially by the very important stage of the User Industry i.e. Garmenting, Retail and Fashion. Today through digitalization and AI one can easily track the details of flow and operations of fibre, yarn, fabric up to Garment, retail and fashion stage. Thus connecting the manufacturers and processors of textiles (fibre, yarn, fabric) and machines/spares/accessories with Garment, retail and Fashion industry for information and requirements of the goods as per Global Market."

*N. D. Mhatre, Director General (Tech), ITAMMA welcomed with a bouquet*


*N. D. Mhatre, Director General (tech), ITAMMA delivering his presentation*

It was followed by presentations from Mr. N. D. Mhatre, Director General (Tech), ITAMMA on Role of

Bharat's Fabric, Branded Garments and Fashion Industry Including Export Potential in Global Textile Market- giving information on Bharat's textile & apparel market size stressing upon the fact that Textile & Apparel manufacturing have shifted to Asian countries over the years. He also mentioned that T&A sector employs 4.5 crores people in Bharat.

While the garment sector creates employment for 50 individuals per crore of investment as compared to only 8 individuals by spinning, weaving and processing all together. He also mentioned that T&A sector growth should be garment led as it creates excellent Direct Employment Opportunities, uplifts the downstream Processes, engages with Global Brands thus strengthening Bharat's branding globally. Mr. Mhatre explained that there is a need to Promote Exports by offering export subsidies, set-up Skill Centers state-wise depending upon the availability of skilled man-power, and develop Plug-and-Play Infrastructure whereby encouraging the installation of state-of-the art machines.

In the other presentations on "Development of Textile Machines & Accessories in accordance to Garment, Fashion & Retail Industry " he explained that Machine Manufacturing is a process driven exercise based on calculations and standardization while Fashion Designing is driven primarily by creativity and the efforts are towards creating something new each time. Thus both these opposites needs to be blended properly to deliver the quality product which can be accepted in the Global market and leading to country's growth. Bharat's garment manufacturing sector still has a large scope in huge domestic consumption, but we are yet to create a Global brand and paying a premium on western brands even after having Engineering talent.

At present most of the machines used in Indian garmenting sector are imported or assembled. Thus an opportunity is there to modify the existing machines be customized to make use of Smart Manufacturing especially using 5G and IOT enabled machines.

*Ms. Seema Mishra, Founder of Kasrawad Art Cluster, Shivalik Jankalyan Samiti welcomed with a Bouquet*

*Mr. Rahul from Ashra Retail Pvt. Ltd. Channel Partner of TATA Rooftop felicitated with a Memento*


*Speaker from Ashra Retail Pvt. Ltd., Channel Partner of TATA Rooftop*

There were presentations by Ms. Seema Mishra, Founder, Kasrawad Art Cluster, Shivalik Jankalyan Samiti, Mr. Somesh Gupta, Gen Secretary, Ready Made Cluster and Laghu Udyog Bharathi, Mr. Vineet Rajak, CEO, Fashion & Design Garment Association and Mr. Rahul and his colleague from Ashra Retail Pvt. Ltd, TATA Rooftop Channel on "Driving Solarisation in Textile Industry" and also thank them for extending sponsorship for this Seminar.

It was noticed that all the 400 units were having the problem of getting the quality spares for their machines and further they were exploring some export markets.

Accordingly a proposal is discussed with the Authorities of the Cluster in formation of Spare part & Accessories Portable Galary-cum-Clinic inviting ITAMMA Members to display their products in this regard and provide a solution based services to overcome their problems in regard with technical/technological field as well as product development area.

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