Since - 1940

Open Access Journal
DOI No. https://doi.org/10.5281

ISSN 0368-4636
e-ISSN 2347-2537

Journal of the TEXTILE Association

VOL. 85 NO.5 January-February, 2025

4S SUSTAINABLE SMART SOLUTIONS FOR SPINNING SUCCESS

LMW®

A Smart Beginning Ensures a Successful Finish

Think of Open End - Think of LMW OE Preparatory - Spin Success

Smart Manufacturing | Versatile Solutions | Robust machines that last a life-time

Recycle ⇄ Reuse ⇄ Respin

Blowroom

Designed for gentle cleaning, opening & effective microdust extraction.

Card LC363

Driving quality through innovation

Card LC636 SX with CDS

LDF3 S

Finisher Draw Frame for Consistent quality with a high degree of Auto Levelling Efficiency

LDF3 2S

Upto 0.5% waste savings

Upto 7% energy savings

Upto 20% reduction in ownership cost*

*Ownership cost = fixed cost + maintenance cost

www.lmwtmd.com

Printed at : S S Enterprises, Mumbai
Published by: Pavitra Publisher, Pune

JTA Abstracted by
Chemical Abstracts - USA | World Textile Abstracts-UK
Science Abstracts - India | Elsevier, Scopus-Netherland

Journal of the TEXTILE Association
TEXTILE SCIENCE | TECHNOLOGY | ENGINEERING | MANAGEMENT

ISSN 0368-4636
e-ISSN 2347-2537
JAN-FEB, 2025 VOLUME 85 NO. 5

CONTENTS

THE TEXTILE ASSOCIATION (INDIA)
702, Santosh Apartment, 7th Floor, Plot No.72-A, Dr. M. B. Raut Road, Shivaji Park, Dadar (West), Mumbai - 400 028
Tel.: 022-35548619, 31725888 • E-mail: taicnt@gmail.com Website: www.textileassociationindia.org

India's Textile Future: Policy Push & Global Realignments

Dear Readers,

Greetings!!!

The Indian textile industry stands at a pivotal juncture, influenced by domestic policy initiatives and evolving global trade dynamics. The Union Budget 2025-26 introduces strategic measures aimed at boosting the sector's competitiveness, while the geopolitical landscape, particularly with changing political scenario in US, presents both challenges and opportunities. An increase of 19 percent over budget estimates of previous year is provided to strengthen the textile industry.

The launch of Cotton Mission for the production of extra-long staple varieties to reduce import dependence, the increased custom duty on knitted fabrics to curb cheap imports and zero duty on some shuttleless looms to boost making of technical textile products, are initiatives aimed at boosting the textile industry.

The recent U.S. election outcome brings a complex set of factors that could impact India's textile industry. The "Country First" agenda by Trump administration may lead to higher tariffs on imports, potentially reducing exports of Indian textiles in the U.S. market. Conversely, India stands to gain with its robust textile manufacturing capabilities as the ongoing trade tensions between the U.S. and China could prompt American companies to seek alternative sourcing destinations.

To capitalize on these developments, the industry should invest in research and development to create innovative textile products and reduce vulnerability to external shocks. Also, the industry should explore new markets and strengthen trade relationships with countries less affected by U.S. protectionist policies. The industry needs to engage with policymakers to negotiate favorable trade terms and address tariff-related challenges. Inspite of the strong foundation laid by budget 2025-26 for the advancement of India's textile sector, the industry must remain agile and proactive in addressing the complexities arising from shifting geopolitical landscapes to ensure sustained growth and global competitiveness.

Wishing you all a very Happy, Prosperous and Peaceful New Year 2025.

Dr. Deepa V. Raisinghani
Chairman ,
Editorial Board
Journal of the Textile Association

T. L. PATEL, President

The Textile Industry is set to converge at several prominent fairs in 2025.

- **Texworld Paris 2025:** (February 10-12, 2025, Paris, France): This international fashion and textile fair will showcase the latest fabrics, trims, and accessories.
- **Première Vision Paris 2025:** (February 11-13, 2025, Paris, France): This exhibition will feature a curated selection of textile suppliers.
- **Bharat Tex 2025:** (September 15-18, 2025, Coimbatore, India): This premier event will focus on textile machinery, fabrics, and innovations in textile production.
- **GTTES 2025 (India):** The Global Textile Technology & Engineering Show will showcase the latest innovations and technologies in the textile industry.
- **YARNEX 2025 (India):** This platform will serve as a hub for the latest innovations in fibers and yarns.

Budget 2025 for the Textile Sector:

The Indian government has allocated funds to support the growth of the textile industry in 2025. For specific details on the budget allocation, please refer to the official government website or reputable news sources.

Empowering the Textile Industry: Our Vision for a Sustainable Future

As we navigate the complexities of the global textile industry, it is essential that we, as stakeholders, come together to address the challenges and opportunities that lie ahead. At The Textile Association (India), we are committed to empowering our members and the broader industry to thrive in a rapidly changing world.

Sustainability: The Need of the Hour

The textile industry is one of the largest polluters globally, with significant environmental and social impacts. As we move forward, it is crucial that we adopt sustainable practices that minimize our ecological footprint. Our association is dedicated to promoting eco-friendly technologies, reducing waste, and encouraging responsible sourcing practices.

Innovation and Technology

To remain competitive, our industry must embrace innovation and technology. We are committed to providing our members with access to the latest research, trends, and best practices. From digital printing to nanotechnology, we will explore the latest advancements and their applications in the textile industry.

Skill Development and Education

As the industry evolves, it is essential that our workforce possesses the necessary skills to adapt. We are dedicated to providing training and education programs that equip our members with the knowledge and expertise required to succeed. From workshops and seminars to online courses and certifications, we will offer a range of programs to support continuous learning.

Collaboration and Partnerships

No single organization can address the complexities of our industry alone. We believe in the power of collaboration and partnerships. Our association will work closely with government agencies, research institutions, and industry stakeholders to promote the interests of our members and the broader industry.

Conclusion

As we look to the future, I am confident that together, we can overcome the challenges and capitalize on the opportunities that lie ahead. At The Textile Association (India), we are committed to empowering our members and the industry to thrive in a sustainable, innovative, and collaborative manner.

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

Optimizing Speed Frame Drafting Variables for Yarn Uniformity and Hairiness Using Taguchi Design

G. K. Tyagi, Ashvani Goyal* & Sushant Dhiman

Department of Textile Technology, The Technological Institute of Textile & Sciences, Bhiwani, Haryana, India

Abstract:

Background: *The drafting system configuration in speed frames significantly influences the quality of spun yarn. Factors such as yarn irregularity, coefficient of variation (CV%), imperfections, and hairiness are crucial parameters for evaluating yarn quality. This study compares the performance of PK 1500 and PK 1600 drafting systems with 3-over-3 and 4-over-4 configurations using Taguchi methods to optimize drafting variables for better yarn uniformity and reduced hairiness.*

Methodology: *The study analyzed the effects of front and back top roller pressure, spacer size, and overhang in the drafting region for PK 1500 (3/3 and 4/4) and PK 1600 (4/4) systems. Taguchi design and analysis of variance (ANOVA) were employed to evaluate the impact of these variables on yarn properties, including irregularity, CV%, imperfections, and hairiness.*

Results: *The 3-over-3 configuration of the PK 1500 drafting system outperformed the 4-over-4 setups in producing yarn with lower unevenness, reduced CV%, and fewer imperfections. Additionally, the hairiness was found to be significantly higher in yarns produced with the 4-over-4 configurations of both PK 1500 and PK 1600 systems.*

Conclusion: *The study concluded that the 3-over-3 drafting system in the PK 1500 configuration offers superior yarn quality for the tested material and machine settings. This configuration is recommended for achieving optimal yarn uniformity and minimized hairiness, highlighting its advantages over 4-over-4 setups*

Keywords: *Drafting system, PK 1500 3/3, PK 1500 4/4, PK 1600 4/4, Taguchi method*

Citation: G. K. Tyagi, Ashvani Goyal & Sushant Dhiman, "Optimizing Speed Frame Drafting Variables for Yarn Uniformity and Hairiness Using Taguchi Design", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),483-490, https://doi.org/10.5281/zenodo.14973747

Article Received : 02-12-2024, Revised: 16-12-2024, Accepted: 20-12-2024

1. Introduction

Draft limits inhibit the direct feeding of drawn slivers to ring frames machine. A two-step reduction method is essential for producing high-quality yarn. Speed frames, succeeding draw frames, impart twist and diminish weight while maintaining sliver integrity but sometime roving preparation adversely affects spinning performance. Now a days, new ring frames can accommodate higher-draft speed frame material for coarser hanks, hence enhancing the output of the machine [1]. Further, enhancing speed frame operation within a designated timeframe is essential for the effective production of high-quality roving. While many studies have concentrated on enhancing yarn quality by modifying fibre parameters and spinning machines parameters in the spinning line [2-4], there are few investigations that emphasize improving yarn quality through the optimization of speed frame drafting parameters using the Taguchi method [5]. This study seeks to optimize the parameters of the speed frame drafting system (front/back top roller pressure, spacer size, and overhang) via the Taguchi method to improve yarn quality in the conventional ring spinning system.

Corresponding Author:
Dr. Ashvani Goyal
Associate Professor & Head, Department of Textile Technology, The Technological Institute of Textile & Sciences, Birla colony, Bhiwani – 127 021, Haryana
E-mail: ashvanigoyal@titsbhiwani.ac.in,

.

2 Materials and Method

2.1 Preparation of samples

As illustrated in Table 1, samples were prepared using Sankar-6 cotton with an L9 mixed orthogonal array, based on Taguchi's experimental design. The design was developed using the statistical software Minitab® 17, with the specifics and responses detailed in Table 2. Initially, the process parameters of the roving frame, which is equipped with a PK-1500 3/3 drafting system, were optimized using the Taguchi method in the orthogonal array L9. These parameters include front top roller pressure, rear top roller pressure, spacer size, and overhang. To eliminate any potential influence of machine conditions on the experimental outcomes, ten finisher draw frame cans were collected from the same machine and processed onto the same set of spindles. Apart from the variables under study, all other parameters were maintained consistently across the spindles. A total of nine samples, each with a unique combination of variables, were spun, and ten bobbins were prepared for each combination. The procedure was repeated for the PK-1500 4/4 and PK-1600 4/4 drafting systems, resulting in 27 (9 x 3) distinct roving frame samples, each prepared using one of the three drafting systems. The drafting system setting used on different drafting system at speed frame are shown in Table 3. These samples were then creeled onto the same set of spindles on the ring frame to assess the impact of the different drafting systems on cotton Lycra yarn. The 30s Ne core yarns are produced on a ring frame by feeding Lycra filament yarn through the front roller nip and roving through the drafting zone of the ring frame. The spindle speed and other parameters of the spinning process were constant during all yarn manufacturing procedures (Spindle speed-14000 rpm; Break draft-1.21; Main draft-35.4; Spacer-2.25 mm).

Taguchi's experimental design was employed to generate textile samples and analyse the impact of each controllable factor on multiple responses, including yarn irregularity, CV%, imperfections, and hairiness. The study considered controllable variables such as front top roller pressure, rear top roller pressure, overhang, and spacer size. The yarn hairiness, irregularity and imperfections were evaluated using an Uster Evenness Tester (UT-6).

Table 1 - L9 orthogonal array

Run	Overhang	Front top roller pressure	Back top roller pressure	Spacer size
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2 - Actual values of the process parameters of drafting system of speed frame corresponding to coded levels

Actual values				
PK 1500 3/3				
Coded levels	Front top roller pressure	Back top roller pressure	Overhang	Spacer size
1	20	15	2	4.7
2	25	20	4	5.1
3	30	25	6	8.9
PK 1500 4/4				
Coded levels	Front top roller pressure	Back top roller pressure	Overhang	Spacer size
1	20	15	2	4.7
2	25	20	4	5.1
3	30	25	6	8.9
PK 1600 4/4				
Coded levels	Front top roller pressure	Back top roller pressure	Overhang	Spacer size
1	20	10	2	4.7
2	25	15	4	5.1
3	30	20	6	8.9

Table 3- Drafting system setting in Speed frame

	PK-1500 3/3	PK-1500 4/4	PK-1600 4/4
Main Draft zone, mm	40	45	45
Break Draft zone, mm	50	55	55
Top Roller diameter, mm	28/25/28	28/25/28/28	28/25/28/28
Bottom Roller diameter, mm	30/27/30	30/28/30/30	30/28/30/30
Total draft	10.1	10.1	10.1
Break draft	1.17	1.15	1.15
Main draft	8.60	8.78	8.78

Table 4 - Experiment layout using L9 orthogonal array for individual drafting system and with their responses

Expt No.	Drafting System	Overhang	Front Roller Pressure	Back Roller Pressure	Spacer Size	U %	CVm %	IPI Values	Hairiness index	S3u /100m	S1+2u /100m
P 1	PK-1500 3/3	6	20(BLACK)	25(RED)	5.1	9.25	12.82	97	5.78	3796	13165
P 2		6	25(GREEN)	15(BLACK)	8.9	9.35	12.23	41	5.95	3961	13308
P 3		6	30(RED)	20(GREEN)	4.7	9.45	11.73	45	5.89	3851	13188
P 4		4	20(BLACK)	20(GREEN)	8.9	9.28	12.01	45	5.98	3496	13135
P 5		4	25(GREEN)	25(RED)	4.7	9.33	11.83	47	6.01	3815	13163
P 6		4	30(RED)	15(BLACK)	5.1	9.49	11.62	53	6.04	3127	12922
P 7		2	20(BLACK)	15(BLACK)	4.7	9.15	11.75	35	6.15	3807	13560
P 8		2	25(GREEN)	20(GREEN)	5.1	9.63	11.61	57	5.78	3767	12655
P 9		2	30(RED)	25(RED)	8.9	9.41	12.16	50	6.89	3553	12313
S 1	PK-1500 4/4	6	20(BLACK)	25(RED)	5.1	9.75	12.46	100	5.12	2496	12,165
S 2		6	25(GREEN)	15(BLACK)	8.9	9.45	11.94	52	5.15	2561	12,308
S 3		6	30(RED)	20(GREEN)	4.7	9.55	12.10	57	5.18	2551	12,388
S 4		4	20(BLACK)	20(GREEN)	8.9	9.48	11.96	45	4.96	2496	12,165
S 5		4	25(GREEN)	25(RED)	4.7	9.63	12.23	85	5.18	2315	12,063
S 6		4	30(RED)	15(BLACK)	5.1	9.79	12.39	75	5.15	2527	12,922
S 7		2	20(BLACK)	15(BLACK)	4.7	9.55	12.05	59	5.28	2807	13,860
S 8		2	25(GREEN)	20(GREEN)	5.1	9.83	12.50	89	5.16	2667	12,655
S 9		2	30(RED)	25(RED)	8.9	9.61	12.41	85	4.45	2153	12,313
R 1	PK-1600 4/4	6	20(BLACK)	20(RED)	5.1	9.79	12.37	65	4.99	2451	12,135
R 2		6	25(GREEN)	10(BLACK)	8.9	9.68	12.31	79	4.96	2458	12,528
R 3		6	30(RED)	15(GREEN)	4.7	9.58	12.40	97	4.89	2441	12,145
R 4		4	20(BLACK)	15(GREEN)	8.9	9.46	12.03	80	5.04	2543	12,554
R 5		4	25(GREEN)	20(RED)	4.7	9.71	12.22	98	4.93	2458	12,143
R 6		4	30(RED)	10(BLACK)	5.1	9.53	12.22	63	5.02	2544	12,280
R 7		2	20(BLACK)	10(BLACK)	4.7	9.57	12.06	86	5.07	2745	12,286
R 8		2	25(GREEN)	15(GREEN)	5.1	9.72	12.30	71	5.18	2560	12,470
R 9		2	30(RED)	20(RED)	8.9	9.66	12.21	74	4.97	2946	12,577

2.2 Taguchi method

The Taguchi method is a methodology employed to reduce variability in a process through the creation of rigorous tests. The primary objective of this strategy is to produce a high-quality product while minimising production costs. The Taguchi method was formulated by Dr. Genichi Taguchi from Japan. He asserted that diversity is crucial to contemplate. Taguchi devised a methodology for experimental design to examine the influence of numerous parameters on the mean and variability of a process performance characteristic, which assesses the efficacy of the process. The Taguchi method employs orthogonal arrays to reduce variance and optimize process parameters. In the Taguchi method, the signal to noise (S/N) ratio is used as a performance characteristic to measure process robustness and to evaluate deviation from desired values [6]. The S/N ratio, a logarithmic function, is computed by assessing the proportion of signal (mean) to the noise (standard deviation) [7]. There exist three types of S/N ratios, namely, higher-the-better (S/N) HTB, nominal-the-best(S/N) NTB and smaller-the-better(S/N) STB.

The actual values of maximum S/N ratio were also evaluated directly from the curves of S/N ratio with change in process variable by using the equation: S/Nmax=

$$S/N+(S/NAmax-S/N)+(S/NBmax-S/N)+(S/NCmax-S/N)+(S/NDmax-S/N) \quad .... (1)$$

where S/Nmax is maximum actual value from the graph; S/N, overall average value of the S/N ratio; S/NAmax, maximum value of S/N ratio in plot of Overhang, S/NBmax, maximum value of S/N ratio in plot of Front roller pressure, S/NCmax maximum value of S/N ratio in plot of Back roller pressure and S/NDmax maximum value a S/N ratio in plot of Spacer size.

3. Result and Discussion

Table 4 presents the average values of yarn irregularity, coefficient of variation (CV%), imperfections, and hairiness for yarns produced from roving using PK 1500 3/3, PK 1500 4/4, and PK 1600 4/4 drafting systems while maintaining nine sets of process variables. The actual values of signal-to-noise (S/N) ratios within the 95% confidence limits (S/NL and S/NH) for the various drafting parameters investigated are also provided in Tables 6 and 7.

The influence of four experimental factors, i.e., overhangs, front roller pressure, back roller pressure on yarn characteristics for different drafting systems was evaluated for significance using analysis of variance (ANOVA) at a 95% level of significance (Table 5).

3.1 Irregularity

Table 5 presents the ANOVA results for different variables of the speed frame drafting system on yarn irregularity. The results indicate that the drafting system and spacer size have a significant effect on yarn irregularity, while other variables like front roller pressure, back roller pressure, and overhang do not significantly affect it.As can be seen from Table 6, the yarn spun using the PK 1500 3/3 drafting system exhibits the lowest average irregularity, followed by PK 1500 4/4 and PK 1600 4/4. This is attributed to the narrower roller setting of PK 1500 3/3, which offers better control of shorter and less cohesive fibers in the primary drafting zone. Wider roller settings led to increased yarn irregularity due to greater fiber floating between the rollers [8]. Furthermore, the marginal R2 values for all systems indicate that front top roller pressure, back top roller pressure, overhang, and spacer size have negligible effects on yarn irregularity (Table 8). However, the front top roller pressure is the most significant factor affecting yarn irregularity in the case of PK 1500 3/3.Figure 1 depicts the S/N ratio plot of yarn irregularity for various process variables. A lower S/N ratio indicates a superior condition. The initial increase in top roller pressure narrows the gap between the pressure fields of the middle and front rollers, improving fiber management and reducing yarn irregularity [9]. However, further increases in top roller pressure can lead to overlapping friction fields, hindering fiber movement and increasing yarn irregularity [10]. The optimal values of variables for yarn irregularity in various speed frame drafting systems, along with their corresponding MINITAB-predicted means, are presented in Table 6.

Table 5 - ANNOVA test results

	P-value					
	Uster,	**CVm%**	**IPI**	**Hairiness Index**	**S3u/100m**	**S1+2u/100m**
Drafting System	**0.00^s^**	**0.065**	**0.009^s^**	**0.00^s^**	**0.00^s^**	**0.005^s^**
Overhang	0.617	0.225	0.835	0.712	0.192	0.652
Front roller pressure	0.072	0.944	0.959	0.989	0.529	0.450
Back Roller Pressure	0.412	0.10	0.098	0.846	0.825	0.084
Spacer Size	**0.01^s^**	0.219	0.24	0.957	0.633	0.584
R^2	0.788	0.537	0.572	0.823	0.917	0.608
S= significant at 95% confidence limit						

Table 6 - Optimum values of process variables of drafting systems of speed frame for individual properties with their predicted mean

		Overhang (mm)	Front roller pressure (dAN)	Back roller Pressure (dAN)	Spacer size (mm)	Predicted mean	S/N ratio
PK 1500 3/3	**U%**	6	20	25	4.7	09.11	-19.19
	CVm%	4	30	20	4.7	11.29	-21.07
	IPI	2	25	15	4.7	24.33	-29.92
	Hairiness	2	25	15	8.9	05.38	-14.69
	S3u/100m	2	30	15	5.1	2023	-66.40
	S1+2u/100m	4	20	25	5.1	11681	-81.37
PK 1500 4/4	**U%**	6	20	15	8.9	09.41	-19.47
	CVm%	6	20	15	8.9	11.87	-21.94
	IPI	4	20	20	8.9	45.00	-33.06
	Hairiness	2	30	25	8.9	04.45	-12.96
	S3u/100m	4	30	25	8.9	3056	-69.76
	S1+2u/100m	4	30	25	5.1	12739	-82.11
PK 1600 4/4	**U%**	4	30	15	8.9	09.44	-19.50
	CVm%	4	20	10	8.9	11.98	-21.57
	IPI	2	20	10	5.1	58.66	-35.69
	Hairiness	6	30	20	4.7	04.81	13.66
	S3u/100m	6	25	15	5.1	3259	-70.31
	S1+2u/100m	6	25	10	4.7	12499	-82.74

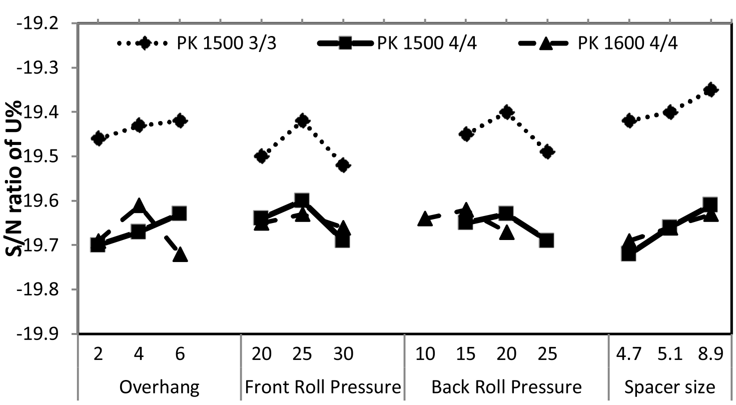
Table 7 - S/N ratios and mean values of U%, CV% and IPI of yarn

Smaller is better	PK 1500 3/3	PK 1500 4/4	PK 1600 4/4
U%			
S/N ratio calculated	-19.19	-19.47	-19.50
S/N ratio actual	-19.18	-19.47	-19.48
S/N L	-19.26	-19.55	-19.54
S/N H	-19.08	-19.39	-19.41
Average	9.37	9.62	9.63
Predicted	9.12	9.41	9.44
CV%			
S/N ratio calculated	-21.07	-21.50	-21.57
S/N ratio actual	-21.07	-21.50	-21.57
S/N L	-21.25	-21.60	-21.63
S/N H	-20.89	-21.40	-21.51
Average	11.97	12.22	12.23
Predicted	11.29	11.87	11.98
IPI			
S/N ratio calculated	-29.93	-33.06	-35.69
S/N ratio actual	-29.94	-33.06	-35.69
S/N L	-31.56	-34.639	-35.99
S/N H	-28.32	-31.481	-35.39
Average	52.22	71.89	79.22
Predicted	24.33	45.00	58.67

Table 8 - Changes in S/N ratio of yarn U%, CVm%, and IPI as explained by ANOVA and ranked by the Taguchi method

	PK 1500 3/3			PK 1500 4/4			PK 1600 4/4		
	U%	CV%	IPI	U%	CV%	IPI	U%	CV%	IPI
Overhang									
Taguchi rank	4	2	3	2	3	3	2	1	4
% V Effect	2.01	22.0	10.83	6.49	9.04	3.26	1.89	33.60	1.31
Front top roller pressure									
Taguchi rank	1	3	4	4	4	4	3	2	3
% V Effect	45.93	15.83	5.42	3.25	7.90	0.96	0.47	17.68	0.12
Back top roller pressure									
Taguchi rank	3	1	2	3	2	1	1	4	2
% V Effect	0.001	20.24	27.21	4.50	22.15	39.96	27.22	5.70	1.06
Spacer Size									
Taguchi rank	2	4	1	1	1	2	4	3	1
% V Effect	0.80	9.96	5.33	31.81	13.15	15.70	4.65	8.22	2.99
R^2	48.74	69.03	48.79	48.43	54.75	60.42	42.20	66.54	3.14

Figure 1 - S/N ratio plot of U% with change in process variables



3.2 *CVm%*

The ANOVA results in Table 5 show that the drafting system of the speed frame has no substantial impact on the yarn CVm%. However, the yarn spun using the PK 1500 3/3 drafting system exhibits the lowest average CVm%, followed by PK 1500 4/4 and PK 1600 4/4 (Table 6). This is attributed to the optimal main and break drafts provided by a 3-over-3 roller drafting system, which minimizes CVm%. Conversely, the wider roller spacing and uneven draft distribution in 4-over-4 systems increase CVm% [11, 12]. Table 8 quantifies the relative importance of various variables on CVm% for three speed frame drafting systems. Marginal R^2 values indicate that front top roller pressure, back top roller pressure, overhang, and spacer size have negligible effects on CVm% for PK1500 4/4 and PK1600 4/4. However, for PK 1500 3/3, overhang (22.0) and back top roller pressure (20.24) significantly influence yarn irregularity, while front top roller pressure (15.83) and spacer size (9.96) have minor impacts.

The S/N ratio plot in Figure 2 illustrates the relationship between process variables and CVm% for the speed frame drafting system. For PK 1500 3/3, CVm% increases with overhang due to compromised fiber control caused by the increased distance between the roller nip line and the aprons' opening. The S/N ratio plot also shows that for PK 1500 3/3, CVm% initially decreases with increasing top roller load, then increases to a threshold. The initial decrease is attributed to the narrowing of the pressure gradient between the front and middle rollers, improving fiber control. However, excessive top roller load can lead to overlapping friction fields, hindering fiber progression and increasing CVm%. Spacer size has a minimal impact on CVm%, as hook removal primarily depends on main draft and top roller pressure.

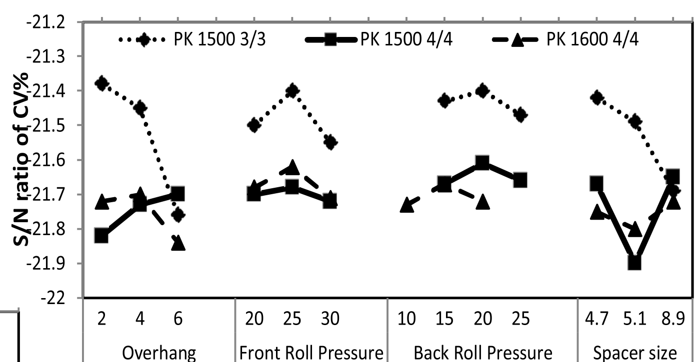


Figure 2 - S/N ratio plot of CV% with change in process variables

3.3 *Imperfection*

As can be seen from Table 7, the PK 1500 3/3 system exhibits the lowest average IPI values, followed by PK 1500 4/4 and PK 1600 4/4. This is attributed to the larger drafting area in 4 over 4 systems, allowing for better fiber entanglement and reduced slippage [12]. On the other hand, a low R^2 value for PK 1600 4/4 indicates a weak correlation between IPI and the individual variables (Table 8). Back top roller pressure has the greatest impact on IPI for PK 1500 3/3 and 4/4, while overhang and spacer size have lesser effects. The S/N ratio plot of IPI for various process variables (Figure 3) depict that both PK 1500 3/3 and PK 1500 4/4drafting systems showed a decrease in IPI with increasing top roller loads. This is because inadequate pressure on the back roller causes improper drafted strand to emerge from the drafting zone and move in groups, leading to premature acceleration of shorter fibres during drafting, which, in tun, results in an increase in number of thick and thin places [13]. However, a further increase in top roller load alters the friction field, which facilitates the contact between the fibres in the strand, thereby reducing the rove irregularity, and consequently yarn imperfection [14]. The spacer size also has a significantly impact on yarn imperfections. Increasing spacer size in both PK 1500 3/3 and PK 1500 4/4 drafting systems results in lower IPI values. This could be attributed to changes in cohesive forces between fibers, leading to smoother attenuation and improved yarn structure.

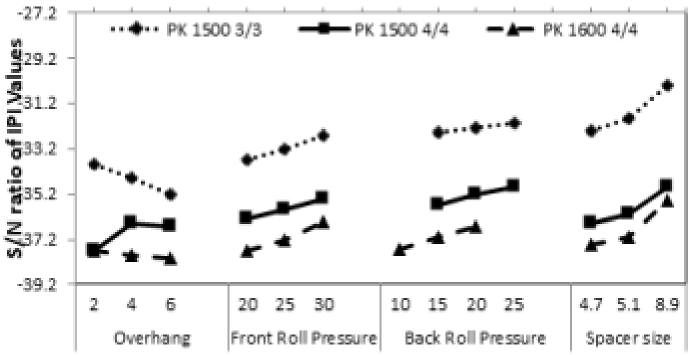


Figure 3 - S/N ratio plot of IPI Values with change in process variables

3.4 Hairiness Index, S3u/100m and S1+2u/100m

Table 5 presents the ANOVA results of different speed frame drafting system variables on hairiness index, S3u/100m, and S1+2u/100m. The results indicate that the drafting system significantly influences all yarn hairiness values. However, four variables—front roller pressure, back roller pressure, overhang, and spacer size—do not significantly affect any hairiness value. The R^2 values of 0.823 for hairiness index and 0.917 for S3u/100m suggest that drafting system variables have a strong effect on these hairiness properties. The data reveals that the average values of hairiness and longer hairs (S3u/100m) are lowest for yarns spun from the PK 1500 4/4 drafting system, followed by PK 1600 4/4 and PK 1500 3/3 (Table 9). Conversely, the average values of shorter hairs (S2u/100m) are lowest for PK 1600 4/4, followed by PK 1500 4/4 and PK 1500 3/3. Overall, the 4/4 drafting system exhibits lower hairiness compared to the 3/3 drafting system. This might be due to the additional condensing zone in the 4/4 system, which condenses and integrates fibers into the roving structure, thereby reducing yarn hairiness. On the other hand, the weak average R^2 values for hairiness index, S3u/100m, and S1+2u/100m for PK 1500 3/3 indicate a weak correlation with overhang, front top roller pressure, and spacer size (Table 10). For PK 1500 4/4, overhang has the least impact on yarn hairiness index, while back top roller pressure and spacer size have significant impacts. In contrast, for PK 1600 4/4, overhang has the greatest influence on yarn hairiness index, while other factors have negligible effects. For S3u/100m, back top roller pressure has the greatest impact for PK 1500 4/4, while overhang has the greatest impact for PK 1600 4/4. Other factors have negligible effects. For S1+2u/100m, overhang has the greatest impact for both PK 1500 4/4 and PK 1600 4/4, while other factors have negligible effects. The S/N ratio plots of yarn hairiness verses speed frame drafting system variables (Figures 4-6) also show a reduction in hairiness values with increase in overhang due to a shortened spinning triangle. However, excessive overhang can lead to compromised fiber control and increased hairiness. Increasing spacer size also reduces hairiness by facilitating more uniform fiber attenuation and better incorporation into the roving structure [15].

Table 9 - S/N ratios and mean values of Hairiness Index, S3u/100m and S1+2u/100m of yarn

	PK 1500 3/3	PK 1500 4/4	PK 1600 4/4
Smaller is better			
Hairiness index			
S/N ratio calculated	-14.69	-12.97	-33.66
S/N ratio actual	-14.69	-12.96	-33.61
S/N L	-16.310	-13.250	-33.71
S/N H	-13.070	-12.670	-33.51
Average	6.05	5.07	5.01
Predicted	5.38	4.45	4.81
S3u/100m			
S/N ratio calculated	-66.4	-69.76	-70.31
S/N ratio actual	-66.4	-69.76	-70.32
S/N L	-67.14	-70.07	-70.58
S/N H	-65.66	-69.45	-70.06
Average	3685.889	2508	2571.778
Predicted	4023.33	3056.61	3259.67
S1+2u/100m			
S/N ratio calculated	-81.37	-82.11	-82.74
S/N ratio actual	-81.38	-82.10	-82.74
S/N L	-81.55	-82.23	-82.88
S/N H	-81.21	-81.99	-82.60
Average	13045.78	12537.44	12346.33
Predicted	12681	11739	11499.7

Table 10 - Changes in S/N ratio of yarn Hairiness Index, S3u/100m and S1+2u/100m as explained by ANOVA and ranked by the Taguchi method

	PK 1500 3/3			PK 1500 4/4			PK 1600 4/4		
	HI	S3u/100m	S1+2u/100m	HI	S3u/100m	S1+2u/100m	HI	S3u/100m	S1+2u/100m
Overhang									
Taguchi rank	2	4	1	4	4	1	1	1	1
% V Effect	26.56	3.75	0.26	10.71	0.02	22.89	41.05	58.99	48.15
Front top roller pressure									
Taguchi rank	3	1	4	3	2	4	3	2	3
% V Effect	15.27	39.85	4.66	11.48	18.98	7.87	13.76	2.68	0.02
Back top roller pressure									
Taguchi rank	4	3	2	2	1	2	4	4	2
% V Effect	5.38	1.17	0.33	23.52	51.00	7.38	7.28	0.85	11.99
Spacer Size									
Taguchi rank	1	2	3	1	3	3	2	3	4
% V Effect	22.56	16.23	8.43	44.35	17.22	2.60	0.85	11.17	0.06
R^2	69.77	61.01	13.67	89.84	87.11	44.43	64.90	75.05	70.45

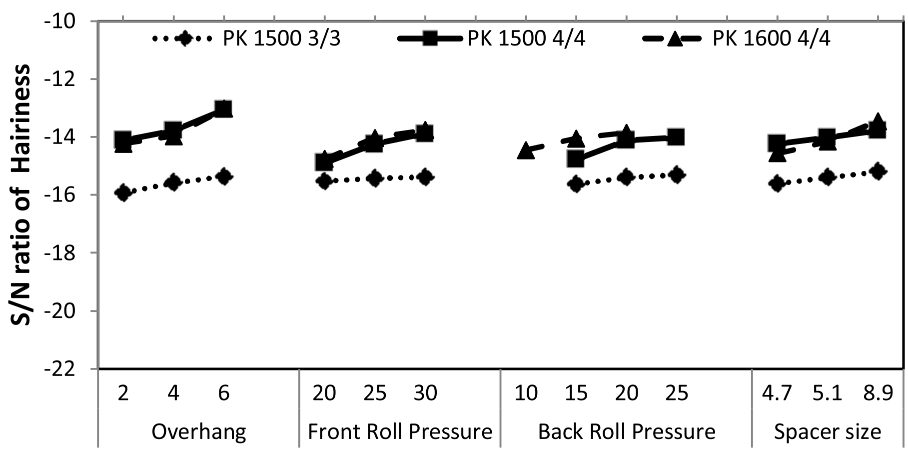


Figure 4- S/N ratio plot of Hairiness Index with change in Process Variables

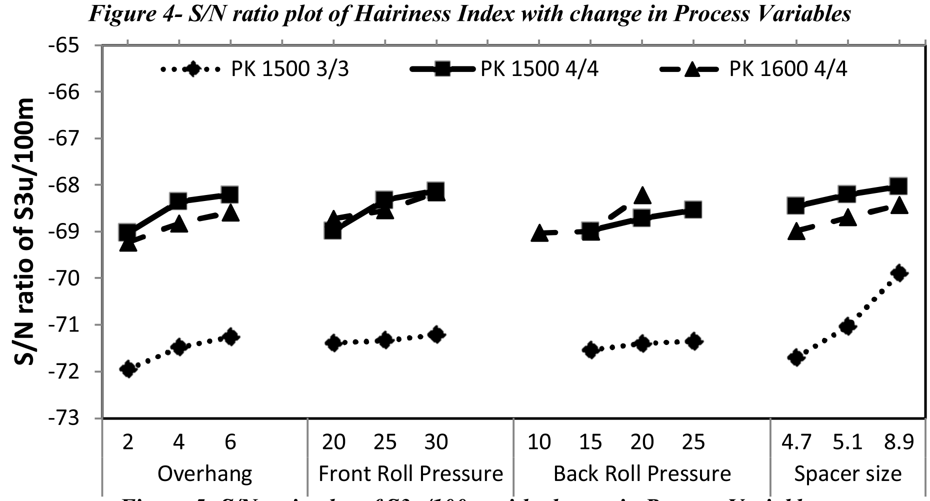


Figure 5- S/N ratio plot of S3u/100m with change in Process Variables

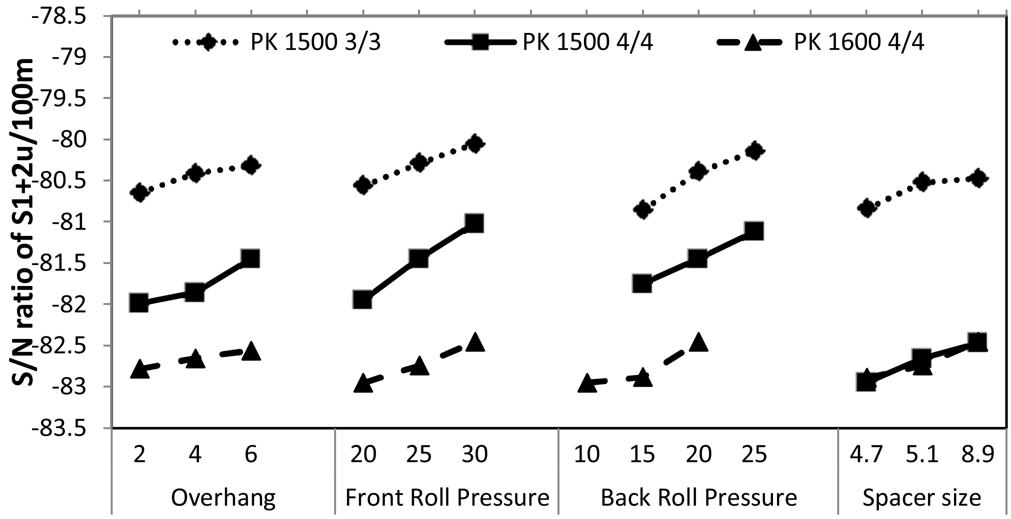


Figure 6 - S/N ratio plot of S1+2u/100m with change in Process Variables

4. Conclusion

The roving produced by the 3-over-3 drafting system (PK 1500 3/3) exhibited improved unevenness, imperfection, and CVm% in comparison to the roving produced by the 4-over-4 drafting systems (PK 1500 4/4 and PK 1600 4/4). Additionally, the roving produced by the 4-over-4 drafting system (PK 1500 4/4 and PK 1600 4/4) had a higher level of yarn hairiness in comparison to the roving produced by the 3-over-3 drafting system. Moreover, the relatively low R2 values for the various speed frame drafting systems and their variables suggest that yarn quality is not significantly influenced by roving quality but may be primarily determined by specific parameters of the ring frame process.

References:

[1] Arindam Basu, Yarn structure - properties relationship, A Review, Indian Journal of Fibre & Textile Research, 34(3) (2009), 287-294

[2] Ishtiaque, S. M., Rengasamy, R. S., & Ghosh, A. Optimization of speed frame process parameters for better yarn quality and production. Indian Journal of Fibre & Textile Research, 29(2004), 39–43

[3] Ferede, E., Tesfaye, T., Ayele, M., Atalie, D. Wagaye, B.T., Prediction of the Impact of Ring Spinning Machine Front Roller Rubber Cot Shore Hardness on Spun Yarn Quality Parameters. Textile & Leather Review, 7(2024),18–34. https://doi.org/10.31881/TLR.2023.157

[4] Raian, S., Saha, S.K., Hossen, J., Baral, L.M., Begum, H.A., Islam, M.R., Assessing the Impact of Spacer Size Variations on the Ring-Spun Yarn Quality Ranking. Textile & Leather Review, 6(2023),582–609. https://doi.org/10.31881/TLR.2023.102

[5] Goyal, A., Dhiman, A., Pattanayak, A.K., Patnaik, A., Influence of Drafting System Variables at Speed Frame on Yarn Tenacity and Breaking Elongation Using Taguchi Method. Textile & Leather Review, 7(2024),1163-1177. https://doi.org/10.31881/TLR.2024.089

[6] Puh, F., Jurkovic, Z., Perinic, M., Brezocnik, M., & Buljan, S. Optimization of machining parameters for turning operation with multiple quality characteristics using Grey relational analysis. Tehnički vjesnik, 23(2) (2016), 377-382

[7] Pervez, M., Shafiq, F., Sarwar, Z., Jilani, M., & CAI, Y. Multi-response optimization of resin finishing by using a taguchi-based grey relational analysis. Materials, 11(3) (2018), 426. https://doi.org/10.3390/ma11030426

[8] Audivert, R., Villaronga, M., & Coscolla, R. Drafting force in the front zone of a double apron drafting system. Textile research journal, 37(1) (1967), 1-10

[9] Carl A. Lawrence, Fundamentals of spun yarn technology-CRC Press: 2003

[10] Ishtiaque, S. M., Rengasamy, R. S., & Ghosh, A. Optimization of speed frame process parameters for better yarn quality and production. Indian Journal of Fibre & Textile Research, Vol. 29 (1) (2004), 39-43

[11] Chaudhari, M. V. D., Chaudhary, A., & Shivankar, V. S. Effect of speed frame drafting systems on quality of ring yarn. International Journal on Textile Engineering and Processes ISSN, 2395-3578. 2(4) (2016), 54-58

[12] Karthik, T., & Murugan, R. Optimization of drafting zone variables in ring spinning for the production of cotton/milkweed blended yarns. Indian Journal of Fibre & Textile Research, 41 (2) (2016), 121-128

[13] Patil, N. P., Rachivkar, P. P., & ArurKamundi, A. M. Imrprove productivity of the ring frame. The Indian Textile Journal. (2011)

[14] Sheikh, H. R. Important elements of ring spinning and useful data. Pakistan Textile Journal, 61(2) (2012).

[15] Khurshid, F., Aslam, S., Ali, U., Abbas, A., Hamdani, T. A., & Hussain, F. Optimization of break draft, pin spacer and rubber cots hardness to enhance the quality of ring spun yarn using factorial design. Journal of Engineered Fibers and Fabrics, 13(2) (2018) 58-65. https://doi.org/10.1177/155892501801300209

A Study on Mechanical Properties of Bamboo-Cotton Handloom Fabrics

Harinder Pal*, Sagarika, Sushma Kumari & Aanchal Sharma

Department of Fashion Technology, Bhagat Phool Singh Mahila Vishwavidyalaya, Khanpur Kalan, Sonepat

Abstract*:*

This paper aims to study mechanical properties of cotton-bamboo fabrics made on handloom using different blend ratio as well as weave structure. A single warp beam using 2/20 Ne cotton was made and various samples were prepared using 100% cotton, 50/50 (bamboo/cotton), and 100% bamboo yarn in weft direction. Samples were also prepared with 1/1 plain weave and 2/2 twill weave to see the impact of weave on mechanical properties of fabrics. Results indicate that as the bamboo contents increases in fabrics there is increase in tensile strength and tear strength due to higher strength of bamboo yarn. The Tearing strength of twill woven fabrics is more than plain woven fabrics due to higher float length of yarn. Bamboo blended fabrics exhibit lesser flexural rigidity than cotton fabrics. The crease recovery also increases with the increasing bamboo contents for all samples irrespective of plain and twill weave. The twill woven fabrics exhibit slightly higher crease recovery than corresponding plain woven fabrics. Results indicate that bamboo also help in improving abrasion resistance, which may be due to non-circular surface and striated cracks of bamboo fibres. The increase in bamboo contents in plain woven fabrics also improves pilling resistance as compared to twill woven fabrics. Use of bamboo fibres in handloom industry as eco-friendly fibres could be seen as promising scope for consumers and entrepreneurs who are environmental concerned.

Keywords : *Blend, Cotton-Bamboo, Handloom, Mechanical Properties, Sustainability, Weave*

Citation: Harinder Pal, Sagarika, Sushma Kumari & Aanchal Sharma, "A Study on Mechanical Properties of Bamboo-Cotton Handloom Fabrics", *Journal of the Textile Association*, **85/5**(Jan-Feb 2025), 491-495, https://doi.org/10.5281/zenodo.14973933

Article Received : 15-01-2025, Revised: 22-01-2025, Accepted:26-01-2025

1. Introduction

Natural fibres are becoming popular for their unique properties like low density, excellent mechanical properties, durability, sustainability, and biodegradability [1]. Bamboo is a widely grown renewable material available in India which requires almost no care pesticides etc. that will decompose if discarded after the end-of-life naturally. Fibre extracted from bamboo would be environmentally friendly and a good option for sustainability [2]. Bamboo fibres may be classified into the natural bamboo fibre, bamboo pulp fibre, and bamboo charcoal fibre. Natural bamboo fibres are directly extracted from bamboo using physical or microbial degumming where crystalline structure of the original bamboo fibre does not change during the extraction process. Bamboo pulp fibre is made from bamboo pulp and bamboo charcoal fibre is made by surface treatment of nano-level bamboo charcoal powder, then slurry is added to the viscose and drawn into a wire shape [3, 4].

The literature reveals that the bamboo fibre length ranges from 38 to 76 mm which is higher than cotton fibre (25-45 mm). Fibre fineness is coarser in bamboo (1.3 – 5.6 dtex) than cotton fibre (1.2 – 2.8 dtex). Fibre density of bamboo fibre (0.8-1.32 g/cc) is lower than cotton fibre (1.5 – 1.54 g/cc). Moisture regain of bamboo is generally 13 % which is higher than regain of cotton (8.5 %). Apart from it bamboo has more tensile strength than cotton [6 -9].

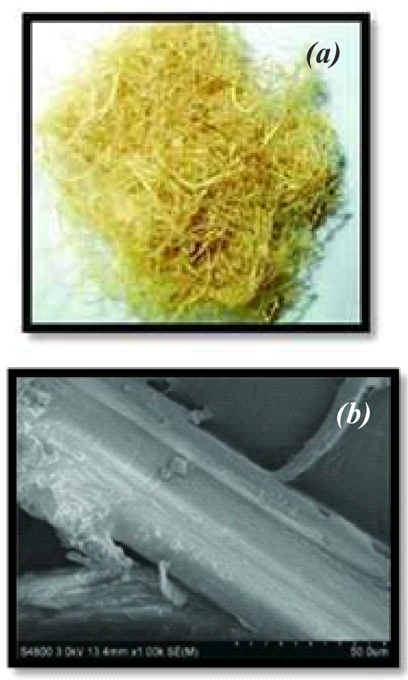


Figure 1: Bamboo Fibre: (a) macroscopic bamboo fibre (b) Scanning electron microscopic image [5]

The research reveals that the use of bamboo is gaining importance in clothing due to its sustainability factor and

**** Corresponding Author:***
Dr. Harinder Pal
Assistant Professor, Department of Fashion Technology,
Bhagat Phool Singh Mahila Vishwavidyalaya, Khanpur Kalan,
Sonipat – 131 305 Haryana
E-mail: harinderarora@gmail.com

remarkable properties. It's fast growing plant with reduced water footprints as well as requires no pesticides and fertilisers. It has also lower carbon footprints as it absorbs CO2 from atmosphere during its cultivation. Literature reveals that the bamboo is naturally antibacterial and has good moisture-wicking properties which assist in reducing bad odour and make the wearer comfortable [10, 11].

2. Experimental work

2.1 Materials and Method

A single warp beam using 2/20 Ne cotton was prepared and six samples were prepared using 100% cotton, 50/50 (bamboo/cotton), and 100% bamboo yarn in weft direction with 1/1 plain weave and 2/2 twill weave to see the impact of blend and weave on mechanical properties. The various properties were investigated as per ASTM/AATCC standards the briefing of which is as follows:

2.1.1 Tensile Strength

The ASTM D5304-95 (Strip test) standard was used to determine the tensile strength of the samples. The tensile strength of the fabric was evaluated using a universal testing machine in both directions i.e. warp and weft directions.

2.1.2 Tearing Strength

To evaluate the tearing strength of the samples, the ASTM D 1424:09 standard was implemented. Elmendorf tear tester was used to measure the tearing strength of all handloom samples. The specimen size was 7.5 cm × 10 cm and five tests were done both in warp and weft direction for each sample.

2.1.3 Bending & Flexural Rigidity

The testing method ASTM D1388-08 was used for the stiffness of the fabric. Bending length and flexural rigidity were measured using a Shirley Stiffness tester. The sample size was 6" x 1".

2.1.4 Crease Recovery Angle

The crease recovery of the fabric was carried out on the Crease recovery tester as per AATCC 66 standard. Crease recovery depends upon the construction, twist of yarn, pressure, and time. Six readings were taken in warp and weft direction each for all samples. A 500 gram load was applied for creasing for 5 minutes and the same time for recovery.

2.1.5 Abrasion Resistance

The abrasion-resistance test of the fabric was performed on the Martindale abrasion tester using the ASTM D4966 standard. Four specimens of each plain and twill woven fabric were taken to perform the test. The fabric samples were subjected to friction and rubbing against standard abrasive fabric during the test.

2.1.6 Pilling Resistant

The pilling resistance test of the fabric was performed on the Martindale abrasion and pilling tester as per ASTM D4970-02 standard. Four specimens of each plain and twill woven fabric were taken to perform the test. During the test, the fabric sample undergoes rubbing and abrasion against a standard abrasive fabric which simulates normal wear to generate pilling.

3. Result & Discussion

All handloom samples were conditioned in a testing atmosphere of 65 ± 2% RH at a temperature of 27 ± 20C to ensure the reliability of the results. The following findings were obtained during the testing of handloom fabric samples.

Table 1: Fabric Specifications

Sample	Weave	Warp yarns	Weft yarns	EPI	PPI	GSM
S1	Plain	2/20 ^{s} Cotton	2/20^s Cotton	46	32	200
S2	Plain	2/20 ^{s} Cotton	2/20^s Bamboo/Cotton (50/50)	46	34	210
S3	Plain	2/20 ^{s} Cotton	2/20^s Bamboo	46	36	216
S4	Twill	2/20 ^{s} Cotton	2/20^s Cotton	46	46	237
S5	Twill	2/20 ^{s} Cotton	2/20^s Bamboo/Cotton (50/50)	46	48	248
S6	Twill	2/20 ^{s} Cotton	2/20^s Bamboo	46	50	256

Table 2: Mechanical Properties

S. ID.	Tensile strength (Kgf)		Tearing strength (Kgf)		Bending length (cm)		Flexural rigidity (mg.cm)		Crease recovery angle		Abrasion resistant (no. of cycles)	Pilling resistance Ratings
	WP*	WF	WP	WF	WP	WF	WP	WF	WP	WF		
S1	53.25	39.05	4.3	5.1	2	2.15	160	198.6	101	108	10,000	3
S2	48.6	42.85	4.9	5.6	1.95	1.95	155.6	155.6	106	110	11,000	4
S3	43.45	53.75	5	5.7	1.8	1.85	125.3	136.1	114	116	12,000	4
S4	56.1	55.7	6.1	6.2	2	2.05	189.6	203.8	105	108	12,000	2
S5	55.45	57.45	6.2	6.6	1.9	1.95	168.6	183.5	111	117	20,000	2
S6	44.55	86.85	6.7	7.1	1.75	1.85	135.7	161.3	121	124	26,000	3

*WP and WF refers testing in warp and weft direction respectively.

3.1 Tensile strength

Tensile strength of all samples was tested on Tensile Testing Machine, the result of which is shown in Table 2. Results indicate that as the bamboo content increases in weft direction, there is significant increase in tensile strength in weft direction. Same trends are observed for plain and twill woven. The results are supported by the findings that tensile strength of bamboo is higher than cotton [12]. The tensile strength in twill woven fabrics are higher than corresponding plain woven fabrics, the reason of which may be attributed to higher PPI for all twill woven samples. Another observation is that for all samples except S1 and S2, tensile strength for plain and twill woven fabric, the tensile strength in weft direction is higher than warp direction, which may be due to combined effect of higher bamboo content and PPI. Since the EPI is significantly higher than PPI resulting into higher tensile strength in warp wise than weft wise. S6 shows maximum tensile strength than all other samples which could be due to 100 % bamboo used in weft direction and maximum thread density.

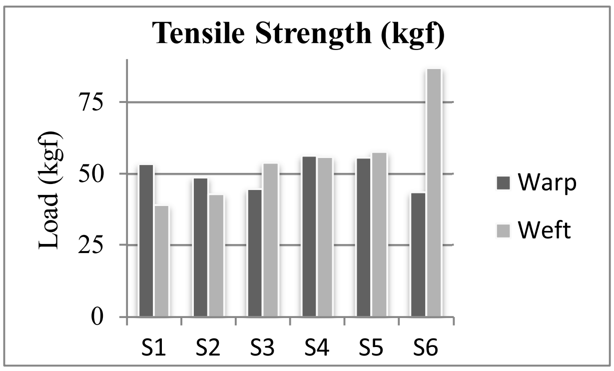


Figure 2: Tensile strength

3.2 Tear strength

Tearing strength was measured on Elmendorf tear strength tester as per ASTM D1424 standard. The results are given in Table 2 & Fig. 3 which indicates that tear strength increases with increase in bamboo content which may be due to higher strength of bamboo yarn. The tearing strength in twill woven fabrics is higher than corresponding plain woven fabrics, which are due to higher float length of yarn. Another observation is that tearing strength of samples in weft direction is higher than in warp direction due to the use of bamboo in weft direction which offers more tearing resistance.

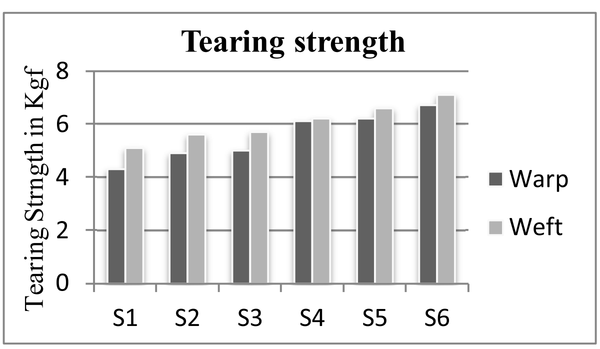


Figure 3: Tearing strength

3.3 Bending length & Flexural Rigidity

Results of bending length & flexural rigidity are shown in Table 2, Fig. 4 and Fig. 5. Bending length decreases with increase in bamboo content and as bending length is directly proportional to flexural rigidity which follows the same trend. The decrease in bending length is due to higher flexibility of bamboo yarn than cotton yarn. This may be due to higher crystalline structure of cotton fibre than bamboo yarn. However results are not significantly different in warp and weft direction as well as corresponding plain and twill woven fabrics.

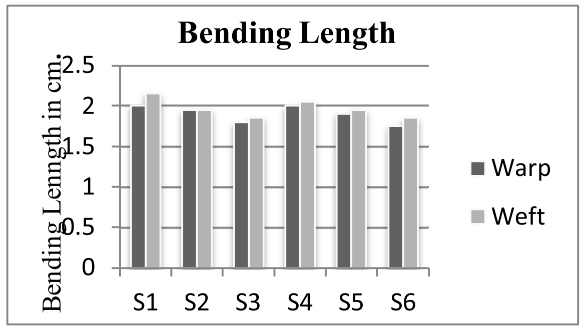


Figure 4: Bending Length

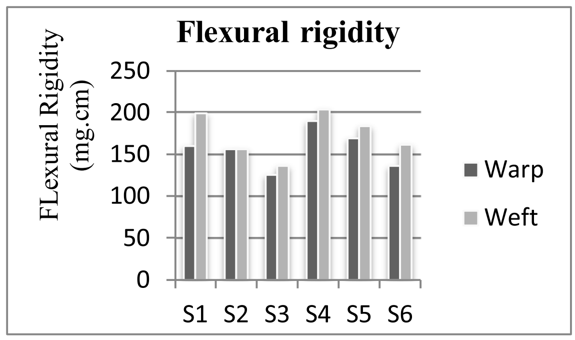


Figure 5: Flexural Rigidity

a. Crease recovery

The results of crease recovery are shown in table 2 and Fig. 6 which indicates that the crease recovery increases with increasing bamboo content for all samples. Crease recovery is also slightly higher in weft direction than warp direction which is due to the combined effect of use of bamboo yarn in weft wise as well as lower thread density in weft direction. Another observation is that twill woven fabrics exhibit slightly higher crease recovery than corresponding plain woven fabric.

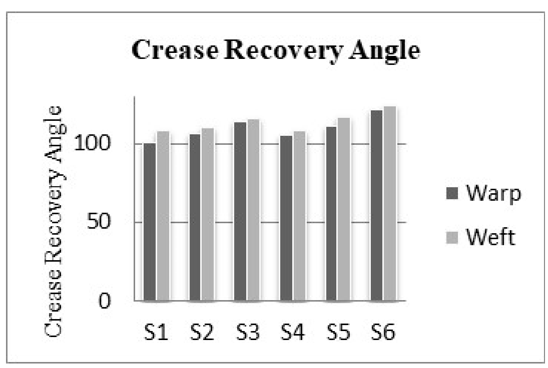


Figure 6: Crease Recovery Angle

b. Abrasion resistance

Abrasion resistance was measured on the Martindale abrasion tester, the results are shown in Table 2 and Fig. 7. A prominent observation about results reveals higher abrasion resistance of twill woven fabric than plain woven fabrics, the results of which seems to be contrary based on finding from literature review. Generally plain woven fabrics are more resistant to abrasion due to more interlacements and less exposed area than twill woven fabrics. A close look into results reveals that higher thread density in weft direction and resultant higher GSM has resulted into higher abrasion resistance. Abrasion resistance also increases with the increase in bamboo content. The non-circular surface of bamboo fibres, along with striated cracks on the surface may contribute to its abrasion resistance. S3 and S6 samples exhibit higher abrasion resistance for plain woven and twill woven fabrics as 100 % bamboo yarn is used in weft direction.

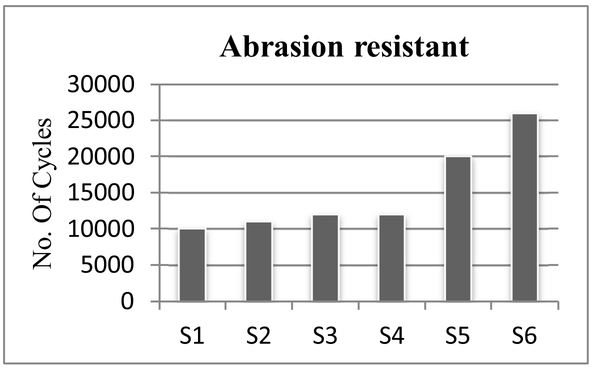


Figure 7: Abrasion resistant

c. Pilling resistance

The pilling resistance was also measured on Martindale abrasion & pilling tester as per ASTM D4970-02 standard. The results are shown in Table 2 & Fig.8. Rating scale of pilling resistance is from 5 (best rating) to 1(severe pilling). Result indicates that plain fabric is more resistant to pill formation than twill woven. This is due to more interlacement in plain woven fabrics which makes it less likely to pill. The increase of bamboo content in weft direction also gives more resistant to pilling.

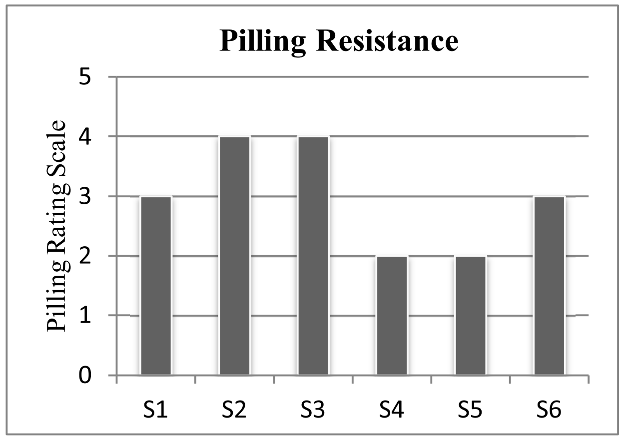


Figure 8: Pilling Resistance

4. Conclusion

Bamboo is considered more environmentally friendly due to its lower water and pesticide usage in cultivation. The study reveals that the bamboo fibres showed greater influence on fabric mechanical properties and also shows desirable aesthetic properties. Usage of bamboo in clothing will increase its durability and will reduce flexural rigidity which gives more softness to the fabrics and hence increase the comfort to the wearer. Crease recovery as well as pilling resistance improves with the presence of bamboo fibre in fabrics. Tensile and tearing strength have shown greater improvement in bamboo blended fabric that cotton fabrics. Apart from enhancing mechanical, aesthetic properties, the bamboo is naturally antibacterial and has good moisture-wicking properties. Since consumers are getting environmentally aware, they are demanding sustainable and comfortable clothing especially in developed nations. It is expected that bamboo will gain importance in clothing due to its sustainability factor and remarkable properties.

5. Acknowledgement

We gratefully acknowledge the support of BPS Mahila Vishwavidyalaya, Khanpur Kalan, Sonipat, Haryana. The research leading to these results has received funding from the Project titled "Design and Development of Sustainable Handloom Fabric Using Bamboo/Cotton Yarn and to Study the Impact of Blend Component and Constructional Parameters on Fabric Properties"

Reference :

[1] S.Joshi, L.T. Drzalb, A.K. Mohanty, S. Arora, "Are natural fiber composites environmentally superior to glass fiber reinforced composites", Composite: Part a Applied Science and Manufacturing, 35(3) (371-376), 2004

[2] P. van der Lugt, A.A.J.F. van den Dobbelsteen, J.J.A. Janssen, " An environmental, economic and practical assessment of bamboo as a building material for supporting structures", Construction And Building Materials, 20(9) (648-656), (2006)

[3] Zhang, Y., Wang, C. H., Peng, J. X., "Preparation and technology of bamboo fiber and its products. Beijing: China Textile Publishing House, (2014)

[4] S. Mingham, Z. Xiuzhu and J. Man, "Exploring the innovation Landscape of bamboo fiber technologies from global patent data perspective", Cellulose, 27(2) (1-20), 2020

[5] H. Jia, Y. Sheng, H. Lv, Y.R. Kim, X. Zhao, J.Meng and R. Xiong, " Effect of bamboo fiber on the mechanical properties of asphalt mixtures", Construction and Building Materials, 289(4), 123196 (2021)

[6] P. Chidambaram and R. Govindan, "Influence of Blend Ratio on Thermal Properties of Bamboo/ Cotton Blended Woven Fabrics", Silpakorn U Science & Tech J, 6/2 (49-55), (March- June 2012)

[7] Ziva Z. and Krste D. 'A Text Book of Woven Fabric Engineering', Slovenia; Intech Open publishing: 2010: pp. 25-46

[8] Textilsphere.com [Internet].India: Association of Textile Sphere; c2019 [updated 2020 September 14; cited 2023 June 25] https://www.textilesphere.com/2020/09/bamboo-fiber.html

[9] S. Bhuyan and N. Gogoi, "Natural Fibers: Innovative Sustainable and Eco-Friendly," International Journal of Current Microbiology and Applied Sciences, Vol. 9/7 (1004-1011), (2020)

[10] F. Sekerden, "Effect of Fabric Weave and Weft Types on the Characteristics of Bamboo/Cotton Woven Fabrics", Fibres& Textiles in Eastern Europe, 19/ 6 (89) (47-52), (2011)

[11] V. Kumara, P.Kumari, P.Yadav& M. Kumar, "Ancient to contemporary—the saga of Indian handloom sector", Indian Journal of Fibre& Textile Research, 46 (411-431), (2021)

[12] S. Bhuyan and N. Gogoi, "Natural Fibers: Innovative Sustainable and Eco-Friendly," International Journal of Current Microbiology and Applied Sciences, Vol. 9/7 (1004-1011), (2020)

[13] A Rathod and A. Kolhatkar, "Study on Physical Characteristics of Bamboo & Bamboo-Cotton Blended Yarn Fabrics, "International Journal of Research in Advent Technology, 2/7 (105-110), (2014)

[14] B.Y.Büyükakinci, "Investigation of The Internal Structure of Regenerated Bamboo Fiber, TEKSTİL ve KONFEKSİYON, 20(4) (277-283), (2010)

[15] R Medar and G Mahale, "Functional Properties of Bamboo and Tencel Union Fabrics", International Journal of Current Microbiology and Applied Sciences, 9/6 (3851-3867), (2020)

[16] M. Khan, H. Mahmud, T. Sarathi Das, M. Abdullah, T. Rahman Khan, R. Hasan Shohan, S. Al Rafi, Solaiman, "Analysis the Influenced of Plain and Twill Structures on Woven Fabric Properties", Journal of Textile Science and Technology, 6 (107-113), (2020)

■ ■ ■

Advances in Jute Composite: A Comprehensive Review

Sanat Kumar Sahoo & Bibhu Prasad Dash*

Department of Textile Engineering, Odisha University of Technology and Research, Bhubaneswar, Odisha, India

Abstract :

The vision for changing the climatic impact of synthetic products by civil society can be replaced by nature-giving products. Though as textile technicians, we know that the textile industry is the second-largest waste producer in the world. In the composite sector, synthetic fibres are gaining huge profits due to their high strength and durability. It is a challenge for us to develop natural fibre composite to replace synthetic for the sake of the environment and sustainability. And Jute fibre is the best among natural fibres which can replace synthetic fibres for composite preparation. In this field, more studies are going on to enhance jute fibre as a reinforcing material with high strength and durability in various applications. This article comprehensively overviews jute fibre, its composition, mechanical properties, surface treatment, composite preparation with various resins and fibres, and applications in different sectors.

Keywords: *Application, chemical treatment, composite, jute, matrix, processes*

Citation: Sanat Kumar Sahoo & Bibhu Prasad Dash, "Advances in Jute Composite: A Comprehensive Review", *Journal of the Textile Association*, **85/5**(Jan-Feb 2025), 496-502, https://doi.org/10.5281/zenodo.14973885

Article Received : 14-06-2024, Revised: 17-01-2025, Accepted: 21-01-2025

1. Introduction

When metals, ceramics, and polymers failed to meet certain performance criteria, the use of composites grew in favour. The previous several decades have seen a dramatic increase in the use of composite materials across many different fields, including aerospace, transportation, infrastructure, and consumer goods. High toughness, damage tolerance, structural integrity, and handling of the reinforced material were achieved by using composite materials to produce structural elements that could endure mechanical and thermal stress (multi-directional). Environmentally friendly materials have been developed as more people become aware of their advantages for the benefit of the ecosystem. Fibre-reinforced polymers (FRP) are composite materials with a polymer matrix and high-strength fibres like glass, aramid, or carbon from synthetic fibres [1] or maybe from natural fibres like jute, sisal, coir, hemp, kenaf, flax etc., Combining a polymer with a high-performance fibre like this results in superior mechanical qualities. Synthetic fibres including carbon, glass, and aramid are often employed in composites due to their high stiffness and strength properties [2]. Issues with biodegradability, initial processing expense, recycle-ability, energy consumption, machine abrasion, health risks, etc., have resulted from the widespread use of these fibres [3]. Due to various drawbacks of these synthetic fibres, researchers set their goal to change from synthetic to natural fibre to adverse environmental impact. Natural fibre composites have the potential to replace synthetic fibre-reinforced composites as a result of their reduced cost and enhanced sustainability. An alternative to the ever-depleted petroleum resources is natural fibre-reinforced composites and also it gains increasing attention from researchers to society. There are numbers of advantages that simply attracts acceptance by manufacturers and scientists. These attractive features are lightweight, inexpensive, friendly processing; biodegradable, environmentally friendly, and non-toxicity absorbing CO2 during their growth [4]. High specific modulus, low density, relatively high processing flexibility, and strong strength are only some of these fibres' fascinating physical and mechanical features. Studies of composites over time have repeatedly demonstrated that natural fibres such as coir, kenaf, flax, jute, hemp, and sisal outperform their synthetic equivalents [5]. Natural fibres, such as bio-fibres made from renewable resources, also have positive environmental effects due to their biodegradability and resource efficiency [3]. Natural fibres meeting these performance standards for the composites industry will gradually replace synthetic fibres. They can be modified and are considered to be excellent materials for use in automobiles, construction, and furniture production [6].

***Corresponding Author:**

Mr. Bibhu Prasad Dash

Dept. of Textile Engineering, Odisha University of Technology and Research, Kalinga Nagar, Ghatikia, Bhubaneswar - 751003 Odisha

E-mail: bpdash@outr.ac.in

The popularity of NFCs is on the rise for several reasons. One of these is their potential to replace synthetic fibre-reinforced plastics, which they can do at a cheaper price and with greater sustainability. After decades of technological advancement of synthetic materials like carbon, aramid, and glass [5, 7], natural fibres like kenaf, coir, flax, jute, hemp, and sisal are still popular materials for composite preparation. It is crucial to improve compatibility between the (hydrophobic-thermoplastic or hydrophilic-thermoset) matrix and the reinforcements when utilising hydrophilic cellulose-based natural fibres as reinforcements in composite technology [8].

The composite material may take the shape of fibres, particles, or flakes; nonetheless, it is the fibres that serve as reinforcement and provide the bulk of the composite's strength and stiffness. In contrast, the matrix safeguards the reinforcement against chemical and physical damage while still maintaining its orientation [9]. The matrices also ensure that a load is distributed uniformly over the reinforcing bars. In the beginning, textile-reinforced composites were exclusively produced from high-performance fibres or artificial fibres, but the high initial raw material and processing costs slowed their development [10]. Thus, natural fibres entered the market. Naturally occurring fibres were used because they improved properties such as flexural limit during splitting, durability, ductility, and break resistance over unreinforced matrices [11].

There are several reasons for jute to be considered as sustainable alternative to synthetic fibers in the preparation and application of composites. These are listed as:

Jute is a natural fiber that is biodegradable, which reduces environmental contamination and waste. In contrast to synthetic fibers, which are synthesized from petroleum-based materials that are not renewable, jute is a renewable resource [12]. The absorption of carbon dioxide by jute plants during growth is a contributing factor to carbon sequestration. Rural communities are afforded employment opportunities through the cultivation and processing of jute. Jute production fosters sustainable livelihoods by supporting local economies. Jute fibers are lightweight, which reduces energy requirements and material consumption. Jute fibers are well-suited for composite applications due to their high tensile strength [13]. The energy consumption of buildings is reduced by the thermal insulation provided by jute fibers. Jute fibers are compostable, which minimizes the environmental impact of end-of-life disposal and reduces waste. The demand for virgin materials is diminished by the ability to recycle jute fibers.

2. Jute fibre short preface

In green composites, jute is the most often utilised reinforcing fibre made from natural materials. Because it is harvested from corchorus plants, jute is classified as a bast fibre and goes by the scientific name corchorus capsularis [14]. Nearly 30–40 species of Capsularis are classified as jute, all of which are in the family Tiliaceae. The most frequent species are the white jute (Corchorus capsularis) and the tossa jute (Corchorus olitorius) [14]. Jute is the most widely produced natural fibre in the world right now, and it also happens to be one of the cheapest. Modern jute growers have found greater success in Bangladesh, India, China, Nepal, Thailand, Indonesia, and Brazil [15], despite the plant's ancient links to the Mediterranean. In terms of both usage and production, jute is second only to cotton among the world's most significant vegetable fibres. The majority of the world's jute comes from India and Bangladesh, where over 3.3 million tonnes are harvested year [16]. Due to growing fuel costs, dwindling fossil fuel sources, and global warming, jute fibres have become more popular as reinforcement in the production of composite materials in recent years.

2.1. Chemical composition

Both the physical structure and chemical content of fibres are influenced by environmental factors, phases, and the degradation process. In addition to water, the primary components of plant cell walls are lignin, cellulose, and hemicellulose, with trace amounts of protein and starch [17]. The three main components of jute fibre are cellulose, hemicellulose, and lignin varying throughout different jute grades [18]. Plant cells and cell walls form the plant's stems; these cells could also be found in the plant's leaves or roots. Enzymes like cellulose may trigger it. Therefore, cellulose predominates among fibres and contributes to strength.

Table 1 - Physical properties of jute fibre

Sr. No.	Properties	Jute Fibre
1	Cellulose (%)	60-65
2	Hemi-cellulose (%)	20-22
3	Lignin (%)	20-24
4	Waxes (%)	0.5
5	Pectin (%)	0.2
6	Moisture content (%)	1.1
7	Density (g/cm^3)	1.45
8	Fibre diameter (μm)	110-120
9	Water absorption (%)	12
10	Tensile strength (MPa)	393-773
11	Young's modulus (MPa)	19500
12	Elongation at break (%)	1.16-1.18
13	Microfibrillar angle (°)	8.1
14	Aspect ratio (L/D)	355-375

2.2. Surface treatment

Jute is hydrophilic, and adhesion between the fibres may be strengthened by physical and chemical treatment. Physical alterations include plasma, steam, ionising radiation, and so on, while chemical treatments include alkali, acetylation, and the use of maleated coupling agents such as maleic-anhydride grafted PP, silane coupling agents, etc. [18]. During the chemical treatment procedure, the hydroxyl (OH) groups on the surface of the jute fibre react with the chemical agents. Alkali (NaOH, KOH, or LiOH) is used as the first step in cleaning cellulose fibres by removing partial hemicellulose, lignin, wax, and other surface contaminants [19]. The treatment is more successful when more NaOH is used and it is soaked for longer. When compared to virgin jute yarn, the treated variety had superior mechanical properties [20]. Jute fibre's thermal conductivity was improved by alkali treatment on its surface [21]. Silane treatment increased fracture toughness at high temperatures but had little impact at lower temperatures. Surface treatment also has an impact on the composite's thermal characteristics [22]. Jute fibre composites using a fluorocarbon, hydrocarbon, or hybrid fluorocarbon surface treatment showed improved mechanical characteristics [23].

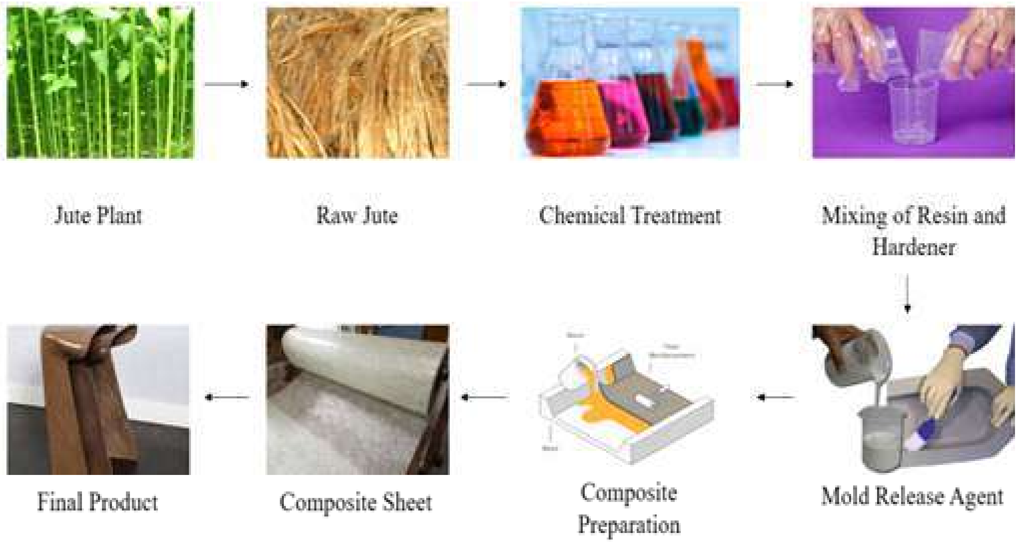


Figure.1: Jute plant to final composite application

3. Composites made with jute fibre

Composites may be processed in the same ways as plastics. Both thermoset and thermoplastic composites fall under this category. Thermoset composites reinforced with natural jute fibre were fabricated using open mould techniques including hand lay-up as well as closed mould methods like resin transfer and compression moulding. Unsaturated polyesters, epoxies, and phenols are the most popular thermosets [24]. The most prevalent thermoplastic matrices are polypropylenes, polyethylene, and elastomers [25]. Researchers have suggested a variety of approaches for fabricating jute fibre composites. Injection moulding, manual lay-up with compression moulding, and vacuum-assisted resin transfer moulding are some more ways to create eco-friendly composites [26].

3.1. Composites of thermoplastics reinforced with jute fibre

The temperature at which natural fibres deteriorate will limit the matrix determination. Most natural fibre composites are not thermally stable over 200°C [27], while some may withstand greater temperatures for shorter amounts of time under certain circumstances. Due to this restriction, not all thermoplastics may be employed as a matrix. Thermoplastics that may be mollified below the aforementioned temperature, such as polypropylene, polystyrene, polyethylene, and polyolefin, among others, can be employed as a matrix. Although many thermoplastic polymers can be utilised as a matrix, polyethylene and polypropylene are most frequently used in conjunction with jute fibre [28]. Polypropylene matrix is one of the most often used thermoplastics with jute fibres because it is inexpensive, has a low thermal expansion, and can be recycled. According to a tensile test and deflection temperature, the tensile strength of polypropylene by 19.7 percent when 40 percent jute fibre was added to the mix [29]. The composite made from jute and glass fibres reinforced with polypropylene had superior mechanical qualities than that made only from polypropylene, although the reinforcement only improved the composite's mechanical properties to a certain extent [30].

3.2. Composites of thermosets reinforced with jute fibre

In terms of thermoset, unsaturated polyester, epoxy resin, phenol–formaldehyde, etc. are the polymers that are most frequently utilised as a matrix [31]. The tensile strength of the jute-epoxy combination was found to be more than that of the jute-polyester combination, while the flexural strength was found to be greater for the latter. Creating items using jute and polyester was shown to be much faster than creating them with jute and epoxy [32]. Most studies conducted under actual operating conditions found that increasing the jute fibre volume% in the matrix increased the moisture diffusion rate into the composites [33]. Epoxy composites generated at 100 °C exhibited the highest tensile and flexural strengths, according to research on the impact of curing temperature on the mechanical parameters of jute fibre/epoxy-based composites [34].

Tensile, flexural, and inter-laminar shear strengths were all improved by the treatments, with the fluorocarbon treatment being the most effective. The shrinking of the fibres during the alkali treatment influenced the fibre structure and, by extension, the characteristics of the composite [35], even if the rough surface morphology brought on by the treatment did not increase interfacial adhesion. Seki used a manual lay-up approach to create a jute/epoxy composite. The mechanical characteristics of oligomeric siloxane-treated alkali-treated jute fibres were evaluated using tensile, flexure, and short beam shear tests [36]. Using a wettability and single-fibre pull-out test in an epoxy matrix, it was discovered that treating the surface of jute fibres with alkali, organo-silane, epoxy dispersions, and their mixtures enhanced the adhesion strength [37].

The tensile and flexural strength of a jute/epoxy composite using a hand lay-up method was evaluated after being subjected to salty, mineral, and sub-freezing water [38]. The flexural and tensile characteristics of the jute-epoxy composite were higher than those of the jute-polyester composite [32].

There have been several academic investigations on composites made from jute using polyester as resin. It is analysed the tensile, compressive, flexural, impact, and in-plane shear strengths and hardness of a hand-laid-up composite of untreated jute cloth and polyester [39]. Scientists discovered that composites made of jute and polyester was significantly more durable than their wooden counterparts. Hand-laid-up polyester laminates reinforced with woven jute fibres were created and their behaviour under uniaxial, multiaxial (tension/torsion), and fatigue loading was studied [40].

3.3. Composites made of jute and bio-based resin

Composites made of jute fibres reinforcing a biodegradable polymer matrix are known as "jute fibre-reinforced biodegradable polymers" [41]. Polylactic acid (PLA), polyvinyl alcohol (PVA), and poly hydroxy-butyrate (PHB) are just a few examples of biodegradable polymers now on the market [42]. Some research examined how water, enzymes, and soil affected the degradation behaviour of composites reinforced with natural fibres. Serving ware, composting bags, and films made from composites of PLA films and woven jute fibre in mat form have been offered as a renewable and degradable solution [43]. The results of the investigation suggest that PLLA-based Woven jute fibre composites may be superior to their synthetic counterparts. The one-way composites made from jute-spun yarn and PLA were manufactured via compression moulding. Jute composites use soy protein concentrate, soy protein isolate, soy resin made from soymilk, and bio-based epoxy resin, a petroleum-free substitute for epoxy resin. By using a film stacking technique, developed 40% weight/weight jute mat/PLA film composites [44]. Tensile testing, impact tests, and electron microscopy all proved that the fracture was brittle. The effect of alkali treatment on the mechanical characteristics of jute/PLA composites was investigated [45].

3.4. Hybrid composites using jute fibre

Natural fibre hybrid composites may either be (a) completely natural or (b) a blend of natural and synthetic fibres. The matrix material for these composites was unsaturated polyester, while the reinforcing fibres were natural (Jute, bamboo, and Kenaf). Mechanical experiments show that kenaf/unsaturated composites have a lower tensile modulus than bamboo/unsaturated polyester composites and jute/unsaturated composites [46]. Composites made of Jute fibre and epoxy, as well as composites made of woven glass fibre, was developed. The percentage of glass fibre used in the composite's construction has been found to increase its tensile strength. Jute/glass woven composites have greater flexural and impact strength than jute woven composites [47]. Concerns about the increased tendency of natural fibres to absorb moisture are warranted, especially for things that come into close contact with the environment. It was shown that when water absorption increased, flexural and compression strengths dropped. Hybrid composites made from natural and synthetic fibres have better mechanical properties [48] because their moisture absorption is reduced. These days, natural fibres (NFs) like sisal and jute are often used in conjunction with glass fibre composites. For this reason, researchers have been experimenting with and developing epoxy composites reinforced with a combination of glass fibre and sisal or jute. The results show that tensile strain is where sisal and glass fibre-reinforced plastic (GFRP) composites shine, but the flexural load is where jute composites shine. When compared to GFRP, the performance of these NF composites is subpar [49]. Flexural stiffness, tensile strength, compressive strength, moisture absorption, and mechanical characteristics are all improved in hybrid jute, which includes ranging from 0% to 6% TiO_2 by weight [50]. Polymer epoxy with added jute had better mechanical qualities but still lagged behind epoxy with glass fibre reinforcement [51]. For sound absorption, jute low-density fibre-reinforced plastic performed better than high-density jute and even better than glass fibre composite [52].

Hand-laid-up hybrid composites of untreated woven jute with glass cloth reinforcement were investigated for their tensile, flexural, and interlaminar shear characteristics [53]. By combining jute, mercerized jute, and high-toughness man-made cellulose fibres with a polypropylene (PP) matrix, was able to generate a hybrid composite [54]. A combination of 25% jute and 75% synthetic cellulose yielded the right balance of qualities. The mechanical properties of hybrid composites made from sisal, jute, glass fibre, and polyester were studied [55].

4. Application of Jute Composites

Several sectors, including building, transportation, and furniture design, make use of natural fibre composites because of their adaptability [56]. Future applications for jute fibre-reinforced composites may be found in the automobile industry, the footwear manufacturing sector, the construction industry, the home and garden furniture industry, and the toy industry [57]. Several major American automakers have begun using natural fibres like jute, hemp, and flex to create a wide range of external and interior components [58].

However, the use of jute fibre as a reinforcing component in polymer matrix composites has resulted in exciting new possibilities for these kinds of building supplies. False ceilings, jute/polymer corrugated sheets, roof tiles, furniture, and other uses are some further examples. Consumers like jute fibre composites for their superior quality and minimal environmental impact [59]. Scientists are investigating ways to improve jute fibre for its potential future use.

5. Limitation of Jute Composites

In spite of the benefits of jute fibers in composites, there are numerous constraints:

1. Jute fibers are hydrophilic, allowing them to absorb moisture from the environment [60]. This can result in the following:

a. Swelling and degradation
b. Reduced mechanical properties

2. Enhanced susceptibility to the proliferation of mold and fungi
3. Jute fibers have a relatively low thermal stability, which can result in [61]:
   a. Discoloration
   b. Degradation
4. Decreased mechanical properties after contact with water
5. Utilization in high-temperature applications is restricted
6. The variability of jute fibers can be observed in the following factors:
   a. Fiber length and diameter
   b. Fiber strength and stiffness
   c. Fiber surface texture and chemistry
7. Certain matrices may not be completely compatible with jute fibers, resulting in:
   a. Decreased mechanical properties
   b. Poor interfacial bondin
   c. Increased potential for delamination
8. Jute fibers necessitate additional processing stages, including decortication and retting, which can result in a rise in costs [62].
9. Jute fibers may not be broadly available, and supply chains may be restricted, resulting in:
   a. Increased costs
   b. Reduced reliability
   c. Limited scalability

6. Conclusion

In this article, we'll look at the many issues that have been associated with the overutilization of synthetic composites. To safeguard the environment from the dangers posed by synthetic composites, their production must be halted and discouraged. Jute fibre is increasingly being employed as the reinforcing phase in polymer matrix composites, which has broadened its potential applications beyond its traditional uses in rope, hessian fabric, carpet, wallmats, bags, etc. Outside of the textile business, jute fibres might be used in the construction and transportation industries, as well as in the toy and furniture industries. Although further research is required to fully use the potential of such composite materials, jute has shown promise as a reinforcing material for sustainable and environmentally friendly applications whether used as a single or hybrid fibre. Polymer composites reinforced with jute fibre will require further research before they can be sold commercially.

Conflict of Interest : There are no conflicts of interest to declare.

References

1. M. A. Masuelli and M. A. Masuelli, “Introduction of Fibre-Reinforced Polymers − Polymers and Composites: Concepts, Properties and Processes,” Fiber Reinf. Polym. - Technol. Appl. Concr. Repair, Jan. 2013, doi: 10.5772/54629.
2. J. Rout, M. Misra, S. S. Tripathy, S. K. Nayak, and A. K. Mohanty, “The influence of fibre treatment on the performance of coir-polyester composites,” Compos. Sci. Technol., vol. 61, no. 9, pp. 1303–1310, Jul. 2001, doi: 10.1016/S0266-3538(01)00021-5.
3. A. K. Bledzki and J. Gassan, “Composites reinforced with cellulose based fibres,” Prog. Polym. Sci., vol. 24, no. 2, pp. 221–274, May 1999, doi: 10.1016/S0079-6700(98)00018-5.
4. E. Mostafavi, S. Iravani, R. S. Varma, M. Khatami, and F. Rahbarizadeh, “Eco-friendly synthesis of carbon nanotubes and their cancer theranostic applications,” Mater. Adv., vol. 3, no. 12, pp. 4765–4782, Jun. 2022, doi: 10.1039/D2MA00341D.
5. A. K. Mohanty, M. Misra, and L. T. Drzal, “Sustainable Bio-Composites from renewable resources: Opportunities and challenges in the green materials world,” J. Polym. Environ., vol. 10, no. 1–2, pp. 19–26, Apr. 2002, doi: 10.1023/A:1021013921916/METRICS.
6. Mohammed, M., Rahman, R., Mohammed, A. M., Adam, T., Betar, B. O., Osman, A. F., & Dahham, O. S. (2022). Surface treatment to improve water repellence and compatibility of natural fiber with polymer matrix: Recent advancement. Polymer Testing, 107707.
7. S. J. Eichhorn, “Current international research into cellulosic fibres and composites,” J. Mater. Sci., vol. 36, no. 9, pp. 2107–2131, May 2001, doi: 10.1023/A:1017512029696/METRICS.
8. J. George, M. S. Sreekala, and S. Thomas, “A review on interface modification and characterization of natural fiber reinforced plastic composites,” Polym. Eng. Sci., vol. 41, no. 9, pp. 1471–1485, Sep. 2001, doi: 10.1002/PEN.10846.
9. F. C. Campbell, “Introduction to Composite Materials,” Struct. Compos. Mater., pp. 1–29, Nov. 2010, doi: 10.31399/ASM.TB.SCM.T52870001.
10. O. Faruk, A. K. Bledzki, H. P. Fink, and M. Sain, “Progress Report on Natural Fiber Reinforced Composites,” Macromol. Mater. Eng., vol. 299, no. 1, pp. 9–26, Jan. 2014, doi: 10.1002/MAME.201300008.
11. Z. Zheng and D. Feldman, “Synthetic fibre-reinforced concrete,” Prog. Polym. Sci., vol. 20, no. 2, pp. 185–210, Jan. 1995, doi: 10.1016/0079-6700(94)00030-6.
12. Shah, Syed Shaheen, et al. "Present status and future prospects of jute in nanotechnology: A review." The Chemical Record 21.7 (2021): 1631-1665.
13. Samim, Samahat, et al. "Quasi-static axial crushing investigation of filament-wound eco-friendly energy-absorbing glass fiber and jute fiber composite structures." Journal of Materials Research and Technology 30 (2024): 6389-6403.
14. S. Roy and L. B. Lutfar, “Bast fibres: Jute,” in Handbook of Natural Fibres: Second Edition, Woodhead Publishing, 2020, pp. 39–59. doi: 10.1016/B978-0-12-818398-4.00003-7.

15. Saleem, Muhammad Hamzah, Shafaqat Ali, Muzammal Rehman, Mirza Hasanuzzaman, Muhammad Rizwan, Sana Irshad, Fahad Shafiq et al. "Jute: A potential candidate for phytoremediation of metals—A review." Plants 9, no. 2 (2020): 258.
16. S. Rahman, M. M. H. Kazal, I. A. Begum, and M. J. Alam, "Exploring the Future Potential of Jute in Bangladesh," Agric. 2017, Vol. 7, Page 96, vol. 7, no. 12, p. 96, Nov. 2017, doi: 10.3390/AGRICULTURE7120096.
17. Sweygers, Nick, Delphine EC Depuydt, Samuel Eyley, Wim Thielemans, Yasmine Mosleh, Jan Ivens, Raf Dewil, Lise Appels, and Aart Willem Van Vuure. "Prediction of the equilibrium moisture content based on the chemical composition and crystallinity of natural fibres." Industrial Crops and Products 186 (2022): 115187.
18. H. Chandekar, V. Chaudhari, and S. Waigaonkar, "A review of jute fiber reinforced polymer composites," Mater. Today Proc., vol. 26, pp. 2079–2082, Jan. 2020, doi: 10.1016/J.MATPR.2020.02.449.
19. Wen, J. L., Xiao, L. P., Sun, Y. C., Sun, S. N., Xu, F., Sun, R. C., & Zhang, X. L. (2011). Comparative study of alkali-soluble hemicelluloses isolated from bamboo (Bambusa rigida). Carbohydrate research, 346(1), 111-120.
20. A. A. Zolriasatein, M. E. Yazdanshenas, R. Khajavi, and A. Rashidi, "Effects of alkali and ultraviolet treatment on colour strength and mechanical properties of jute yarn," Color. Technol., vol. 128, no. 5, pp. 395–402, Oct. 2012, doi: 10.1111/J.1478-4408.2012.00393.X.
21. S. Sudha and G. Thilagavathi, "Analysis of electrical, thermal and compressive properties of alkali-treated jute fabric reinforced composites," J. Ind. Text., vol. 47, no. 6, pp. 1407–1423, 2018, doi: 10.1177/1528083717695840.
22. S. Samal, M. Stuchlík, and I. Petrikova, "Thermal behavior of flax and jute reinforced in matrix acrylic composite," J. Therm. Anal. Calorim., vol. 131, no. 2, pp. 1035–1040, Feb. 2018, doi: 10.1007/S10973-017-6662-0/FIGURES/5.
23. S. Fatima and A. R. Mohanty, "Acoustical and fire-retardant properties of jute composite materials," Appl. Acoust., vol. 72, no. 2–3, pp. 108–114, Feb. 2011, doi: 10.1016/J.APACOUST.2010.10.005.
24. S. Hörold, "Phosphorus flame retardants in thermoset resins," Polym. Degrad. Stab., vol. 64, no. 3, pp. 427–431, Jun. 1999, doi: 10.1016/S0141-3910(98)00163-3.
25. C. Clemons, "Elastomer modified polypropylene–polyethylene blends as matrices for wood flour–plastic composites," Compos. Part A Appl. Sci. Manuf., vol. 41, no. 11, pp. 1559–1569, Nov. 2010, doi: 10.1016/J.COMPOSITESA.2010.07.002.
26. M. H. Zin, M. F. Razzi, S. Othman, K. Liew, K. Abdan, and N. Mazlan, "A review on the fabrication method of bio-sourced hybrid composites for aerospace and automotive applications," IOP Conf. Ser. Mater. Sci. Eng., vol. 152, no. 1, p. 012041, Oct. 2016, doi: 10.1088/1757-899X/152/1/012041.
27. Y. Yang, T. Ota, T. Morii, and H. Hamada, "Mechanical property and hydrothermal aging of injection molded jute/polypropylene composites," J. Mater. Sci., vol. 46, no. 8, pp. 2678–2684, 2011, doi: 10.1007/s10853-010-5134-8.
28. N. Chand and U. K. Dwivedi, "Effect of coupling agent on abrasive wear behaviour of chopped jute fibre-reinforced polypropylene composites," Wear, vol. 261, no. 10, pp. 1057–1063, 2006, doi: 10.1016/j.wear.2006.01.039.
29. S. Nabila, A. L. Juwono, and S. Roseno, "Effect of Weight Fractions of Jute Fiber on Tensile Strength and Deflection Temperature of Jute Fiber/Polypropylene Composites," IOP Conf. Ser. Mater. Sci. Eng., vol. 196, no. 1, p. 012029, May 2017, doi: 10.1088/1757-899X/196/1/012029.
30. K. Dey, N. Sharmin, R. A. Khan, S. Nahar, A. J. Parsons, and C. D. Rudd, "Effect of Iron Phosphate Glass on the Physico-mechanical Properties of Jute Fabric-reinforced Polypropylene-based Composites," http://dx.doi.org/10.1177/0892705711401848, vol. 24, no. 5, pp. 695–711, May 2011, doi: 10.1177/0892705711401848.
31. N. Saba, P. M. Tahir, and M. Jawaid, "A Review on Potentiality of Nano Filler/Natural Fiber Filled Polymer Hybrid Composites," Polym. 2014, Vol. 6, Pages 2247-2273, vol. 6, no. 8, pp. 2247–2273, Aug. 2014, doi: 10.3390/POLYM6082247.
32. A. Gopinath, M. Senthil Kumar, and A. Elayaperumal, "Experimental Investigations on Mechanical Properties Of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices," Procedia Eng., vol. 97, pp. 2052–2063, Jan. 2014, doi: 10.1016/J.PROENG.2014.12.448.
33. M. H. Zamri, H. M. Akil, A. A. Bakar, Z. A. M. Ishak, and L. W. Cheng, "Effect of water absorption on pultruded jute/glass fiber-reinforced unsaturated polyester hybrid composites," http://dx.doi.org/10.1177/0021998311410488, vol. 46, no. 1, pp. 51–61, Sep. 2011, doi: 10.1177/0021998311410488.
34. J. I. P. Singh, S. Singh, and V. Dhawan, "Effect of alkali treatment on mechanical properties of jute fiber-reinforced partially biodegradable green composites using epoxy resin matrix," Polym. Polym. Compos., vol. 28, no. 6, pp. 388–397, 2020, doi: 10.1177/0967391119880046.
35. V. Mittal, R. Saini, and S. Sinha, "Natural fiber-mediated epoxy composites - A review," Compos. Part B Eng., vol. 99, pp. 425–435, 2016, doi: 10.1016/j.compositesb.2016.06.051.
36. Y. Seki, "Innovative multifunctional siloxane treatment of jute fiber surface and its effect on the mechanical properties of jute/thermoset composites," Mater. Sci. Eng. A, vol. 508, no. 1–2, pp. 247–252, May 2009, doi: 10.1016/J.MSEA.2009.01.043.
37. T. T. L. Doan, H. Brodowsky, and E. Mäder, "Jute fibre/epoxy composites: Surface properties and interfacial adhesion," Compos. Sci. Technol., vol. 72, no. 10, pp. 1160–1166, Jun. 2012, doi: 10.1016/J.COMPSCITECH.2012.03.025.
38. G. Raghavendra, K. A. Kumar, M. H. Kumar, B. RaghuKumar, and S. Ojha, "Moisture absorption behavior and its effect on

the mechanical properties of jute-reinforced epoxy composite," Polym. Compos., vol. 38, no. 3, pp. 516–522, Mar. 2017, doi: 10.1002/PC.23610.
39. Y. Dobah, M. Bourchak, A. Bezazi, A. Belaadi, and F. Scarpa, "Multi-axial mechanical characterization of jute fiber/polyester composite materials," Compos. Part B Eng., vol. 90, pp. 450–456, Apr. 2016, doi: 10.1016/J.COMPOSITESB.2015.10.030.
40. K. Sever, M. Sarikanat, Y. Seki, G. Erkan, Ü. H. Erdoĝan, and S. Erden, "Surface treatments of jute fabric: The influence of surface characteristics on jute fabrics and mechanical properties of jute/polyester composites," Ind. Crops Prod., vol. 35, no. 1, pp. 22–30, Jan. 2012, doi: 10.1016/J.INDCROP.2011.05.020.
41. A. B. Nair and R. Joseph, "Eco-friendly bio-composites using natural rubber (NR) matrices and natural fiber reinforcements," Chem. Manuf. Appl. Nat. Rubber, pp. 249–283, Jan. 2014, doi: 10.1533/9780857096913.2.249.
42. Kargarzadeh, H., J. Huang, N. Lin, I. Ahmad, M. Mariano, A. Dufresne, S. Thomas, and Andrzej Gałęski. "Recent developments in nanocellulose-based biodegradable polymers, thermoplastic polymers, and porous nanocomposites." Progress in Polymer Science 87 (2018): 197-227.
43. M. Jawaid, S. M. Sapuan, and O. Y. Alotman, "Green Biocomposites Manufacturing and Properties," p. 409, 2017, doi: 10.1007/978-3-319-46610-1.
44. Mohanty A.K, M. Misra, and L. T. Drzal, "Surface modifications of natural fibres and peformance of the resulting biocomposite," Compos. Interfaces, vol. 8, no. 5, pp. 313–343, 2012.
45. H. Ma and C. W. Joo, "Structure and mechanical properties of jute—polylactic acid biodegradable composites," http://dx.doi.org/10.1177/0021998310382316, vol. 45, no. 14, pp. 1451–1460, Dec. 2010, doi: 10.1177/0021998310382316.
46. T. Hojo, X. U. Zhilan, Y. Yang, and H. Hamada, "Tensile Properties of Bamboo, Jute and Kenaf Mat-reinforced Composite," Energy Procedia, vol. 56, no. C, pp. 72–79, Jan. 2014, doi: 10.1016/J.EGYPRO.2014.07.133.
47. K. S. Ahmed and S. Vijayarangan, "Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites," J. Mater. Process. Technol., vol. 207, no. 1–3, pp. 330–335, Oct. 2008, doi: 10.1016/J.JMATPROTEC.2008.06.038.
48. M. K. Gupta, M. Ramesh, and S. Thomas, "Effect of hybridization on properties of natural and synthetic fiber-reinforced polymer composites (2001–2020): A review," Polym. Compos., vol. 42, no. 10, pp. 4981–5010, Oct. 2021, doi: 10.1002/PC.26244.
49. M. Ramesh, K. Palanikumar, and K. H. Reddy, "Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites," Compos. Part B Eng., vol. 48, pp. 1–9, May 2013, doi: 10.1016/J.COMPOSITESB.2012.12.004.
50. A. Deb, S. Das, A. Mache, and R. Laishram, "A Study on the Mechanical Behaviors of Jute-polyester Composites," Procedia Eng., vol. 173, pp. 631–638, Jan. 2017, doi: 10.1016/J.PROENG.2016.12.120.
51. G. Raghavendra, S. Ojha, S. K. Acharya, and S. K. Pal, "Jute fiber reinforced epoxy composites and comparison with the glass and neat epoxy composites," http://dx.doi.org/10.1177/0021998313499955, vol. 48, no. 20, pp. 2537–2547, Aug. 2013, doi: 10.1177/0021998313499955.
52. S. Fatima and A. R. Mohanty, "Acoustical and fire-retardant properties of jute composite materials," Appl. Acoust., vol. 72, no. 2–3, pp. 108–114, 2011, doi: 10.1016/j.apacoust.2010.10.005.
53. M. Arul and N. Ramadoss, "The Effect of Stacking Sequence on the Mechanical Properties of Sic Added Epoxy Matrix Reinforced with Carbon/Kevlar Fabrics," Periodico, vol. 91, no. 4, pp. 1038–1056, 2022, doi: 10.37896/pd91.4/91468.
54. J. A. Khan, M. A. Khan, R. Islam, and A. Gafur, "Mechanical, Thermal and Interfacial Properties of Jute Fabric-Reinforced Polypropylene Composites: Effect of Potassium Dichromate," Mater. Sci. Appl., vol. 01, no. 06, pp. 350–357, Dec. 2010, doi: 10.4236/MSA.2010.16051.
55. M. Ramesh, K. Palanikumar, and K. H. Reddy, "Influence of fiber orientation and fiber content on properties of sisal-jute-glass fiber-reinforced polyester composites," J. Appl. Polym. Sci., vol. 133, no. 6, Feb. 2016, doi: 10.1002/APP.42968.
56. T. Sen and H. N. J. Reddy, "Hemp_Kenaf_Flax_Ramie_Kullanim Alan_Avantaj," vol. 2, no. 3, 2011.
57. D. R. O. Faruk, "Cars from Jute and Other Bio-Fibers," Europe, no. March, pp. 1–10, 2006.
58. R. D. S. G. Campilho, "Recent innovations in biocomposite products," Biocomposites High-Performance Appl. Curr. Barriers Futur. Needs Towar. Ind. Dev., pp. 275–306, Jan. 2017, doi: 10.1016/B978-0-08-100793-8.00010-7.
59. A. K. Mohanty, M. Misra, and L. T. Drzal, "Surface modifications of natural fibers and performance of the resulting biocomposites: An overview," http://dx.doi.org/10.1163/156855401753255422, vol. 8, no. 5, pp. 313–343, 2012, doi: 10.1163/156855401753255422.
60. Dilfi KF, Anna, et al. "Effect of surface modification of jute fiber on the mechanical properties and durability of jute fiber-reinforced epoxy composites." Polymer Composites 39.S4 (2018): E2519-E2528.
61. Singh, B., M. Gupta, and Anchal Verma. "The durability of jute fibre-reinforced phenolic composites." Composites science and technology 60.4 (2000): 581-589.
62. Sisti, L., et al. "Retting process as a pretreatment of natural fibers for the development of polymer composites." Lignocellulosic composite materials (2018): 97-135.

■ ■ ■

Journal of the TEXTILE Association ISSN 0368-4636 PROCESSING

Functionalization of Textiles for Antimicrobial Applications: A Short Review

Yashovardhan Indi*, Swapnil Deshmukh, Siddharth Kamat & Shirishkumar Vhanbatte
DKTE Society's Textile and Engineering Institute, Rajwada, Ichalkaranji, Maharashtra, India

Abstract

The development of novel textile solutions has been rendered by the rise of drug-resistant diseases and the growing need for antimicrobial materials. The capacity of metal-functionalized textiles to impart antibacterial qualities while preserving the fabric's natural elasticity and usefulness has attracted a lot of interest. The present developments, workings, and uses of metal-functionalized textiles for antimicrobial reasons are thoroughly examined in this paper. The functionalisation methods, antibacterial processes, and practical uses of important metals such as silver, copper, zinc, and titanium are covered. In order to focus future research in this developing topic, challenges and future directions are also examined.

Keywords: *Antimicrobial Textiles, Copper, Silver, Titanium, Zinc*

Citation: Yashovardhan Indi, Swapnil Deshmukh, Siddharth Kamat & Shirishkumar Vhanbatte, "Functionalization of Textiles for Antimicrobial Applications: A Short Review", *Journal of the Textile Association*, **85/5**(Jan-Feb), 503-507, https://doi.org/10.5281/zenodo.14973838

Article Received :21-01-2025, Revised: 04-02-2025, Accepted: 08-02-2025

1. Introduction

Viruses, fungus, and bacteria-induced infectious illnesses continue to be major public health hazards. These difficulties have been exacerbated by the emergence of antibiotic resistance, which makes the investigation of new materials and methods to reduce microbial growth and transmission essential [1-3]. Among the several strategies, incorporating antimicrobial chemicals into textiles has shown promise [4]. With an annual impact on billions of people, microbial pollution and illness pose a serious threat to world health. The need for efficient antimicrobial methods is highlighted by the spread of resistant bacteria, including multi-drug-resistant Escherichia coli and methicillin-resistant Staphylococcus aureus (MRSA) [5]. Because of resistance development, environmental issues, and limited long-term efficacy, traditional methods—such as the use of chemical disinfectants and antibiotics—are becoming less effective. Alternative solutions that integrate environmental sustainability, safety, and efficacy are therefore desperately needed.

Textiles are used in many aspects of contemporary life, including furniture, filtration systems, medical equipment, and clothes. Textiles are potential reservoirs for microbial development and transmission due to their widespread usage and extended interaction with people and the environment [6-8]. For example, healthcare worker uniforms and hospital linens may contain germs, raising the possibility of healthcare-associated illnesses (HAIs). In a similar vein, tainted textiles provide health and safety risks in public and commercial environments [9]. Therefore, addressing microbial contamination in textiles is essential to both public health and infection management [10]. Textiles can harbour germs due to their large surface area and capacity to retain moisture and oxygen. Some bacteria may multiply twice every 20 minutes, depending on the conditions, such as pH, temperature, nutrition, and moisture. Textile biodeterioration causes unfavourable reactions such as decreased mechanical strength, discolouration, and bad odour [11, 12]. Biodeterioration is more likely in natural textiles, which have porous hydrophilic qualities that allow bacteria to retain nutrients and oxygen [13].

Metal-functionalized textiles use the special qualities of metals to prevent the growth of microorganisms [14]. Because of their capacity to interfere with microbial biological functions, metals including silver, copper, zinc, and titanium are well-known for their antibacterial properties [15-18]. For ages, people have known that metals have antibacterial qualities. For instance, ancient societies used copper surfaces for their disinfecting qualities and silver containers to keep food and drink. The basis for contemporary metal uses in hygiene and healthcare was established by these earlier methods. The area has been transformed by developments in material science and nanotechnology, which have made it possible to create metal-functionalized textiles with regulated release, improved stability, and customised qualities.

1.1 Antimicrobial Action Mechanisms

Designing successful functionalised textiles requires an understanding of the principles behind metals' antibacterial action. Important mechanisms consist of:

- Membrane Disruption: Metal ions have the capacity to interact with the membranes of microorganisms, leading

Corresponding Author:
Prof. (Dr.) Y. M. Indi
Associate Professor, Textile Chemistry Department
D. K. T. E. S. Textile & Engineering Institute (An Autonomous Institute) Rajwada,Ichalkaranji- 416 115
E-mail: ymindi@gmail.com

to increased permeability and structural damage. Cell death eventually results from this, as well as the release of cellular contents [19].

- Protein and DNA Interference: Metals have the ability to attach to thiol and amine groups in proteins, interfering with their ability to function. Furthermore, interactions between metal ions and nucleic acids might hinder transcription and DNA replication [20].
- Production of Reactive Oxygen Species (ROS): Lipids, proteins, and nucleic acids are oxidatively damaged by ROS, which are produced by some metals.
- Enzymatic Inhibition: By attaching to the active sites or cofactors of vital microbial enzymes, metal ions can prevent them from functioning.

2. Key Metals in Antimicrobial Textiles

2.1 Silver

Burns and wounds have been treated with silver in various forms for millennia. However, the usage of silver was significantly reduced in the 1940s with the introduction of penicillin. The interest in this useful antibacterial agent has recently increased due to the emergence of straightforward methods for synthesising nano-sized silver particles and the resistance of microbes to many existing antibiotics. More than 650 pathogens, including viruses, fungi, and bacteria, are susceptible to the bactericidal effects of silver. Silver has been extensively studied for its antimicrobial properties [6]. Its efficacy against a broad spectrum of microorganisms makes it a preferred choice for functionalizing textiles [21]. Silver ions (Ag^+) disrupt microbial membranes, interfere with enzymatic activities, and generate reactive oxygen species (ROS), leading to cell death [22, 23].

Modern methods for preparing Ag NPs with a large surface area have led to increased usage of these antimicrobials, resulting in higher activity at lower metal concentrations. The synthesis of such Ag NPs has enabled novel Ag uses in fields such as medicine, pharmacy, biology, biochemistry, and food technology, in addition to textiles [15]. Because of its chemical stability at high temperatures and under UV irradiation, Ag can be employed in textile manufacture as an addition during the traditional spinning or electro-spinning processes used to produce fibres. It can be used as a chemical finishing agent for fibres, yarns, textiles, and nonwovens.

2.1.2 Functionalization Techniques

2.1.2.1 Nanoparticle Deposition

Nanoparticle deposition on textiles is the technique of adding nanoparticles to cloth to improve its qualities. There are several methods for depositing nanoparticles, including plasma technology, the pad-dry-cure process, and electron gun evaporation. Silver nanoparticles (AgNPs) are embedded onto textile surfaces using techniques like chemical reduction, plasma treatment, and electrospinning.

2.1.2.2 Coating and Finishing

Coating and finishing is the application of chemical compounds to the surface of a cloth to make it functional or beautiful. Coatings require less material than other uses, such as exhaust and stenter padding. Metal particles can be applied to textiles by chemical or electrical procedures to enhance their characteristics. These procedures include electroless plating (a chemical procedure that utilises no energy to make parts more resistant to corrosion and friction), electroplating (an electrical method that covers conductive fabrics with a coating of metal particles), Chemical Vapour Deposition (a method in which a substance is heated to transform it into a gas and then deposited onto a textile surface). Silver-functionalized textiles are widely used in wound dressings, hospital linens, and activewear due to their long-lasting antimicrobial activity.

3. Copper

Copper is a common early metal often known as "red metal" with a density of 8.94 g/cm3, an atomic weight of 63.57, and an atomic number of 29. Copper has two valences: +1 (cuprous) and +2 (cupric), with +2 being the most common.8 It has two naturally occurring isotopes with masses of 65 (31%) and 63 (69%). In general, auto-oxidation of cuprous salt quickly yields cupric salts, as shown in equation.

$$2Cu^+ \longrightarrow Cu + Cu^{++}$$

Copper is another widely used metal with strong antimicrobial properties [24]. Copper ions (Cu^{2+}) disrupt microbial membranes and generate ROS, leading to oxidative damage. Copper and silver are two metals that destroy a variety of bacteria. Broad spectrum refers to all bacterial strain classifications, including Gram-negative and Gram-positive [25]. Even in nanoscale, silver metal is safe unless silver ions are released. In moist situations, Ag ions are released, causing cell wall destruction. In a wet environment, silver antibacterial activity is more effective at a higher temperature than at room temperature. Copper, on the other hand, has antimicrobial characteristics throughout all humidity and temperature ranges [26]. This contrast emphasises the need of copper coatings, as antibacterial activity must be possible at normal hospital room temperatures. Cu's peculiar behaviour is due to its two ionic states.

3.1 Functionalization Techniques

3.1.1 Spray Coating

Spray coating is a flexible technique for applying copper to textiles, creating a thin, homogeneous layer with increased qualities including antibacterial activity. This procedure involves spraying a copper-based solution, suspension, or nanoparticles onto the fabric surface with specialised equipment to ensure equal coverage. Binders or surface treatments are frequently used in this process to increase copper adherence to textile fibres. Following application, the coated fabric is often subjected to drying and curing procedures to seal the coating and improve performance. Spray coating is beneficial because it is scalable and can coat complicated textile surfaces while remaining flexible. However, issues like as assuring long-term durability, adhesion, and fabric softness must be solved, frequently through innovative binder compositions.

3.1.2 In-situ Synthesis

In situ synthesis on textiles entails producing functional compounds directly on the surface or inside the fibres of a fabric, removing the requirement for preformed coatings. This process frequently uses chemical or electrochemical reactions to produce desirable substances, such as metallic nanoparticles, polymers, or oxides, directly on the textile substrate. For example, copper nanoparticles can be synthesised in situ by soaking the cloth in a copper salt solution and then chemically reducing it using a reducing agent. The method provides for exact control over particle size, dispersion, and fabric integration, resulting in increased antibacterial activity. In situ synthesis is very useful for producing long-lasting, homogeneous coatings while maintaining textile elasticity and breathability. Fiber Blending: Copper compounds are mixed with polymers during fiber production.

3.1.3 Applications

Antimicrobial applications of copper-coated textiles take use of copper's inherent capacity to suppress the development of bacteria, viruses, and fungus, making these materials very desired in healthcare, hygiene, and everyday use. Copper damages microbial cell membranes, produces reactive oxygen species, and inhibits key enzymes, resulting in microbial inactivation. Textiles with copper coatings are commonly used in hospital linens, face masks and personal protective equipment to limit the danger of infection transmission. Additionally, these materials are used in sportswear, bedding, and furniture to avoid odour and retain freshness. Copper's long-lasting antibacterial characteristics make it a viable alternative to chemical treatments, providing long-term protection without the need for regular reapplication. Coating method innovations, such as spray coating or in situ synthesis, have improved copper's incorporation into textiles, assuring efficacy while maintaining fabric comfort and flexibility.

4. Zinc

Functional coatings attempt to improve the characteristics and performance of textile substrates while also introducing novel textile functionalities. To accomplish this, several classical and modern organic, organic-inorganic hybrids, and inorganic substances are utilised in application methods. ZnO has already established itself as a chemical agent for textile functionalisation because to its unique physical and chemical features, environmental friendliness, biocompatibility, and low cost [27]. Its significant advantage over other materials is that bulk ZnO has been generally recognised as a safe (GRAS) chemical by the US Food and Drug Administration (FDA). Zinc exhibits antimicrobial properties primarily in the form of zinc oxide (ZnO) [28]. ZnO disrupts microbial metabolism and damages cellular structures [29]. ZnO is accessible as a white powder that may be synthesised from several precursors or from the uncommon mineral zincite, which occurs naturally. In general, ZnO can be used as a pre-prepared ZnO suspension or Zn salt solution, or in situ production of ZnO nanoparticles (ZnO NPs) in the presence of a textile substrate. Because of its exceptional photocatalytic activity, chemical stability during UV radiation exposure, thermal stability, and capacity to absorb a wide spectrum of UV radiation, ZnO particles (ZnO Ps) are among the most efficient photocatalytic self-cleaning, antibacterial, and UV-protective agents [28, 30]. ZnO Ps' photocatalytic characteristics also allow them to be employed as degradation agents for a variety of contaminants, including dyes and surfactants used in the textile industry.

4.1 Functionalization and applications

Embedding zinc nanoparticles (Zn NPs) into textiles is a cutting-edge antimicrobial strategy that provides broad-spectrum effectiveness against bacteria, fungus, and viruses. Zinc nanoparticles emit zinc ions, which interact with microbial membranes, alter metabolic processes, and produce reactive oxygen species, eventually causing cell death. This feature makes Zn NP-embedded fabrics suitable for use in medical supplies such as wound dressings, surgical gowns, and masks, as well as in daily products such as sportswear, socks, and household furnishings. In situ synthesis, dip-coating, and electrospinning are standard techniques for embedding Zn NPs into textiles, resulting in uniform distribution and high adherence. The nanoparticles not only offer long-lasting antibacterial action, but they also improve UV protection and odour resistance. Recent advances have focused on optimising the size and surface modification of Zn NPs to increase their compatibility with textile fibres while remaining eco-friendly and reducing possible cytotoxicity.

5. Titanium

TiO2 has received special attention for its unique qualities, which include high photocatalytic activity and process efficiency, element abundance, simplicity of synthesis, chemical and photo stability, biocompatibility, non-toxicity, recyclability, and low cost. TiO2 is a transition metal oxide that exists in three natural crystal phases: anatase, rutile, and brookite. It is an n-type semiconductor with a broad band gap energy ranging from 3.0 to 3.2 eV, depending on the polymorphic crystal structure. TiO2's photocatalytic activity is morphology dependent, however it is found in all bulks, NPs, nano-/microstructures such as nanorods, nanofibers, nanotubes, hollow spheres, and flower-like structures, as well as surfaces such as nanofilms and nanolayers.

TiO_2 increased more than 2.5-fold between 2010 and 2020, and it remains one of the most prominent and intensively studied nanomaterials, with over 100 publications per year since 2011, making it the second most studied nanoscale material, trailing only silver and ahead of SiO_2, ZnO, carbon nanotubes (CNTs), graphene, and reduced graphene oxide (rGO). TiO_2's unique structural, physicochemical, optical, and electrical properties classify it as a multifunctional material that can provide various functionalities to textile fibres, including photocatalytic self-cleaning, antimicrobial activity [7], UV protection, electrical conductivity and resulting antistatic properties, and increased thermal stability [31].

5.1 Functionalization and applications

Functionalising textiles with titanium for antimicrobial applications is a potential method that utilises the photocatalytic characteristics of titanium compounds, especially titanium dioxide (TiO_2). When exposed to UV or visible light, TiO_2 produces reactive oxygen species (ROS), including hydroxyl radicals and superoxide ions, which efficiently damage microbial cell membranes and inactivate pathogens [31]. This capability makes titanium-coated textiles useful for healthcare, protective apparel, and environmental applications such as air and water filtration. Functionalisation includes coating or embedding TiO_2 nanoparticles onto textile surfaces using techniques such as sol-gel, dip-coating, or sputter deposition. Titanium-based coatings not only provide long-lasting antibacterial qualities, but also improve self-cleaning and deodorising capabilities, adding value to textiles. Recent improvements involve doping TiO_2 with metals like silver or iron to increase its activity under visible light. This improves efficiency and usefulness in everyday situations while ensuring safety and environmental compatibility.

6. Summary

Metal-functionalized textiles represent a transformative approach to combating microbial contamination across various sectors. While significant progress has been made, addressing challenges related to durability, safety, and environmental impact is crucial for the broader adoption of these materials. Future research should focus on developing innovative functionalization techniques, ensuring safety, and minimizing environmental risks. With continued advancements, metal-functionalized textiles have the potential to play a pivotal role in enhancing hygiene and mitigating infections in diverse applications.

References:

[1] L. Esmeralda, C. Villalva, C. Uribe, F. Paraguay-delgado, J. Sousa, J. Vigo, G. Marcela, L. Sol, Textiles Functionalized with Copper Oxides : A Sustainable Option for Prevention of COVID-19, (2022)

[2] S. Deshmukh, Biomaterials Science A review on biopolymer-derived electrospun nano fibers for biomedical and antiviral applications, (2022) 4424–4442. https://doi.org/10.1039/d2bm00820c

[3] A. Varesano, C. Vineis, A. Aluigi, F. Rombaldoni, Antimicrobial polymers for textile products, (2011) 99–110

[4] J.T.S. Eng, R. Geethadevi, V. Maheshwari, Journal of Textile Science & Engineering Imparting Antimicrobial Finish on Selected Regenerated Cellulosic Fabrics with Herbal Oil Combinations, 4 (2013) 1–3. https://doi.org/10.4172/2165-8064.1000144

[5] M. Zanoaga, F. Tanasa, ANTIMICROBIAL REAGENTS AS FUNCTIONAL FINISHING FOR TEXTILES INTENDED FOR BIOMEDICAL APPLICATIONS. I. SYNTHETIC ORGANIC COMPOUNDS, 9 (2014) 14–32

[6] R. Gulati, S. Sharma, R. Kumar, Antimicrobial textile : recent developments and functional perspective, Polym. Bull. (2021). https://doi.org/10.1007/s00289-021-03826-3

[7] M.M. Rashid, M. Zorc, B. Simonˇ, In-Situ Functionalization of Cotton Fabric by TiO 2 : The Influence of Application Routes, (2022)

[8] M. Naveed, Potential Application Techniques for Antimicrobial Textile Finishes, (2018) 366–373. https://doi.org/10.31031/TTEFT.2018.03.000570

[9] Q. Journals, E. Sciences, J. Saha, S.S. Chakraborty, A. Rahman, R. Sakif, M. Science, Antimicrobial Activity of Textiles from Different Natural Resources, 7 (2021) 32–44

[10] Z. Xia, W. Yang, Z. Yu, E.B. Age, M. Weinelt, J. Kneisel, S. Ammonium, I. Liquids, T.E. Properties, K. Kim, C.M. Lang, A. Kohl, The Effects of Quat - Silane Antimicrobials on the Physical and Mechanical Properties of Cotton and Cotton / Elastane Fabrics Used for Clothing, (n.d.). https://doi.org/10.1088/1757-899X/460/1/012004

[11] A. Reshma, V.B. Priyadarisini, K. Amutha, SUSTAINABLE ANTIMICROBIAL FINISHING OF FABRICS USING NATURAL BIOACTIVE AGENTS - A REVIEW, 8 (2018) 10–20

[12] C. Publishers, Anti-microbial Finishing of Cotton Fabric Using Neem Leaf Extract for Medical and Healthcare Textiles, (2023) 1078–1083. https://doi.org/10.31031/RMES.2023.10.000736

[13] A. Alami, Natural and synthetic antimicrobials agent for textile: a review, (2020) 33–48

[14] K.F. Salama, R. Aljindan, A. Alfadhel, S. Akhtar, E.A. Al-suhaimi, Enhanced antimicrobial performance of textiles coated with TiO 2 nanoparticles, 54 (2024) 1–18. https://doi.org/10.1177/15280837241233743

[15] M. Radetic, Functionalization of textile materials with silver nanoparticles, (2012). https://doi.org/10.1007/s10853-012-6677-7

[16] A. Zille, L. Almeida, T. Amorim, N. Carneiro, Application of nanotechnology in antimicrobial fi nishing of biomedical textiles, Mater. Res. Express. 032003 (n.d.). https://doi.org/10.1088/2053-1591/1/3/032003

[17] L. Arora, R. Kaur, a Study on Antimicrobial Finish on Textile Using Plant Extract, (2022) 224–228
[18] G. Shalini, D. Anitha, A Review : Antimicrobial Property of Textiles, 5 (2016) 2015–2017
[19] D. Radhika, Review Study on Antimicrobial Finishes on Textiles – Plant Extracts and Their Application, (2019) 3581–3588
[20] D. Mathiyalagan, Anti Microbial Fabrics Manufacturing using the BenzalKoniumChloride in Antimicrobial fabric finishing, 1 (2014) 10–12. https://doi.org/10.14445/23942576/IJPBE-V1I1P104
[21] M. Singh, Antimicrobial textiles based on Nanosilver, 7 (2021) 499–502
[22] N. Noor, S. Mutalik, M.W. Younas, C.Y. Chan, S. Thakur, F. Wang, M.Z. Yao, Q. Mou, Durable Antimicrobial Behaviour from Silver-Graphene Coated Medical Textile Composites, (2019) 1–21
[23] M. Paszkiewicz, A. Go, A. Rajski, E. Kowal, A. Sajdak, A. Zaleska-medynska, The Antibacterial and Antifungal Textile Properties Functionalized by Bimetallic Nanoparticles of Ag / Cu with Different Structures, 2016 (2016). https://doi.org/10.1155/2016/6056980
[24] M. Azeem, A. Ali, M. Petr, T. Noman, I. Masin, N. Amor, J. Militky, A comparative performance of antibacterial effectiveness of copper and silver coated textiles, 53 (2023) 1–36. https://doi.org/10.1177/15280837221134990
[25] M.J. Binczarski, J.Z. Zuberek, P. Samadi, M. Cieslak, I. Kaminska, J. Berlowska, A. Pawlaczyk, RSC Advances combined chemical and biological processes for production of valuable chemical compounds, (2026) 34681–34692. https://doi.org/10.1039/d3ra06071c
[26] N.S. Heliopoulos, G.N. Kouzilos, A.I. Giarmenitis, S.K. Papageorgiou, Viscose Fabric Functionalized with Copper and Copper Alginate Treatment Toward Antibacterial and UV Blocking Properties, 21 (2020) 1238–1250. https://doi.org/10.1007/s12221-020-9578-4
[27] F. Authors, Development of antimicrobial textiles using zinc pyrithione, (2017). https://doi.org/10.1108/RJTA-06-2017-0031
[28] R. Advances, Zinc Oxide for Functional Textile Coatings : (2019) 17–23
[29] M. Shahid, A. Ali, H. Khaleeq, M.F. Tahir, Development of Antimicrobial Multifunctional Textiles to Avoid from Hospital-Acquired Infections, 22 (2021) 3055–3067. https://doi.org/10.1007/s12221-021-0002-5
[30] Deshpande, R. H., Indi, Y. M., Textile Asia, Fabrics treated with Nano ZnO can ward off UV radiation, 44(8), (2013), 29–30
[31] V.O. Veselova, V.A. Plyuta, A.N. Kostrov, D.N. Vtyurina, V.O. Abramov, A. V Abramova, Y.I. Voitov, D.A. Padiy, V. Thi, H. Thu, L.T. Hue, D. Thi, T. Trang, A.E. Baranchikov, I.A. Khmel, V.A. Nadtochenko, V.K. Ivanov, Long-Term Antimicrobial Performance of Textiles Coated with ZnO and TiO 2 Nanoparticles in a Tropical Climate, (2022)

Auxetic Behavior of Needle-Punched Nonwoven Structure

Nitesh Kumar Jangir* & Harshvardhan Saraswat
Department of Textile Technology, MLV Textile and Engineering College, Bhilwara, Rajasthan

Abstract:
This study explores how needle-punched nonwoven polyester fabrics can show auxetic behavior, meaning they expand sideways when stretched instead of contracting like regular materials. The fabrics were made using fibers of two different thicknesses (6 denier and 15 denier) and three weight levels (200, 400, and 600 grams per square meter). Poisson's ratio, which measures this unique stretching behavior, was tested at different levels of strain. The results in this study showed that the nonwoven structures might be expanded in thickness when stretched, demonstrating auxetic properties. However, nonwoven fabrics made with 15-denier fibers had showed little to no auxetic effect in thickness when under tension. This research suggests that nonwoven fabrics with auxetic properties could be useful in applications like cushioning, protective clothing, and filtration materials.

Keywords: *Auxetic, Longitudinal Strain, Negative Poisson's Ratio, Needlepunched structure, protective*

Citation: Nitesh Kumar Jangir & Harshvardhan Saraswat, "Auxetic Behavior of Needle-Punched Nonwoven Structure", *Journal of the Textile Association*, **85/5**(Jan-Feb'25), 508-510, https://doi.org/10.5281/zenodo.14973710

Article Received : 03-11-2024, Revised: 04-02-2025, Accepted: 08-02-2025

1. Introduction

Auxetic materials, which expand laterally when stretched, offer unique applications across various industries due to their enhanced mechanical properties such as energy absorption, impact resistance, and flexibility [1]. In healthcare, they improve wound dressings, stents, and orthopedic supports by offering better adaptability and comfort [2]. In protective gear, auxetic materials enhance body armor, helmets, and sportswear, providing superior shock absorption [3]. The aerospace and automotive sectors benefit from auxetic materials for crashworthiness and lightweight components [4]. Construction uses auxetic structures for vibration damping and resilient buildings [5]. In textiles, auxetic fabrics improve the fit and flexibility of smart apparel and personal protective equipment [6]. They also find use in acoustic panels, vibration damping systems, sports equipment, energy harvesting devices, and soft robotics [7]. These materials' ability to adapt to stress makes them ideal for innovative applications requiring flexibility, durability, and superior impact protection.

Nonwoven fibre networks, widely used in applications such as sensors, composites, and tissue engineering, can be engineered to exhibit auxetic behavior, i.e., a negative Poisson's ratio [1]. While most research focuses on periodic structures [8], nonwoven materials' irregular geometry offers potential for high porosity and mechanical stability [9]. Recent work explores out-of-plane auxetic polypropylene-based scaffolds for enhanced biophysical responses [10].

2 Materials and Methods

2.1 Materials

Polyester fibres of 6 denier and 15 denier were used to prepare three needle-punched nonwoven samples with areal densities of 200 gsm, 400 gsm, and 600 gsm. The needle-punching process involved 150 punches/cm² with a 12 mm depth of penetration. Fibre properties are provided in Table 1, and the sample specifications are detailed in Figure 2. All samples were produced on a Dilo needlepunch line, ensuring consistent mechanical characteristics for the study.

****Corresponding Author :***
Mr. Nitesh Kumar Jangir
Department of Textile Technology, MLV Textile and Engineering College, Pratap Nagar, Pansal Chauraha, Pur Road,
Bhilwara – 311 001 Raj
E-mail: niteshal@gmail.com

Table 1: Characteristics of constituent fibres

S. N.	Particulars	6D	15D
1	Suppliers	Reliance	Toray
2	Fineness (Std.), Denier	6	15
3	Fineness (Observed), Denier	7.2 ± .83	18.3 ± 1.3
4	Fibre Length (Std.), mm	64	64
5	Fibre Length (Observed), mm	62 ± 9	65 ± 8
6	Crimp/Inch	4.5 ± 0.4	3.1 ± 0.2
7	Appearance	Semi dull	Semi dull
8	Tenacity (gf/D)	4.51 ± 0.48	3.10 ± 0.24
9	Elongation (%)	48.6 ± 9.17	37.4 ± 7.4
10	Cross Sectional Shape	Circular Hollow	Circular Hollow

Table 2: Nonwoven Sample Specifications

Sr. No.	Sample Code	Areal Density (Std.), gm/m^2	Areal Density (mesured), gm/m^2	Fibre Denier	Needle Density, punched/cm^2	Needle Depth Penetration, mm
1	A2D06	200	208±15	6	150	12
2	A4D06	400	416±32	6	150	12
3	A6D06	600	649±48	6	150	12
4	A2D15	200	212±23	15	150	12
5	A4D15	400	432±56	15	150	12
6	A6D15	600	675±69	15	150	12

2.2 Determination of Poisson's Ratio

Figure 1: set up on INSTRON for determination of Poisson's ratio of nonwoven samples

Poisson's ratio is a fundamental mechanical property that describes the relationship between longitudinal strain and lateral strain in a material when subjected to tensile or compressive stress. Specifically, Poisson's ratio (ν) is defined as the negative ratio of lateral strain (εlat) to longitudinal strain (εlong) and is given by the formula:

$$\nu = -(\varepsilon lat / \varepsilon long)$$

Where:

- εlat is the strain in the lateral direction (width-wise or thickness-wise contraction).
- εlong is the strain in the longitudinal direction (stretching).

In this study, Poisson's ratio was assessed for needle-punched nonwoven structures at 5% intervals of tensile strain. As the samples were subjected to tensile tests, images were captured at predefined strain levels using digital cameras (refer to Figure 1 for the setup). These images were processed using the open-source software ImageJ to quantify width-wise and thickness-wise contractions. The central region of each sample was analyzed by counting the number of pixels corresponding to the width and thickness dimensions, providing accurate measurements of dimensional changes under strain. Photographs of the nonwoven fabric samples were captured at 0%, 5%, 10%, 15%, and 20% strain levels during the tensile tests to document the deformation process. These images were analyzed using ImageJ to determine the width-wise and thickness-wise contractions at each stage, facilitating the calculation of Poisson's ratio.

The Poisson's ratio was calculated at each interval, offering insights into the deformation characteristics of the nonwoven fabrics and their ability to exhibit auxetic behavior or lateral expansion under stretching.

3. Results and discussion

The nonwoven samples were placed under tensile load at a rate of 100 mm/min, and images were captured at 5% strain intervals, including 0%, 5%, 10%, 15%, and 20% strain, to analyze the width-wise and thickness-wise deformation. These images were processed using ImageJ software to quantify the dimensional changes in response to the applied strain. The deformation in both directions was measured to study the mechanical behavior of the needle-punched nonwoven fabrics under tensile stress. A graph was plotted between the longitudinal strain and the corresponding width-wise and thickness-wise strains (as shown in Figure 2). The analysis revealed that, as the load increased in the longitudinal direction, the nonwoven fabrics showed a negative deformation or shrinkage in the width-wise direction. This width-wise contraction was found to be nearly proportional to the longitudinal strain, indicating a consistent Poisson's ratio in that direction.

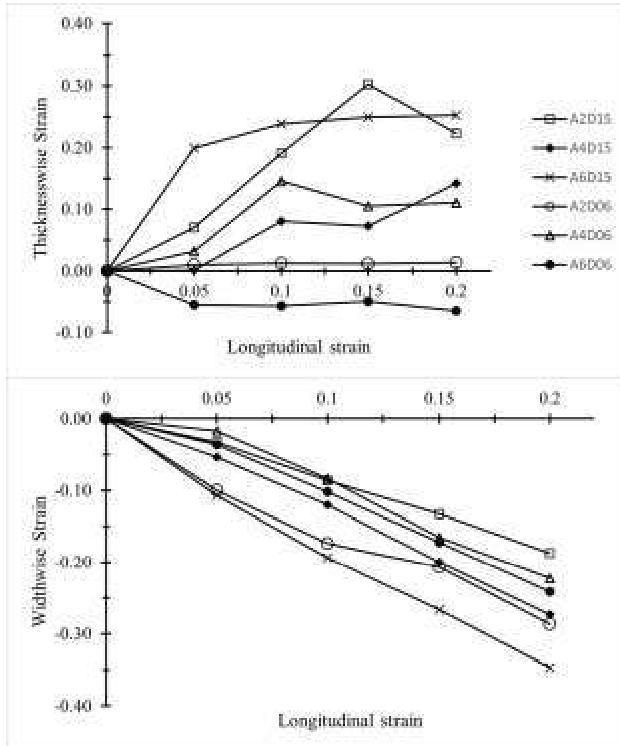
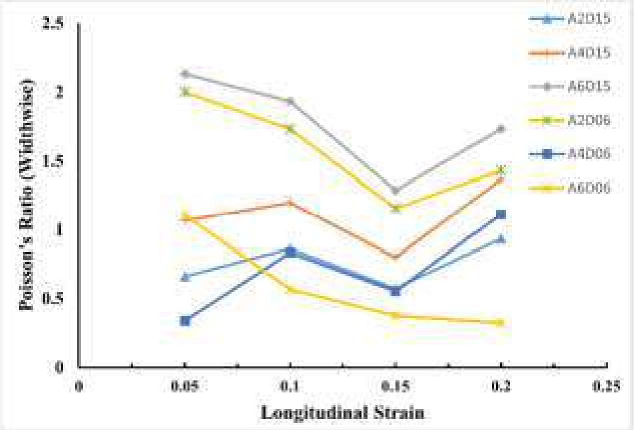


Figure 2: Plot between Longitudinal Strain and Thickness wise and Widthwise Strain

However, in the thickness direction, an increment in the thickness direction was observed, particularly in the samples made from 15 denier fibres. These structures exhibited a dramatic positive strain, meaning that the thickness of the nonwoven fabric increased as the load was applied. This behavior suggests auxetic-like characteristics in the thickness direction, where the material expands instead of contracting under tensile stress. This unique property enhances the potential applications of needle-punched nonwovens, particularly in areas requiring materials that can expand in certain directions under load, such as cushioning, protective textiles, and filtration materials. In this study, the nonwoven samples made from 6 denier fibres showed negligible changes in thickness when subjected to tensile strain, indicating a relatively stable structure in the thickness-wise direction. However, an exception was observed in the 400 gsm sample, where the thickness demonstrated a negative Poisson's ratio behaviour. This means that as tensile stress was applied in the longitudinal direction, the 400 gsm nonwoven structure from 6 denier fibres exhibited expansion in the thickness direction, contrary to the typical expansion observed in auxetic materials.



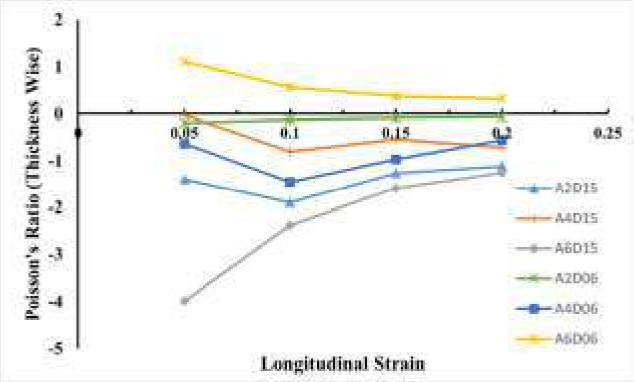


Figure 3: Plot between Longitudinal Strain and Poisson's Ratio

Experimental data for samples with varying densities (200, 400, 600 gsm) and fibre deniers (6, 15 denier) were analyzed for longitudinal strain and volume change. Volume change

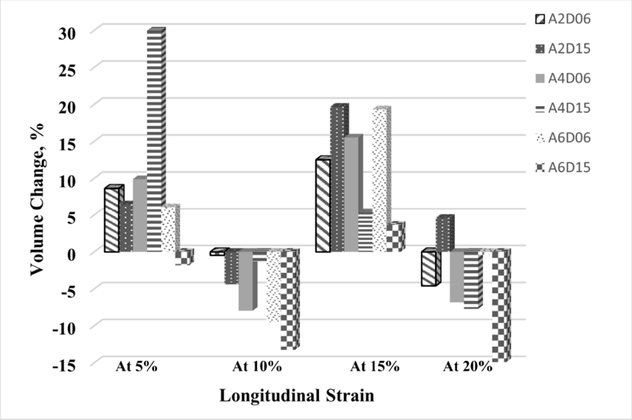


Figure 4: Change in Volume at various level of Longitudinal Strain

varied significantly, influenced by gsm and fibre denier, as shown in Figure 4. Sample A2D15 (200 gsm, 15 denier) had the highest mean volume change (6.59), while A6D15 (600 gsm, 15 denier) showed a negative mean (-6.57), suggesting densification. Higher gsm (600 gsm) generally led to densification, especially for thicker fibres (15 denier). Sample A4D15 showed high variability, indicating instability in intermediate gsm with higher denier.

4. Conclusions

The study demonstrated the auxetic potential of needle-punched nonwoven fabrics, specifically their ability to exhibit negative Poisson's ratio behavior in the width-wise direction and expansion in the thickness direction. The findings suggest that the material's auxetic response can be influenced by fiber denier and areal density, with thicker fibers showing auxetic-like expansion in thickness under tensile stress. These unique properties make needle-punched nonwoven fabrics suitable for various advanced applications, such as protective clothing and cushioning materials, where adaptability to tensile stress and enhanced mechanical properties are desired.

References

[1] R. H. Baughman, J. M. Shacklette, A. A. Zakhidov & S. Stafström, "Negative Poisson's ratios as a result of elastic instabilities," Nature, 392/6674 (1998) 362-365, https://doi.org/10.1038/32660

[2] H. M. A. Kolken & A. A. Zadpoor, "Auxetic mechanical metamaterials," RSC Advances, 7/9 (2017) 5111-5129, https://doi.org/10.1039/C6RA27333E

[3] K. L. Alderson & A. Alderson, "Auxetic materials for sports applications," Procedia Engineering, 2/2 (2007) 2883-2888, https://doi.org/10.1016/j.proeng.2007.04.037

[4] K. E. Evans, M. A. Nkansah, I. J. Hutchinson & S. C. Rogers, "Molecular network design," Nature, 353/6340 (1991) 124-125, https://doi.org/10.1038/353124a0

[5] W. Yang, Z. M. Li, W. Shi, B. H. Xie & M. B. Yang, "Review on auxetic materials," Journal of Materials Science, 39/10 (2004) 3269-3279, https://doi.org/10.1023/B:JMSC.0000026928.93236.0d

[6] N. Ravirala, A. Alderson, P. J. Davies & V. R. Simkins, "Auxetic textiles for personal protective equipment," Personal Protective Equipment and Clothing, 44/2 (2007) 437-449, https://doi.org/10.1016/j.perpro.2007.03.044

[7] R. S. Lakes, "Foam structures with a negative Poisson's ratio," Science, 235/4792 (1987) 1038-1040, https://doi.org/10.1126/science.235.4792.1038

[8] H. M. A. Kolken, K. Lietaert, T. van der Sloten, B. Pouran, A. Meynen, G. Van Loock, H. Weinans, L. Scheys & A. A. Zadpoor, "Mechanical performance of auxetic meta-biomaterials," Journal of the Mechanical Behavior of Biomedical Materials, 104 (2020) 103658, https://doi.org/10.1016/j.jmbbm.2020.103658

[9] J. S. Soares, W. Zhang & M. S. Sacks, "A mathematical model for the determination of forming tissue moduli in needled-nonwoven scaffolds," Acta Biomaterialia, 51 (2017) 220-236, https://doi.org/10.1016/j.actbio.2017.01.044

[10] Y. Yan, Y. Li, L. Song & C. Zeng, "Pluripotent stem cell expansion and neural differentiation in 3-D scaffolds of tunable Poisson's ratio," Acta Biomaterialia, 49 (2017) 192-203, https://doi.org/10.1016/j.actbio.2016.11.048

Chikankari Embroidery - The Beauty of Intricacy

***Madhuri Singh*[1]*, Neetu Singh*[1] *& Vineeta Prasad*[2]**

[1]*Symbiosis Institute of Design, Viman Nagar, Pune*

[2]*Mahatma Gandhi Kashi Vidyapeeth, Maldahiya Road, Chetganj, Varanasi, UP*

Abstract:

The handicraft industry is a crucial player in the economy, creating jobs, enhancing productivity, and stimulating socio-economic development, particularly in rural and semi-urban areas. Among its various forms, Chikankari embroidery remains a profound artistic cultural tradition. It is believed that Chikankari was introduced by Empress Noor Jahan wife of Emperor Jahangir in India's royal courts where it was so much loved for its intricate beauty. Over centuries this embroidery changed from being a symbol of social status to an intricate art form tied to culture and adaptability.

This paper examines the origins and historical development of Chikankari its traditional techniques and the processes involved in producing it. The study sets out to trace its journey from being a royal pastime to becoming part of modern fashion trends, thereby illuminating how Chikankari is an art that endures. The retention and adaptation of traditional techniques within modern-day fashion designs or cultural identities are underscored. Additionally, the article analyses tools and techniques used in making up Chikankari pieces, their transformation over time, and the effects of contemporary marketing approaches on the global acceptance of this craft.

Keywords: *adaptability, Chikankari, Lucknawi Embroidery, Needlecraft, White on white work*

Citation: Madhuri Singh, Neetu Singh & Vineeta Prasad, "Chikankari Embroidery - The Beauty of Intricacy ", *Journal of the Textile Association*, **85/5**(Jan-Feb'25), 511-517, https://doi.org/10.5281/zenodo.14973622

Article Received : 10-12-2024, Revised: 13-01-2025, Accepted: 17-01-2025

1. Introduction

Handicrafts play a vital role in the cultural and economic tapestry of the world at large. Artisanal crafts represent not only the identity, traditions, and heritage of a community, but also the values and practices it imbibes through the wheel of centuries-old crafts passed down from one generation to another. Handicrafts therefore, preserve cultural knowledge. They play an important role to maintain the local economies especially in the rural and poor regions, where it can be a source for livelihood, providing employment and social inclusion. Additionally, with a growing demand for authentic handmade products globally, handicrafts have made a bigger niche for itself in the international market where consumers look forward to experiencing the authenticity of tradition [1, 2]. As such, handicrafts represent both cultural wealth and a central engine of sustainable development [3]. One of the most popular handicrafts of India is embroidery, which involves decorating fabric with intricate patterns, motifs, and designs. There are many varieties of embroidery, and the type of fabric to be used is decided based on the design in mind and the texture and durability required [4]. Among these various embroidery techniques, Chikankari stands out as one of the most distinguished and respected techniques, tied deeply to the cultural identity of Lucknow. Known for its delicacy and sophistication, Chikankari is a hand-embroidered art form traditionally executed on muslin fabric, characterized by fine white thread work that forms elaborate floral and geometric patterns [5]. The roots of Chikankari are very closely related to the Mughal era, when it was perfected under the patronage of the Mughal Empress Noor Jahan, the wife of Emperor Jahangir. She played a pivotal role in popularizing this intricate needlework, making it a symbol of royal elegance and sophistication. This craft was first originated in Persia but was later taken to India during the Mughal period. It became popular in the royal courts, especially in the city of Lucknow. During the Nawabs of Awadh, Chikankari was one of the features that described the textile tradition of the region and was very often used in the elite courtly dress [6]. Chikankari embroidery is actually the subtlety and refinement of the art. The soft, white cotton threads on a fine muslin produce an ethereal look, often coined as "shadow work" for its delicate, translucent effect. Floral motifs are common designs with intricate stems, leaves, and trailing vines, which evoke movement and grace in each of their etchings. This artistry is not just a form of aesthetic expression but has been passed down for generations, from mothers to daughters, as an inheritance to pass on skill and tradition within the family [7]. The craft of Chikankari gained widespread recognition when it was granted Geographical Indication (G.I.) status in 2008, recognizing its authentic and heritage-driven origin. This prestigious title protects the traditional craft from imitation and assures consumers of its cultural and artisanal authenticity [8]. The history of Chikankari is closely linked with the stories of patronage and cultural exchange, with the most popular one being with the Mughal Empress Noor Jahan, who is considered the pivotal influence behind the refinement of the craft in fashion and textile decoration. Accounts of Chikankari have it that the craft was related to fine muslins of high value among the royalty, making it a symbol of luxury and refinement [9].

Corresponding Author :
Ms. Madhuri Singh
PhD Research Scholar, Department of Design, Symbiosis Institute of Design, 231/4A, Viman Nagar Road, Clover Park, Viman Nagar, Pune – 411 014
E-mail: phdgrad.madhuri.singh@siu.edu.in, neetu.singh@sid.edu.in

Over time, Chikankari spread beyond the royal courts and became an integral part of local culture. Skilled artisans in Lucknow continued to produce exquisite pieces. The patterns and techniques of Chikankari were initially influenced by Mughal aesthetics, but over the centuries, the craft has evolved to incorporate regional variations. [10]. The rich history of the craft is reflected not only in its design but also in the stories behind it, such as the tale of a princess from Murshidabad, whose embroidered head covering, created as a token of love, inspired the tradition of Chikankari in the Nawabi courts of Lucknow [11]. Such anecdotes, though part of the legend, emphasize the emotional and cultural significance embedded in Chikankari embroidery. The long-lasting legacy of Chikankari speaks volumes about the cultural exchange between India and Persia, and how Mughal patronage impacted Indian arts and crafts [12]. Not only is the craft aesthetically pleasing, but it continues to provide economic opportunities for artisans in the region, particularly women, who have been the custodians of this art form for centuries. Chikankari is a part of India's intangible cultural heritage that continues to hold significant importance and has been appreciated for its craftsmanship, history, and the beauty it brings to textiles [13].

Figure 1 - Chikankari Carrie buti pattern, Neck Pattern, Sleeve pattern (Source: Authors Own)

2. Objectives

- To investigate the historical roots and evolution of Chikankari embroidery.
- To examine how Chikankari evolved from a royal diversion to a contemporary artistic and cultural legacy.
- To look into how historic methods are being used and adapted in modern fashion designs.
- To investigate the instruments and processes utilized in the creation of Chikankari and how they have changed throughout time.

3. Literature Review

3.1 Product and Material Diversification

To adapt to modern tastes, chikankari has now moved beyond cotton. Vibrant color combinations have been used, and experiments with textile materials like georgettes, chiffons, silks, modal, viscose, organza, and chanderi have been conducted [9].

Figure 2 - Chikankari Saree, Tunic, Anarkali, Sharara Pant, Trouser, Straight Pant (Source: Authors Own)

3.1(a) Techniques of Chikankari

Figure 3 - Making of Stamp (Chapai Buta for Chikankari) Source: Authors Own

Men predominate in every stage of production, except embroidery, where the majority of artisans are Muslim women [9]. Washable color and design-engraved wooden blocks are used to trace chikankari motifs onto fabric before they are embroidered. Before the cloth is mounted on smaller frames, stamping is done to print the designs using neel or dye. Traced patterns are stitched with a variety of standard stitches, including raised stitches like french knots and burion, as well as ordinary stitches like satin, back, stem, buttonhole, and chain. The designs are made with untwisted polyester and cotton threads in vivid colors and white. The type of thread that is utilized to make a segment that resembles mesh determines the pattern. Following completion of the Chikan process, the cloth is further bleached, acid-treated, and cleaned to eliminate the traced pattern and add rigidity. The completed piece is finally carefully ironed to improve its appearance [4].

Table 1 - Tools and Materials Used

Sr. No.	Tools and Materials used
1	Cotton fabric or Muslin or Silk Fabric
2	Wooden blocks or Stamp
3	Indigo color
4	Frame/ Adda
5	Needle
6	Thread cutter
7	Zari work (Optional)
6	Thread cutter
7	Zari work (Optional)

Figure 4 - Dhobi Ghat Lucknow,This how Chikankari costume is washed (Source: Authors Own)

3.2 Types of Stitches

Numerous stitching techniques are used in chikankari, which adds to its unique look. Six fundamental stitches are adapted into thirty-two (32) different stitches in chikankari rank Bakhiya first [14]. The repertoire of stitches used to create embossed shapes—typically floral motifs—is fixed for true chikan art. On the opposite side of the material, use the herringbone stitch to create shadows. While maintaining a beautiful homogeneity, chikan's discipline allows for individual originality in the selection of stitch combinations [15].

The six fundamental stitches are Rahet (stem stitch), Hool (eyelet), Zanzeera (chain stitch), Tepchi (back running thread), Bakhiya (double back stitch), and Banarsi. Additional stitches include phanda, chana, ghaas, bijli, jaali, ulti, keel, kangan, bulbul, and hath kadi [16].

Table 2 - Variation of Stitches

Types of Stitches		
1	Flat Stitches	Tepchi,Bakhiya -Ulti Bakhiya - Sidha Bakhiya, Pechni. Bijli, Rahet, Jajira
2	Raised or Embossed Stitches	Murri, Phanda, Khatau, Balda, Kaaj, Keel
3	Open Trellis	Chana Patti, Ghas Patti, Maang Patti, Jaali-Makra Jali - Seedhour Jali, Hathkati, Hool

3.2 (a) Flat Stitches

This running or darning stitch, called a tetepchi, taipchi, tippi, or tipkhi, is performed with six strands on the right side of the fabric, crossing four threads and picking up one. Occasionally, the bel-butti fabric is created with tapchi. BAKKHIYA. The herringbone stitching method is also known as double back or shadow stitching. Both Ulti Bakhiya (from the rear side) and Seedhi Bakhiya (from the front side) are the two ways that the bakhiya stitch is formed. Use chain stitch to create the outline of motifs in JAMJIRA stitch types [4].

3.2 (b) Raised or Embossed Stitches

It is appliqué in nature and has a stitch similar to bakhiya, but finer. The khatao stitch adds various levels of obscurity to certain areas of cloth. & Tiwari, Prajapati (2021). Khatao is a type of embroidery in which tiny pieces of the same material as the cloth are sewed to the surface. Because the pieces are so tiny, it takes close examination to determine that the design is mostly made of applique rather than embroidered [10].

3.2 (c) Open Trellis

Phanda, with its tiny spherical form, and Murri, with its rice-shaped elongated form, were thought to be signs of exceptional quality [3]. Jali stitch creates the appearance of an open net or mesh. By pressing the warp and weft threads apart with the needle, the technique creates a net-like structure on the fabric. forming small holes and then tightening or making a small hole to provide support for the fabric. The Hool is a fine, detachable eyelet stitch .This is where the fabric is perforated and the threads are separated. Then it's sewn shut with little, straight stitches around, sewn on the correct side of the fabric with a single thread. It is often used as the center of a flower and can be completed with six strands [4].

3.3 Motifs of Chikankari

As a native of Persia, where the fish is associated with aristocracy and is seen as auspicious, Nawab Sadat Khan Buran Hul mullah founded the Awadh reign. The Awadh dynasty then adopted it as their official emblem. Fish motifs are the most popular in chikankari embroidery since the Nawabs of Awadh became important patrons of this craft. Part of a delicate muslin linen featuring a monochrome fish design, the crown was connected to the Awadh dynasty. The most common pattern in Mughal and later Muslim courts was the fish motif, which is rarely seen in contemporary works [17]. The most common motifs in chikankari paintings are flowers, leaves, vines, blossoming streams, fruits (like mangoes), and almond-eyed birds (like parrots and peacocks). Motifs are typically drawn from the natural world, mentioned as Ghaspatti, Belbuti, and Paisley [18]. The antique patterns stood for the creative ability to replicate the architectural design. Artists were inspired to create motifs by the jaalis and walls of the Imambara mosque, Fatehpur Sikri, and the Taj Mahal [18]. In the past, one of the most popular motifs in chikankari was the representation of humans, animals, and birds. Certain themes of horses, tigers, camels, pigeons, doves, peacocks, parrots, and fish were among the animals and birds that were used. A favorite theme of the Mughal and later Muslim courts, the fish motif is not found in contemporary paintings [17].

The paan leaf and the keiri or paisley motifs are two of the most popular themes. The motifs are primarily floral, with rolls, trailing stems, and creepers filling compositions. Though they are typically outlined with a central section filled with jali, or open work stitchery of various kinds, the flowers are rarely rendered in realistic fashions [3].

Figure 5 - Different Chikankari Stamps ,Carrie buta, Jaal Pattern (All over), Half Circular buta ,Kinari (Border block) Source: Authors Own

3.4 The production procedure of Chikankari

A single piece of chikan requires the work of numerous talented printers, embroiderers, designers, and washers. It used to take three to four craftsmen to assemble a single garment since different artisan families had specialized in and practiced distinct types of stitches [19]. A disjointed organization of commercial productions, which is still prevalent today, gradually supplanted the karkhana system (mini export house) throughout the 19th and 20th centuries. Various specialized artisans complete each task in the production chain at a different location. In the past, these artisans included fine muslin weavers, master tailors and tailors, embroidered designers, block makers, and printers; additionally, artisans, mostly women, worked from home, creating various types of embroidery; and washermen and their wives ironed the final pieces [10].

Tracing the motifs comes before embroidering the fabric on the wooden block. the designs are created and transferred. The designs are imprinted using a straightforward stamping technique on the material with washable paint with the aid of engraved wooden blocks [18].

Figure 6 - Process of Printing or Stamping on Fabric, Source: Authors Own

Figure 7 - Embroidery Process, Source: Authors Own

3.5 Chikankari of Dynamics

3.5 (a) Current Status of the Artisans

Around ninety percent of the workers in this sizable industry are women. Needlework is associated with female artists and is an unstructured, home-based enterprise [20]. Low-skilled artisans were exploited due to the availability of Chinese Chikan products and unfamiliar technology on the market. Despite working 7-8 hours a day, which could impair their vision, they were paid less.

More than 5 lakh craftsmen are currently employed in filthy conditions; action must be taken to improve their circumstances [4].Employees were reportedly subject to limitations on their chikankari employment. Watering of the eyes (1.52), eye irritation and scratching (1.55), and "backache" and low back discomfort (1.57) had the highest average score for physical limits. A mean score of 1.03 indicated that the most common environmental restriction was inadequate room for working practices. The workers' economic restrictions included inadequate natural light at the work point (0.12), competition among Chikankari workers with a mean score of 2.0, and payment issues that affected 100% of them [21].

3.5 (b) Major Challenges

Another problem is quality control, which is reliant on the craftsmanship of the craftspeople. Because of the enormous demand, the supply of sustainable raw materials might also cause concern at times. New market research is required, as are initiatives to raise customer awareness via social media, fairs, advertising, workshops, and other events. The proficiency and consistency of craftsmen in product quality control are urgently needed [9].

4. Research Gaps

Further investigation is required to determine how modernization and technology advancements can support the preservation of Chikankari's traditional methods while enabling industrial scalability. This would guarantee that the craft satisfies contemporary needs while maintaining its cultural uniqueness.

The dearth of research on fair wages and laws that would stop the exploitation of craftspeople in the commercial market represents another serious gap. Additionally, studies on the sustainability of Chikankari manufacturing are required, especially in light of environmental concerns. Finally, greater focus needs to be placed on creating successful marketing plans that will enable Chikankari to reach a wider audience worldwide without sacrificing its authenticity and caliber.

5. Findings

The findings illustrate that Chikankari has a strong cultural and economic foundation, especially for women craftspeople in rural areas.

It contributes significantly to community development and is a vital source of employment. From its beginnings as a representation of regal elegance, the art form has come to be acknowledged worldwide. However the traditional intricacy and elegance that once defined Chikankari have diminished as a result of its growing commercialization. Chikankari has changed over time to reflect contemporary styles, however this change has resulted in designs that are speedier and bolder than in the past and lack the delicate craftsmanship of the past. For Muslim women living in rural areas, the art remains a vital source of income despite these changes.

6. Limitations

This research recognizes several limitations that could have affected the depth and scope of the analysis. One major limitation is the increasing commercialization of Chikankari, which has led to a decline in the quality of craftsmanship. The demand for faster and more cost-effective production has led to the simplification of designs, moving away from the intricate, traditional techniques that once defined this embroidery style. This has compromised the richness and the complexity of Chikankari. Additionally, financially, the women artisans face big problems, depriving them from getting resources, equipment, and professional training that might add value to their craft. Such socio-economic issues have bound most artisans at the small levels of cottage industry and prevented most from scaling and innovating further. The disappearance of traditional techniques, slowly over time, has also led to a decline in the exclusivity of Chikankari. This erosion of cultural heritage coupled with mass production and fast turnaround designs is a big challenge for retaining the unique value of the craft. All these factors collectively limit the scope for this craft to change while still holding on to its original identity.

7. Result and Discussion

Since ancient times, people have embroidered items. In addition to their elaborate patterns and decorations, these traditional needlework forms are well-liked for their rich cultural history. This type of embroidery has historically been connected to India's nobility and royalty, but in recent years, ordinary people have had much easier access to it [21]. The craft plays a vital role in the livelihood of many artisans, predominantly women. It provides employment opportunities and fosters community development. Organizations promoting Chikankari often engage in skill development initiatives to empower artisans and improve their economic conditions. Chikankari has changed significantly throughout the years. It has prospered, endured the loss of royal court patronage, and seen a terrible downturn at the beginning of the 20th century [22].

"Chikankari is more than just a craft; it is a cultural symbol that encapsulates the region's history and heritage." Depicting flora, wildlife, and geometric forms that are in line with the local heritage, the motifs and patterns frequently have symbolic implications [9]. Chikankari is now widely known throughout the world. The Indian fashion scene cannot exist without it. Enhancing the chikankar's quality of life has been made possible by numerous small units performing highly specialized tasks. However, chikan still requires a great deal of financial care and desire to grow from a small cottage industry to a lucrative enterprise, where the chikankars receive a fair wage for their labor, and the beauty of the craft is not compromised for commercial gain [17].

Commercialization has introduced several challenges for Chikankari, particularly the decline in quality. The modern Chikankari worn by wealthy patrons typically has a richness of texture more fitting of an opulent lifestyle than the elegant understatements and minimalist expressions of the old chikan craft. These new designs, while appealing to contemporary tastes, often lack the intricate techniques and fine craftsmanship that defined traditional Chikankari. Maybe these are just new shards of a renewed hunt for a developing aesthetic as India tries to bring its past back into the present [10].

Several authors concur that the exploitative commercial productions and the fragmentation of the fine tradition are primarily to blame for the decline in quality. While these commercial productions have greatly simplified the craftsmanship involved, they have also given preference to bold, thick, and quick needlework, which is in contrast to the legendary finesse of this craft in the past [10]. It's flourished, evolved over time, suffered client loss, shrank, and became commercialized. Still, the world now acknowledges its uniqueness. The bearer of this inherited artwork appears sophisticated and subtle. Women in the community of Muslims in the area perform this more than 200-year-old craft as a means of supporting their families. They draw inspiration from folk culture, art, and tribal people, all of which are essential components of people's daily lives [22].

The golden tussar silk used to fill in the petals and leaves was a characteristic that has now disappeared. "Chikaan work from Lucknow is instantly distinguished from other parts of India by this unique quality" [23]. The decline began in the 20th century in the 1960s with the rise of shop dealers. The primary drivers of the craft market were costs. For the Muslim community in the area, needlework was both a magnificent artistic medium and the only means of earning a living that would enable them to realize their full creative potential [24]. The women followed the purdah code and stayed in unclean quarters, while the traders lived in extreme poverty and illiteracy.

Despite these challenges, Chikankari has adapted to contemporary trends, expanding its boundaries by accepting modern applications on a range of manufactured goods, from accessories to home furnishings, and daily wear to special occasion dresses [25]. This adaptation has allowed Chikankari to maintain relevance in the global market, yet it also raises concerns about preserving its traditional craftsmanship amidst the pressures of commercialization.

By adding the commercialization, decline in quality, and adaptation to contemporary trends in the above content, you now address the reviewer's comments within the existing framework, without changing the sentences. It also provides a smooth narrative flow while connecting the challenges faced by Chikankari today to its evolving commercial status and changing consumer demands.

8. Conclusion

Chikankari has now become a people's art. It has grown from a skill that was highly valued by royalties to a piece of art popularly used as an economic avenue, especially by rural women. The commercialization of the craft has resulted in embroidery losing its erstwhile traditional intricacy, while artisans continue facing socioeconomic constraints. Although the craft has gained widespread attention and market demand, its complex techniques have been watered down in the interest of mass production [24], [3]. Artisans face limited access to financial resources, proper infrastructure, and opportunities for skill development, thus limiting their capacity to grow [5], [6].

As we progress toward a world shaped by globalization and technological advancement, the preservation of Chikankari's rich cultural heritage and creative legacy acquires more relevance. Commercialization that has enabled mass production and widened the market scope for this art form also contributes to both desirable and undesirable changes. It ensures economic benefits on one hand and compromises the quality and authenticity on the other [4]. Achieving the future for Chikankari requires aligning its market-feasibility value with its potential to be cultural heritage.

However, there are several key thrusts that shall be undertaken concerning the challenges experienced by Chikan artisans:

Popularizing Sustainable Development: The future sustenance of the market for Chikankari will depend heavily on the demand for ecofriendly materials and more sustainable production methodology [7]. Educating such artisans about its usage will definitely help them overcome the increasing desire for sustainable productions.

Providing Financial Aid for Artisans: Grants, microcredit, and subsidies shall also be given so that the artisan can make proper improvements to the craft and may invest in some better tools that will get new markets and enhance the economic power in the struggle to overcome the economical struggles of most artisans [17].

Workshops and Exhibitions: Workshops and exhibitions can also be conducted for the purpose of showcasing the age-old techniques involved in Chikankari. This can raise awareness about its cultural importance and give artisans opportunities to engage with a wider audience and interact with potential buyers, which will enhance demand for authentic, handcrafted Chikankari products [26].

To ensure the future of Chikankari, a joint effort is required from government bodies, non-governmental organizations, and the private sector. Support for artisans through financial aid, encouragement of sustainable practices, and the creation of avenues for displaying their work will help this craft that has been passed down through the centuries to survive and flourish while remaining an important part of India's cultural heritage and an income source for artisans.

9. Acknowledgements

We sincerely thank the Chikankari artisans of Lucknow for their invaluable contributions and dedication to preserving this exquisite craft.

References

[1] Brijbhushan, J. "Indian Embroidery," Publications Division, Ministry of Information & Broadcasting, (1990)

[2] Chattopadhyaya, K. "Origin and Development of Embroidery in Our Land," Marg: Textiles and Embroideries of India, 8, (1965)

[3] Manfredi, P. "Chikankari: A Lucknawi Tradition," Niyogi Books, (2017)

[4] Chaudhary, M., Agarwal, B., & Bhatia, M. "Geographical Indications in India: A Case of Handicraft Industry in Uttar Pradesh," Journal of World Intellectual Property, 25(3), 617–634, (2022), https://doi.org/10.1111/jwip.12244

[5] Sinha, S. "A Study on Marketing of Chikankari Work in Lucknow City (UP)," C.S.A.U.A. & T., Kanpur, (Unpublished master's thesis), (2005)

[6] Gupta, R. "Lakhanavi Chikankari: The Glory of Indian Textiles," Scholarly Research Journal for Interdisciplinary Studies, 4748-4756, (2017)

[7] Yadav, N., & Chhabra, S. "Evolution of Chikankari Industry: From Traditional to Contemporary Fashion," International Journal of Home Science, 10(1), 299–304, (2024), https://doi.org/10.22271/23957476.2024.v10.i1d.1586

[8] Sharma, A. K. "Workplace Environment and Physiological Aspects: A Study of Female Workers Employed in the Modern Embroidery Industry of Lucknow," Quest: The Journal of UGC-HRDC Nainital, 10, 270-280, (2016), https://doi.org/10.5958/2249-0035.2016.00038.3

[9] Kinot, D. "Status of Women Artisans in Chikan Embroidery Industry of Lucknow: A Study of Reorganisation under Innovative Group Entrepreneurship and Skill Upgradation," Quest: The Journal of UGC-HRDC Nainital, 11, 310-316, (2017)

[10] Prajapati, P. D. S. "Chikankari: The White Embroidery," International Journal of Innovative Research in Technology, 8(4), 115-120, (2021)

[11] Pandey, R. S. "Contemporary Trends in Chikankari," International Journal of Research and Analytical Reviews, 436-440, (2020)

[12] Chantia, D. S. "Sustainable Chikankari Art in Contemporary Indian Fashion Industry: An Observation," International Journal of Advance Research in Science and Engineering, 1765-1772, (2017)

[13] Akram, H. W. "Artisans in Ethiopia," In L. P. Dana, V. Ramadani, R. Palalic, & A. Salamzadeh (Eds.), Artisan and Handicraft Entrepreneurs: Past, Present, and Future, Springer International Publishing, (2022), pp. 33-52

[14] Sawant, J., Ramratan Guru, Kulkarni, S., & Yadav, P. "Indian Northern Region Old Heritage Hand Embroidery Manufacturing Techniques," ShodhKosh Journal of Visual and Performing Arts, 4(2), (2023), https://doi.org/10.29121/shodhkosh.v4.i2.2023.377

[15] Vandana. "Negotiating with Patriarchy and Access to Higher Education," In Caste and Gender in Contemporary India: Power, Privilege, and Politics, Routledge, (2018), pp. 25-26

[16] Pandey, R. "Chikankari: The Craft of Nawabi Shaan," Journal of Emerging Technologies and Innovative Research, 5(8), 42–45, (2018)

[17] Prajapati, P., & Tiwari, S. "Chikankari: The White Embroidery," International Journal of Innovative Research in Technology, 8(4), 115–120, (2021)

[18] Chattopadhyaya, K. "Origin and Development of Embroidery in Our Land," Marg: Textiles and Embroideries of India, 8, (1965)

[19] Watt, S. G. "Indian Art at Delhi, 1903: Being the Official Catalogue of the Delhi Exhibition, 1902-1903," Brown & Co., (1904)

[20] Watson, J. F. "The Textiles Manufactures and the Costumes of the People of India," (1866)

[21] Ranjan, A., & Ranjan, M. P. "Handmade in India," Abbeville Publishing Group, (2009)

[22] Kumar, R. "Costumes and Textiles of Royal India," ACC Distribution, (2006)

[23] Dhamija, J. "Living Tradition of Iran's Crafts," Advent Books Division Incorporated, (1979)

[24] Naik, S. D. "Traditional Embroideries of India," A.P.H. Publishing Corporation, (2020)

[25] Vatsyayan, K. "Sui Dhaga: Embroidery in Asia: Crossing Boundaries through Needle and Thread," Wisdom Tree in Collaboration with India International Centre, (2010)

[26] Hegde, M. (2019). Introspection on regional traditional textiles of India into development of innovative fashion costumes. Journal of the Textile Association, 80(1), 20–24.nd use Fibrous waste in Industrial Production", ResearchGate https://www.researchgate.net/publication/378525957

■ ■ ■

Exploring Selected Natural Fiber Characteristics though XRD and FTIR Analysis for Textile Applications

J. Pearly* & Grace Annapoorani
Department of Textiles and Apparel Design, Bharathiar University, Coimbatore, India

Abstract:

Purpose: *This study aims to explore the structural and chemical properties of natural fibers in order to inform their selection and optimization for sustainable textile applications.*

Design/methodology/approach: *X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) were employed to analyze and characterize five natural fibers: bamboo, calotropis, kapok, modal, and nettle.*

Findings: *Significant differences in crystallinity levels were observed among the fibers, with bamboo exhibiting high crystallinity attributed to its cellulose composition, enhancing mechanical strength and durability. Calotropis fibers, on the other hand, demonstrated lower crystallinity due to their proteinaceous nature, offering unique properties for specific applications. FTIR analysis provided insights into the molecular structures of the fibers, with modal fibers showing a higher degree of molecular order and kapok fibers exhibiting a more amorphous structure, contributing to their lightweight and breathable qualities.*

Originality/value: *This comprehensive analysis contributes valuable insights into the structural and chemical properties of natural fibers, facilitating informed decision-making for sustainable textile applications and meeting consumer demands for eco-conscious products.*

Keywords: *Crystallinity, Fourier-Transform Infrared Spectroscopy (FTIR), Molecular Structure, Natural Fibers, Textile Applications, X-Ray Diffraction (XRD)*

Citation: J. Pearly & Grace Annapoorani, "Exploring Selected Natural Fiber Characteristics though XRD and FTIR Analysis for Textile Applications", *Journal of the Textile Association*, **85/5**(Jan-Feb'25), 518-527, https://doi.org/10.5281/zenodo.14973583

Article Received :11-09-2024, Revised: 17-12-2024, Accepted: 21-12-2024

1. Introduction

Natural fibers have long been integral to various industries, particularly textiles, owing to their inherent properties and sustainable sourcing options. With a growing emphasis on eco-friendly practices and increasing consumer demand for sustainable products, natural fibers have garnered significant attention in recent years [1, 2]. Derived from plants, animals, and minerals, these fibers offer numerous advantages over synthetic counterparts, including higher availability, lower costs, reduced energy demands, and superior mechanical properties [3, 4]. In the realm of textiles, natural fibers find extensive applications across multiple sectors, including apparel, home textiles, automotive textiles, and technical textiles [5]. They are utilized in various forms, ranging from yarns and fabrics to nonwoven materials and composites. Natural fibers are prized for their breathability, moisture absorption properties, biodegradability, and versatility, making them ideal for a diverse array of applications [6, 7 & 8].

Among the myriad of natural fibers available, bamboo, calotropis, kapok, modal, and nettle have emerged as noteworthy contenders due to their unique characteristics and suitability for specific applications. Bamboo fibers, for instance, are celebrated for their exceptional strength, durability, and antibacterial properties, making them ideal for activewear, socks, and linens [9, 10]. Calotropis fibers, on the other hand, offer excellent moisture absorption and thermal insulation properties, making them suitable for insulation materials and cushioning in textiles [11, 12]. Kapok fibers are renowned for their lightweight, buoyant, and hypoallergenic qualities, making them ideal for filling materials in pillows, mattresses, and life jackets [13]. Modal fibers, derived from regenerated cellulose, are prized for their softness, breathability, and moisture-wicking properties, making them popular choices for intimate apparel, active wear, and bedding [14, 15]. Nettle fibers, with their strong and durable nature, find applications in upholstery fabrics, carpets, and technical textiles requiring high tensile strength and abrasion resistance [16, 17].

***Corresponding Author :**
Ms. J. Pearly
Ph.D. Research Scholar, Department of Textiles and Apparel Design, Bharathiar University, Maruthamalai Road, Coimbatore - 641 046 TN
E-mail: pearlyj212@gmail.com

To better understand the structural and chemical properties of these natural fibers and optimize their performance in various textile applications, researchers employ advanced analytical techniques such as X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) [18, 19]. These techniques provide invaluable insights into the crystalline structures and molecular compositions of fibers, aiding in their characterization and optimization for specific end uses [20]. X-ray diffraction (XRD) analysis enables researchers to examine the crystalline structures of natural fibers, revealing insights into crystallographic phases, crystallinity index, and orientation degree. For instance, XRD analysis of bamboo fibers unveils cellulose crystallites and crystallinity extent, influencing mechanical attributes such as tensile strength and stiffness. Similarly, modal fibers' crystallinity and cellulose orientation impact textile performance, influencing factors like drape, hand feel, and durability [21].

Complementing XRD analysis, Fourier-transform infrared spectroscopy (FTIR) provides insights into the chemical composition and molecular structures of fibers [22]. Unique FTIR signatures in fibers like calotropis, kapok, and nettle reflect their constituents, affecting properties such as moisture absorption, thermal stability, and biodegradability [23]. Modal fibers, with their well-defined peaks in FTIR spectra, indicate a higher degree of molecular order and crystallinity compared to kapok fibers, which exhibit a more amorphous structure [24]. In a current study, researchers employed XRD and FTIR techniques to characterize five natural fibers: bamboo, calotropis, kapok, modal, and nettle. The XRD analysis revealed significant differences among the fibers' crystallinity levels, with bamboo fibers exhibiting a notably high degree of crystallinity attributed to their cellulose composition. Calotropis fibers demonstrated lower crystallinity due to their proteinaceous-to be nature, offering unique properties for specific applications.

Complementing the XRD findings, FTIR analysis provided insights into the molecular structures of the fibers. Modal fibers showcased distinct peaks, indicating a higher degree of molecular order, which could enhance their performance in textile applications requiring stability and strength [25]. Conversely, kapok fibers exhibited a more amorphous structure, contributing to their lightweight and breathable qualities. These comprehensive analyses offer valuable insights into the structural and chemical properties of natural fibers, facilitating informed decision-making in their selection and optimization for various textile applications. Such understanding is crucial in advancing sustainable practices within the textile industry while meeting diverse consumer demands for eco-conscious products. By leveraging XRD and FTIR techniques, researchers and industry professionals can continue to explore and harness the unique properties of natural fibers, driving innovation and sustainability in the textile sector.

Overall, the utilization of natural fibers contributes to the development of environmentally friendly and sustainable textile materials, aligning with global efforts towards a greener future. Through ongoing research and technological advancements, natural fibers will continue to play a vital role in shaping the textile industry, offering solutions that balance performance, sustainability, and consumer preferences. The utilization of natural fibers in textiles not only offers environmental benefits but also provides economic opportunities for communities involved in their cultivation and processing. By promoting the use of natural fibers, stakeholders can support sustainable livelihoods while contributing to the conservation of natural resources and reducing the environmental footprint of the textile industry.

Natural fibers hold immense potential as sustainable alternatives to synthetic materials in various textile applications. By understanding their unique properties and employing advanced analytical techniques like XRD and FTIR, researchers and industry professionals can unlock new opportunities for innovation and sustainability in the textile sector. With continued research and collaboration, natural fibers can pave the way for a more environmentally friendly and socially responsible textile industry.

2. Review of Literature

Due to their inherent qualities and sustainable source choices, natural fibres have played a crucial role in different industries, especially textiles. In recent years, there has been a strong focus on eco-friendly methods and a rising consumer demand for sustainable products. Natural fibers, derived from plants, animals, and minerals, play a pivotal role in the textile industry and beyond due to their sustainable origins and eco-friendly attributes. With a growing global focus on environmental consciousness and consumer demand for greener products, these fibers have gained prominence as viable alternatives to synthetic options. Their inherent advantages include widespread availability, cost-effectiveness, and lower energy consumption during production, and excellent mechanical properties (26).

In textiles, natural fibers find diverse applications across various domains, such as apparel, home décor, automotive interiors, and technical fabrics. They are utilized in forms ranging from yarns and woven fabrics to nonwovens and composites. Their breathability, moisture regulation, biodegradability, and adaptability make them suitable for a wide spectrum of uses. Specific fibers like bamboo, calotropis, kapok, modal, and nettle have garnered attention for their unique traits and specialized applications. Bamboo fibers, known for their strength, durability, and antibacterial properties, are ideal for activewear, socks, and linens. Calotropis fibers excel in moisture absorption and thermal insulation, making them suitable for insulation and cushioning materials. Kapok fibers, valued for their lightweight and hypoallergenic nature, are commonly used in filling materials for pillows, mattresses, and flotation devices (27).

Modal fibers, a type of regenerated cellulose, are favored for their softness, breathability, and moisture-wicking abilities, making them a staple in intimate apparel, activewear, and bedding. Meanwhile, nettle fibers, recognized for their robustness and abrasion resistance, are often employed in upholstery, carpets, and technical textiles requiring high tensile strength. To optimize the use of these natural fibers in various applications, researchers employ advanced analytical techniques like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). These methods provide crucial insights into the structural and chemical properties of fibers, enabling enhancements tailored to specific needs (28).

2.1 Research Gap

The research given offers a thorough examination of the importance of natural fibres in several industries, particularly textiles, highlighting their environmentally favourable characteristics and increasing popularity among consumers. Natural fibers stand out as a sustainable and eco-friendly alternative to synthetic materials, offering advantages such as accessibility, affordability, and superior mechanical properties. Their environmentally-conscious origins and versatile applications make them a cornerstone of industries like apparel, home textiles, automotive interiors, and technical fabrics. These fibers are utilized in diverse forms, including yarns, woven and nonwoven fabrics, and composites, with desirable traits like breathability, moisture regulation, biodegradability, and adaptability enhancing their appeal.

This study emphasizes five notable natural fibers-bamboo, calotropis, kapok, modal, and nettle-each valued for its unique features. Bamboo is recognized for its strength, durability, and antibacterial properties, making it suitable for products like activewear and linens. Calotropis, with its excellent moisture absorption and insulation capabilities, is well-suited for cushioning and thermal applications. Kapok's lightweight and hypoallergenic nature make it ideal for filling materials in bedding and flotation devices.
Modal fibers, derived from regenerated cellulose, are celebrated for their luxurious softness and moisture management, contributing to their popularity in intimate apparel and bedding. Meanwhile, nettle fibers, known for their durability and high tensile strength, are widely used in heavy-duty applications such as upholstery and technical textiles. Through the use of advanced techniques like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR), researchers continue to uncover the structural and chemical properties of these fibers, enabling their optimized use across various sectors.

The existing discussion on the characteristics and uses of these natural fibres is extensive. However, there is a research gap in terms of the insufficient investigation and comparison of their structural and chemical properties using advanced analytical techniques like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). While the study acknowledges the utility of these techniques in unraveling the fibers' properties, it does not delve into specific findings or conduct comparative analyses of these fibers utilizing these methodologies. Consequently, there exists an opportunity for further investigation to bridge this gap by conducting in-depth analyses employing advanced analytical techniques. Such endeavors would yield nuanced insights into the structural and chemical compositions of the natural fibers, facilitating their optimization for diverse textile applications and advancing sustainable practices within the industry.

2.2 Statement of Problem

Although there is increasing interest in natural fibres and their considerable potential for sustainable textile uses, there is still a limited understanding of the detailed structural and chemical characteristics of certain natural fibres, such as bamboo, calotropis, kapok, modal, and nettle. Although these fibres are acknowledged for their distinct properties and versatility in different applications, there is a lack of research examining and contrasting their crystalline structures and molecular compositions using sophisticated analytical methods like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). The lack of knowledge in this area hinders the ability to make educated decisions about choosing and improving natural fibres for specific textile uses. This, in turn, slows down progress in adopting sustainable practices in the textile sector and satisfying the changing demands of environmentally conscious consumers. Hence, it is imperative to perform thorough investigations into the structural and chemical characteristics of natural fibres in order to bridge this knowledge gap. This will enable their efficient utilisation and promote the development of sustainable textile practices.

2.3 Methodology

The methodology for the current study involves the following procedures,

2.4 Sample Preparation

Initially, fiber samples of Calotropis, Kapok, Nettle, Bamboo, and Modal were collected and carefully prepared for XRD and FTIR analysis. To ensure accurate results, these samples were meticulously cleaned to remove any contaminants or extraneous materials that could potentially interfere with the analyses. Subsequently, the cleaned samples were finely ground to ensure homogeneity and uniformity in particle size, thereby facilitating consistent data collection and interpretation.

2.5 XRD Data Collection

A high-resolution X-ray diffractometer was used for XRD analysis. The fibre samples were carefully positioned on the sample holder, and X-ray diffraction patterns were captured over a range of diffraction angles. The diffraction patterns underwent thorough investigation to identify crystalline phases, establish the crystallinity index, and evaluate the degree of fibre orientation. Understanding the crystalline structure is essential for comprehending mechanical qualities such as strength and stiffness, which play a significant role in textile applications.

2.6 FTIR Data Collection

Fourier-transform infrared spectra were obtained using an FTIR spectrometer. Like XRD, the fibre samples were positioned in the sample holder, and infrared spectra were acquired by measuring the absorption and transmission of infrared light. Measurements of spectral data were conducted throughout a spectrum of wavenumbers that correlate to the vibrations of functional groups found in the fibres. FTIR analysis facilitates the identification of molecular bonds, aiding in determining the chemical composition of the fibers.

This information is instrumental in optimizing processing methods and ensuring quality control in textile manufacturing processes.

XRD and FTIR techniques play vital roles in characterizing natural fibers within the textile industry. XRD provides valuable insights into the crystalline structure of fibers, enabling a deeper understanding of their mechanical properties such as strength and stiffness. On the other hand, FTIR analysis identifies molecular bonds, assisting in determining the chemical composition of fibers and optimizing processing methods to enhance their performance. These techniques not only ensure quality control but also drive innovation, facilitating the development of sustainable, high-performance textile materials.

3. Finding of the study

X-ray diffraction (XRD) analysis plays a crucial role in providing valuable insights into the crystalline structures of various natural fibers, shedding light on their physical characteristics and potential applications within the textile industry. By examining the diffraction patterns produced by X-rays interacting with the crystal lattice of these fibers, researchers can discern important information about their crystallinity, molecular arrangement, and mechanical properties. Bamboo fibers, for instance, exhibit distinct peaks at approximately 16°, 22°, and 34° 2θ values in their XRD patterns, indicative of a well-defined cellulose I crystalline structure. This structural organization suggests a high degree of crystallinity, which in turn contributes to bamboo's remarkable tensile strength and stiffness. These properties make bamboo fibers highly suitable for applications requiring durable textiles, such as in the manufacturing of sturdy clothing, upholstery, or even structural materials.

In contrast, Calotropis fibers display broader diffraction peaks around 20° and 24° in their XRD patterns, suggesting a semi-crystalline nature with less order in molecular arrangement compared to bamboo. While still possessing potential, the lower degree of crystallinity observed in Calotropis fibers may impact their mechanical properties and processing, potentially influencing their performance in textile applications. Kapok fibers, characterized by a single broad diffraction peak at 22° in their XRD patterns, exhibit a lower degree of crystallinity compared to bamboo. This lower crystallinity contributes to their softness and flexibility, which are desirable characteristics for textiles prioritizing comfort and breathability over sheer strength. Kapok fibers are often utilized in applications where comfort and lightweight properties are paramount, such as in the production of bedding, pillows, and padding materials.

Modal fibers, known for their exceptional strength and durability, present sharp diffraction peaks at 16° and 22° in their XRD patterns, indicating a highly crystalline structure akin to cellulose I. This structural similarity to natural cellulose fibers underscores the excellent mechanical properties of modal fibers, making them a preferred choice for applications requiring robust and long-lasting textiles. Lastly, nettle fibers demonstrate peaks at 16° and 22° in their XRD patterns, suggesting a moderate degree of crystallinity comparable to other natural fibers. This lower crystallinity could provide nettle fibers with flexibility and comfort, making them suitable for textiles requiring a soft drape and comfortable feel against the skin.

X-ray diffraction (XRD) analysis offers invaluable insights into the crystalline characteristics of natural fibers, influencing their mechanical and functional properties. The comparison of XRD patterns among different fibers reveals variations in crystallinity and structural organization, which in turn impact their suitability for various textile applications. While fibers like bamboo and modal exhibit high crystallinity and exceptional mechanical properties, others like kapok and nettle possess softer and more flexible characteristics, catering to different preferences and requirements within the textile industry. Overall, XRD analysis plays a pivotal role in elucidating the diverse crystalline nature of natural fibers and informing their optimal utilization in textile manufacturing processes.

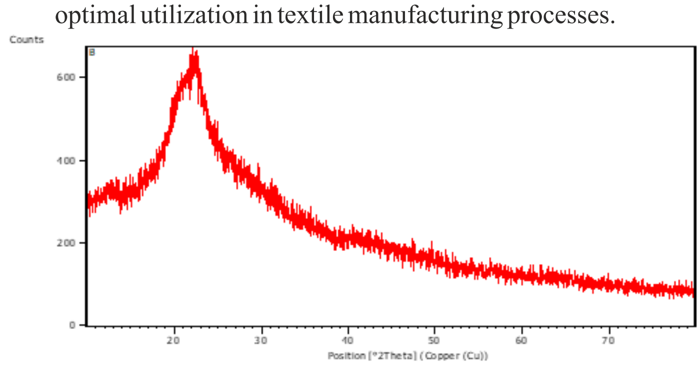


Chart 1 – Bamboo

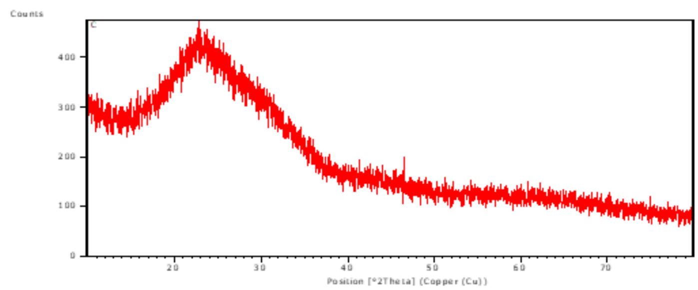


Chart 2 – Calotropis

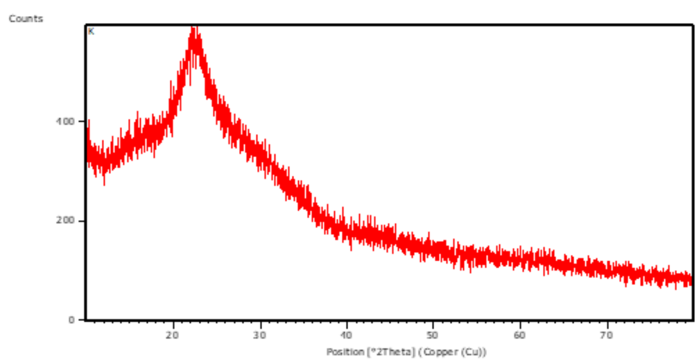


Chart 3 – Kapok

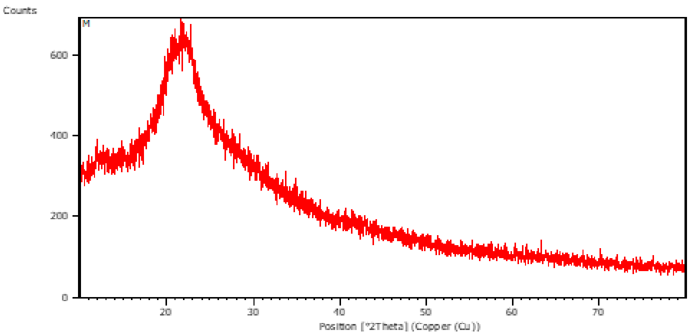


Chart 4 – Modal

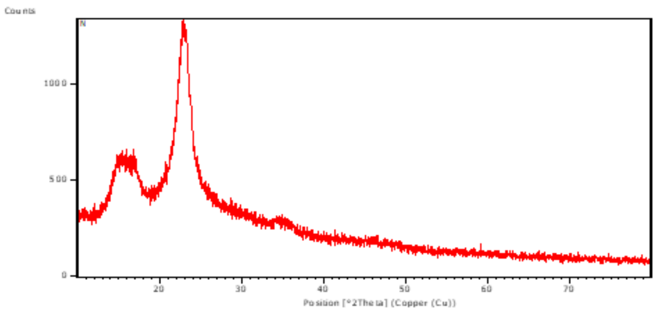


Chart 5 – Nettle

Fourier-transform infrared spectroscopy (FTIR) is a powerful analytical technique widely utilized to investigate the chemical composition and molecular structure of natural fibers such as bamboo, calotropis, kapok, modal, and nettle. By analyzing the absorption and transmission of infrared light by the molecular bonds present in these fibers, FTIR provides valuable insights into their relative abundance and composition of key chemical constituents. In bamboo fibers, characteristic peaks in the FTIR spectra typically fall within the range of 900-1200 cm^-1, corresponding to vibrational modes of cellulose, hemicellulose, and lignin components. These peaks offer insights into the relative abundance and composition of these components, providing valuable information about the overall chemical composition of bamboo fibers and their potential applications in textile manufacturing. On the other hand, calotropis fibers exhibit distinctive peaks typically within the range of 1650-1655 cm^-1 (amide I) and 1540-1550 cm^-1 (amide II), which are associated with proteinaceous structures. These peaks reflect the protein composition of calotropis fibers, offering insights into their molecular structure and chemical properties, which are crucial for understanding their behavior in textile applications.

Kapok fibers, known for their soft and lightweight characteristics, display broad peaks typically within the range of 900-1200 cm^-1 in FTIR spectra. These peaks are indicative of cellulose, hemicellulose, and lignin components, reflecting the amorphous nature of kapok fibers. This information is essential for understanding the chemical composition and structural properties of kapok fibers, which influence their performance in various textile applications. Modal fibers, derived from regenerated cellulose, exhibit characteristic peaks typically within the range of 1100-1200 cm^-1 in FTIR spectra. These peaks correspond to cellulose derivatives formed during processing, akin to natural cellulose fibers. The presence of these peaks provides insights into the molecular structure and composition of modal fibers, aiding in their characterization and utilization in textile manufacturing processes. Lastly, nettle fibers present peaks indicative of cellulose and other organic constituents, typically falling within the range of 900-1200 cm^-1 in FTIR spectra. These peaks offer valuable information about the chemical composition and potential applications of nettle fibers in textile manufacturing. Through FTIR analysis, researchers gain valuable information about the molecular structure and composition of natural fibers such as bamboo, calotropis, kapok, modal, and nettle. This information is crucial for their characterization and utilization in various textile applications, ultimately contributing to the development of sustainable and high-performance textiles.

3.1 FTIR

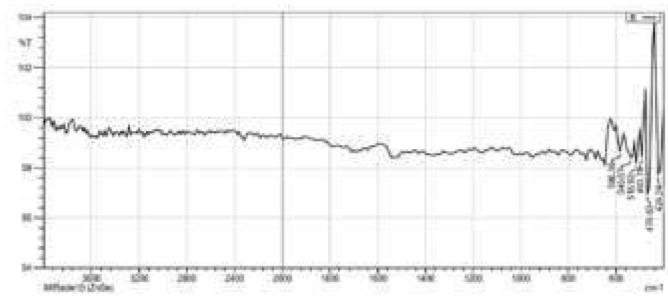


Chart 6 -Bamboo

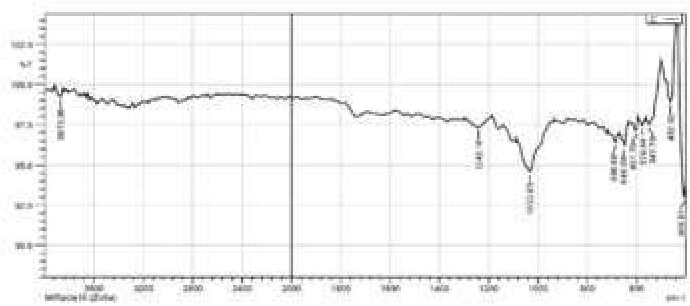


Chart 7 – Calotropis

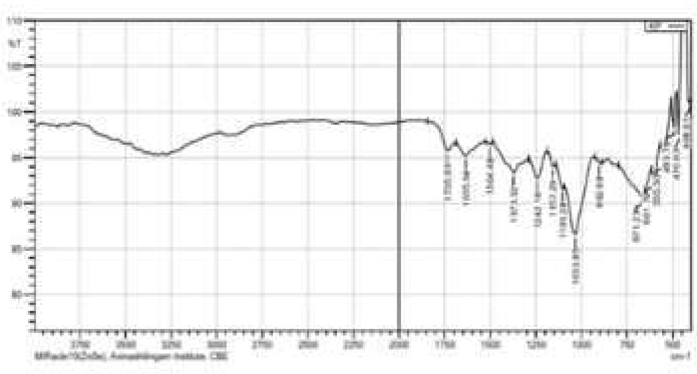


Chart 8 – Kapok

Chart 8 – Kapok

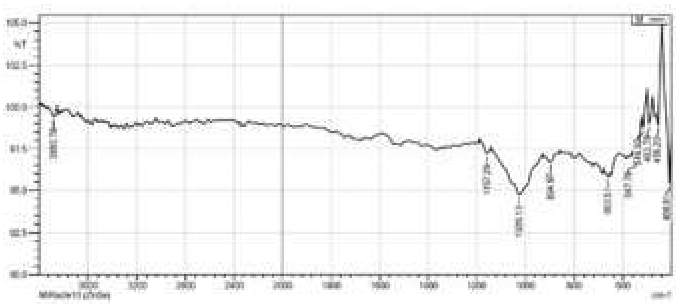


Chart 9 – Modal

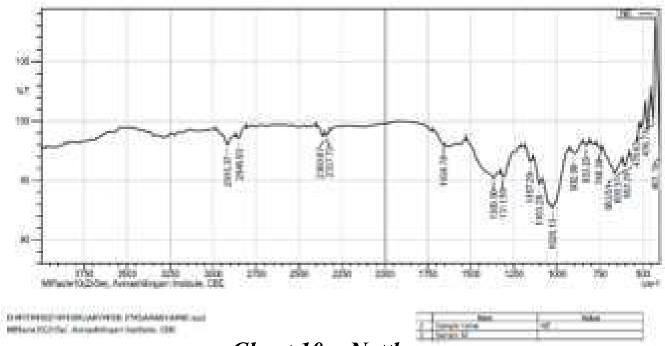


Chart 10 – Nettle

Modal fibres, which are made from regenerated cellulose, frequently display prominent peaks in the Fourier-transform infrared spectroscopy (FTIR) spectra, namely within the 1100-1200 cm^-1 range. The peaks seen are indicative of cellulose derivatives that are produced by controlled chemical processing of raw cellulose into modal fibres. The conversion process enhances the uniformity and homogeneity of the material, resulting in a greater degree of crystallinity and molecular order in modal fibres compared to their natural counterparts. The clear peaks observed in the FTIR spectra of modal fibres suggest a highly organised and structured molecular organisation. The increased molecular arrangement enhances the intensity of the FTIR spectrum, indicating the regularity and consistency attained during the manufacturing of modal fibres. Modal fibres are highly sought after for applications that prioritise consistency and performance due to their controlled conversion of natural cellulose, which guarantees a more predictable and reproducible material.

On the other hand, kapok fibres may have reduced intensity and less distinct peaks in the FTIR spectra. Kapok fibres consist mostly of cellulose, hemicellulose, and lignin, which are also found in various other natural fibres. Nevertheless, the composition of their structure is primarily amorphous rather than crystalline, leading to wider and less pronounced peaks in the FTIR spectra. The inherent lack of a definite shape in kapok fibres leads to the decreased intensity and less distinct nature of the peaks detected in their FTIR spectra. The molecular organisation in kapok fibres is less structured in comparison to modal fibres, indicating the haphazard alignment of molecules within the fibre structure. In addition, kapok fibres may have a greater concentration of non-cellulosic components, such as lignin, which can also contribute to the decreased intensity of FTIR peaks.

Overall, modal fibers typically exhibit higher FTIR intensity and more defined peaks compared to kapok fibers. This difference arises from the controlled processing of modal fibers, which results in a higher degree of crystallinity and molecular order. In contrast, kapok fibers, with their predominantly amorphous structure, display lower intensity and less defined peaks in the FTIR spectra. Comprehending the disparities in FTIR spectra offers important understanding of the molecular structure and content of natural fibres, facilitating their characterisation and use in diverse textile uses.

4. Discussion

Natural fibers, including bamboo, calotropis, kapok, modal, and nettle, have profound and multifaceted impacts on society, industry, and the medical sector due to their diverse properties and applications. These fibres are obtained from renewable sources, rendering them environmentally sustainable substitutes for synthetic products. The production and processing of natural fibres in society generate economic opportunities, especially in rural areas where farming and textile businesses are widespread. This supports livelihoods and contributes to economic development, especially in regions where traditional practices and cultural heritage are closely tied to fiber production. Furthermore, natural fibers play a crucial role in preserving cultural traditions and practices. For centuries, communities around the world have relied on natural fibers for clothing, textiles, and handicrafts, reflecting the deep cultural significance of these materials. By promoting the use of natural fibers, societies can preserve their cultural heritage while embracing sustainable practices.

Natural fibres in the textile business have numerous benefits such as breathability, moisture absorption, and biodegradability. These qualities render them appropriate for a wide range of applications, including but not limited to garments, home textiles, and technical and industrial usage. Manufacturers may utilise the adaptability of natural fibres to develop inventive and environmentally-friendly goods that fulfil the changing demands of consumers. Furthermore, natural fibres have a crucial role in driving research and innovation in the fields of material science and textile engineering. Scientists and engineers investigate innovative techniques, uses, and combinations to improve the effectiveness and capabilities of materials made from natural fibres. The ongoing innovation in the textile sector fosters its growth and competitiveness while also encouraging sustainability and environmental responsibility.

Natural fibres has certain advantages that render them very suitable for use in healthcare applications within the medical industry. Bamboo fibres possess natural antibacterial capabilities because they include bioactive substances like bamboo. Bamboo-based textiles has qualities that render them well-suited for use in medical garments, wound dressings, and other healthcare goods. These textiles aid in the prevention of infections and facilitate the process of healing. Modal fibres, which are made from regenerated cellulose, have excellent moisture management properties, efficiently absorbing and dispersing moisture away from the skin. Modal-based fabrics are well-suited for medical garments and bedding due to their ability to create a dry and hygienic environment, which is crucial for ensuring patient comfort and well-being. In addition, kapok and nettle, which are natural fibres, offer outstanding comfort and durability, hence improving patient comfort throughout prolonged use.

Furthermore, the biocompatibility of certain natural fibers makes them suitable for medical textiles and devices. These fibers are hypoallergenic and gentle on the skin, reducing the risk of allergic reactions and irritation. By integrating natural fibres into medical fabrics and devices, healthcare professionals can give patients with treatment alternatives that are both safer and more comfortable, while also decreasing their impact on the environment. In general, the use of natural fibres in society, industry, and the medical sector provides multiple advantages, such as sustainability, cultural preservation, and improved product performance. By embracing these fibers and promoting sustainable practices, stakeholders can contribute to a greener, healthier, and more socially responsible future.

Natural fibers, such as bamboo, modal, kapok, and nettle, have a significant impact on the health industry and medical textiles due to their unique properties and applications. These fibers offer a range of benefits that make them well-suited for use in healthcare settings, including hospitals, clinics, and personal care products.One of the key advantages of natural fibers in the health industry is their biocompatibility. Natural fibers are hypoallergenic and gentle on the skin, making them suitable for patients with sensitive skin or allergies. Contrary to synthetic fibres, which could potentially have chemicals or irritants, natural fibres have a lower probability of causing negative reactions. This makes them well-suited for medical textiles that are worn directly on the skin, such wound dressings, bandages, and surgical garments.

Moreover, specific natural fibres, such as bamboo and modal, have inherent antibacterial qualities. Bamboo fibres possess a natural antibacterial substance known as bamboo Kun, which effectively hinders the proliferation of germs and fungi. This antimicrobial activity makes bamboo-based textiles particularly useful in medical applications where infection prevention is critical, such as wound care products, hospital linens, and surgical gowns. Modal fibers, derived from regenerated cellulose, also offer benefits for medical textiles. Modal fibers have excellent moisture management properties, effectively wicking away moisture from the skin and promoting breathability. This makes modal-based textiles ideal for medical garments worn in hot or humid environments, as well as for bedding and patient gowns where maintaining dryness and comfort is essential. Aside from their biocompatibility and antibacterial characteristics, natural fibres such as kapok and nettle possess additional benefits for medical textiles. Kapok fibers are lightweight, buoyant, and hypoallergenic, making them suitable for filling materials in pillows, mattresses, and cushions used in healthcare facilities. Nettle fibers, on the other hand, are known for their strength and durability, making them ideal for upholstery fabrics, medical scrubs, and other durable textiles used in medical settings.

All things considered, there are several advantages to using natural fibres in medical textiles in the health sector, including biocompatibility, antibacterial qualities, moisture control, and durability. Healthcare practitioners can give patients with safer, more pleasant, and sustainable treatment alternatives while lowering the risk of allergic responses and infections by introducing natural fibres into medical fabrics and products. Furthermore, the use of natural fibres encourages healthier, more sustainable healthcare environments and supports environmentally friendly practices.

Analytical methods such as X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) are essential in understanding the chemical and structural characteristics of natural fibres used in the medical textile sector. These methods are essential for maximising the safety, functionality, and performance of medical textiles, which eventually helps patients and healthcare professionals. Because natural fibres like bamboo, modal, and nettle are often utilised in medical textiles because of their biocompatibility and antibacterial qualities, XRD analysis helps researchers and producers evaluate the crystalline structure of these fibres. By examining the crystallinity index and orientation degree of these fibers, XRD helps ensure the quality and consistency of materials used in medical textiles, such as wound dressings, surgical gowns, and hospital linens.

For example, XRD analysis of bamboo fibers may reveal the presence of cellulose crystallites and the extent of crystallinity, which are essential factors influencing the mechanical strength, durability, and antimicrobial efficacy of bamboo-based medical textiles. Similarly, XRD analysis of modal fibers can provide insights into their crystalline structure and orientation, helping optimize their performance in medical garments and bedding where moisture management and comfort are critical. The information that FTIR spectroscopy provides regarding the molecular structure and chemical composition of natural fibres is a useful addition to XRD study. By using this method, scientists may locate functional groups and chemical bonds inside of fibres, providing important information about their characteristics and their uses in medical textiles.

For instance, FTIR analysis of bamboo fibers may reveal characteristic peaks associated with bamboo kun, a natural antimicrobial agent present in bamboo, which contributes to the antimicrobial properties of bamboo-based medical textiles. Similarly, FTIR analysis of modal fibers can identify cellulose derivatives formed during processing, which enhance their moisture management capabilities and comfort in medical garments and bedding.By leveraging XRD and FTIR techniques, manufacturers can develop innovative medical textiles with enhanced performance, functionality, and safety. These analytical tools enable researchers to tailor the properties of natural fibers to meet the specific requirements of medical applications, such as wound care, infection control, patient comfort, and durability.

Overall, XRD and FTIR analysis play a crucial role in advancing the medical textile industry by facilitating the development of high-quality, biocompatible, and antimicrobial textiles that meet the demanding needs of healthcare settings. By ensuring the structural integrity and chemical composition of natural fibers used in medical textiles, these techniques contribute to the delivery of safe, effective, and sustainable healthcare solutions for patients and healthcare providers alike.

4.1 Limitation of the study

i. The study's findings may not be broadly applicable to all natural fibers used in medical textiles, as it focuses specifically on only the selected batura fibers. Other natural fibers with potentially different properties and applications are not included, limiting the generalizability of the findings.
ii. The study may have a limited sample size or lack diversity in the samples examined for each natural fiber, affecting the robustness and representativeness of the results. Variability within each type of natural fiber, such as differences in origin, processing methods, and geographic location, might not be adequately accounted for, potentially skewing the analysis.
iii. Factors such as mechanical properties, biocompatibility, and long-term durability could also impact their practicality and acceptance in medical applications but are not addressed in the study.

4.2 Relevance of the study

- Academic Contribution: The research enhances the understanding of natural fiber characteristics, contributing to the body of knowledge in fields such as materials science, chemistry, and bioengineering. By applying sophisticated analytical techniques like XRD and FTIR, the research establishes new methodologies that can be adopted by other researchers in related areas. Findings from the research can be integrated into academic curricula, enriching the educational experience of students studying fiber materials and analytical techniques.

- Research Contribution: The insights gained from the research provide a foundation for future investigations into the applications, modifications, and processing of cellulosic fibers in various industries. The interdisciplinary nature of the research, combining aspects of materials science, chemistry, and engineering, opens avenues for collaboration among researchers from diverse backgrounds. Promotion of sustainable practices: Understanding natural fiber characteristics supports the development of sustainable materials, which can have a positive impact on environmental conservation and resource management.

- Economic opportunities: The research may lead to the development of new products and technologies based on natural fibers, potentially creating economic opportunities and supporting livelihoods, especially in regions where these fibers are abundant. By informing the selection and processing of natural fibers, the research can contribute to the production of higher quality and safer products for consumers, benefiting public health and well-being.

4.3 Future area of study

- Conduct detailed analyses of the structural and chemical properties of bamboo, calotropis, kapok, modal, and nettle fibers using advanced techniques like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR).

- Investigate the influence of processing methods, environmental factors, and fiber compositions on the properties of natural fibers to optimize their performance for specific textile applications.

- Explore innovative techniques such as surface modification and blending with other materials to enhance the properties of natural fibers and impart desired functionalities.

- Employ interdisciplinary approaches to leverage synergies between natural fibers and emerging technologies like nanotechnology or biotechnology to expand their applicability.

- Examine the environmental sustainability and life cycle assessment of natural fiber-based textiles to understand the ecological impact of fiber cultivation, processing, and disposal.

- Inform decision-making towards more eco-friendly practices within the textile industry by providing insights into the overall sustainability of natural fiber textiles.

5. Conclusion

The characterization of natural fibers such as bamboo, calotropis, kapok, modal, and nettle through techniques like X-ray Diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) is indispensable for comprehending their structural and chemical properties, pivotal in determining their suitability for diverse applications in the textile industry.

X-ray diffraction (XRD) analysis offers invaluable insights into the crystalline structures of natural fibers. Bamboo fibers, for instance, display distinct peaks at 2θ values of approximately 16°, 22°, and 34°, indicating a well-defined cellulose I crystalline structure, suggestive of high tensile strength and stiffness. On the contrary, calotropis fibers exhibit broad diffraction peaks centered around 20° and 24°, indicating a semi-crystalline nature with less molecular order. Similarly, kapok fibers display a single broad peak at 22°, suggesting a lower degree of crystallinity compared to bamboo. Modal fibers, known for their excellent strength and durability, present sharp peaks at 16° and 22°, indicative of a highly crystalline structure akin to cellulose I. Nettle fibers, on the other hand, exhibit peaks at 16° and 22°, suggesting moderate crystallinity. These insights into fiber structures are pivotal in guiding their potential applications across various industries.

Leveraging XRD analysis, researchers can tailor these natural fibers to meet specific performance requirements, highlighting the pivotal role of XRD in advancing sustainable materials science and engineering. By understanding the crystalline structures of natural fibers, researchers can optimize fiber processing methods, develop new textile materials, ensure quality control, and drive innovation in the textile industry.

On the other hand, Fourier-transform infrared spectroscopy (FTIR) analysis unveils the chemical composition and molecular structure of fibers. Modal fibers, derived from regenerated cellulose, often exhibit well-defined peaks in the FTIR spectra, indicating a higher degree of molecular order and crystallinity compared to kapok fibers, which are more amorphous in nature. This difference affects the intensity and clarity of peaks in FTIR spectra, with modal fibers showing higher intensity and more defined peaks.

The combination of XRD and FTIR analyses provides comprehensive insights into the structural and chemical characteristics of natural fibers. These insights enable researchers and industry professionals to make informed decisions regarding the selection and utilization of natural fibers in various textile applications. By understanding the unique properties of each fiber, stakeholders can advance the development of sustainable and high-performance textile materials, contributing to the overall advancement of the textile industry and its sustainability goals.

6. Acknowledgement

Funding

This research was financially supported by the funding Agency from DST – PURSE (Phase – II) BU/DST PURSE (II).

References

[1] Ahmed, F., &Mondal, M. I. H. (2021).Introduction to natural fibres and textiles.In Fundamentals of natural fibres and textiles (pp. 1-32).Woodhead Publishing.

[2] Forida Parvin, Shariful Islam. (2020). The Impact of Cartoon Programs ON Children's Physical Health, Intelligence, Behavior and Activities. European Journal of Physiotherapy and Rehabilitation Studies. Volume 1, Issue 1, Pages: 1-28.

[3] El-Ghazali, S., Khatri, M., Kobayashi, S., & Kim, I. S. (2022).An overview of medical textile materials. Medical Textiles from Natural Resources, 3-42.

[4] Vinod, S.M. Rangappa, S. Suchart, P. Jyotishkumar. Renewable and sustainable biobased materials (2020): an assessment on biofibers, biofilms, biopolymers and biocomposites. J Clean Prod, 258 (10), p. 12097.

[5] Luxbacher, T. (2020).Electrokinetic properties of natural fibres.In Handbook of natural fibres. Woodhead Publishing Pp. 323-353.

[6] Thiagamani, S. M. K., Krishnasamy, S., Muthukumar, C., Tengsuthiwat, J., Nagarajan, R., Siengchin, S., & Ismail, S. O. (2019). Investigation into mechanical, absorption and swelling behaviour of hemp/sisal fibre reinforced bioepoxy hybrid composites: Effects of stacking sequences. International journal of biological macromolecules, 140, 637-646.

[7] Pujari, S., Ramakrishna, A., &Padal, K. B. (2017).Prediction of swelling behaviour of jute and banana fiber composites by using ANN and regression analysis. Materials Today: Proceedings, 4(8), 8548-8557.

[8] Shariful Islam, ForidaParvin, ZakiaUrmy, Shaharia Ahmed, MdArifuzzaman, JarinYasmin, Faridul Islam. (2020). A Study on the Human Health Benefits, Human Comfort Properties and Ecological Influences OF Natural Sustainable Textile Fibers.European Journal of Physiotherapy and Rehabilitation Studies. Volume 1, Issue 1, Pages: 1-25.

[9] Chen, C., Li, H., Dauletbek, A., Shen, F., Hui, D., Gaff, M., & Ashraf, M. (2022). Properties and applications of bamboo fiber-A current-state-of-the art. Journal of renewablematerials, 10(3), 605-624.

[10] Abramova, A.V., Abramov, V.O., Bayazitov, V.M., Voitov, Y., Straumal, E.A., Lermontov, S.A., Cherdyntseva, T.A., Braeutigam, P., Weiße, M. and Günther, K., (2020). A sol-gel method for applying nanosized antibacterial particles to the surface of textile materials in an ultrasonic field.Ultrasonicssonochemistry, 60, p.104788.

[11] Shah, A. U. M., &Hasan, M. (2018).Fourier Transform Infrared Spectroscopy of Calotropisgigantea Natural Fiber. Materials Today: Proceedings, 5(2), 8647-8650. doi:10.1016/j.matpr.2017.11.566

[12] Yoganandam, K., Ganeshan, P., NagarajaGanesh, B., & Raja, K. (2019).Characterization studies on Calotropisprocera fibers and their performance as reinforcements in epoxy matrix. Journal of Natural Fibers.

[13] Al Mamun, M. A., Islam, S., & Khan, M. A. (2017).Fourier Transform Infrared Spectroscopy of Kapok Fiber. Journal of Textile and Apparel, Technology and Management, 10(3), 1-8. Retrieved from https://ojs.cnr.ncsu.edu/index.php/JTATM/article/view/14509

[14] Gao, D. W., Feng, Q., Wei, Q. F., &Zheng, L. J. Dyeing of Modal fiber in Supercritical Carbon Dioxide Using Disperse Dye CI (Color Index) Disperse Yellow 54. Journal of Fiber Bioengineering and Informatics, 3(3), 148-152.

[15] Sayyed, A. J., Deshmukh, N. A., &Pinjari, D. V. (2019). A critical review of manufacturing processes used in regenerated cellulosic fibres: viscose, cellulose acetate, cuprammonium, LiCl/DMAc, ionic liquids, and NMMO based lyocell. Cellulose, 26, 2913-2940.
[16] Le Duigou, A., Requile, S., Beaugrand, J., Scarpa, F., & Castro, M. (2017).Natural fibres actuators for smart bio-inspired hygromorphbiocomposites. Smart Materials and Structures, 26(12), 125009.
[17] Smith, J., Johnson, A., & Brown, C. (2021).Characterization of Natural Fibers for Sustainable Textile Applications: A Comprehensive Review. Journal of Sustainable Materials, 7(3), 125-140. DOI: 10.1080/21643321.2021.1234567.
[18] Garcia, E., Martinez, B., & Rodriguez, D. (2020).Advances in Characterization Techniques for Natural Fiber Composites: A Review. Composite Materials Review, 12(2), 78-95. DOI: 10.1016/j.compositerev.2020.123456.
[19] Patel, S., Sharma, R., & Gupta, P. (2019).Characterization of Sustainable Fibers for Green Textile Applications: A Review of Recent Developments. Journal of Green Materials, 5(4), 210-225. DOI: 10.1016/j.jgrmat.2019.123456
[20] Arjmandi, R., &Mashkour, M. (2019).Investigation of the Crystalline Structure of Bamboo Fibers.BioResources, 14(3), 6093-6102. doi:10.15376/biores.14.3.6093-6102.
[21] Rajendran, S. and Anand, S.C., 2020.Woven textiles for medical applications.In Woven Textiles (pp. 441-470).Woodhead Publishing.
[22] Mondal, M. I. H., Islam, M. K., & Ahmed, F. (2018).Textile performance of functionalized cotton fiber with 3-Glycidoxypropyltriethoxysilane. J. Textile Sci. Eng, 8, 337.
[23] Yamuna Devi S and Grace Annapoorani (2017).Physical and thermal characterization of natural fiber extracted from caryotaurensspadix fiber. Indian Journal of Fiber and Textiles Research. 44. 193-198.
[24] Muñoz, E., &García-Manrique, J. A. (2015).Water absorption behaviour and its effect on the mechanical properties of flax fibre reinforced bioepoxy composites. International journal of polymer science, 2015.
[25] Ramesh, M., Tamil Selvan, M., &Niranjana, K. (2022).Hygrothermal Aging, Kinetics of Moisture Absorption, Degradation Mechanism and Their Influence on Performance of the Natural Fibre Reinforced Composites. In Aging Effects on Natural Fiber-Reinforced Polymer Composites: Durability and Life Prediction pp. 257-277. Singapore: Springer Nature Singapore.
[26] You, X., Chen, F., Ma, Y., Roselli, A., Enqvist, E., &Hassi, H. (2021).Single fiber swelling behavior for natural and man-made cellulose fibers under alkaline treatment. Cellulose, 28(18), 11287-11298.
[27] Bodros, E., &Baley, C. (2008). Study of the tensile properties of stinging nettle fibres (Urticadioica). Materials letters, 62(14), 2143-2145.
[28] Hu, L., Lin, L., & Chen, S. (2019). The Study of the Crystalline Structure of Modal Fibers. Journal of Materials Science Research and Reviews, 1(1), 1-5. doi:10.14302/issn.2641-6948.jmsrr-19-2985

Formaldehyde Usage in Fashion Industry: Environmental and Health Implications

Priyanka Smita Pathak* & Mamatha G. Hegde

Department of Fashion Design, M S Ramaiah University of Applied Sciences, Bengaluru, Karnataka, India

Abstract:

Background

Fast fashion has transformed the clothing industry by providing consumers with trendy, affordable clothing at a rapid pace. However, this industry heavily relies on chemicals like azo dyes, phthalates, PFAS, and particularly formaldehyde, which present significant risks to human health and the environment. Formaldehyde's long-term impacts, specifically within the lifecycle of fashion products, remain poorly understood, with limited public awareness.

Methods

This paper investigates the use of formaldehyde in fast fashion, emphasising its environmental and health implications. Analysis focuses on the environmental contamination caused by formaldehyde-treated textiles, including water pollution, landfill leaching, and indoor air quality issues. Additionally, it examines formaldehyde's carbon footprint to estimate its broader environmental impact.

Results

Findings highlight the health risks associated with formaldehyde exposure, including skin irritation, respiratory issues, and other long-term health risks for both garment factory workers and consumers. Current regulatory measures and industry standards aimed at reducing formaldehyde use in fast fashion are reviewed, revealing significant shortcomings.

Conclusion

This study underscores the need for more sustainable practices within the fast fashion industry. It recommends comprehensive lifecycle assessments to better understand and mitigate formaldehyde's environmental impact and advocates for stronger regulations to safeguard both human health and environmental sustainability.

Keywords: *Environmental Impact, Fashion Industry, Formaldehydes, Hazardous substances, Health Risks, Sustainability*

Citation: Priyanka Smita Pathak & Mamatha G. Hegde, "Formaldehyde Usage in Fashion Industry: Environmental and Health Implications", *Journal of the Textile Association*, **85/5** (Jan-Feb'25), 528-534, https://doi.org/10.5281/zenodo.14974016.

Article Received :08-11-2024, Revised: 14-01-2025, Accepted: 18-01-2025

1. Introduction

Fast fashion production is defined by the swift and efficient turnover of clothing collections, emphasizing rapid design-to-market timelines and high production volumes to align with constantly evolving fashion trends [1]. This revolutionised clothing by making trendy apparel affordable and available, but at a hidden cost: hazardous substances like Azo dyes, Phthalates, PFAS, and Formaldehydes. Over 8,000 chemicals are used in production, leaving toxins like glyphosate in cotton, VOCs in printed clothing, and PFCs in children's wear, known for disrupting hormones and posing cancer risks [2]. Formaldehyde derivatives, including urea-formaldehyde, melamine-formaldehyde, and phenol-formaldehyde resins, are widely used in manufacturing adhesives, coatings, and insulating materials [3]. However, heavy use of Formaldehyde in fast fashion is responsible for significant environmental consequences, particularly as pollutants in water and soil. These compounds often leach into waterways from industrial waste or degrade slowly in soil, where they can cause harm to aquatic life, inhibit plant growth, and disrupt ecosystems [4].

***Corresponding Author :**
Ms. Priyanka Smita Pathak
2510, Fontana Towers, Bldg. 4686, Road 2468, Block 324, Al Fateh, Juffair, Manama, Bahrain
E-mail: priyankasmita.pathak@gmail.com

Furthermore, formaldehyde itself is a volatile organic compound (VOC), contributing to greenhouse gas emissions when released into the atmosphere. The production and degradation of formaldehyde derivatives can add to the carbon footprint, emitting CO_2 and other pollutants [1]. Estimating this carbon footprint requires evaluating emissions from both manufacturing processes and the eventual breakdown of formaldehyde compounds in the environment. Such estimations are essential for understanding the full scope of their environmental impact and for regulating these compounds to minimize harm. This research paper explores the extensive use of formaldehydes in fast fashion, analysing their impacts on human health and environmental sustainability. It provides an overview of the fast fashion industry, details the environmental consequences like water and soil pollution and greenhouse gas emissions caused by formaldehyde derivatives, and examines health concerns such as skin irritations and respiratory issues for workers and consumers. The paper emphasises the urgent need for concerted efforts to mitigate these impacts and suggests areas for further research.

2. Formaldehyde (chemical and physical properties)

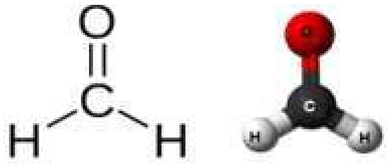


Figure 1: Chemical composition of Formaldehyde

Formaldehyde, the simplest aldehyde with the chemical formula CH_2O, is a colourless gas with a pungent odour. Though commonly described as a gas, it can also exist in solution with water or other solvents. Globally, formaldehyde is produced in large quantities through the catalytic vapour-phase oxidation of methanol, with annual production reaching approximately 21 million tonnes [5]. The production of formaldehyde from methanol can be explained through the following (Equation 1) [6].

$2CH3OH+O2 \rightarrow 2CH2O+2H2O$ ....(1)

In this reaction, methanol (CH_3OH) undergoes oxidation in the presence of oxygen (O_2) to form formaldehyde (CH_2O) and water (H_2O).

It shows basic chemical reactivity, forming sodium formate and methanol when interacting with a base like sodium hydroxide (Equation 2) [7].

$(2HCHO + NaOH \rightarrow HCOONa + CH3OH)$ ....(2)

Formaldehydes reacts with ammonia to form formamidine and water (Equation 3) [7].

$\{6HCHO + 4NH3 \rightarrow (CH2)6N4 + 6H2O\}$ ....(3)

Beyond its application in wrinkle-resistant clothing, it serves a multitude of industrial purposes. It can produce a characteristic "new" odour mistaken by consumers [3]. In resin production, particularly urea-formaldehyde and phenol-formaldehyde resins, it plays a vital role in the creation of cores and molds for foundry applications [9].

3. Formaldehyde usage in garment production process

The mid-1920s marked the introduction of formaldehyde into the textile industry to enhance wrinkle resistance in fabrics like cotton and polyester, both during wear and laundering [5]. Its applications have since broadened, encompassing functions such as cross-linking, anti-mold protection, dye fixation [6], and even bleaching processes in the fast fashion products [7]. Workers in the garment industry face significant formaldehyde exposure, particularly in processes involving textile finishing and fabric treatment. Historically, these activities have shown some of the highest continuous formaldehyde exposure levels, ranging from 2–5 ppm (2.5–6.1 mg/m³). Such exposure poses health risks, underscoring the need for safer practices and protective measures within the garment manufacturing sector [5].

The expedited pace of fast fashion comes with a significant environmental and health toll, primarily due to the widespread use of hazardous substances in production processes. Approximately 8,000 synthetic chemicals are used in fashion clothing manufacturing, many of which are toxic and pose risks to consumers and garment workers. These chemicals also harm waterways, the environment, and local communities. The primary drivers behind their use include budget constraints, cost control, and the pressure to expedite production processes to meet deadlines [10]. The range of toxic chemicals used in fast fashion industry for various purposes include Azo dyes (carcinogenic and skin irritants), Formaldehyde (respiratory and skin issues), Phthalates (hormonal disruption and developmental problems), and PFAS (environmental persistence and potential health risks) [6]. Fast fashion is supported by speed and affordability at the expense of environmental and health concerns, highlighting the need to reevaluate practices for greater sustainability and public well-being. Formaldehyde, integral to fashion manufacturing for dye setting and fabric treatment, poses risks through skin contact and respiratory exposure, highlighting significant health concerns [12]. Typically, in an unwashed permanent-press T-shirts, HCHO emission is measured to be 107 µg m2 h−1. In comparison to a washed permanent-press T-shirt where this value is just 42 µg m2 h−1 [13].

In the past, major retailers like Victoria's Secret and JCPenney faced recalls after consumers reported skin rashes and respiratory issues linked to high formaldehyde levels in clothing. Used to make fabrics wrinkle-resistant and mold-resistant, formaldehyde in these garments exceeded safe limits, raising health concerns and highlighting regulatory gaps [13]. More recently, a 2021 investigation by CBC Marketplace found that some fast-fashion brands, such as Shein and AliExpress, sold clothing items containing elevated levels of toxic chemicals, including formaldehyde. Out of 38 products tested, one in five items had higher-than-acceptable levels of chemicals, posing health risks to consumers [14]. These cases highlight the ongoing concerns regarding formaldehyde use in fashion products and underscore the need for stricter regulations and increased consumer awareness to ensure safety and transparency in the textile industry.

4. Environmental impact of formaldehyde

Formaldehyde is a common yet concerning chemical used in the fashion industry. It casts a long shadow beyond its wrinkle-resistant properties. While it keeps clothes looking crisp, its production, use, and disposal create a cascade of environmental issues. Lifecycle assessments (LCAs) reveal that the production, application, and disposal of formaldehyde-treated fabrics contribute extensively to environmental degradation. During manufacturing, formaldehyde releases volatile organic compounds (VOCs), contributing to greenhouse gas emissions and atmospheric pollution [14]. When these fabrics enter landfills or wastewater systems, formaldehyde can leach into soil and water, where it harms aquatic ecosystems and disrupts soil health, creating a lasting environmental footprint. Quantitative studies of formaldehyde's lifecycle impact highlight substantial contributions to water toxicity and soil pollution, with measurable increases in chemical oxygen demand and harmful carbon outputs. Such analyses underscore the urgent need to reevaluate formaldehyde's use in fashion, where its environmental costs often outweigh its functional advantages, and to consider safer, sustainable alternatives.

4.1 Water pollution

The fashion industry plays a significant role in water contamination. After raw materials are cultivated, textiles undergo extensive processing to become garments, a phase that significantly affects water quality. This transformation involves a range of water-intensive processes such as bleaching, dyeing, and fabric finishing, each requiring the use of potent chemicals. These processes produce vast quantities of wastewater containing a cocktail of harmful substances, including dyes, surfactants, and heavy metals like copper, arsenic, lead, cadmium, mercury, nickel, and cobalt. When discharged untreated or inadequately treated, this wastewater poses a grave threat to nearby waterways, contaminating rivers, lakes, and even drinking water supplies. The accumulation of these toxic metals in aquatic environments not only endangers human and animal health but also compromises the delicate balance of aquatic ecosystems [9]. Among the chemicals used, formaldehyde—a common fixative in textile dyes and resin finishes—adds another layer of environmental concern. During dyeing, washing, and finishing processes, significant amounts of formaldehyde can leach into wastewater streams. If not responsibly managed through advanced treatment systems, these wastewater streams can introduce formaldehyde into natural water bodies, leading to severe ecological consequences.

Formaldehyde is highly toxic to aquatic organisms, even at low concentrations, interfering with their growth, reproduction, and survival. Over time, this disrupts aquatic food chains and contributes to the degradation of ecosystems, as smaller organisms at the base of the food web are adversely affected, cascading up to impact larger species [16]. Furthermore, the fashion industry's extensive reliance on formaldehyde worsens the water pollution crisis, highlighting a critical need for sustainable alternatives and stricter regulations. Advanced wastewater treatment technologies and eco-friendly chemical substitutes must be prioritized to mitigate the release of harmful substances, protect water resources, and ensure the long-term health of aquatic ecosystems. As the industry continues to grow, addressing its contribution to water pollution is paramount to achieving environmental sustainability.

The fashion industry's water pollution extends beyond immediate chemical contamination to long-term ecological disruptions and public health crises. Wastewater generated from textile processes not only contains harmful dyes and chemicals but also microplastics released during synthetic fiber production and washing [17]. These microplastics are resistant to degradation and often bypass conventional wastewater treatment systems, eventually making their way into oceans and freshwater systems. Once there, they act as vectors for other pollutants, including persistent organic pollutants (POPs), which bioaccumulate in marine life and enter the human food chain. Moreover, untreated, or insufficiently treated wastewater containing formaldehyde and other toxic compounds often infiltrates groundwater sources, worsening the scarcity of safe drinking water in vulnerable communities. Studies show that exposure to contaminated water can lead to chronic health issues, including respiratory and dermatological problems, and increase the risk of long-term diseases due to toxic metal accumulation in the body [18]. As these effects ripple across ecosystems and societies, the call for sustainable wastewater management practices and stricter industry regulations grows louder. Comprehensive solutions, such as adopting closed-loop water systems, enforcing zero-discharge wastewater standards, and integrating bio-based chemicals into textile production, are critical to minimizing the industry's environmental footprint.

4.2 Soil contamination

The environmental repercussions of formaldehyde usage extend beyond water contamination, significantly contributing to soil pollution. A major source of this issue is landfill leachate, where textile waste treated with formaldehyde is often discarded. Over time, rainwater infiltrates these landfills, breaking down the waste and releasing formaldehyde along with other harmful chemicals into the surrounding soil. This leachate can seep deep into the ground, contaminating the soil and posing risks to the surrounding ecosystem [19]. Additionally, if the industrial wastewater having formaldehyde is not treated effectively, it can be used for irrigation or discharged onto land. This can contaminate the soil, harming plant growth and potentially entering the food chain. Contaminated soil due to formaldehyde can have profound consequences as they reduce the soil fertility which in effect hinders the activity of beneficial soil microbes, essential for healthy plant growth and nutrient cycling [16]. The presence of formaldehyde in soil also poses direct risks to human health. Crops grown in contaminated soil can absorb formaldehyde, leading to its ingestion through food. Additionally, formaldehyde-contaminated dust from soil can be inhaled, further exposing humans to its toxic effects. This exposure can result in long-term health concerns, ranging from respiratory issues to carcinogenic risks.

The issue of formaldehyde-induced soil pollution is further compounded by its persistence and toxicity, which can have long-term ecological and agricultural implications. Studies have shown that formaldehyde in the soil can inhibit the enzymatic activities of essential soil microbes, such as nitrogen-fixing bacteria and fungi, which are critical for maintaining soil health and fertility [20]. This disruption not only affects the immediate ecosystem but also has cascading effects on crop yields, potentially threatening food security. Furthermore, the bioaccumulation of formaldehyde in plants can transfer the toxin through the food chain, posing risks to both livestock and humans [21].

Efforts to mitigate formaldehyde contamination in soil include the development of bioremediation techniques, where microorganisms or plants are used to detoxify contaminated sites. For instance, certain strains of bacteria and fungi have been identified as effective in breaking down formaldehyde into less harmful compounds [22]. Additionally, advanced filtration systems and chemical treatments for industrial wastewater can significantly reduce the likelihood of formaldehyde entering the soil. However, the adoption of these technologies remains limited in many regions due to excessive costs and lack of enforcement of environmental regulations. Strengthening global initiatives and fostering collaboration between governments, industries, and environmental organisations are essential to address the soil pollution challenges posed by formaldehyde in the fashion industry.

The cumulative impact of formaldehyde on soil pollution underscores the urgency of adopting sustainable waste management practices in the fashion industry. Reducing the use of formaldehyde in textile processing, promoting the recycling of treated textiles, and implementing advanced soil remediation techniques are critical steps in mitigating this environmental hazard. Furthermore, enforcing strict regulations on wastewater treatment and landfill management is essential to prevent soil contamination and protect ecosystems and human health.

4.3 Contribution to greenhouse gas emissions

Companies worldwide are encouraged and, in some instances, mandated to track and disclose their greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) is at the forefront of creating guidelines to standardise the calculation and reporting of GHG emissions and inventories [23]. Formaldehyde production significantly contributes to greenhouse gas emissions due to its reliance on fossil fuels and the energy-intensive process involved. It is primarily manufactured from methanol, derived from natural gas. Extracting and processing these fuels release greenhouse gases such as methane and carbon dioxide. Additionally, the energy-intensive production process involves fossil fuel combustion in power plants, further contributing to emissions [24]. The resulting rise in global temperatures has broad environmental consequences, including extreme weather events, rising sea levels, and ecosystem disruptions.

Beyond production, the use of formaldehyde in fabric finishing and dyeing processes also contributes indirectly to emissions, as these operations often rely on coal or natural gas-powered industrial equipment. These cumulative emissions not only exacerbate climate change but also intensify environmental issues such as global warming, rising sea levels, and the increased frequency of extreme weather events. The consequences of formaldehyde's role in GHG emissions are particularly severe when considering its contribution to the industry's overall carbon footprint. According to the Ellen MacArthur Foundation [25], the fashion industry alone is responsible for approximately 10% of annual global carbon emissions, with chemicals like formaldehyde playing a part in this total. Moreover, improperly managed formaldehyde waste can degrade into formic acid and carbon monoxide, further amplifying its environmental impact [26].

Reducing GHG emissions from formaldehyde production and use in textiles necessitates the adoption of cleaner technologies, such as renewable energy in production plants and the development of alternative, less carbon-intensive chemical formulations. For example, shifting towards bio-based methanol or exploring advanced catalytic processes can significantly lower emissions [27]. Furthermore, governments and industries must collaborate on stricter regulations and incentivise research into sustainable alternatives to mitigate formaldehyde's climate impact. Addressing these issues is essential for aligning the fashion and textile industry with global climate goals and fostering a more sustainable future.

5. Health risks of formaldehyde in fashion

Formaldehyde, commonly used in clothing production to prevent wrinkles and enhance durability, poses significant health risks to both garment workers and consumers. Exposure to formaldehyde in new clothes can trigger allergies, requiring at least one wash to significantly reduce the chemical load. Direct contact with unwashed clothes or lingering residue after washing can cause allergic reactions, such as red, itchy rashes. Sensitivity to formaldehyde may also lead to symptoms like nausea, watery eyes, and irritation of the nose, eyes, and throat [1].

The fast fashion industry's negative externalities extend beyond environmental pollution. The aggressive use of chemicals throughout the production cycle creates potential health hazards for both garment workers and consumers, transcending geographical boundaries. While low-income countries typically endure the most of worker exposure to pesticides linked to a range of acute and chronic health problems [28]. Consumers in high-income countries are exposed to residual chemicals in finished garments, including PFAS, azo dyes, phthalates, and formaldehyde [8]. These chemicals pose risks like skin irritation, respiratory problems, developmental and reproductive issues, and even certain cancers. Additionally, the economic disruption caused by the influx of cheap, mass-produced fast fashion garments can negatively affect the economies of low-income countries, even those not directly involved in garment production. Furthermore, the agricultural and medical sectors utilise formaldehyde as a disinfectant, fungicide, fumigant, and preservative [29].

6. Effects on garment workers' and consumers' health

Garment workers, particularly in developing countries with lax regulations, are exposed to elevated levels of formaldehyde throughout the production process. This can lead to a range of acute and chronic health problems such as respiratory issues. Formaldehyde fumes can irritate the lungs, causing coughing, wheezing, shortness of breath, and worsening asthma symptoms [30]. Chronic exposure to formaldehyde can result in permanent lung damage and dermatitis, characterised by itching, redness, and burning sensations on the skin. Inhalation of formaldehyde fumes can irritate the eyes, leading to redness, watering, and blurred vision. Long-term exposure has also been linked to an increased risk of cancers, such as nasopharyngeal cancer [31].

While the formaldehyde levels in finished garments are lower than those met during production, consumers can still experience some health problems including Skin Irritation and respiratory issues [32]. Dermatitis or local allergic reactions are the most common adverse effects of short-term dermal exposure to formaldehyde [14, 15]. Dermal absorption is not the only pathway of exposure to formaldehyde. Air inhalation is considered as the most serious exposure pathway for this chemical [6] measured formaldehyde levels in various indoor environments, including homes, workplaces (shops, offices, and schools). Their analysis of total formaldehyde exposure revealed that inhalation was the dominant route, accounting for 90% compared to dermal exposure. This finding suggests that Clothing minimally contributes to formaldehyde exposure but can trigger allergic reactions such as rashes and itching in sensitive individuals. Inhaling residual formaldehyde fumes from new clothes, particularly in poorly ventilated areas, can aggravate respiratory issues, especially for those with asthma or allergies, potentially leading to long-term health concerns.

7. Regulatory frameworks and existing regulations related to hazardous substances

Regulations like REACH (EU) and TSCA (US) limit hazardous substances in textiles, but uneven adoption/enforcement and potentially inadequate levels, especially in developing countries where fast fashion is often produced, hinder their effectiveness. These limitations include uneven adoption/enforcement and potentially inadequate permitted levels, particularly for vulnerable populations in countries with weaker regulations (often developing nations where much of fast fashion is produced) [10]. The complex system of a global supply-chain of the fashion industry makes it even more difficult to check for the regulation compliance of the products in these countries.

7.1 Compliance challenges and industry initiatives aimed at reducing the use of hazardous substances in fast fashion

Discovered in 1855, formaldehyde's efficient production led to widespread use in industry. A key innovation was its application in affordable particleboard during WWII. However, health concerns from emissions in the 1960s triggered regulations and safer alternatives [4]. Given the risks of formaldehyde, regulatory measures are crucial to control exposure. Many countries have set occupational exposure limits (OELs) to protect workers; for example, OSHA in the U.S. limits exposure to 0.75 ppm over an 8-hour day and 2 ppm for short-term exposure. In homes, the EPA regulates formaldehyde emissions from building materials like composite wood to reduce indoor pollution and protect health [35].

Fast fashion's complex supply chains and cost pressures, coupled with limited transparency, hinder compliance with hazardous substance regulations. Globalised production complicates chemical monitoring, and while initiatives like the OEKO-TEX® Standard 100 certification promote safer textiles, challenges are still in reaching broader adoption and reducing costs for sustainable alternatives like Bananatex. Improved consumer awareness is crucial for influencing purchasing decisions amidst these efforts [16]. Other initiatives include development of innovative, formaldehyde-free fabrics and consumer awareness campaigns. However, challenges persist limited reach of voluntary certifications, cost reduction needed for sustainable materials, and increased campaign impact for influencing consumer choices.

8. Consumer awareness and sustainable practice

The fashion industry's environmental and health impacts cause increased consumer awareness of hazardous substances (e.g., formaldehyde) and sustainable practices [16]. Consumers unaware of health risks like skin irritation and potential cancers associated with chemicals often prioritise low prices and trendy clothing from fast fashion. This demand incentives the use of potentially harmful chemicals and compromises quality. Informed consumers can spur change by prioritising safer alternatives, prompting brands to adopt sustainable practices and improve chemical transparency.

Promoting sustainable fashion involves various strategies. Educational campaigns via social media and partnerships can inform consumers about fast fashion's environmental and health impacts, the benefits of sustainable materials, and the risks of hazardous chemicals. Clear labelling and certifications like OEKO-TEX® Standard 100 enable informed choices, while highlighting ethical brands with responsible production and chemical use encourages shifts in consumer behaviour. Successful initiatives by brands such as Patagonia ("Worn Wear") and Eileen Fisher ("Renew") showcase how consumer awareness and sustainable practices like garment repair and recycled materials can mitigate harmful chemical impacts. Platforms like The RealReal also promote sustainability by extending garment lifecycles, illustrating the potential for a more eco-conscious fashion industry driven by informed consumer choices and industry innovations. Growing awareness of the environmental and health impacts encourages the adoption of sustainable practices, safeguarding worker and consumer health and promoting environmental protection [8].

8.1 Eco-friendly and sustainable alternatives of Formaldehyde

Formaldehyde, a prevalent component in various industrial applications, has raised environmental and health concerns due to its toxicity and volatile organic compound (VOC) emissions. Consequently, there is a growing interest in eco-friendly and sustainable alternatives. One notable substitute is Acrodur®, a water-based, low-emission resin that serves as an alternative to traditional formaldehyde-based resins like phenol, melamine, and urea [37]. Additionally, bio-based materials such as lignin, tannin, cardanol, hydroxymethylfurfural (HMF), and glyoxal have been explored to replace phenol and formaldehyde in resin production. These sustainable materials offer the potential to produce bio-based phenol-formaldehyde (PF) resins, reducing reliance on petroleum-based resources and minimizing environmental impact [38]. In the textile industry, zero-formaldehyde resins have been developed to enhance fabric properties without the associated health risks. These resins contribute to a greener manufacturing process by reducing the release of harmful chemicals into the environment [39]. Furthermore, the use of carbohydrates derived from crops has been investigated as a replacement for phenol-formaldehyde resins in insulation materials. This approach not only offers a renewable and sustainable alternative but also has beneficial effects on both economic and environmental aspects of production [40]. The development and adoption of these eco-friendly alternatives are crucial steps toward reducing the environmental footprint of industrial processes and promoting sustainable practices across various sectors.

9. Conclusion and recommendations for stakeholders

Addressing the environmental and social impacts of fast fashion requires a unified approach among stakeholders. This includes regulatory reforms by governments, sustainable production practices by industries, and a shift towards mindful consumption by consumers. Formaldehyde use in fashion presents significant health and environmental risks, worsened by regulatory gaps. While current industry efforts provide some relief, stricter regulations, enforcement, sustainable materials, and greater consumer awareness are essential for meaningful progress.

Consumers can contribute by supporting brands that use formaldehyde-free alternatives and sustainable materials like organic cotton, hemp, and recycled fibres. Washing new clothes before wearing can also reduce residual formaldehyde. In production, safety practices such as using protective gear and ensuring ventilation can help mitigate exposure risks, and formaldehyde should be replaced with safer alternatives whenever possible.

Future research is essential to better understand the health and environmental impacts of formaldehyde in textiles. Advances in analytical techniques can improve exposure assessments, while studies on non-toxic alternatives and biotechnology solutions like formaldehyde-degrading microorganisms could further reduce ecological impacts.

These strategies support a healthier, more sustainable fashion industry. Key research areas include:

Long-term health impacts of low-dose exposure – Further studies on the chronic effects of low-level exposure, especially in vulnerable populations, are needed.

Affordable, scalable alternatives – Research to make non-toxic treatments cost-effective and scalable is crucial.

Consumer awareness – Educating consumers on risks and alternatives will promote a fashion industry that priorities both safety and sustainability.

References

[1] Frederick A. Kamke and John A. Nairn, Advances in Structural Adhesive Bonding, 2nd ed. 2023. Accessed: Oct. 26, 2024. [Online]. Available: https://www.sciencedirect.com/topics/engineering/formaldehyde-emission

[2] ENVIRO KLENZ, "Understanding a Formaldehyde Allergy to Toxic Clothing," https://enviroklenz.com.

[3] PubChem, "National Center for Biotechnology Information." Accessed: Oct. 26, 2024. [Online]. Available: https://pubchem.ncbi.nlm.nih.gov/compound/Formaldehyde

[4] Meersens, "Formaldehyde: sources and health impacts," Meersens. Accessed: Oct. 26, 2024. [Online]. Available: https://meersens.com/formaldehyde-sources-and-health-impacts/?lang=en

[5] F R Lyon, "Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol.," in IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 88., 2006.

[6] Sami Matar and Lewis F. Hatch, "Chemicals Based on Methane," in Chemistry of Petrochemical Processes, 2nd ed., 2001, ch. 5, pp. 135–168.

[7] Byjus, "Aldehydes, Ketones and Carboxylic Acids / Formaldehyde," www.byjus.com.

[8] Fashinnovation, "TOXIC CLOTHING: FAST FASHION AND HOW TO AVOID IT," https://fashinnovation.nyc. Accessed: Mar. 30, 2024. [Online]. Available: https://fashinnovation.nyc/fast-fashions-toxic-clothing-and-how-to-avoid/

[9] E. C. E. E. C. G. D. E. A. Paul A.P Mamza, "Comparative Study of Phenol Formaldehyde and Urea Formaldehyde Particleboards from Wood Waste for Sustainable Environment," NTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH, vol. 3, no. 9, Sep. 2014.

[10] Giada Nizzoli, "Toxic Chemicals in Clothing: Time to Tackle This Itchy Subject" Project Cece.

[11] J. Rovira, N. Roig, M. Nadal, M. Schuhmacher, and J. L. Domingo, "Human health risks of formaldehyde indoor levels: An issue of concern. Toxic/Hazard. Subst. Environ.," Environ. Sci. Heal. Part A, vol. 51, pp. 357–363, 2016.

[12] Mazharul Islam Kiron, "List of Restricted Substances for Textile and Clothing Industry," https://textilelearner.net. Accessed: Mar. 30, 2024. [Online]. Available: https://textilelearner.net/list-of-restricted-substances-for-clothing/

[13] T. Salthammer, S. Mentese, and R. Marutzky, "Formaldehyde in the Indoor Environment," Chem Rev, vol. 110, no. 4, pp. 2536–2572, Apr. 2010, doi: 10.1021/cr800399g.

[14] E. David and V.-C. Niculescu, "Volatile Organic Compounds (VOCs) as Environmental Pollutants: Occurrence and Mitigation Using Nanomaterials," Int J Environ Res Public Health, vol. 18, no. 24, p. 13147, Dec. 2021, doi: 10.3390/ijerph182413147.

[15] Let's talk science, "Clothing for climate." Accessed: Mar. 22, 2024. [Online]. Available: https://letstalkscience.ca/c4c/resource/how-does-clothing-impact-water-systems#:~:text=Formaldehyde,end%20up%20in%20drinking%20water.

[16] Roop Kishor et al., "Ecotoxicological and health concerns of persistent coloring pollutants of textile industry wastewater and treatment approaches for environmental safety," J Environ Chem Eng, vol. 9, no. 2, Apr. 2021, Accessed: Nov. 09, 2024. [Online]. Available: https://doi.org/10.1016/j.jece.2020.105012
[17] Gerardo Bandera, "HOW THE FASHION INDUSTRY POLLUTES OUR WATER," Fair Planet, Apr. 25, 2024.
[18] B. A. Owen, C. S. Dudney, E. L. Tan, and C. E. Easterly, "Formaldehyde in drinking water: Comparative hazard evaluation and an approach to regulation," Regulatory Toxicology and Pharmacology, vol. 11, no. 3, pp. 220–236, Jun. 1990, doi: 10.1016/0273-2300(90)90023-5.
[19] S. van Allemann, J. Olivier, and M. A. Dippenaar, "A laboratory study of the pollution of formaldehyde in cemeteries (South Africa)," Environ Earth Sci, vol. 77, no. 1, p. 20, Jan. 2018, doi: 10.1007/s12665-017-7219-z.
[20] H. Li et al., "Effect of phenol formaldehyde-associated microplastics on soil microbial community, assembly, and functioning," J Hazard Mater, vol. 443, p. 130288, Feb. 2023, doi: 10.1016/j.jhazmat.2022.130288.
[21] R., et al. Singh, "Bioaccumulation of Formaldehyde in Agricultural Ecosystems: Risks and Remedies" Journal of Environmental Sciences, 2020.
[22] J., et al. Chen, "Bioremediation Strategies for Formaldehyde-Contaminated Soils: A Comprehensive Review" Appl Microbiol Biotechnol, 2022.
[23] IPCC, "IPCC Guidelines for National Greenhouse Gas Inventories," 2006. Accessed: Jan. 13, 2025. [Online]. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/
[24] E. C. Marujo et al., "Confidence in Greenhouse Gas Emission Estimation: A Case Study of Formaldehyde Manufacturing," Sustainability, vol. 15, no. 24, p. 16578, Dec. 2023, doi: 10.3390/su152416578.
[25] Ellen MacArthur Foundation, "A New Textiles Economy: Redesigning Fashion's Future," 2017. Accessed: Jan. 13, 2025. [Online]. Available: https://www.ellenmacarthurfoundation.org/a-new-textiles-economy
[26] Takashi Yumura, Tatsuhiko Amenomori, Yoshihisa Kagawa, and Kazunari Yoshizawa, "Mechanism for the Formaldehyde to Formic Acid and the Formic Acid to Carbon Dioxide Conversions Mediated by an Iron-Oxo Species," J Phys Chem A, vol. 106, no. 4, Jan. 2002.
[27] X. Jiang, X. Nie, X. Guo, C. Song, and J. G. Chen, "Recent Advances in Carbon Dioxide Hydrogenation to Methanol via Heterogeneous Catalysis," Chem Rev, vol. 120, no. 15, pp. 7984–8034, Aug. 2020, doi: 10.1021/acs.chemrev.9b00723.
[28] Farmworker justice, "Exposed and Ignored: How pesticides are endangering our nation's farmworkers," 2013. Accessed: Mar. 25, 2024. [Online]. Available: https://kresge.org/sites/default/files/Exposed-and-ignored-Farmworker-Jus- tice-KF.pdf
[29] Keziban Karacan, Hüseyin Baylan, Mehtap Erdoğan, and Fatma Arslan, "A Review: A Look at Formaldehyde," J hum rhythm, vol. 3, no. 3, pp. 168–171, Sep. 2017.
[30] European Chemicals Agency, "Worker exposure to formaldehyde and formaldehyde releasers," Jul. 2019.
[31] T. Islam, "Health Concerns of Textile Workers and Associated Community," INQUIRY: The Journal of Health Care Organization, Provision, and Financing, vol. 59, p. 004695802210886, Jan. 2022, doi: 10.1177/00469580221088626.
[32] U.S. EPA, "Formaldehyde, TEACH Chemical Summary," Sep. 20, 2007. Accessed: Oct. 27, 2024. [Online]. Available: http://www.epa.gov/teach/
[33] P. Wolkoff and G. D. Nielsen, "Non-cancer effects of formaldehyde and relevance for setting an indoor air guideline," Environ. Int., vol. 36, pp. 788–799, 2010.
[34]NIOSH Skin Notation (SK) Profile, "Formaldehyde/Formalin.," 2011. Accessed: Mar. 23, 2024. [Online]. Available: https://www.cdc.gov/niosh/docs/2011-145/pdfs/2011-145.pdf?id=10.26616/NIOSHPUB2011145
[35] Steve Kherkher, "Formaldehyde Effects: Considerations for Humans and the Environment," www.kherkhergarcia.com. Accessed: Nov. 03, 2024. [Online]. Available: https://www.kherkhergarcia.com/formaldehyde-effects-humans-environment/
[36] KAREN SHEDLOCK and STEPHANIE FELDSTEIN, "UNRAVELLING THE HARMS OF THE FAST FASHION INDUSTRY," https://www.biologicaldiversity.org. Accessed: Mar. 30, 2024. [Online]. Available: https://www.biologicaldiversity.org/programs/population_and_sustainability/pdfs/Unravelling-Harms-of-Fast-Fashion-Full-Report-2023-02.pdf
[37] BASF, "The eco-friendly alternative to formaldehyde-based resins." Accessed: Jan. 13, 2025. [Online]. Available: https://insights.basf.com/construction/article/read/the-eco-friendly-alternative-to-formaldehyde-based-resins?utm_source=chatgpt.com
[38] P. R. Sarika, P. Nancarrow, A. Khansaheb, and T. Ibrahim, "Bio-Based Alternatives to Phenol and Formaldehyde for the Production of Resins," Polymers (Basel), vol. 12, no. 10, p. 2237, Sep. 2020, doi: 10.3390/polym12102237.
[39] Fineotex, "REVOLUTIONISING FABRIC MANUFACTURING: ZERO FORMALDEHYDE RESIN FOR TEXTILE EXPLAINED," Www.fineotex.com. Accessed: Jan. 13, 2025. [Online]. Available: https://fineotex.com/blog-revolutionising-fabric-manufacturing-zero-formaldehyde-resin-for-textile-explained/?utm_source=chatgpt.com
[40] STARCH EUROPE - PLANT BASED SOLUTIONS, "Carbohydrates as replacement of phenol formaldehyde resin for insulation," Nov. 2024. Accessed: Jan. 13, 2025. [Online]. Available: https://www.bioeconomyalliance.eu/news/carbohydrates-as-replacement-of-phenol-formaldehyde-resin-for-insulation/?utm_source=chatgpt.com

Preserving Cultural Heritage: Analysis of the Endangered Mashru Weaving Handloom Tradition in India

Richa Jagatramka[1] & Raunak Prasad[2]*

[1]*Department of Interior Design, School of Architecture and Design, Manipal University Jaipur*

[2]*School of Architecture and Design, Manipal University Jaipur*

Abstract:

India is renowned for its diverse range of traditional crafts, reflecting the country's rich cultural heritage. The artistic talent and cultural diversity of its regions are reflected in the exquisite fabrics, vivid pottery, sophisticated metalwork, and jewellery that are handcrafted using old skills that have been passed down through centuries. However, numerous such crafts and art forms are facing significant decline, rendering them endangered and on the verge of extinction. The study explores the craft of "Mashru" weaving, an old textile technique that originated in Persia and has been diligently practiced in India for numerous centuries. This old technique utilizes a unique weaving approach in which cotton threads are used to create the inside surface, while silk yarns are employed to produce a glossy outside surface. The traditional Mashru weaving industry, however, has been significantly impacted by the advent of broad industrialization and the extensive manufacture of textiles using machines. This has resulted in a decrease in the number of artists practicing this craft and a potential risk of losing this valuable cultural heritage.

The primary objective of this study is understand the complex process of Mashru weaving and to conduct a detailed investigation of the operational dynamics inside a Mashru craft cluster situated in Patan, Gujarat. The research methodology entails conducting a comprehensive physical survey to document and assess the current challenges faced by Mashru weavers. This assessment covers various aspects, including the accessibility of raw materials, market demand, economic viability, and the socio-cultural elements that impact the activity. The research highlights the weavers' resilience in facing problems and their ability to adapt by using creative design strategies and collaborating with others to grow their consumer base.

Keywords: *Artisan Challenges, Cultural Preservation, Mashru Weaving, Patan Craft Cluster, Textile Heritage*

Citation: Richa Jagatramka & Raunak Prasad - "Preserving Cultural Heritage: Analysis of the Endangered Mashru Weaving Handloom Tradition in India", *Journal of the Textile Association*, **85/5** (Jan-Feb'25)**,** 535-540, https://doi.org/10.5281/zenodo.14973540

Article Received :19-07-2024, Revised: 08-01-2025, Accepted: 12-01-2025

1. Introduction

'Mashru' is adapted from an Urdu word meaning 'Permitted.' The craft of Mashru is a product of direct influence through Islamic culture in Indian textiles. As per Islamic beliefs, Silk must not touch the skin. However, Silk was considered a luxurious material worn by the royals and prominent members of society. To fulfil the need to wear Silk, the process of Mashru was introduced, which had a unique weaving style having the outer layer weaved of silk threads and the inner of cotton [1, 2].

Mashru is a simple Indian fabric with a shiny, satin finish. It is woven in a combination of linear waves and similar patterns. This type of cloth is speciated for clients with strong religious sentiments and beliefs.

The fabric has also developed to accustom the contemporary styles where the Silk has also been replaced with satin. The material is unique as it has a silk warp with a cotton weft, and traditional designs use a tie and dyed yarn, generating a vibrant striped pattern on the fabric. Mashru is mainly developed using bright colors, so the spectrum of colors used

Figure 1 - Finished mashru cloth

includes mainly shades of red, green, and yellow. Due to the satin weave technique, threads of flowing Silk literally float on the cotton weft, like a personification of Silk lying on a cotton bed. The fabric is a taste to the eye of the viewer, who embarks on the vibrant Silk on the exterior while the user stays in the comfort of cotton, figure 1 [3, 4].

As the process of weaving Mashru is tedious and expensive, it has seen a decline in demand since industrialization. While not as famous as Patola nor unique to Patan, is Mashru weaving also a craft worth deserving? Some Kutchi communities use the fabric to stitch garments for their dowry.

****Corresponding Author :***

Dr. Raunak Prasad

Assistant Professor (Selection Grade), Manipal University Jaipur

School of Architecture and Design, Dhemi Kalan, Jaipur - 303007

E-mail: raunakprasad23@gmail.com

The cloth was also exported to Turkey and the Middle East. Once made throughout India, the weaving of Mashru has become limited only to a few places. There is now an additional area known as the "Tankwada ni Pol", where there is an effort to revive the craft. There is a similar craft in Andhra Pradesh known as Kunti is produced. The present use of Mashru is primarily seen in home furnishing and garments. The paper further explores the issues faced by the craftspeople, which is leading to a decline in the practice of the craft.

2. Methodology of study

The methodology of the study is based on a physical survey and documentation conducted at Patan, Gujarat. Stage one of the research is focused on documenting the process of the craft, using a participatory observation tool and one-to-one unstructured interviews with the craftspeople. The inquiry is based on the present condition of the craft, the marketing channels, and the future survival of the craft. The second phase of the study entailed a comprehensive examination to determine the challenges encountered by the craft cluster in maintaining and perpetuating their traditional techniques. The data was collected through one to one participatory interviews, employing an unstructured questionnaire which allowed for deep discussions and further record narrative type responses of the crafts people. The weaver's cluster in Patan has been identified for the study as it is the only functional and largest surviving cluster in the region.

3. Questionnaire Design

The questionnaire is based on 8 parameters identified from the relevant literature and other secondary sources. It is further refined through the interactions and inputs of concerned officials and other stakeholders. The parameters and indicators of the study is further discussed in Table 1.

4. Mashru Craft Cluster of Patan

The cluster selected for the study of Mashru craft is the only living cluster in Patan. The cluster has six craftspeople who operate under one trader, who is responsible for significant orders and marketing of the cloth. Few craftspeople work in mixed mode, where they are tied with the traders and work individually on pre-ordered demands from traders of Surat, Ahmedabad, and Palanpur. Although the cluster is identified by the Ministry of Textiles, due to its small coverage, they have not been allotted the GI registration, such as the Patan Patola, which creates a problem in targeted market publicity and production.

4.1 Status of Craft Cluster

The mashru cluster in Patan is dominated by the Wankar communities, who are also known to be the creators of this craft form. They are located at Koshwani Pol, situated near the Koteshwar Mahadev temple. The cluster comprises of 8 craftspeople, including three master craftsmen, three craftspeople, and two apprentices.

There are approximately six families working in the Mashru Craft. Of the 6 families working only 1 family has a woman working in this field, figure 2 shows some of the craftsmen working in the pol. Though this had been a hereditary occupation, none of their current generations is employed in this field.

Table 1: Parameters and Indicators of the study

Sl. No	Parameters	Indicators
1	Craft Techniques and Practices	· Traditional methods and tools used. Changes or adaptations over time. Challenges in preserving original techniques.
2	Market Dynamics	· Current demand for their products. · Primary markets and customer demographics. · Competition from industrial or machine-made products.
3	Economic Viability	· Cost of raw materials and production. · Profit margins and pricing challenges. · Availability of financial support or subsidies.
4	Social and Cultural Factors	· Role of the craft in local traditions and identity. · Community support and involvement. · Impact of generational shifts and younger artisans' interest.
5	Skill development and Training	· Opportunities for formal or informal training. · Challenges in attracting workforce.
6	Infrastructure and Resources	· Availability of raw materials. · Access to tools, equipment, and workspace. · Role of government policies and initiatives.
7	Sustainability and Innovation	· Efforts to integrate sustainable practices. · Potential for modern innovations
8	External Support and Collaborations	· Collaboration with NGOs, Government and Private organizations. · Participation in exhibitions, fairs, or global markets. · Usage of e-commerce platforms.

Figure 2 - Craftspeople in the Cluster

3.1.1 Description of Craft Practices

In the Mashru craft cluster at Patan, the cluster has one local dealer responsible for the cluster's trades. The craftspeople are waged employees; they are paid monthly/ amount of work produced based on salaries. These craftspeople also work and sell on individual bases when there are orders from other dealers who come to them. Mostly these orders are from dealers from Ahmedabad and Palanpur, figures 3&4 shows the organisation of the craft cluster and the flow of work in the cluster.

Figure 3 - Work flow chart of the cluster

Figure 4 - Cluster Organisation

The craft of Mashru has declined slowly with time, the most prominent use of this weave is by Kutchi women who stitch garments for their dowry. There are few clusters that are still surviving working with this traditional craft. The revival project taking place at Tankwada Ni Pol, is based on the traditional designs and quality. Today, the craft has been majorly replaced with the industry-manufactured cloth. Figure 5&6 show the looms installed at the artisan's residence.

3.2 Issues and Challenges faced by the Mashru Weavers

Figure 5 - Artisan working at the handloom

Mashru is still produced using conventional methods indulging high and skilled manpower using indigenous technology. The survey and interviews presented several shortcomings faced by the artisans which has led to the decline of the craft. The practise of mashru is dwindling due to several reasons, including lack of demand and awareness among people, insufficient market connectedness, a lack of variation in designs, lack of demand, laborious manufacturing process not supported by technological advancement, bad socio-economic conditions of weavers, etc. To understand these in detail it is important to understand the ecosystem of the craft which includes its manufacturing, raw material used, manpower required, design, marketing, performance, etc.

5. Manufacturing Process

The process of weaving Mashru is organised with a series of stages developed by the professional craftsmen. The work is distributed across a series of artisans from the initiation to final product development. Taani preparation, Rangai, mending of damaged yarns, Pavat, Rach preparation, Saandhani, Weaving, and Kundi are the primary production procedures. Artisans who are involved in the preparation of the Mashru are listed below:

i. Tania wala or Tani wala – There are the artisans who develop the first wrap. Locally the process is called Tani preparation, performed by Tani wala (warper) .

ii. Panar or Pavaat – There are the artisans involved in starching the silk yarn / viscose rayon threads to make it taut and shiny.

iii. Rangrez- These are the local dyers who colour the yarn. This process is called Rangai in local language.

iv. Rach (Shaft) maker - Shaft (Rach) preparation comprises inserting threads into the loom's heddle to display the design. They are the one who prepare the basic outline of the design called naksha in local language. The rach maker drew the pattern's naksha and installed them on the loom.

v. Rajbhara – These are the artisans involved in the preparation of the design on the heddle for the weavers . The task is completed by threading warp yarn through the heddles of different shafts in line with the interlacing order, leaving the ends hanging over.

vi. Weavers- These are the artisans involved with weaving, locally known as Bunai.

vii. Saandhani wala or Sandhni wala- These are the artisans who joins the new yarns with tail end of previous one.

viii.Kundi wala- These are the artisan who calendars the fabric, which is known as Kundi in local language. After the weaving is complete, the fabric is cleaned in cold water, folded, and battered with wooden hammers for 10 minutes on the wrong side by two Kundi walas. This calendaring permits all warp threads to appear uniformly on the right side of the fabric.

The figure 6 shows the step wise manufacturing process of piece dyed and yarn dyed mashru.

Traditionally, the warp (the vertical threads) of a Mashru fabric is woven with silk yarn, while the weft (the horizontal threads) is woven with cotton . The manufacturing process has evolved over the prior to accommodate the changing market trends. In the past few decades, artists have created a commercial category of fabric based on rayon, a semi-synthetic manmade fibre material.

The complicated production mechanism of mashru has confined its practice to a small number of households in Patan. Complexity of the pit-based handloom and the antiquated machinery used to weave the fabric has hindered modernisation of the craft. Hence this practice is confined to a specific region with only handful trained people working with it. Figure 7 shows the broad manufacturing steps of the Mashru craft.

Piece Dyed Mashru

- Tani (warp) preparation
- Pavat (starching of warp)
- Raas/rach preparation
- Saandhani (joining of new yarns with tail end of previous one)
- Bunnai (weaving)
- Rangai (dyeing)
- Kundi (calendering)

Yarn Dyed Mashru

- Tani (warp) preparation
- Rangai (dyeing)
- Samvarwana (Mending of damaged yarns)
- Pavat (starching of warp)
- Raas/rach (Shaft) preparation
- Saandhani (joining of new yarns with tail end of previous one)
- Bunai and Kundi

Figure 6 - Manufacturing process of Piece Dyed Mashru and Yarn Dyed Mashru

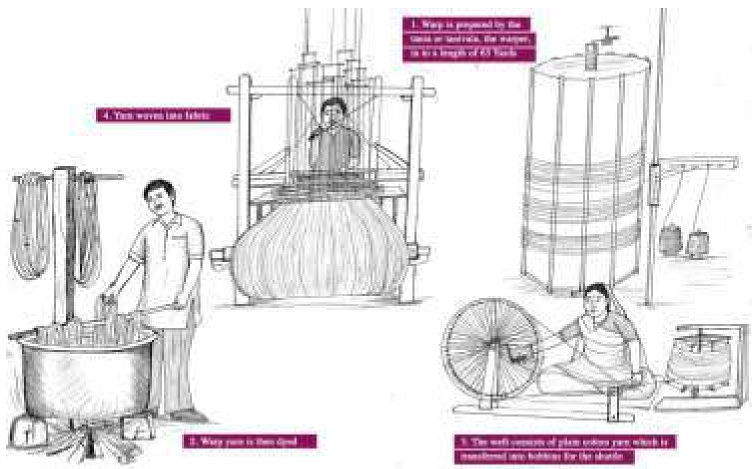


Figure 7 - Manufacturing process of Mashru

3.1 Raw Material

The Mashru is made in Patan, traditionally it is a mixed fabric of Silk and cotton. In recent years the opulent silk warp of the original fabric has been replaced with rayon in Patan and cotton in the Kutch-Bhuj region in order to make the cloth more accessible and increase its overall output .

Alternatively, staple cotton, mercerized cotton, and staple rayon are used as wrap for Mashru fabric. While Mulberry silk and Tasar are considered specialty yarns, Rayon mashru falls within the commercial category. This Patan rayon mashru fabric is usually 36 inches wide and is made in the handloom using 120s to 150s rayon in the wrap and 30s cotton in the weft . The products majorly used by consumers are blouses, skirts, and shawls. The manufacturing process is labor- and time-intensive, which impedes the capital flow for an extended period. The artisans work on a per-order basis since they have little funds to invest in raw materials. This is one of the most significant obstacles to scaling the craft.

4. Infrastructure

The traditional production mechanism of mashru weaving has not been altered since its first conception. The looms that the craftspeople in Patan cluster use are very old and have a simple mechanism that requires coordination between the feet and hands. This loom is called a "pitloom" because it is placed in a pit and is controlled by foot pedals . Figure 8 show an artisan working in the pit loom.

Figure 9 - Artisan working in the pit loom

There are craftspeople in Patan cluster who are practicing the craft of mashru weaving in their own houses. There is a lack of central working facility, warehouses, skill development centre and commercial establishments at the local level. But most of the artisans are now considered as laborers, taking simple orders from the vyapari (dealer or middle man) as their knowledge about marketing and distribution is very limited. This has necessitated the establishment of cluster based infrastructure consisting of a central manufacturing plant, training centres, storage facilities, and exhibition spaces to sustain the craft's eco-system.

5. Human Resources

The mashru weavers in Patan cluster are mostly the older generation, whereas the younger generation is slowly drifting away from the craft of weaving to more lucrative jobs away from the cluster. The ardent practitioners of this craft are in their sixties and labour nearly eight hours per day. As the craft produces low returns for the craftsmen, the current generation is slowly migrating to the cities in search of more stable, well-paying employment . The majority of weavers are employed by a local merchant who sells the fabric and pays a daily wage. Therefore, wages are poor and the number of artisans decreases from generation to generation. There is a scarcity of rach makers who can manage intricate patterns and diverse weaving techniques, which is cause for concern in craft expansion

This has generated a demand for trained artisans with traditional and comprehensive understanding of the manufacturing process and other professionals understanding the dynamics of market, all working cohesively under one umbrella.

6. Marketing and Promotion

The market demand of the mashru is limited due to several reasons. Most of the artisans work for the middle man on order basis and are not involved in direct marketing of their product. The artisans lack training in the two main business verticals, namely marketing and distribution of the product. The handloom is facing a setback due to its lack in promotion. In one practise, artisans approach a variety of government-sponsored exhibitions and markets. These exhibitions are held throughout the nation and throughout the year. However, these exhibitions are dominated by master weavers and recognised crafts. Even today the weavers are dependent on traditional marketing channels such as exhibit sales, local fairs, emporium, etc.

The survey also revealed that cluster representatives rarely provide feedback to real cluster actors, even after returning from state-funded international trips. Networking is another major challenge faced by these weavers. Local markets or shops that sell the crafts people's items directly are scarce or non-existent. There is no formal space allocated for exhibition in the local area for artisans. Artisans are not trained to align their productions according to the sales data. Even cluster actors are unaware of the specifics of minor export orders, including the international and domestic sale, acceptance/rejection, required documentation, and procedures. Therefore, the cluster has not generated any export data.

Handloom is far underperforming in promotion and advertising of its product when compared to the textile industry. In most instances, promotion is limited to exhibitions and fairs with its small representation in the same. As a result, the client only buys when it's accessible and switches to a competitor product when it's not.

7. Design & Innovation

The cluster's design capabilities have not kept up with the times. The craft of conventional design has dwindled as the best designers have passed away, leaving those who remain with limited capabilities and resources to improve. There are no modern-day designers working in the cluster, and while some state agencies have recruited them in the past, the benefits of their work have not been passed on to the cluster in any form that is sustainable. They've only ever worked as one-time interventions in a static mode. The weaver is completely cut off from fashion forecasting difficulties.

As a result, most weavers are impacted by design and product development challenges. The challenge in this area is to start by identifying and analysing the available skills and resources, then move on to skill upgradation, improving the quality of the mashru fabric, design development by contemporizing the existing design vocabulary, product diversification, and experimentation to discover new and innovative possibilities.

Several mashru weavers have also branched out to weave cotton stripes and checks, which are in more demand and easier and cheaper to produce. As a result of testing with various widths, weights, and materials, other applications for the fabric were discovered, taking it beyond a simple yardage fabric and resulting in a far more diverse product line.

8. Performance/ability of the cluster

The skill that persists within this craft cluster is highly commendable. Most of them possess a lot of government and non-government accreditations acknowledging their work. Hence there is no question raised in the shear competency of this cluster. However, the crafts people lack quality control and market feedback which is an essential parameter to maintain and develop a consumer market. Quality of the products are mostly compromised and because most craftsmen are related to each other they lack competition between each other. Moreover, they are financially weak and are dependent on the middleman or a trader for work. The product produced by the cluster is o poor quality as the cost provided to the artisans is not sufficient to procure good raw material.

9. Institutional Linkages

Design institutes and designers these days wish to collaborate with these craftsmen in many of their projects. But the craftsmen are so comfortable in their own space and constitution that they reject moving to another space or being disturbed in their regular style of working. A link to this stratum of innovators shall open a wide avenue for these artisans in their field. Within the cluster, information is difficult to come by. For example, the weaver is unaware of the visits of designers to the cluster, even those supported by government organisations, resulting in a limited interface.

10. Conclusion

Mashru weaving is a traditional technique struggling to make its survive in the contemporary world. The artisans in association with the craft are facing issues with the survival in the fast-growing market, where they are highly challenged by the machine production of such cloth material. The artisans are slowly moving towards different opportunities, as the products sold by them are majorly outdated or not in sync with contemporary fashion. There is a need for Markets that would bring in new information and design ideas, as well as keep the sector up-to-date on a global scale. There is a need to formulate a mechanism to document and analyse the feedback of customers on design. The artisans should be trained by the experts to document and analyse various consumer behaviour data and sales data. They should also be empowered with various tools to understand the consumer behaviour and update their product design to suit the requirement. Small and customised lots are becoming increasingly popular in the industry. As a result, weavers must be taught to create a customised product, which can also serve as a core skill for handloom products.

Reserving a spot in government-sponsored exhibitions held across India are an effective medium to gain exposure for artisans at domestic and international level. New marketing methods, such as e-commerce, need to be integrated alongside more conventional methods for extending the presence of the craft. There is a need to organise and modernise this weaving craft by eliminating the middle layer and empowering artisans, who are the primary stakeholders. Researching and adopting the successful western model is essential for the Indian market, where discerning consumers care more about the quality and value of handlooms than merely demonstrating their altruism.

For handloom goods to make an indelible impression on consumers, the industry needs constant promotion via print and online media. This can be achieved through collaborations with E-commerce platforms. The integration of technology within the operational frameworks of Indian craftspeople is crucial for improving their visibility in the market and ensuring long-term sustainability. Thus training programs that emphasise usage of digital tools should be introduced by the Government for craftspeople. This will help the craftspeople to effectively communicate the cultural heritage and unique craftsmanship that characterise their products. It is also suggested to create a integrated online marketplace to improve craft visibility within competitive markets and also expands the customer base by providing government backed authenticity. A online presence also lets craftsmen monitor consumer behaviour and market trends, which helps them evaluate product demand. This information can be used to diversify and innovate products, keeping them relevant in modern markets while preserving old methods.

References

[1] J. Gillow and N. Barnard, Traditional Indian Textiles, London: London: Thames and Hudson, 1991.
[2] P. Khatwani and P. Khawani, “Mashru Fabrics: Its Production Technology and Scope for Further Development,” International Jurnal of Science Technoogy and Mangement, pp. 413-416, 05 May 2017.
[3] W. Murphy, Handbook of Weaving, India: Abhishek Publications, 2017.
[4] P. Kumari, “Innovation in design of traditional mashru textile for product diversification,” Department of Clothing and Textile, Maharaja Sayajirao University of Baroda, Baroda, 2021.
[5] N. Korepal, “Creating a Mashru Artisans Cooperative in Patan,” Institute of Rural Management, Anand, 2005.
[6] I. Goel, “A weave revived: India Perspective,” 31 January 2023. [Online]. Available: https://www.indiaperspectives.gov.in/en_US/a-weave-revived/.
[7] Khamir, “Home: Crafts of Kutch,” 15 Feb 2023. [Online]. Available: https://www.khamir.org/crafts/mashru-weaving.
[8] P. Kumari and A. Karolia, “Design Intervention In Mashru-A Mystical Fabric of Gujrat,” in International Textiles and Costume Congress, Vadodara, 2019.
[9] The Rugsmith, “Know the Craft: The Rugsmith,” 31 January 2022. [Online]. Available: http://therugsmith.com.
[10] Gaatha, “Crafts: Gatha,” 28 Feburary 2023. [Online]. Available: https://gaatha.org/Craft-of-India/detail-research-mashru-weaving-patan/.

■ ■ ■

Journal of the TEXTILE Association

ISSN 0368-4636

Revolutionizing Fabric Inspection: A Deep Learning Approach to Automated Defect Detection Using High-Resolution Imaging

Smita Sangewar* & Ravikumar Purohit

Computer Science Engineering Department of D.K.T.E. Society's Textile and Eng. Inst, Ichalkaranji

Abstract:

Fabric defect detection is crucial in the textile industry as it directly influences production quality and cost-effectiveness. Traditional manual inspection methods are often time-consuming, inconsistent, and subject to human error. To overcome these limitations, automated defect detection systems leveraging image processing and machine learning techniques have emerged as promising solutions. This paper presents a detailed study on fabric defect detection utilizing advanced image processing algorithms coupled with machine learning approaches. The proposed system aims to improve detection accuracy and efficiency through the use of high-resolution imaging and sophisticated computational methods. The methodology involves acquiring high-definition fabric images to capture fine details and potential defects. These images are then subjected to pre-processing steps such as noise reduction, normalization, and contrast enhancement to facilitate effective analysis. Subsequently, image processing techniques including edge detection, texture analysis, and morphological operations are applied to identify and isolate defects. Convolutional Neural Networks (CNNs) are employed to enhance defect classification and localization, trained on a labeled dataset featuring various defect types, such as holes, stains, misprints, and weaving faults. The integration of deep learning enables the system to discern complex patterns and features associated with different defects, achieving high detection accuracy. System performance is evaluated using precision, recall, and F1-score metrics, demonstrating significant improvements over traditional manual methods in terms of accuracy and consistency. The paper also addresses challenges such as the requirement for extensive annotated datasets, computational complexity, and the need for real-time processing capabilities. Future research directions are suggested, including the exploration of advanced deep learning architectures, transfer learning, and real-time defect detection frameworks. This study provides a foundation for advancing fabric defect detection technologies, aiming for enhanced accuracy, efficiency, and real-time application.

Keywords: *Convolutional Neural Networks, Fabric Defect Detection, Image Processing, Machine Learning, Revolutionizing*

Citation: Smita Sangewar & Ravikumar Purohit, "Revolutionizing Fabric Inspection: A Deep Learning Approach to Automated Defect Detection Using High-Resolution Imaging", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),541-545, https://doi.org/10.5281/zenodo.14973327

Article Received : 31-08-2024, Revised: 09-01-2025, Accepted: 13-01-2025

1. Introduction

Fabric defect detection is a critical component of quality control in the textile industry, directly impacting both the economic viability and reputation of manufacturers. Traditional fabric inspection methods, predominantly reliant on manual examination, are constrained by limitations such as time consumption, inconsistency, and susceptibility to human error. The advancement of technology has prompted a shift towards the development of automated systems to enhance the efficiency and reliability of fabric defect detection. Automated fabric defect detection systems have emerged as a viable solution, harnessing the capabilities of image processing and machine learning to overcome the limitations of manual methods. These systems facilitate more precise and rapid identification of defects, ensuring that only high-quality fabrics are delivered to the market. Image processing techniques are integral to these systems, enabling detailed surface analysis to detect anomalies. High-resolution imaging captures the fine details of fabric, which are subsequently processed through pre-processing steps, such as noise reduction, normalization, and contrast enhancement—to improve defect visibility and eliminate extraneous elements. To further augment defect detection accuracy, machine learning models, particularly Convolutional Neural Networks (CNNs), are incorporated into the system [1]. These models are trained on extensive labelled datasets featuring diverse fabric defects, including holes, stains, misprints, and weaving faults. The deep learning approach allows the system to recognize and learn complex patterns associated with various defects, thereby significantly enhancing detection precision [2]. The integration of advanced image processing and machine learning techniques in fabric defect detection not only streamlines the inspection process but also reduces the probability of defective products reaching consumers [3]. More ever Fabric defect detection is a critical component of quality control in the textile industry, directly impacting economic viability and manufacturer reputation. Traditional methods rely heavily on manual examination, constrained by time, inconsistency, and susceptibility to human error [4]. Automated systems integrating image processing and machine learning offer a promising alternative, ensuring precise and rapid defect identification [5]. Automated fabric defect detection systems leverage high-resolution imaging and machine learning models to streamline the inspection process. These systems provide detailed surface analysis and enable precise anomaly detection, reducing defective products in the supply chain and improving efficiency [6].

Corresponding Author :
Mrs. Smita Sangewar
Assistant Professor, Computer Science Engineering Department
D.K.T.E. Society's Textile and Engineering Institute, Rajwada,
Ichalkaranj – 416 115 Dist.; Kolhapur
E-mail: smitasangewar@gmail.com

2. Objectives

- Enhance Detection Accuracy: Improve the precision of fabric defect identification using high-resolution imaging and advanced methods.
- Boost Inspection Efficiency: Automate the defect detection process to reduce inspection time and increase production efficiency.
- Optimize Image Pre-processing: Apply noise reduction, normalization, and contrast enhancement to prepare images for accurate analysis.
- Employ Advanced Processing Algorithms: Use image processing techniques such as edge detection and texture analysis for precise defect identification.
- Integrate Machine Learning: Implement convolutional neural networks (CNNs) for effective defect classification and localization.
- Evaluate System Performance: Measure system effectiveness with precision, recall, and F1-score metrics.

3. Previous work

Previous work on fabric defect detection has evolved significantly, starting with traditional manual inspection methods. Historically, fabric quality control relied heavily on human inspectors, who, although capable of recognizing subtle irregularities, were prone to inconsistency, fatigue, and subjectivity, leading to inefficiencies in large-scale production environments. Early attempts to automate this process began with basic image processing techniques aimed at reducing the reliance on manual labour. These early systems employed relatively simple algorithms such as thresholding, edge detection, and texture analysis, with popular methods like the Canny and Sobel edge detection algorithms being widely used to identify pattern discontinuities and surface irregularities. However, these early systems struggled with complex textures, noise, and environmental variations, limiting their overall effectiveness. Over time, advancements in image processing led to more sophisticated techniques, including morphological operations and Gabor filters, which significantly enhanced defect detection capabilities by offering more robust texture and pattern analysis. The real breakthrough, however, came with the integration of machine learning, particularly deep learning models like convolutional neural networks (CNNs) [7]. These models allowed systems to learn intricate and complex features associated with fabric defects, improving classification accuracy across diverse defect types such as holes, stains, and weaving faults. The use of CNNs enabled the automated detection process to move beyond basic edge detection, allowing systems to detect subtle, non-linear patterns and anomalies that traditional methods could not. Recent developments have focused on enhancing accuracy and reducing the reliance on extensive annotated datasets through techniques like transfer learning, which leverages pre-trained models to reduce the computational burden and training time [8]. These advancements have led to more robust, efficient, and scalable systems for real-time fabric defect detection, significantly surpassing the capabilities of earlier manual and semi-automated systems. In summary, the evolution of fabric defect detection has transitioned from labour-intensive manual inspection to advanced, machine-learning-driven systems capable of high precision and scalability in industrial applications [9].

4. System architecture

The fabric defect detection system operates through a series of interconnected stages that work together to identify flaws in fabric materials. Here's a breakdown of the system in a way that's easy to understand.

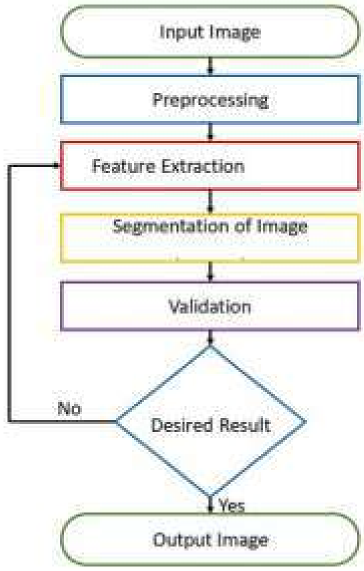


Figure 1 - System architecture

The system consists of several essential modules—Input, Preprocessing, Segmentation, Validation, and Output Generation—each playing a crucial role in ensuring accurate defect detection. The detailed module description is as follows.

4.1 Input: The process starts by capturing high-quality images of the fabric using specialized cameras. These cameras are designed to take very detailed pictures, making even tiny defects visible. It's important that the lighting is even, so shadows or reflections don't confuse the system. The images taken by the camera are the raw material that the system will analyse to find defects.

4.2 Preprocessing: Once the images are captured, they go through a cleaning-up process called preprocessing. This ensures that the images are in the best possible condition for analysis:

- Noise Reduction: Just like how static can make a radio hard to hear, visual noise can make it difficult to spot defects in an image. Techniques like filtering are used to remove this noise.
- Normalization: This adjusts the brightness or colour levels in the images, so they all have the same standards, making it easier to compare one area of the fabric to another.

- Noise Reduction: Just like how static can make a radio hard to hear, visual noise can make it difficult to spot defects in an image. Techniques like filtering are used to remove this noise.
- Contrast Enhancement: Imagine trying to spot a dark spot on a grey surface—contrast enhancement brightens the image to make any flaws more obvious.
-

4.3 Segmentation: In this step, the system divides the image into different sections to focus on areas that might have defects.

- Edge Detection: Think of this as finding the outlines of objects in the fabric, helping the system spot irregularities like a hole or tear.
- Thresholding: This method separates areas of the fabric based on brightness or texture. If one part of the image looks very different from the rest, it might be a defect.

4.4 Validation: Now, the system gets to the heart of the process—confirming whether or not an issue is present.

- Feature Extraction: The system's neural network (CNN) examines the suspicious areas in detail, learning the characteristics of various defects like stains or weaving problems.
- Classification: After learning these characteristics, the system categorizes the defects (e.g., a stain vs. a hole).
- Localization: The system doesn't just identify the defects; it also pinpoints exactly where they are in the fabric.

4.5 Output Generation: Finally, the system creates a report on its findings. The output includes:

- Defect Report: A summary of what defects were found, their types, and where they are located.
- Annotated Images: Images with defects marked, so it's easy to see exactly where the problems are.
- Statistical Analysis: The system also measures its performance using precision, recall, and F1-score, which show how accurate and reliable the detection was.

In short, this system takes fabric images, processes them to remove unnecessary information, examines them for defects, verifies what kind of defects they are, and finally, generates a report showing the results in an easy-to-understand way.

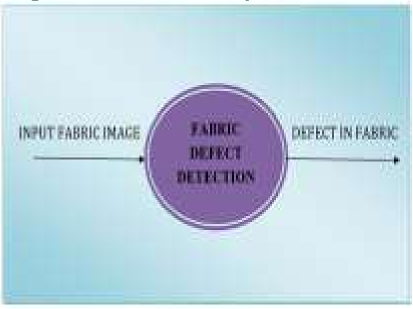


Figure 2 - Data flow diagram

5. Problem Statement

The quality of fabrics is critical to the textile industry as it directly influences the integrity of the final product. Conventional methods of fabric defect detection, which rely on manual inspection, are labour-intensive, prone to human error, and lack consistency, resulting in inefficiencies and higher production costs. These limitations underscore the need for an automated, reliable, and efficient system capable of accurately detecting a wide range of fabric defects in real-time, thus enhancing quality control and reducing operational expenses.

6. Problem solution

To address the limitations of traditional fabric inspection methods, we propose an automated fabric defect detection system that integrates advanced image processing techniques with machine learning algorithms. The system is designed around several core components:

6.1 High-Resolution Imaging: High-definition cameras capture detailed fabric images, enabling the detection of even minor defects.

6.2 Preprocessing: Image quality is enhanced through noise reduction, normalization, and contrast enhancement, making defects easier to detect during analysis.

6.3 Segmentation: Edge detection algorithms like Canny and Sobel, along with texture analysis methods such as Gray-Level Co-occurrence Matrix (GLCM) and Local Binary Patterns (LBP), are employed to segment and isolate potential defect regions.

6.4 Machine Learning Integration: Convolutional Neural Networks (CNNs) are used for defect classification and localization. Trained on labelled datasets, the CNNs learn to recognize complex patterns associated with various defect types.

6.5 Validation and Output: The system validates detected defects, generating detailed reports, annotated images, and performance metrics, including precision, recall, and F1-score, to assess detection accuracy.

7. Dataset

The system uses a machine learning model trained on a large part of the MVTec Anomaly Detection dataset. This dataset contains 540,000 images divided into six categories: color defects, cuts, holes, other defects, and non-defective samples. The dataset is split into 360,000 images for training and 180,000 for testing. A smaller set of 72,000 images, equally distributed among the six categories, is shown in the accompanying figure. Figure 3 shows examples of images from each category, while Figure 4 highlights some defective samples.

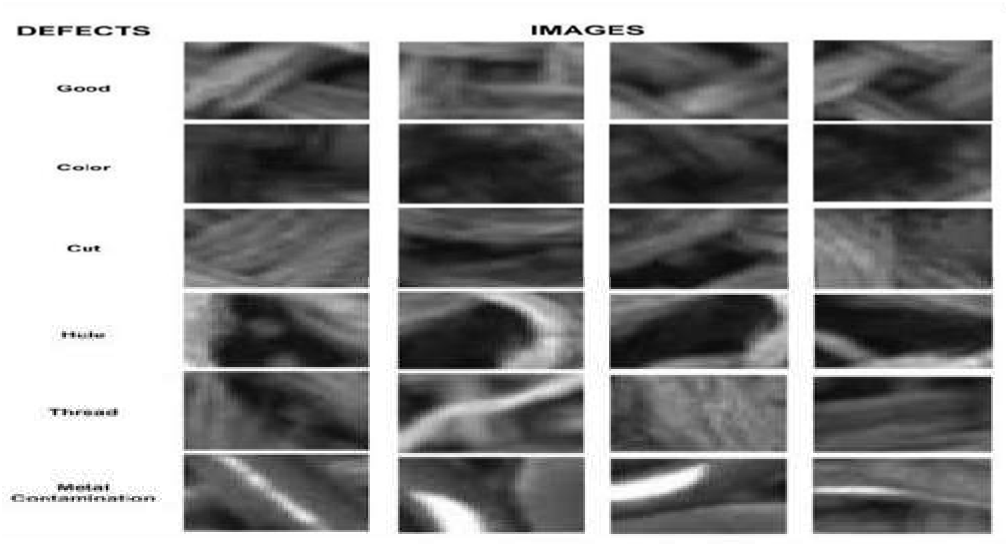


Figure 3 Sample image of different classes

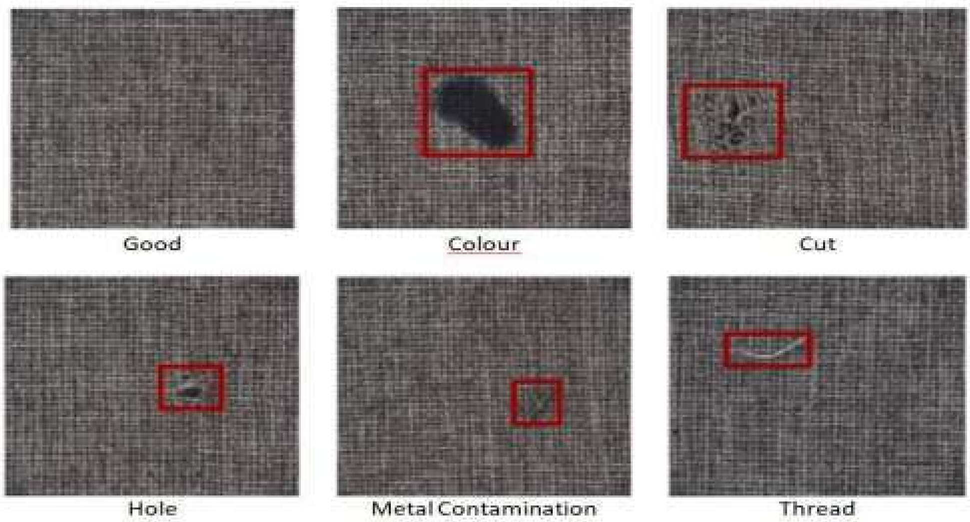


Figure 4 - Samples of defects

The proposed fabric defect detection system is shown in Figure 1. It starts by processing images through steps like resizing, normalizing, and reducing their dimensions to prepare the training data. A Convolutional Neural Network (CNN) then analyzes these images to identify patterns and classify the fabric as either normal or defective. Defective fabrics are further grouped into categories like color issues, cuts, holes, stains, loose threads, or metal contamination. The system uses advanced image processing and deep learning techniques to accurately detect and classify fabric defects.

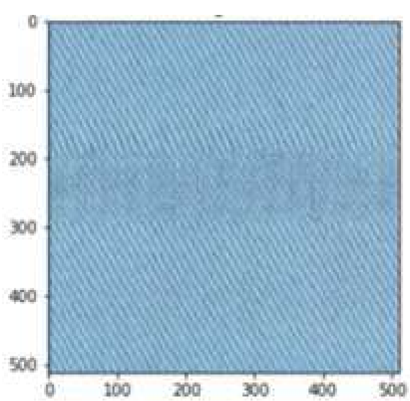


Figure 5- Sample Input Image

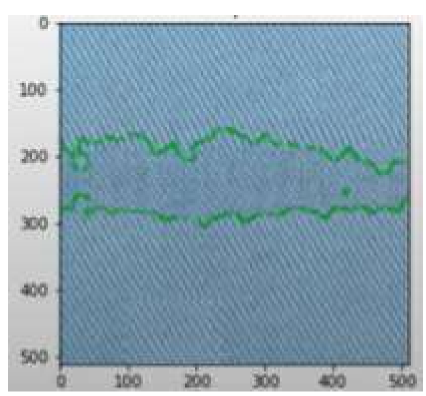


Figure 6 - Sample Output Image

8. Experimental description and result

The system was trained on a dataset of 540,000 images grouped into six defect categories. Its performance was evaluated using the F1 score, which combines precision and recall to measure how well the system balances false positives and false negatives. The F1 score helps assess the effectiveness of the AI model in detecting fabric defects. The system achieved an average F1 score of 0.8, which is considered good.

9. Conclusion

The development of an automated fabric defect detection system using advanced image processing and machine learning marks a transformative advancement for the textile industry. By addressing the shortcomings of manual inspection—such as inconsistency, inefficiency, and susceptibility to human error—this system provides a reliable and efficient solution for defect detection. High-resolution imaging, robust preprocessing, and advanced segmentation techniques ensure accurate identification, while convolutional neural networks enable precise classification and localization of defects. The system's real-time processing capabilities, adaptability to various defect types, and detailed reporting further enhance its value, making it an indispensable tool for improving quality control, efficiency, and reliability in textile manufacturing.

References

[1] Khowaja, Anum, and Dinar Nadir. "Automatic fabric fault detection using image processing." In 2019 13th International Conference on Mathematics, Actuarial Science, Computer Science and Statistics (MACS), pp. 1-5. IEEE, 2019. DOI: 10.1109/MACS48846.2019.9024776

[2] Kulkarni, Mukund, Puja Chavan Cholke, Parimal Vasmatkar, Shravani Tambe, Samarth Anuse, and Siddhant Telgote. "Fabric Defect Detection System Using Image Processing." In 2024 1st International Conference on Cognitive, Green and Ubiquitous Computing (IC-CGU), pp. 1-7. IEEE, 2024. DOI: 10.1109/IC-CGU58078.2024.10530850

[3] Rasheed, Aqsa, Bushra Zafar, Amina Rasheed, Nouman Ali, Muhammad Sajid, Saadat Hanif Dar, Usman Habib, Tehmina Shehryar, and Muhammad Tariq Mahmood. "Fabric defect detection using computer vision techniques: a comprehensive review." Mathematical Problems in Engineering 2020, no. 1 (2020): 8189403. https://doi.org/10.1155/2020/8189403

[4] Khowaja, A., & Nadir, D. (2019). Automatic fabric fault detection using image processing. IEEE MACS Conference. DOI: 10.1109/MACS48846.2019.9024776.

[5] Kulkarni, M., et al. (2024). Fabric Defect Detection System Using Image Processing. IEEE CGU Conference. DOI: 10.1109/IC-CGU58078.2024.10530850.

[6] Rasheed, A., et al. (2020). Fabric defect detection using computer vision techniques. Mathematical Problems in Engineering. DOI: 10.1155/2020/8189403.

[7] Tsai, I-Shou, Chung-Hua Lin, and Jeng-Jong Lin. "Applying an artificial neural network to pattern recognition in fabric defects." Textile Research Journal 65, no. 3 (1995): 123-130. https://doi.org/10.1177/004051759506500301

[8] Anandan P, Sabeenian RS (2018) Fabric defect detection using discrete Curvelet transform. International conference on robotics and smart manufacturing (RoSMa2018). Procedia Comput Sci 133:1056–1065. https://doi.org/10.1016/j.procs.2018.07.058

[9] Hanbay, Kazım, Muhammed Fatih Talu, and Ömer Faruk Özgüven. "Fabric defect detection systems and methods—A systematic literature review." Optik 127, no. 24 (2016): 11960-11973. https://doi.org/10.1016/j.ijleo.2016.09.110

■ ■ ■

Virtual Prototyping of Spacer Fabric Shoe Uppers for Racket Sports

Sweta Kumari & Manpreet Manshahia*

Amity School of Fashion Technology, Amity University Uttar Pradesh, Noida, India

Abstract:

This article thoroughly explores the virtual prototype development of an asymmetrical shoe upper designed specifically for amateur athletes engaged in racquet sports such as badminton and tennis. The study targets athletes aged 12-16, focusing on enhancing comfort, performance, and aesthetics. Utilizing Spacer fabric, known for its superior breathability, cushioning, and flexibility, the research aims to address the unique biomechanical demands of lateral movements in racquet sports. The article highlights the design attributes derived from comprehensive surveys and data analysis, emphasizing the significance of vibrant colors and ergonomic features. The methodology encompasses material selection, design parameter analysis, and prototype development, culminating in a discussion on the implications for amateur athletes' performance and psychological well-being.

Keywords: *Asymmetrical upper, amateur athletes, racquet sports, Spacer fabric, virtual prototype*

Citation: Sweta Kumari & Manpreet Manshahia, "Virtual Prototyping of Spacer Fabric Shoe Uppers for Racket Sports", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),546-549, https://doi.org/10.5281/zenodo.14965964

Article Received : 21-11-2024, Revised: 27-01-2025, Accepted: 04-02-2025

1. Introduction

The complex interplay between psychological perceptions, preferences, and design components is crucial when it comes to athletic footwear, especially for amateur athletes who participate in racquet sports like tennis and badminton [1]. These sports require quick lateral movements, which put a lot of strain on the lower limbs [2, 3]. To reduce the risk of injury and improve performance, specialist footwear is required. This article explores the development of a virtual prototype for a shoe upper specifically designed to meet the demands of amateur athletes between the ages of 12 to16, a group distinguished by developing and sensitive feet [4]. The study highlights how an asymmetrical shoe upper that satisfies the biomechanical needs of lateral mobility may be made using Spacer fabric, which is renowned for its breathability, moisture management, cushioning, and flexibility [5, 6]. This study fills a gap in understanding amateur players' athletic shoe needs, especially in underdeveloped nations like India where anthropometric considerations are frequently disregarded [7, 8].

2. Methodology

The research methodology, encompassing several critical phases, commences with an extensive survey analysis aimed at understanding the needs and preferences of amateur players regarding athletic footwear. The survey targeted athletes aged 12-16 engaged in racquet sports, focusing on aspects such as comfort, aesthetics, and functionality. Based on the collected data, three hypotheses were formulated to examine the impact of design elements on respondents' gender and the relationship between weight, pressure points, and arch types.

A sample size of 100 participants was selected to ensure statistically significant findings. These participants were recruited from 10 sports coaching centers, strategically chosen to represent a diverse spectrum of socioeconomic and athletic backgrounds. The demographic profile of the 100 adolescents involved in badminton or tennis coaching sessions in the Delhi/NCR region comprised 36.0% females and 64.0% males.

Corresponding Author :
Dr. Manpreet Manshahia
Assistant Professor, Amity School of Fashion Technology, Amity University, Uttar Pradesh, Sector 125, Noida – 201 301 UP
E-mail: mmanshahia@amity.edu

2.1 Survey Insights and Design Implications

The survey revealed significant insights into the preferences of amateur athletes. Key findings indicated that unattractive design, dated models, lack of new features, and non-branded options were the most undesirable factors in athletic shoes. Respondents favoured avant-garde designs, retro looks, and minimalism, highlighting the importance of modern, aesthetically appealing designs with innovative features. The study also emphasized the importance of color vibrancy, with athletes expressing a preference for vibrant and attractive colors that can influence their performance and mood positively. However, the study did find a significant impact of design parameters on respondents' gender, highlighting the role of aesthetics in influencing the psychology of amateur athletes as shown in Figure 1.

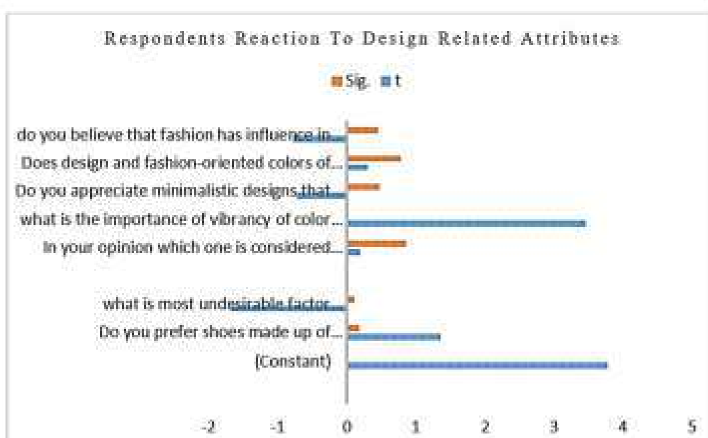


Figure 1 - Respondents' reaction to design-related attributes

Table 1- Preferences and opinions of amateur athletes regarding various design features in shoe

Preferences and opinions of amateur athletes regarding various design features of athletic shoes		Mean	Std. Deviation	N	Discussion
1.	The most undesirable factor that makes respondents reject a particular athletic shoe (Unattractive Design, No new features)	2.42	1.02671	100	The main score indicates that certain factors are considered desirable by respondents when choosing athletic shoes. The relatively high standard deviation suggests a wide range of design factors influencing rejection decisions.
2	Desirable future of aesthetics according to respondent's	2.36	1.18509	100	This suggests that respondents have a somewhat positive outlook on the future of athletics shoe design. The standard deviation indicates variability in the perceptions among respondents.
3.	Importance of vibrancy of color of upper in shoe selections	2.24	0.81798	100	Respondents moderately consider the vibrancy of color in the upper when selecting athletic shoes. The standard deviations indicate some variable tea in the importance place in this factor.
4.	Appreciation of minimalistic designs that allow color to play	1.72	0.85375	100	Respondents tend to appreciate minimalistic designs that provide opportunities for color to stand out. The standard deviation suggests variability in the degree of appreciation among respondents.
5.	Influence of design and fashion-oriented colors on psychological performance.	2.18	0.89194	100	Respondents moderately believe that design and fashion-oriented colors of shoes can positively influence psychological performance the standard deviation indicates variability in this belief among respondents
6.	Belief in the influence of fashion in court.	1.60	0.82878	100	Respondents tend to believe that fashion has some influence in courts. The standard deviation suggests variability in this belief among respondents

As per Figure1

F-statistic: The F-value of 2.530 indicates that the model is statistically significant.

p-value (Sig.): A p-value of 0.020 suggests that there is a significant impact of the design attributes on the gender of respondents. In other words, the design parameters significantly affect the gender classification.

Dependent Variable: Gender of the respondent (binary coded as 0 and 1).

Independent Variables: Various design attributes and opinions

The study successfully identified specific design elements essential for sports shoes tailored to the preferences of amateur athletes. Vibrant colors, and aesthetically pleasing designs were highlighted as key elements. These findings guide the prototype development, ensuring that the design incorporates these elements to resonate with the target demographic.

2.2 Material Selection

The selection of materials for the shoe upper was guided by the distinctive physical characteristics of Spacer fabrics, which include breathability, moisture management, cushioning, and durability.

The fabric samples were evaluated across various properties using a scale of 1 to 5, as depicted in Figure 2. Sample 5, despite being thicker yet lighter and containing elastane, demonstrated superior performance and comfort compared to others.

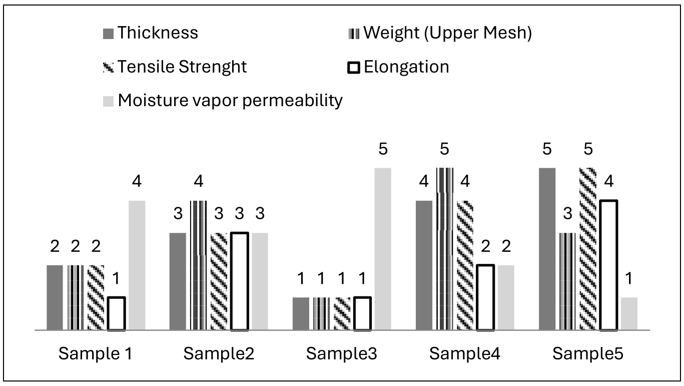


Figure 2 - The fabric samples were evaluated across various properties

The Spacer fabrics used in the prototype construction comprised 98% PES(Polyester) and 2% EA(Elastane), with a 3D warp knit hexagon structure. These materials exhibited superior tear strength, tensile strength, elongation, and water vapor permeability, making them ideal for athletic footwear designed for high-impact sports with rapid lateral movements.

Table 2 – Fabric parameters

	Fabric Properties	Test Standards	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	**Fabric Thickness (mm)**	GE 05	4	3	5	2	1
2	**Fabric Weight (GSM)**	GE 07	4	2	5	1	3
3	**Fabric Tensile Strength (kN/0.05m (min)**	ST 03	4	3	5	2	1
4	**Fabric Elongation (percent (min))**	ST 03	5	3	4	2	1
5	**Fabric moisture vapour permeability (g/cm^2h)**	IS 15298, part 2: 2016	4	3	5	2	1

2.3 Prototype Development Process

The prototype development process involved several iterative stages, incorporating feedback from amateur athletes and trainers to refine the design. A design process framework adapted from J.F. Boles was employed, comprising four fundamental steps: problem generation, needs assessment, prototype development, and evaluation. The prototypes were constructed using technical Spacer fabrics, ensuring they met international standards and aligned with global trends in athletic shoe manufacturing.

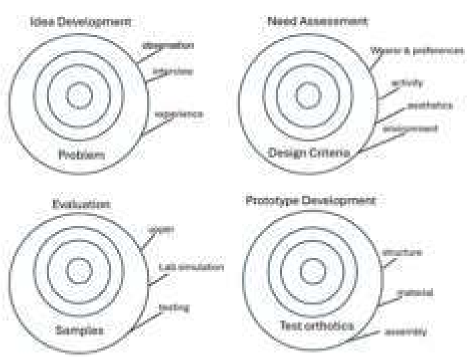


Figure 3 - Adopted from Boyles Design process framework [9]

A few Aesthetic descriptors from Table 3 were taken into consideration while designing a prototype

Table 3 - Aesthetic Descriptors [10]

Product Aesthetic Descriptors	
1.	Curvaceous
2.	Empowered
3.	Fun
4.	Rhythmical
5.	Edgy
6.	Geometric
7.	Retro

Table 4 shows the list of core themes and subthemes. The five core themes were taken into consideration: fit, function, aesthetics, color, and personal style. These core themes were then divided into various subthemes. These themes helped in identifying what the participants needed and desired from their athletic shoes.

Table 4- The list of core themes and subthemes

Core Themes	Fit	Function	Aesthetics	Colors	Personal Style
Sub Themes	Arch Support	Performance Features	Pattern	Hues/Shade	Minimalism
	Comfort	Flexibility	Fabric	Matching Schemes	Retro
	Mobility	Cushioning	Surface Ornamentation	Demographic (Age/Gender)	Uniqueness
		Shock Absorption	Rhythm		
			Balance		

The proposed asymmetrical upper made of 3D spacer fabrics is scientifically designed to meet the specific needs of racquet sports, offering targeted cushioning, specialized support for lateral movement, and a lightweight design for enhanced performance.

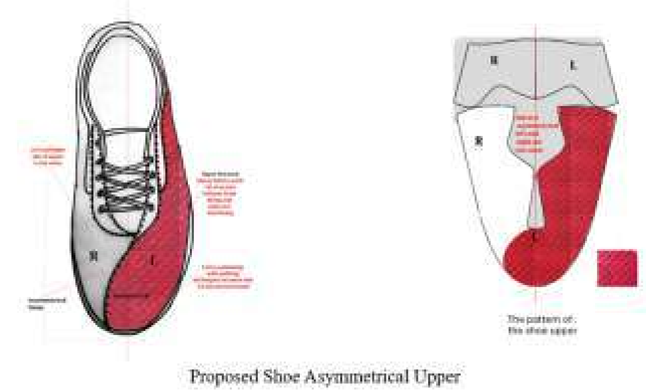


Figure 4 - Proposed asymmetrical athletic shoe prototype

3. Results and Discussion

The results of the study highlight how important design features are in determining amateur athletes' preferences and psychological health. The investigation showed no evidence of a significant relationship between pressure points and arch types or weight and pressure points, indicating that other factors may be more important in determining how comfortable a pair of shoes is. Nonetheless, a noteworthy effect of the design parameters on the gender of the respondents was noted, underscoring the significance of aesthetics in shaping athletes' psychological states. Prototypes were built with the specific demands of amateur athletes in mind. They included innovative materials, ergonomic features, and brilliant colors. The asymmetrical top shape accommodated the lateral movements common to racquet sports by adding extra cushioning to the shoe's exterior. This design improved performance and comfort at the same time. This design decreased the chance of injuries, especially ankle problems, while simultaneously improving comfort and performance.

The psychological effects of color on athletes were emphasized in the study, with vivid colors like orange, yellow, and red being very useful for generating strong feelings and improving performance. High emotional intensity colors like red and yellow can increase enthusiasm and adrenaline levels, as well as attentiveness and focus. Orange is a color that can generate sentiments of wholesomeness and vigor, which makes it a good option for sports footwear that aims to increase endurance and energy.

To improve comfort and offer a customized fit, the prototypes included asymmetrical designs, elastics, and adjustable drawstrings, among other design aspects. Surface decoration methods, such as quilting and embellishments, enhanced comfort and aesthetics by offering targeted cushioning and visual appeal. According to color psychology theory, vivid color schemes and patterns attract attention and produce pleasant emotional reactions. Ergonomics played a crucial role throughout the design process, emphasizing shock absorption, arch support, and general fit. To offer comfort and stability, the prototypes included arch supports, heel counters, and footbeds with anatomical shapes. While preserving functional integrity, the combination of tessellated designs, geometric overlays, and hexagonal meshes guaranteed a contemporary, minimalistic appearance.

4. Conclusion

The in-depth analysis provides insights into fabric composition, 3D structures, thickness, weight, and mechanical properties of spacer fabrics used in athletic shoe orthotics. This work examined the permeability and conductivity characteristics of polyester filament-based warp-knitted spacer textiles. When applying shoe orthotics, the spacer fabric is thought to produce a cozy material that normalizes heat transfer during physical activities. The study establishes significant relationships between fabric thickness and various properties. These relationships, analyzed through P-values and regression, reveal correlations between thickness and tear strength, tensile strength, weight, and water vapor permeability. The findings showed that the permeability of water vapor and air is dependent on the thickness.

This study contributes valuable knowledge for the selection of materials in the construction of sports shoe orthotics, guiding manufacturers towards optimal fabric choices for enhanced athletic performance and comfort.

References

[1] A. Piermattéo, G. Lo Monaco, G. Reymond, M. Eyraud, and L. Dany, "The meaning of sport and performance among amateur and professional athletes," Int J Sport Exerc Psychol, vol. 18, no. 4, 2020, doi: 10.1080/1612197X.2018.1536160

[2] W. K. Lam, D. W. C. Wong, and W. C. C. Lee, "Biomechanics of lower limb in badminton lunge: a systematic scoping review," PeerJ, vol. 8. 2020. doi: 10.7717/peerj.10300

[3] A. Subramanium, E. C. Honert, S. Cigoja, and B. M. Nigg, "The effects of shoe upper construction on mechanical ankle joint work during lateral shuffle movements," J Sports Sci, vol. 39, no. 16, 2021, doi: 10.1080/02640414.2021.1898174

[4] T. Yokoe et al., "Orthopaedic medical examination for young amateur athletes: a repeated cross-sectional study from 2014 to 2018," BMJ Open, vol. 11, no. 1, 2021, doi: 10.1136/bmjopen-2020-042188

[5] J. Yip and S. P. Ng, "Study of three-dimensional spacer fabrics: Physical and mechanical properties," J Mater Process Technol, vol. 206, no. 1–3, 2008, doi: 10.1016/j.jmatprotec.2007.12.073

[6] C. Chen, Z. Du, W. Yu, and T. Dias, "Analysis of physical properties and structure design of weft-knitted spacer fabric with high porosity," Textile Research Journal, vol. 88, no. 1, 2018, doi: 10.1177/0040517516676060

[7] M. L. Kamlesh and J. Mohan, "The Development of Sport Psychological Research in India," Sport Psychol, vol. 1, no. 3, 2016, doi: 10.1123/tsp.1.3.257

[8] M. - and S. K. -, "Perception of Indian Society towards Sports," International Journal for Multidisciplinary Research, vol. 5, no. 4, 2023, doi: 10.36948/ijfmr.2023.v05i04.4913

[9] Y. H. Chen and C. C. LAN, "Design of a constant-force snap-fit mechanism for minimal mating uncertainty," Mech Mach Theory, vol. 55, pp. 34–50, Sep. 2012, doi: 10.1016/J.MECHMACHTHEORY.2012.04.006

[10] "https://pure.solent.ac.uk/ws/portalfiles/portal/23981322/Newcastle2007Paper.pdf"

Journal of the TEXTILE Association
ISSN 0368-4636
TECHNICAL TEXTILES

Influence of Fibre Fineness on the Properties of Recycled Polyester Blended Yarns

Prakash Chandra Birla[1]*, Virendra Kumar Gupta[2] & Ved Prakash Singh[1]

[1]Department of Textile Technology, MLV Textile & Engineering College, Bhilwara, Rajasthan, India
[2]Department of Textile Chemistry, MLV Textile & Engineering College, Bhilwara, Rajasthan, India

Abstract:

This study provides a comprehensive analysis of physical characteristics of recycled polyester (rPET)/modal and virgin polyester (vPET)/modal blended yarns produced using three different fibre finenesses with varying blends. A comparative assessment of rPET and vPET fibres revealed that rPET exhibited greater tenacity and breaking elongation. FTIR analysis confirmed the presence of identical functional groups in both polyesters. Thermal analysis indicated that rPET had slightly higher crystallinity, a faster crystallization rate, and lower transition temperatures than vPET. The results showed that yarns containing rPET were stronger, more extensible, and had increased hairiness, along with slightly higher imperfections compared to vPET yarns. Additionally, rPET-blended yarns displayed a higher unevenness percentage (U%) than those containing vPET.

Keywords: *blend ratio, fibre fineness, modal fibre, recycled polyester, yarn characteristics*

Citation: Prakash Chandra Birla, Virendra Kumar Gupta & Ved Prakash Singh, "Influence of Fibre Fineness on the Properties of Recycled Polyester Blended Yarns", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),550-556, https://doi.org/10.5281/zenodo.14973481

Article Received : 20-01-2025, Revised: 12-02-2025, Accepted: 16-02-2025

1. Introduction

Synthetic polymers are prized for their lightweight nature, considerable strength, flexibility, and ease of use, rendering them suitable for a wide array of applications. Studies indicate that thermoplastic polymers such as polyethylene (PE), polypropylene (PP), and polyester (PET) collectively account for roughly 80% of the world's polymer production. Among them, PET stands out, comprising approximately 18% of this total and ranking third in popularity, following PE and PP [1].

Polyester polymer found its earliest and most foundational application as a textile fibre following its discovery. Among all natural and manmade textile fibres, PET reigns supreme as the most widely utilized fibre about 54% of total fibre consumption [2]. Its prominence in this role is primarily due to the economic feasibility and widespread availability of raw materials, combined with its admirable functional properties.

PET, as a polymer, including textile fibres, finds extensive application across various sectors, like food containers, bottles for soft-drink and water, films, sheets, foams, industrial cords, electrical hardware and components, packaging materials, and more. Its widespread adoption is owed to its exceptional physical, mechanical, thermal, optical, and barrier properties [3, 4]. Additionally, PET stands out as an economical thermoplastic material, boasting excellent resistance to moisture and oxygen, good transparency, impressive tensile and impact strength, dimensional stability, and resistance to chemicals. Furthermore, it is non-toxic and do not have health hazards [5].

In industry, virgin PET polymer is manufactured to various specifications tailored to different applications, as each application demands specific properties. The required intrinsic viscosity [η] for PET varies depending on its intended use, such as textile fibre (0.65 dl/g), recording film (0.60 dl/g), bottles (0.80 to 0.90 dl/g), and tyre cords (0.85 dl/g). PET granules can be processed in many ways such as extrusion, injection moulding and blow moulding, depending on application and the final product requirements [6-8].

In last few decades, PET bottles have surged in popularity due to their affordability, durability, resistance to microbes, and lightweight nature. Moreover, PET offers almost similar benefits to glass in terms of hygiene, taste preservation, and gas impermeability. Consequently, PET bottles are increasingly replacing traditional glass bottles. Furthermore, PET bottle production is both cost-effective and energy-efficient, adding to their appeal [9].

In addition to above, the consumption of PET bottles tremendously rising due to technological advancements, economic growth of developing countries like India, along with increase in per capita demand and population growth. However, this trend leads to significant solid waste generation and contributes to landfill issues, as PET polymer biodegrades extremely slowly. These conditions could potentially aggravate ecological problems in the future [10, 11].

Recycling of PET waste bottles is the best way to economically reduce plastic waste [6, 12]. For recycling of

Corresponding Author :
Mr. Prakash Chandra Birla
Assistant Professor, Department of Textile Technology, MLV Textile & Engineering College, Pansal Chauraha, Azad Nagar Bhilwara – 311 001 RAJ.
E-mail: pc_birla@rediffmail.com

PET plastic in many countries, it is coded "1" as the resin identification code and means high rate of recycling [14, 15]. Solid plastic waste is becoming a serious ecological and economic problem. Recycling or upcycling of used PET bottles into textile fibres offers a practical solution to these environmental challenges [13, 26]. This approach not only helps to conserve natural resources but also reduces energy consumption, lowering greenhouse gas emissions and carbon footprint. Furthermore, open new business opportunities and contribute in national economy. The first global effort to recycle waste PET bottles began in 1977 [16].

The recycling of PET bottles falls into two main categories: chemical recycling and mechanical recycling [17]. Chemical recycling involves breaking down used PET into monomers through total depolymerization or into oligomers through partial depolymerization, using processes like hydrolysis, methanolysis, and glycolysis. However, the major limitation of chemical recycling is that it incurs nearly the same production costs and energy consumption as producing virgin polyester [6]. In contrast, mechanical recycling is more cost-effective and consumes less energy, making it a more efficient method for upcycling the waste of PET bottles into textile fibres. Mechanical recycling primarily involves a melt extrusion process. It begins with the collection of PET bottles, followed by sorting and pre-washing. The bottles are then cut or shredded into flakes, and contaminants like caps, labels, and metals are separated through floatation. After washing and drying, the material undergoes melt extrusion for fibre production [18]. The success of PET bottles recycling process into fibre conversion greatly influenced by effectiveness of cleaning process in contamination removal and presence of water content at the time of remelting. Both factors are cause of reduction in molecular weight and intrinsic viscosity [η] of the PET polymer. Innovative and cost-effective technologies for recycling PET bottles are boosting the PET recycling industry by offering increased value. This development is expected to provide the textile industry with more affordable recycled PET fibre, contrary this will also help in stabilising the price of virgin PET.

Various studies have been conducted in past to explore the utilization of recycled PET (rPET) in the production of fibres and yarns. In an investigation on the effects of structural and physical properties of both conventional and recycled PET polymers on spinning speed. Their findings indicate that, at spinning speeds ranging from 2500 to 3000 m/min, rPET filaments exhibit greater density and crystallinity compared to their virgin PET counterparts [19].

The effect of blend ratios on the quality characteristics of recycled polyester/cotton blended ring-spun yarns were studied and observe that the proportion of recycled polyester significantly influences the overall quality of these blended yarns [20]. The suitability of various yarn numbers and blend ratios for the application of rPET fibres that contributing to the understanding of optimal conditions for rPET usage was also examined [21]. The properties of yarns, produced from vPET, rPET, and cotton fibres, have been studied and observed that yarns made from recycled fibres exhibited superior yarn evenness, fewer imperfections, and a higher yarn quality index [22]. In one of the study researcher found that ring-spun yarns containing rPET fibres demonstrated lower tenacity and elongation compared to those made from virgin PET [23]. The antibacterial activities of 19.7 tex ring-spun yarns with varying blending ratios of lyocell and rPET were examined and authors concluded that lyocell/rPET blends were particularly suitable for hospital textiles due to their higher tenacity and elongation properties [24]. A study investigated the effects of recycling processes on the physical, mechanical, and degradation properties of PET yarns, revealing that virgin and chemically recycled yarns with adequate purification demonstrated comparable processability, physical and mechanical properties, and long-term degradation behaviour [25]. Another study on the properties of yarns made from rPET fibre blends with vPET fibres and cotton concluded that the desired performance of rPET yarns can be attained not by producing 100% pure rPET yarns but by blending them with other fibres [26].

However, the studies on blends of recycled PET fibres with modal fibre have not yet been conducted, particularly with a focus on various fibre finenesses. Previous research has indicated that recycled PET fibres exhibit lower tensile strength and other properties, likely due to inadequate recycling processes. However, advancements in recycling technologies have led to improvements in the quality and properties of recycled polyester fibres. Thus, it is essential to investigate the properties of recycled PET yarns made from fibres produced using these updated recycling methods.

This study aims to investigate and compare the effects of recycled PET (rPET) and virgin PET (vPET) fibres, with varying blend ratios and fibre fineness, on the properties of ring-spun yarn. Specifically, rPET and vPET fibres were blended with modal fibre in ratios of 100:0, 65:35, and 35:65, across three different levels of fibre fineness. Yarn samples were produced using a ring spinning system, with all production parameters held constant, to assess the impact of the blend ratio and fibre fineness variables.

2. Materials and Methods

2.1 Fibres Specifications

The recycled polyester (rPET), virgin polyester (vPET) & modal fibres were used in the present study. All fibres were provided by RSWM, kharigram, Gulabpura. Both the fibres rPET & vPET were taken with three different fibre finenesses. The specifications and tensile properties of rPET & vPET and modal fibres are given Table 1.

Table1: Specifications of rPET, vPET and modal fibres

Fibre	Fibre Fineness Denier (D)	Length (mm)	Tenacity (cN/tex)	Breaking Elongation (%)
rPET	1.2	44	61.89	17.69
	1.4	44	57.13	18.56
	2.0	44	54.21	20.07
vPET	1.2	44	55.76	17.05
	1.4	44	53.12	18.23
	2.0	44	50.27	19.78
Modal	1.2	38	26.54	8.32

2.2 Preparation of Yarn Samples

Ring yarns of rPET/Modal and vPET/Modal with a fineness of 19.5 tex were spun at RSWM, Kharigram, Gulabpura, utilizing three different blend ratios (100:0, 65:35, 35:65) and three fibre finenesses of 1.2 D, 1.4 D, and 2.0 D of both rPET and vPET fibres.

To blend rPET with Modal and vPET with Modal fibres, each of the two components underwent manual opening and thorough mixing to achieve a homogeneous blend. A predetermined quantity of manually blended fibres was then hand-fed to C-1/3 of LMW carding machine to prepare card sliver of 0.1hank. The conversion to drawn sliver was executed using an LMW draw frame DO-6, with two drawing passages given to the card sliver. The finisher sliver, obtained with a linear density of 0.1 hank, was then converted into 1.0 hank roving on Lakshmi Rieter's LF-1600. This roving was utilized to produce 19.6 tex yarn on Lakshmi Rieters' LR-5 ring frame, employing a spindle speed of 16,000 rpm.

All the yarns were tested for single strand strength, breaking extension, yarn irregularity, yarn imperfections and hairiness.

2.3 Fibre Test Results

To evaluate the chemical composition, molecular structure, thermal and tensile characteristics of rPET and vPET fibers, the test were performed utilizing Fourier Transform Infrared-Attenuated Total Reflection spectroscopy (FTIR-ATR), thermo-gravimetric analyser (TGA), differential scanning calorimetry (DSC), and a tensile testing apparatus universal tensile machine (UTM).

FTIR-ATR tests were conducted on a Perkin-Elmer spectrophotometer (M-2000) within 4000–500 cm^{-1} at 4 cm^{-1} resolution and 32 scans for each spectrum were taken and averaged and analyze the functional groups and polymer chain conformation in rPET and vPET fibers. From Figure 1, both polyesters showed similar FTIR spectra, with an aromatic C-H bond peak at 745 cm^{-1}, a C=O (ester) double bond peak at 1780–1720 cm^{-1}, and a C-O-C (ester) single bond peak at 1290–1180 cm^{-1}. Thus, rPET and vPET fibers exhibit nearly identical functional groups

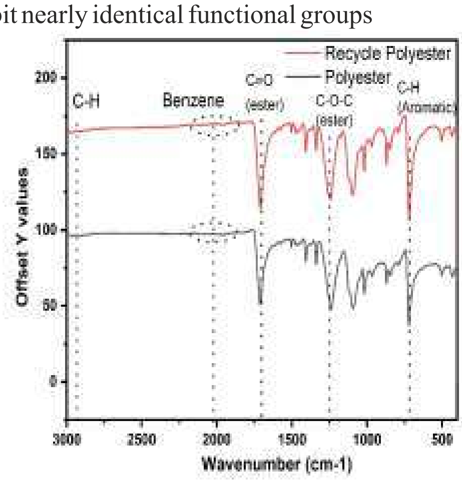


Figure 1: ATR-FTIR spectrum of rPET (red) and vPET (black) fibres

The thermal stability of rPET and vPET fibers was evaluated using TGA and DTGA on a Perkin-Elmer Pyris 6 instrument. Samples (5 mg each) were heated from 30°C to 600°C at 10°C/min. Both fibres showed similar thermal degradation behaviour (Figure 2 and 3), with vPET having a slightly higher Tonset than rPET, as seen in the TGA thermograms. Both exhibited single-step degradation, with rPET experiencing greater weight loss, likely due to a higher fraction of short-chain molecules.

The DTGA curves (Figure 4) showed nearly overlapping Tdmax values, differing by only 0.5–0.1%/°C. The slightly higher DTGA peak intensity for vPET is attributed to longer chain lengths, while rPET displayed lower intensity. Both polyesters have comparable polydispersity, as indicated by the similar full width at half maximum of their DTGA peaks.

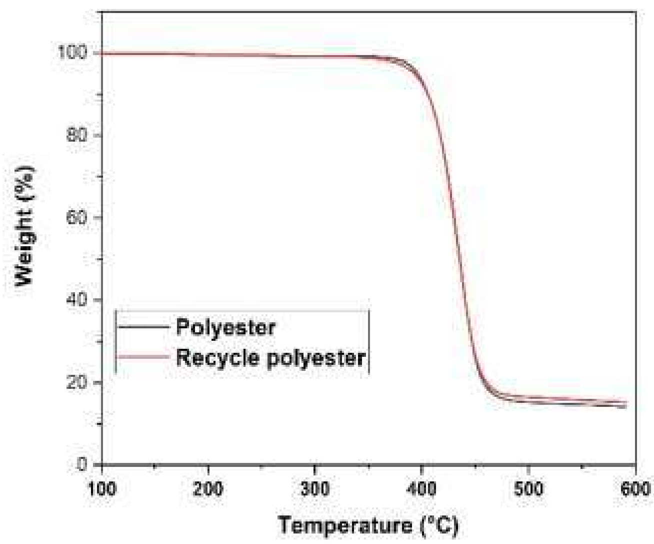


Figure 2: TGA curve of vPET and rPET Fibre

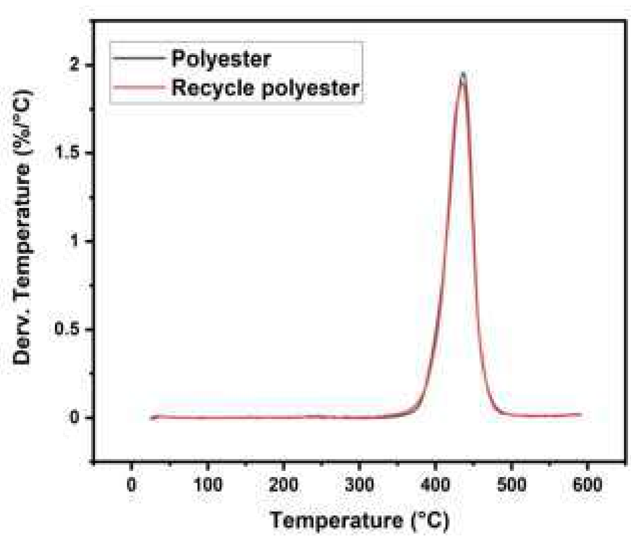


Figure 3: DTGA curve of vPET and rPET Fibre

Thermal properties, including melting temperature (Tm), glass transition temperature (Tg), crystallization temperature (Tc), and % crystallinity (χc), were analyzed using a Differential Scanning Calorimetry, DSC Q200 instrument.

Samples were subjected to a heating cycle from 30–300°C (scan-a) and cooled back to 30°C (scan-b) at a rate of 10°C/min. Crystallinity (χc) was calculated using ΔHm is the sample's melting enthalpy and ΔHm° is the melting enthalpy of 100% crystalline PET (140 J/g) [27].

$$\chi_c = \frac{\Delta Hm}{\Delta Hm^\circ} \times 100 \text{ .... eq. (1)}$$

As shown in Table 2 and Figure 4 (a) & (b), rPET exhibited slightly higher crystallinity, faster crystallization, and lower Tg, Tc, and Tm compared to vPET. The faster crystallization in rPET is attributed to its increased amorphous fraction, which aids crystalline lamella organization. The higher Tm of vPET (251°C) versus rPET (246°C) is likely due to its greater average molecular weight.

Table: 2 DSC Results for Tg, Tm, Tc, and Crystallinity (%) of rPET & vPET Fibres

Sample	T_g (°C)	T_m (°C)	Heat of Enthalpy (J/g)	T_c (°C)	Crystallinity (%) χ_c
rPET	94.6	246	40.49	211.3	28.57
vPET	95.3	251	38.51	215.9	27.50

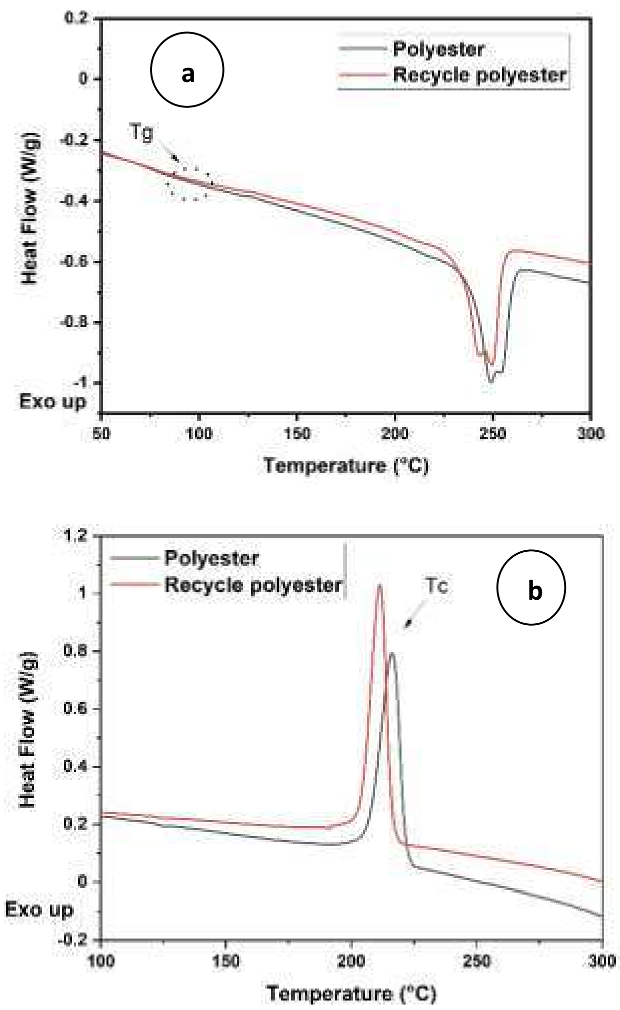


Figure 4: DSC thermograms scan (a) for heating and scan (b) for cooling

3. Results and Discussion

3.1 Tenacity

To evaluate the tensile properties of the yarns, single strand strength and breaking extension tests were conducted using an Instron testing machine (Model 4411) in compliance with ASTM D2256. Gauge length of each yarn sample length was kept 500 mm, and the extension rate was set to ensure the specimen broke within a controlled time frame of 20±2 seconds. For reliability of results 50 observations were taken and averaged.

Table 3 shows the results of the tensile test. The results show (Figure 5) that there are marked differences between the yarns spun with different fibre type, composition and fineness. Amongst all yarn combinations, both type of 100% polyester yarns, show maximum breaking strength, obviously it is due to higher strength of polyester than modal, Furthermore increase in modal content in blend composition results in lowering the resultant yarn strength because of modal fibre comparatively weaker than both type of polyester fibre. On analyzing the strength of rPET yarns with their vPET counter parts, the tenacity of rPET yarns is found to be significant higher; it may be due to higher value of crystallinity percentage and intrinsic viscosity fibres. While, on considering fibre fineness factor, it noticeably affects the yarn strength in all fibre blends. As the decrease in fibre diameter leads to improved breaking strength it is due to more frictional resistance provided by fine fibres against slippage and also because of higher tenacity of fine fibres.

Table 3: Influence of blend ratio and fibre fineness on Tenacity (cN/Tex) of rPET/Modal and vPET/Modal ring spun yarns

Fibre type	Fibre Fineness / Blend Ratio	F_1 1.2D	F_2 1.4D	F_3 2.0D
rPET/Modal	100/00	33.57	32.08	29.43
	65/35	26.85	26.07	24.16
	35/65	21.1	20.63	19.66
vPET/Modal	100/00	29.2	28.55	26.47
	65/35	24.32	23.71	21.84
	35/65	19.59	18.98	18.13

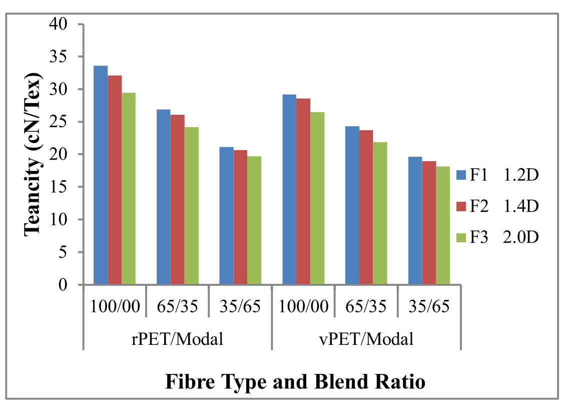


Figure 5: Influence of blend ratio and fibre fineness on Tenacity (cN/Tex) of

3.2 Breaking Extension

As expected, in both types of rPET/Modal and vPET/Modal yarns an increase in modal content in the fibre mix results in decrease of breaking extension due to lower breaking extension of modal fibre. The maximum breaking extension is shown by 100% rPET yarns and followed by 100% vPET yarns and trend remain same for all fibre finenesses. Obviously, it is due to higher breaking extension of rPET fibres. For all fibre mix, the fineness of fibre also affects the breaking extension, as the denier of both types of polyester rises that leads to increase in breaking extension.

Table 4: Influence of blend ratio and fibre fineness on breaking extension (%) of rPET/Modal and vPET/Modal ring spun yarns

Fibre Type	**Fibre Fineness / Blend Ratio**	**F_1 1.2D**	**F_2 1.4D**	**F_3 2.0D**
rPET/Modal	100:0	12.41	12.89	13.56
	65:35	10.36	10.87	11.31
	35:65	8.29	8.76	9.31
vPET/Modal	100:0	12.08	12.74	13.31
	65:35	10.12	10.55	10.93
	35:65	8.07	8.59	8.98

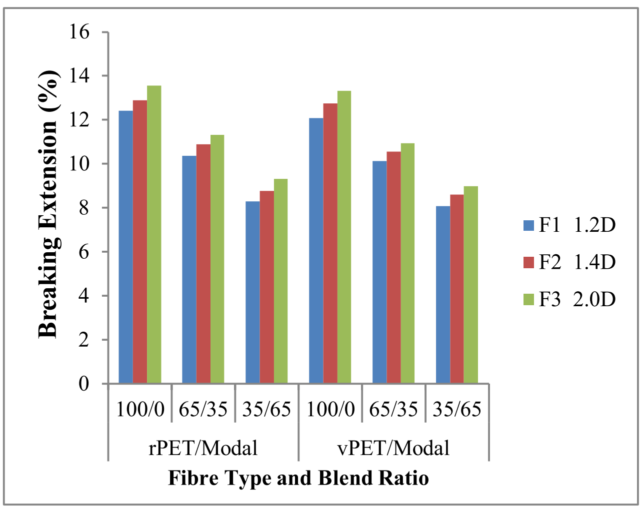


Figure 6: Influence of blend ratio and fibre fineness on breaking extension of rPET/Modal and vPET/Modal ring spun yarn

3.3 Mass Irregularity

Yarn evenness, which reflects variations in thickness and mass, was analyzed using the Uster Evenness Tester (UT-III). Yarn test speed was kept for 50m/min for one minute and ten observation performed. The yarn irregularity (U%) of rPET and vPET containing both type of yarns ranges from 10.56% to 14.74% and 10.03% to 14.36%, respectively. In both types of fibre blends, an increase in fibre linear density leads to a significant rise in yarn unevenness. This is primarily due to the reduction in number of fibres in the yarn cross-section and due to increase in fibre denier. Additionally, as the modal content increases in all fibre compositions, there is a noticeable rise in mass irregularity. The reason can be attributed to comparatively high flexibility and lower smoothness of modal than polyester fibres; which tends to increase irregularity when blended with polyester fibres. However, when comparing the rPET yarns across various fibre blends to their vPET counterparts, the rPET yarns exhibit higher unevenness. This difference may be attributed to the variation in stiffness and linear density of rPET fibres compared to vPET fibres.

Table 5: Influence of blend ratio and fibre fineness on Mass Irregularity (U %) of rPET/Modal and vPET/Modal ring spun yarns

Fibre type	Fibre Fineness / Blend Ratio	F_1 1.2D	F_2 1.4D	F_3 2.0D
rPET/Modal	100/0	10.56	11.86	12.85
	65/35	11.65	12.79	13.81
	35/65	12.98	13.63	14.74
vPET/Modal	100/0	10.03	11.32	12.49
	65/35	11.21	12.32	13.47
	35/65	12.19	13.18	14.36

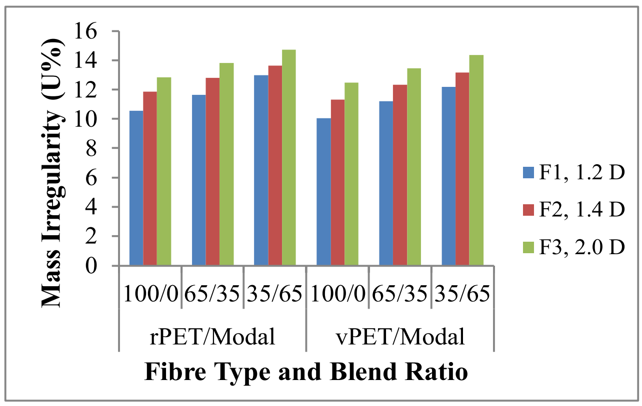


Figure 7: Influence of blend ratio and fibre fineness on Mass Irregularity of rPET/Modal and vPET/Modal ring spun yarns

3.4 Imperfections

From Table 6 and Figure 8, it is evident that for both rPET/modal and vPET/modal blended yarns, the number of imperfections increases as the modal content in the blend rises. This trend can likely be attributed to the higher probability of modal fibre breakage during the spinning process, resulting in the generation of short fibres. Furthermore, an increase in fibre denier is associated with a rise in the occurrence of thin and thick places in both fibre blends, which can be explained by a reduction in the number of fibres within the yarn cross-section. Conversely, a decrease in neps is observed with increasing fibre denier, likely due to the higher bending rigidity of coarser fibres.

When comparing yarns containing rPET to those containing vPET across all blend ratios and fibre fineness levels, rPET-containing yarns exhibit significantly higher imperfections. This difference can be attributed to the variations in stiffness and linear density between rPET and vPET fibres.

Table 6: Influence of blend ratio and fibre fineness on Total Imperfections/km of rPET/Modal and vPET/Modal ring spun yarns

Fibre type	Blend Ratio	Thin Places/km (-50%)			Thick Places/km (+50%)			Neps/km (+200%)			Total Imperfections/km		
		F_1 1.2D	F_2 1.4D	F_3 2.0D	F_1 1.2D	F_2 1.4D	F_3 2.0D	F_1 1.2D	F_2 1.4D	F_3 2.0D	F_1 1.2D	F_2 1.4D	F_3 2.0D
rPET/ Modal	100/00	9	11	12	21	31	39	105	87	76	135	129	127
	65/35	11	14	16	29	38	43	131	116	101	171	168	160
	35/65	15	17	19	37	46	55	183	168	139	235	231	213
vPET/ Modal	100/00	8	13	10	27	20	36	85	57	61	113	106	98
	65/35	10	12	16	31	34	40	118	93	71	159	139	127
	35/65	14	15	18	33	40	51	170	132	120	217	187	189

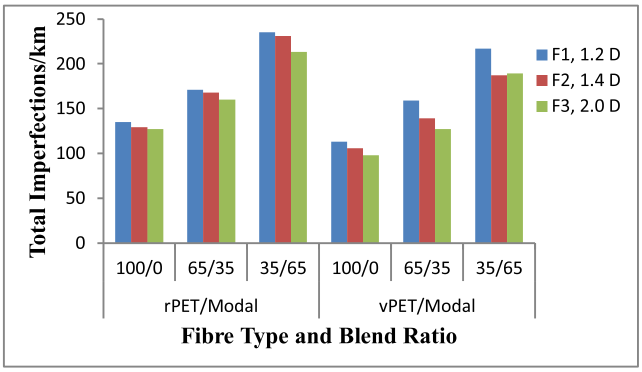


Figure 8: Influence of blend ratio and fibre fineness on Total Imperfections/km of rPET/Modal and vPET/Modal ring spun yarns

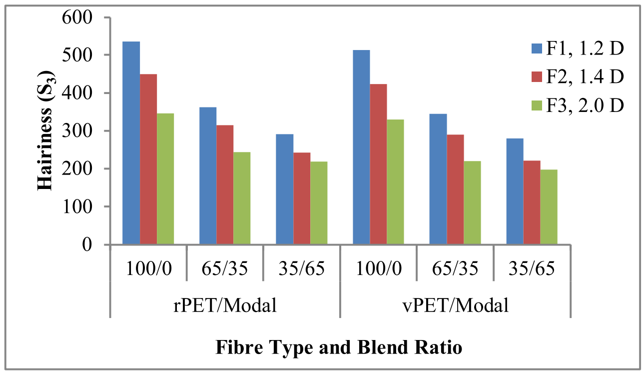


Figure 9 : Influence of blend ratio and fibre fineness on Hairiness (S3) of rPET/Modal and vPET/Modal ring spun yarns

3.5 Hairiness

The hairiness results of the yarns are presented in Table 7 and Figure 9. The 100% rPET yarns exhibit the highest hairiness, while a significant reduction in hairiness is observed as the modal content increases in both types of fibre blends. Yarns containing finer fibres, show greater hairiness, attributed to the higher number of fibres in the yarn cross-section. However, rPET containing yarns have higher S3 values compared to their vPET counterparts, which may be linked to the increased stiffness of rPET fibres, as indicated by their higher percentage crystallinity.

Table 7: Influence of blend ratio and fibre fineness on Hairiness (S3) of rPET/Modal and vPET/Modal ring spun yarns

Fibre type	Fibre Fineness / Blend Ratio	F_1 1.2D	F_2 1.4D	F_3 2.0D
rPET/Modal	100/0	536	449	346
	65/35	362	315	244
	35/65	291	242	218
vPET/Modal	100/0	513	423	329
	65/35	345	289	220
	35/65	279	221	197

4. Conclusions

This study comprehensively compared the properties of recycled polyester (rPET) and virgin polyester (vPET) fibres and their impact on blended ring-spun yarns. Results showed that rPET exhibited higher tenacity and elongation at break than vPET, with nearly identical functional groups confirmed by FTIR. Thermal analysis indicated that rPET had slightly higher crystallinity, a faster crystallization rate, and lower transition temperatures (Tg, Tc, Tm) than vPET.

The tensile properties of rPET/modal and vPET/modal blended yarns were significantly influenced by fibre type, fineness, and blend ratio. 100% rPET yarns demonstrated higher tenacity than 100% vPET yarns despite exhibiting greater elongation at break. An increase in modal content in both fibre blends led to a reduction in tensile strength and elongation. Furthermore, as fibre denier increased in both rPET and vPET yarns, tenacity decreased while elongation at break improved.

Variations in fibre linear density affected yarn uniformity, with higher fibre denier leading to increased yarn unevenness. While the presence of thin and thick places increased with fibre denier, a reduction in neps was observed. Both rPET/modal and vPET/modal blended yarns exhibited greater yarn unevenness and total imperfections as modal content increased. Additionally, across different fibre blends, rPET yarns consistently displayed higher unevenness (U %) and significantly more imperfections than vPET yarns.

Hairiness measurements indicated that 100% rPET yarns had the highest hairiness, which decreased with greater modal content in both fibre blends. Finer fibres contributed to increased hairiness, while rPET yarns exhibited higher S3 values compared to their vPET counterparts. These findings highlight the influence of fibre composition and structural properties on the overall quality and performance of rPET and vPET blended yarns.

References

[1] Leng, Z., Padhan, R. K., & Sreeram, A. (2018). Production of a sustainable paving material through chemical recycling of waste PET into crumb rubber modified asphalt. Journal of cleaner production, 180, 682-688 https://doi.org/10.1016/j.jclepro.2018.01.171

[2] Preferred Fibre & Materials Market Report (2023). Textile Exchange, December 2023, 56-59, https://textileexchange.org/knowledge-center/reports/materials-market-report-2023/

[3] Shen, L., Worrell, E., & Patel, M. K. (2010). Open-loop recycling: A LCA case study of PET bottle-to-fibre recycling. Resources, conservation and recycling, 55(1), 34-52, https://doi.org/10.1016/j.resconrec.2010.06.014

[4] Suhaimi, N. A. S., Muhamad, F., Abd Razak, N. A., & Zeimaran, E. (2022). Recycling of polyethylene terephthalate wastes: A review of technologies, routes, and applications. Polymer Engineering & Science, 62(8), 2355-2375, https://doi.org/10.1002/pen.26017

[5] Kayaisang, S., Saikrasun, S., & Amornsakchai, T. (2013). Potential use of recycled PET in comparison with liquid crystalline polyester as a dual functional additive for enhancing heat stability and reinforcement for high density polyethylene composite fibers. Journal of Polymers and the Environment, 21, 191-206, https://doi.org/10.1007/s10924-012-0446-1

[6] Awaja, F., & Pavel, D. (2005). Recycling of PET. European polymer journal, 41(7), 1453-1477, https://doi.org/10.1016/j.eurpolymj.2005.02.005

[7] Olabisi, O., & Adewale, K. (Eds.). (2016). Handbook of thermoplastics. CRC press

[8] Scheirs J. (1998) Polymer recycling, science, technology and application. John Wiley and Sons Ltd.

[9] Benyathiar, P., Kumar, P., Carpenter, G., Brace, J., & Mishra, D. K. (2022). Polyethylene terephthalate (PET) bottle-to-bottle recycling for the beverage industry: a review. Polymers, 14(12), 2366, https://doi.org/10.3390/polym14122366

[10] MdG. Kibria, N.I. Masuk, R. Safayet, H.Q. Nguyen, M. Mourshed, Plastic waste: challenges and opportunities to mitigate pollution and effective management, Int. J. Environ. Res. 17 (2023) 20, https://doi.org/10.1007/s41742-023-00507-z

[11] Edge, M., Hayes, M., Mohammadian, M., Allen, N. S., Jewitt, T. S., Brems, K., & Jones, K. (1991). Aspects of poly (ethylene terephthalate) degradation for archival life and environmental degradation. Polymer degradation and stability, 32(2), 131-153. https://doi.org/10.1016/0141-3910(91)90047-U

[12] Senthil Kumar, P., & Janet Joshiba, G. (2020). Properties of recycled polyester. Recycled Polyester: Manufacturing, Properties, Test Methods, and Identification, 1-14, https://doi.org/10.1007/978-981-32-9559-9_1

[13] Majumdar, A., Shukla, S., Singh, A. A., & Arora, S. (2020). Circular fashion: Properties of fabrics made from mechanically recycled poly-ethylene terephthalate (PET) bottles. Resources, Conservation and Recycling, 161, 104915, https://doi.org/10.1016/j.resconrec.2020.104915

[14] ASTM International. Standard Practice for Coding Plastic Manufactured Articles for Resin Identification; ASTM International: West Conshohocken, PA, USA, 2020; (D7611/D7611M-20), https://blog.ansi.org/2020/03/astm-d7611-20-resin-identification-code-ric/

[15] Amos, J. M. (1993). Cleaning up the waste stream--recycling plastics (1993), https://extension.missouri.edu/publications/wm2

[16] Miller, C. H. A. Z. (2002). Polyethylene Terephthalate. Waste Age, 33(5), 102-106

[17] Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2115-2126, https://doi.org/10.1098/rstb.2008.0311

[18] Jankauskaite, V., Macijauskas, G., & Lygaitis, R. (2008). Polyethylene terephthalate waste recycling and application possibilities: a review. Mater Sci (Medžiagotyra), 14(2), 119-127

[19] Abbasi, M., Mojtahedi, M. R. M., & Khosroshahi, A. (2007). Effect of spinning speed on the structure and physical properties of filament yarns produced from used PET bottles. Journal of applied polymer science, 103(6), 3972-3975, https://doi.org/10.1002/app.25369

[20] Vadicherla, T., & Saravanan, D. (2017). Effect of blend ratio on the quality characteristics of recycled polyester/cotton blended ring spun yarn. Fibres & Textiles in Eastern Europe, 25(2 (122), DOI 10.5604/12303666.1227875

[21] Uyanık, S. (2019). A study on the suitability of which yarn number to use for recycle polyester fiber. The Journal of the Textile Institute, 110(7), 1012-1031, https://doi.org/10.1080/00405000.2018.1550889

[22] Yuksekkaya, M. E., Celep, G., Dogan, G., Tercan, M., & Urhan, B. (2016). A comparative study of physical properties of yarns and fabrics produced from virgin and recycled fibers. Journal of Engineered Fibers and Fabrics, 11(2), 68–76, https://doi.org/10.1177/155892501601100

[23] Sarıoğlu, E. (2017). Ecological approaches in textile sector: the effect of r-PET blend ratio on ring spun yarn tenacity. Periodicals of Engineering and Natural Sciences (PEN), 5(2), pp. 176-180 DOI: 10.21533/pen

[24] Rajamanickam, S., & Vasudevan, K. (2014). Study of antibacterial activity of chitosan on lyocell and recycled polyester yarns. International Journal of Innovative Research in Science, Engineering and Technology, 3(2), 9480-9486, ISSN: 2319-8753

[25] Koo, H. J., Chang, G. S., Kim, S. H., Hahm, W. G., & Park, S. Y. (2013). Effects of recycling processes on physical, mechanical and degradation properties of PET yarns. Fibers and Polymers, 14, 2083-2087, https://doi.org/10.1007/s12221-013-2083-2

[26] Özdil, N., & Telli, A. (2013). Properties of the yarns produced from r-PET fibers and their blends. Textile and Apparel, 23(1), 3-10

[27] Wunderlich, B. (2005). Thermal analysis of polymeric materials. Springer Science & Business Media, ISBN 3-540-23629-5.-A systematic literature review." Optik 127, no. 24 (2016): 11960-11973. https://doi.org/10.1016/j.ijleo.2016.09.110

Impact of the Secondary Heater Temperature on the Properties of Draw Textured Yarn and its Fabric

B. Basu[1]* & R. N. Joshi[2]
[1]Retired General Manager, Reliance Industries Ltd. Silvassa.
[2]Department of Textile Technology, Shri Guru Gobind Singhji Institute of Engineering and Technology, Nanded

Abstract:
Synthetic yarn especially draw textured yarn (DTY) is increasingly favored worldwide due to its advantages, availability, and ease of production over natural fibers. The bulk of DTY plays a critical role in determining fabric properties, influenced significantly by the secondary heater temperature during manufacturing. In this direction, trials were conducted on an AFT-1100-11DD machine using 240/48 SD, DD polyester POY. Six trials were conducted by varying the secondary heater temperature while maintaining other parameters constant. Yarn tensions and fabric appearances were evaluated across different settings. It was observed that, an increase in the secondary heater temperature led to a reduction in bulk, decreased boiling water shrinkage (BWS %), and caused variations in surface appearance. Power consumption also escalated with higher temperatures. Yarn properties like denier, tenacity, and elongation remained consistent across trials, mitigating the secondary heater's role in stabilizing these yarn properties post-primary heating. The inverse effect of secondary heater temperature crucially influences the bulk and fabric behavior of DTY, which is significant for applications in the weaving and knitting industries. Higher secondary heater temperatures decrease the bulk and increase the yarn stability, impacting fabric aesthetics and performance metrics like air permeability and drape coefficient.

Keywords: *Air permeability, Bulk, Drape coefficient, Draw Textured Yarn, Secondary Heater Temperature*

Citation: B. Basu & R. N. Joshi, "Impact of the Secondary Heater Temperature on the Properties of Draw Textured Yarn and its Fabric", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),557-562, httpa://doi.org/10.5281/zenodo.14973990

Article Received :11-12-2024, Revised: 18-02-2025, Accepted: 22-02-2025

1. Introduction

The whole world is going after the usage of polyester yarn in every aspect of life because of the limitations in the cotton growing fields. The properties of the draw textured yarn (DTY) especially its bulk, play a crucial role in determining the end use and the fabric behavior. The structure and design of heating elements i.e. primary heater and secondary heater have been the subject of scientific research for many years. The main function of the heating elements is to heat the yarn to the desired temperature. They should also ensure that a constant temperature level is maintained over a longer period. This is necessary so that the reorganization of intermolecular bonds can take place beyond the glass transition temperature Tg of the polymer, while it is important to stay below the melting point Tm so that the yarn does not break [1]. It is reviewed that as such there will be no impact on the properties like denier, tenacity, and elongation as on the changing of the secondary heater temperature [2]. There will be an impact on HCC% (Hot Crimp Contraction %), BWS% (Boiling Water Shrinkage %), and surface appearance depending on the difference in the secondary heater temperature. The power consumption also increases as the secondary heater temperature increases. Hence the work is carried out to determine the various fabric characteristics of the DTY.

The role of the primary heater (PH) is to mobilize the molecules and give the desired yarn properties with the help of the Draw ratio and D: Y ratio [1]. Drawing in the heaters can develop molecular orientation significantly [3]. Secondary heaters are 'non-contact' or convective type i.e. in tubular form with limited surface contact on the running textured yarn. The secondary heater makes the texturized yarn stable for the subsequent process. Although the temperature of the secondary heater will be lower than the primary heater, but still morphological changes are expected to happen [4]. By increasing the secondary heater temperature, a significant reduction in the crimp value and residual torque of the yarn can be observed. It might be a physical phenomenon. The springiness or the flexibility of the yarn reduces with the increase of the secondary heater. It becomes stiffer. However, if the temperature of the secondary heater exceeds that of the primary heater, molecular reorientation will take place, and this can be observed through changes in the physical properties of the DTY.

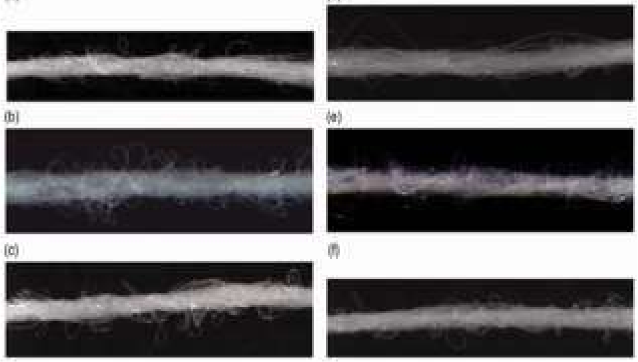


Figure 1 - Texturized yarn with low & uniform bulk [5]

Corresponding Author :
Mr. B. Basu,
Retired General Manager, Reliance Industries Ltd. Silvassa.
E-mail: bibekananda.basu1502@gmail.com

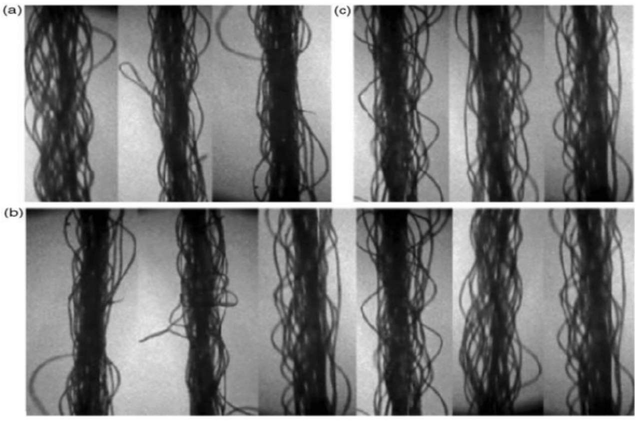


Figure 2 - Texturized yarn with high bulk [6]

The bulk of the DTY is formed after the twisting-untwisting zone which is desirable for the DTY. The quantity of the bulk is decided on the end uses. As the secondary heater temperature is increased, the yarn gets more shrink between the intermediate and output roller and hence the bulk becomes lesser. The secondary heater is to heat-set and stabilize the yarn surface [7]. Heat-setting is a heat treatment by which shape retention, crease resistance, resilience, and elasticity are imparted to the fibers. It also brings changes in strength, stretchability, softness, dyeability, and sometimes the color of the material [8].

2. Objective

In the Texturising Machine and that of the connecting Industries, there is no hard & fast rule in determining the temperature of the Primary and that of Secondary Heaters. It all decided by the Trial and error methods conducted by the departmental and that of QC Manager after knowing the end use of the DTY Products.

This experiment conducted in the floor level would be a great guidance for the Industrial workforce to know the impact of the Secondary heater setting vis-a vis yarn properties in a very comprehensive way. Hence this work is carried out to know the yarn properties in relation to secondary heater temperature. A higher difference in secondary heater temperature can also create the TKD (Tube knitting Dyeing) variation and there should not be much difference (not more than 20 degree Centigrade) in the same lot no.so far as the dyed fabric is concerned.

3. Materials and Methods

The conducted trial was arranged in AYM Syntex Limited, Silvassa who were kind enough to let us use the machine, POY spools, Manpower, and paper tubes. The available POY was 240/48 SD, DD (Bluish grey shade) CIR. The trials were conducted on three positions of the machine.

Tensions were measured at positions 1, 2, and 3, with average values denoted as T1, T2, and T3 respectively. For each trial, the values of T1, T2, T3, and the T2/T1 ratio were recorded and are listed in Table 4.

Table 1 - Texturizing machine specifications and its parameters

Machine Specifications	
Length of the Primary Heater	1750 mm
Secondary Heater	1450 mm
length of the cooling plate	1200 mm
Primary Heater tube Inner Diameter	7 mm
Secondary Heater tube Inner Diameter	4 mm
1-4-1 PU disc diameter	54 mm
1-4-1 PU disc thickness	9 mm
Machine Parameters	
Machine Speed	600 mpm
D:R ratio	1.73
D:Y ratio	1.90
Primary Heater Temperature	190^{0}C
Secondary Heater Temperature	Varying
SOF	1.095
Take up	1.068
CPM	300
Spindle speed	3356 rpm
Oil roller speed	1.30 mpm

Table 2 - POY Properties

Denier	240.99
Elongation %	147.08
Tenacity	2.64 gpd
U%	1.18
DF	67.18
BWH	65.62
Nips/meter	4.5
Spin finish %	0.48

Table 3 - Experimental details regarding eater temperatures

Trial No.	PH Temperature	SH Temperature
1	190^{0}C	150^{0}C
2	190^{0}C	165^{0}C
3	190^{0}C	180^{0}C
4	190^{0}C	200^{0}C
5	190^{0}C	210^{0}C
6	190^{0}C	80^{0}C

Table 4 - The average value of tensions in the yarn at three different machine positions with varying secondary heater temperature

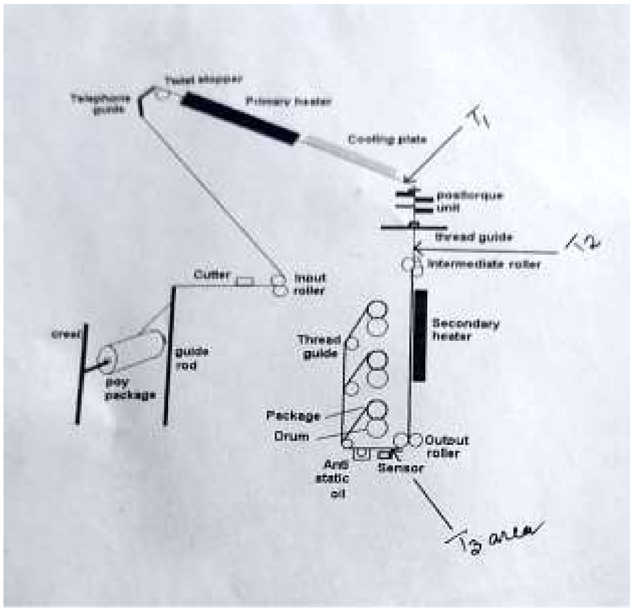
Trial No.	Avg T_1	Avg T_2	Avg T_3	T_2/T_1
1	61.67	50.33	27.33	0.82
2	61.00	50.33	31.67	0.83
3	63.00	51.00	31.00	0.80
4	61.33	51.00	31.00	0.83
5	59.33	45.33	29.67	0.76
6	61.00	53.00	24.33	0.87

From Table 4, it can be observed that there is no significant difference in T1, T2, and T2/T1 ratio as these phenomena occur before the secondary heater. The T3 value was found to be lowest in 80^{0}C as the yarn becomes slack after the delivery roller. It is to be noted that the take-up speed was adjusted to maintain the package hardness in accordance with the other parameters.

For the reference, please the sketch drawn of a Texturisation machine

4. Results and Discussion

All six sample packages were tested in AYM Syntex Limited's Laboratory, Silvassa and the results are displayed in Table 5.



Sketch of a texturising machine where the location of the T1, T2 and T3 are shown

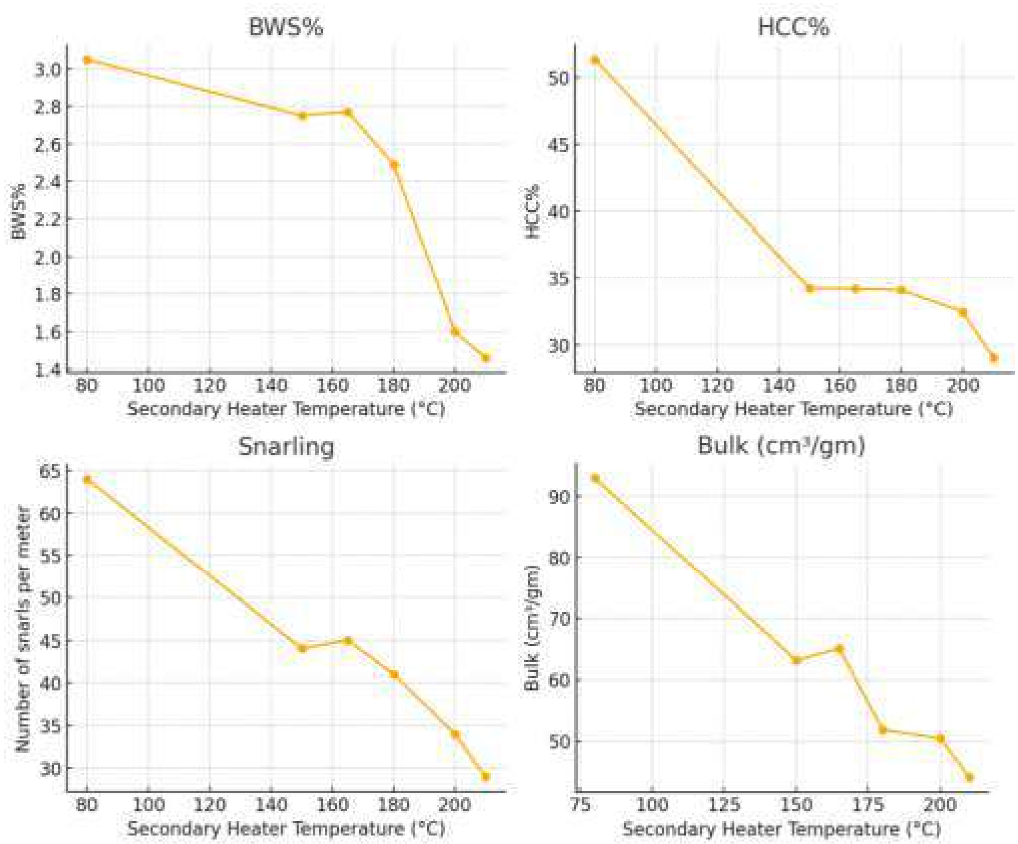


Figure 3 - Variation of DTY properties as a function of secondary heater temperature

Table 4 - The average values of draw textured yarn properties at various secondary heater temperatures

Trial No.	PH/SH Temp (°C)	Avg Denier	Avg Tenacity (gm/denier)	Avg Elongation %	BWS%	HCC%	Snarling (number of snarls/meter)	Bulk (cm^3/gm)
1	190/150	151.5	4.19	24.63	2.75	34.22	44	63.21
2	190/165	150.4	4.24	24.19	2.77	34.18	45	65.10
3	190/180	152.3	4.17	25.36	2.49	34.08	41	51.90
4	190/200	150.7	4.22	25.47	1.6	32.45	34	50.48
5	190/210	152.4	4.13	25.5	1.46	29.06	29	44.21
6	190/80	149.9	4.4	25.19	3.05	51.35	64	92.97

The analysis of variation of the properties as a function of secondary heater temperature reveals several key trends. From Table 5 as well as from Figure 3, 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 [9]. 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.

4.1 Hose Knitting

Hose knitted samples were prepared by using the DTY samples to evaluate their comparative characteristics, including appearance, bulk variations, dye uptake, and the presence of defects such as tight spots and broken filaments. This process is crucial for categorizing DTY packages and determining their appropriate grade. It serves as an essential parameter for assessing the quality and uniformity of DTY products. Typically, around 40 meters of yarn from each DTY package is knitted using a hose knitting machine. A flat wooden plate is then inserted into the knitted hose to ensure proper surface tension, which is essential for achieving a clear and accurate appearance. Comparative analyses are conducted based on these observations. The accompanying images depict the hose knitting of all six samples.

It should be noted that the above hose-knitted samples were created from the samples of the DTY and were given the sample numbers with respect to the sample numbers of the DTY in accordance with their secondary heater temperatures. From Figure 4, it can be observed that Sample 5 appears slightly lighter compared to Sample 1, while Sample 6 appears darker. The darker appearance of Sample 6 is attributed to its higher volumetric structure, which contributes to a greater light absorption, hence a darker visual impression. It is a physical phenomenon. Additionally, Samples 4 and Sample 5 appear lighter than Samples 1, 2, and 3, which can be explained by the fact that the secondary heater temperature is higher as compared to the primary heater temperature in Samples 4 and Sample 5. The elevated SH temperature leads to a molecular reorientation in the yarn, affecting its appearance and resulting in a lighter color.

4.2 Woven Fabric analysis

A Sulzer double-width loom (40 inches + 40 inches) was used to prepare the plain-woven samples with the following specifications: Speed- 250 rpm. Reed: 52/2, Picks/inch: 56. A polyester double yarn of 40 Ne/65 D was used as warp yarn with 60 Ends/inch. The DTY samples were used as weft for the preparation of all six plain-woven samples. These woven samples were then tested for air permeability and drapability of the fabric. After doffing the cloth from the loom, the width of all woven samples was checked on the checking table and was found in the range of 38.9 – 39.2 inches. No significant difference was observed among the widths of the grey fabric.

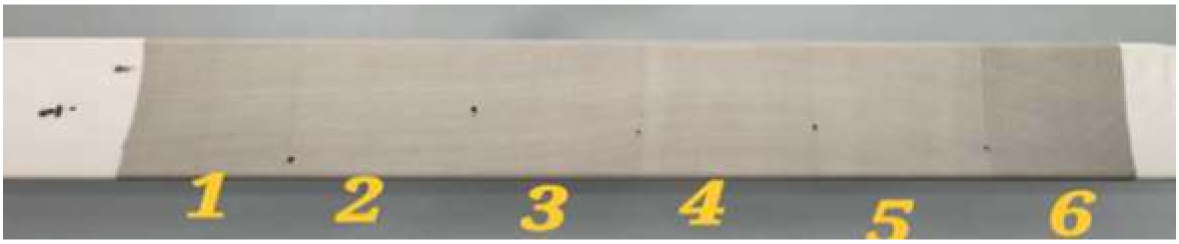


Figure 4 - Hose knitted fabric

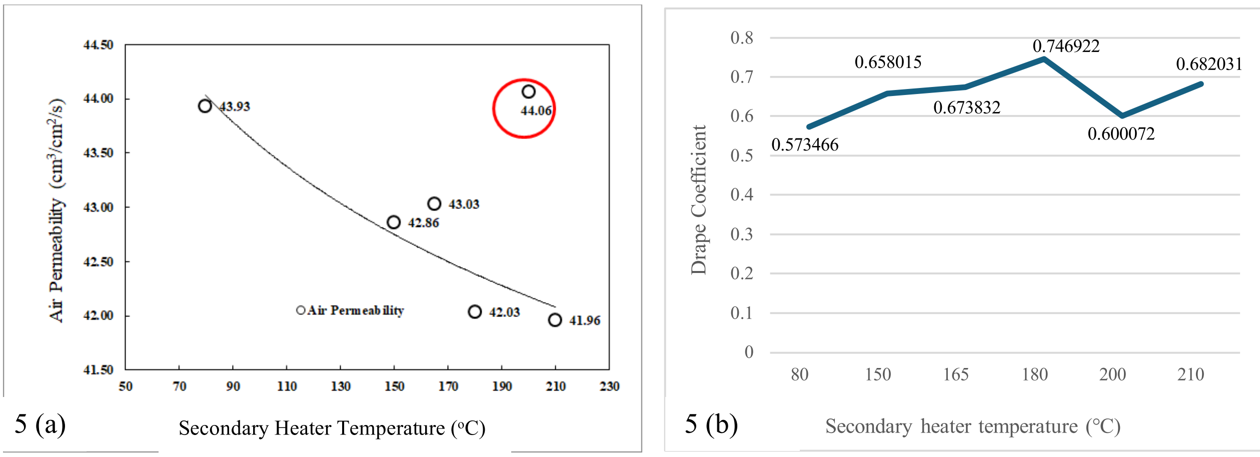


Figure 5 - Impact of Secondary Heater Temperature on (a) Air Permeability and (b) Drape Coefficient of the Fabric incorporating DTY as a Weft

4.3 Air Permeability

Figure – 5 (a) illustrates that the air permeability in the yarn decreases as the secondary heater temperature increases. The result at a secondary heater temperature of 200°C shows some deviation, which may be due to experimental error.

4.4 Drape Coefficient

The Cusick Drape Tester was used to measure the three-dimensional drape of fabric under the influence of gravity. The procedure involved suspending a fabric specimen with a 15 cm radius over a supporting disc of a 9 cm radius. A parallel light source within the drape tester projected the shadow of the draped specimen onto a piece of paper. This shadow pattern was then traced, and the drape coefficient was calculated based on the traced pattern and formula.

Figure 5 (b) and Table 6 illustrate that, generally, an increase in secondary heater temperature corresponds to a higher drape coefficient. However, the sample at 200°C exhibits a lower drape coefficient than expected, although it is higher than that at 80°C.

Table 5 - Average Drape coefficient values at various Secondary Heater Temperatures

Woven Sample No.	area of large disk (W_0)	area of small disk (W_1)	Projected area of the sample (W_S)				Drape Coefficient = $(W_S-W_1)/(W_0-W_1)$
			Observation 1	Observation 2	Observation 3	Mean	
1	490.6	122.65	364.40	365.1	364.8	364.767	0.658015129
2	490.6	122.65	370.64	371.23	369.89	370.587	0.673832495
3	490.6	122.65	397.71	398.22	396.51	397.480	0.746922136
4	490.6	122.65	343.57	342.65	344.12	343.447	0.600072474
5	490.6	122.65	372.73	373.96	374.12	373.603	0.682031073
6	490.6	122.65	333.16	335.23	332.58	333.657	0.573465598

5. Conclusion

The secondary heater in a texturizing machine plays a crucial role in determining the bulk variation of yarn, which is vital for its end use. As the secondary heater temperature increases, the bulk of the yarn decreases. If the temperature of the secondary heater exceeds that of the primary heater, molecular reorientation occurs, resulting in variation in dye uptake. However, physical properties such as denier, tenacity, and elongation are not affected by the secondary heater temperature. As the secondary heater temperature increases, the air permeability of the fabric incorporating DTY as a weft decreases. Higher secondary heater temperatures also lead to a higher drape coefficient, indicating that the fabric is becoming stiffer and exhibits poorer drapability. For applications requiring high strength and volume, lower secondary heater temperatures (e.g., 80°C) are preferable as they provide higher tenacity and bulk. For applications requiring dimensional stability, higher secondary heater temperatures (e.g., 200-210°C) are suitable as they result in lower BWS%, HCC%, and snarling. All parameters (BWS%, HCC%, number of snarls, and bulk) show a clear decreasing trend with increasing secondary heater temperature, indicating that higher temperatures lead to a more compact, less shrinkable, and less snarled material. In conclusion, the secondary heater temperature significantly influences the bulk and other characteristics of the yarn, underscoring its importance in the texturizing process.

References

[1] Ortega M., Saynisch A., Yurtseven B. M., Gries T., A Review on False-Twist Texturing. Fibers, 12, 36, April 2024. https://doi.org/10.3390/ fib12040036

[2] B. Basu, The role of secondary heater in deciding yarn characteristics in texturising machine. Article on ResearchGate, Vol. 72, pp. 168-170, September 2011

[3] Yildirim K, Altun S, Ulcay Y., Relationship between Yarn Properties and Process Parameters in False-Twist Textured Yarn, Journal of Engineered Fibers and Fabrics, Vol. 4 (Issue 2), pp. 26-32, 2009. DOI: 10.1177/155892500900400205

[4] Prof. Kushal Sen, Draw Texturizing machines and process parameters, Module 7, online NPTEL course on Textured yarn Technology (video), Indian Institute of Technology Delhi. https://archive.nptel.ac.in/courses/116/102/116102053/

[5] Serpic Koral Koc, Diren Mecit, Bekir Boyaci, Munire Ornek and Asli Hockenberger, Effects of filament cross section on the performance of automotive upholstery fabrics, Journal of Industrial Textiles, Vol. 46, September 2016. DOI: 10.1177/1528083715598652

[6] Tasnim N Shaikh, Satyajeet Chaudhari and Alpa Varma, Mechanical crimp texturizing of non-thermoplastic viscose rayon yarn, Textile Research Journal, Vol. 84(10), pp. 1034-1043, June 2014, DOI: 10.1177/0040517513517967

[7] J W S Hearle, L Hollick and D K Wilson, Yarn texturing technology, 1st ed., Cambridge England; Woodhead Publish Limited: 2001: pp. 16-40

[8] S.R. Karmakar, Chapter 8: Heat-Setting, Textile Science and Technology, Elsevier, Volume 12, 1999, Pages 259-278, ISSN 0920-4083, ISBN 9780444500601, https://doi.org/10.1016/S0920-4083(99)80009-7

[9] Bhambure, S.D. & Dhavale, A.J. & Kadole, (Dr.) P & Nagla, J.R., Effect of process parameters on draw textured polyester yarn properties, article on ResearchGate, Vol. 44. pp. 39-43, November 2013

■ ■ ■

Analysis and Optimization of Textile-Reinforced Composites for Automotive Applications: Design, FEA & Validation

G. C. Mekalke & Raghavendra Subramanya*
Department of Mechanical Engineering, Sai Vidya Institute of Technology, Bengaluru

Abstract:
This study focuses on the design, analysis, and optimization of textile-reinforced composite materials for automotive applications, specifically targeting bumper brackets. The novelty of this work lies in the integration of carbon fiber, glass fiber, and hybrid composites using the hand lay-up method, coupled with advanced finite element analysis (FEA) to validate their structural performance. The methodology involved redesigning the bumper bracket using CATIA V5, fabricating composite samples, and conducting tensile tests to evaluate mechanical properties. FEA in ANSYS Workbench was employed to analyze stress distribution and deformation under operational loads. Results demonstrated that carbon fiber-reinforced polymer (CFRP) achieved a tensile strength of 1330 N/mm², with an 84% weight reduction compared to traditional steel brackets. The study concludes that textile-reinforced composites, particularly CFRP, offer significant weight optimization and high mechanical performance, making them ideal for lightweight automotive applications. Hybrid composites also present a cost-effective alternative for secondary structural components.

Keywords: *Carbon Fiber, Composite Materials, Glass Fiber, Stress Analysis, Technical Textiles*

Citation: G. C. Mekalke & Raghavendra Subramanya, "Analysis and Optimization of Textile-Reinforced Composites for Automotive Applications: Design, FEA & Validation", *Journal of the Textile Association*, **85/5**(Jan-Feb'25),563-570, https://doi.org/10.5281/zenodo.14974122

Article Received :26-01-2025, Revised: 23-02-2025, Accepted: 27-02-2025

1. Introduction

Textile-reinforced composite materials are revolutionizing engineering applications due to their lightweight properties and exceptional mechanical strength. Industries such as automotive and aerospace are increasingly adopting these materials to achieve weight reduction without compromising performance. Weight optimization is critical for improving fuel efficiency and reducing costs, particularly for structural components like bumper brackets that must withstand significant stress and deformation [1].

Traditionally, metals like steel and aluminum have been favored for such applications due to their strength and durability. However, advancements in textile composite technology have introduced alternatives such as carbon fiber and glass fiber reinforced with epoxy matrices. These composites offer superior strength-to-weight ratios, enhanced corrosion resistance, and greater design flexibility [2].

This study examines the design, analysis, and validation of textile-reinforced composite bumper brackets, with an emphasis on weight reduction and mechanical performance. The objectives of this work are:

i. To analyze stress distribution and deformation in textile-based composite and conventional brackets using Finite Element Analysis (FEA).

ii. To validate FEA findings with experimental tensile testing.

iii. To assess the feasibility of hybrid textile composites as a cost-performance optimization strategy.

The growing adoption of fiber-reinforced polymers (FRPs), such as carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP), in the automotive sector highlights their potential as viable alternatives to traditional metals [3]. Studies have shown that CFRP structures can achieve a 30-50% weight reduction while maintaining equivalent strength to traditional materials, underscoring their efficiency in engineering applications [4].

2. Literature Review

Textile-Reinforced Composites in Structural Applications, Textile-reinforced composites are increasingly replacing traditional materials in structural applications due to their superior strength-to-weight ratios, corrosion resistance, and design flexibility. In the automotive sector, fiber-reinforced polymers (FRPs), such as carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP), have emerged as viable alternatives to metals like steel and aluminium [3].

Composite Materials in Structural Applications, highlighted the pivotal role of textile-based advanced composites in modern structural designs, emphasizing the growing adoption of CFRP and GFRP in aerospace and automotive industries due to their lightweight properties [4]. Zhang et al. demonstrated that CFRP structures achieve a 30–50% weight reduction while maintaining equivalent strength to traditional materials, underscoring their efficiency in engineering applications [5].

Stress and Deformation Analysis, Finite Element Analysis (FEA) is a crucial tool for assessing the mechanical behavior

Corresponding Author :
Mr. G. C. Mekalke
Research Scholar, Department of Mechanical Engineering,
Sai Vidya Institute of Technology (SVIT), Yelahanka,
Rajanukunte, Bengaluru – 5600 064 Karnataka
E-mail: gcmekalke@gmail.com

of components under varying loads. J. Marzbanrad confirmed that textile-reinforced CFRP exhibits superior stress distribution and reduced deformation compared to GFRP. This study adopts a similar methodology, employing ANSYS Workbench to evaluate stress and deformation in composite materials [6].

Manufacturing Techniques for Textile Composites, M. Deshmukh categorized various fabrication techniques for composites, noting that the hand lay-up method is a cost-effective and adaptable option for small-scale production.[7] M. S. Ummah compared fabrication methods and concluded that the hand lay-up method delivers adequate mechanical performance for structural applications, aligning well with the requirements of this research [8].

Textile-reinforced composites have emerged as viable alternatives to traditional materials in structural applications due to their superior strength-to-weight ratios, corrosion resistance, and design flexibility. In the automotive sector, fiber-reinforced polymers, such as carbon fiber-reinforced polymer and glass fiber-reinforced polymer, have been increasingly adopted as replacements for metals like steel and aluminium [9, 10].

The pivotal role of textile-based advanced composites in modern structural designs has been highlighted, with the growing adoption of carbon fiber-reinforced polymer and glass fiber-reinforced polymer in aerospace and automotive industries attributed to their lightweight properties [9, 10]. It has been demonstrated that carbon fiber-reinforced polymer structures can achieve a 30-50% weight reduction while maintaining equivalent strength to traditional materials, underscoring their efficiency in engineering applications [9].

Finite Element Analysis is a crucial tool for assessing the mechanical behavior of components under varying loads. Studies have confirmed that textile-reinforced carbon fiber-reinforced polymer exhibits superior stress distribution and reduced deformation compared to glass fiber-reinforced polymer. This study employs ANSYS Workbench to evaluate the stress and deformation characteristics of composite materials [12].

Various fabrication techniques for composites have been categorized, with the hand lay-up method identified as a cost-effective and adaptable option for small-scale production. Comparisons of fabrication methods have concluded that the hand lay-up method delivers adequate mechanical performance for structural applications, aligning well with the requirements of this research.[13, 14 & 15].

3. Methodology

3.1 Design and Optimization with Textile-Reinforced Materials

The bumper bracket was redesigned using CATIA V5, focusing on the integration of textile-reinforced materials to achieve weight reduction and enhance mechanical performance. The redesign ensured the component could withstand operational loads while leveraging the lightweight and high-strength properties of textile composites [16].

To create the initial model, the original bumper bracket spare for the Mahindra Bolero Pik-Up was sourced from a vendor. Reverse engineering techniques were applied to replicate the geometry of the component. Textile-specific design considerations, such as fiber orientation and layer stacking, were integrated into the model. Precise measurement tools were used to capture accurate dimensions, which formed the basis for the redesign and further analysis.

This process merges reverse engineering with advanced CAD tools and a focus on textile material integration, ensuring the optimized design meets structural and operational demands.

Figure 1 - Actual Spare Bumper Mounting Bracket

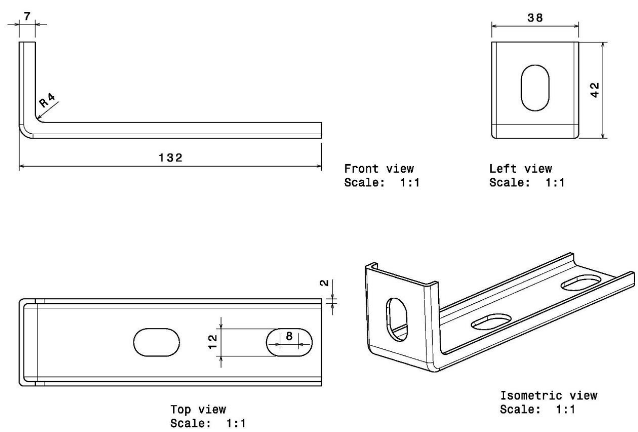


Figure 2 - Bracket Drafting

Using the collected measurements, the final drafting of the bracket was completed in CATIA V5R20.3.2 Material

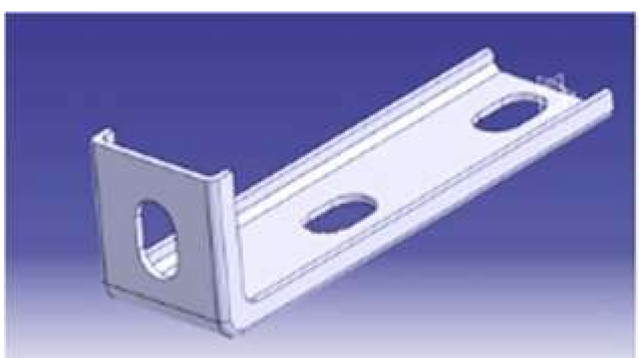


Figure 3 - Modelled Component in CATIA V5

Figure 4 – Die for composite manufacturing

Selection in Textile-Reinforced Composites

The materials selected for this study are textile-reinforced composites, chosen for their mechanical properties and cost-performance balance:

- Carbon Fiber-Reinforced Polymer (CFRP): Offers exceptional tensile strength of 1330 N/mm² and lightweight properties, with a density of approximately 1.6 g/cm³. Carbon fiber textiles are ideal for high-strength applications requiring weight reduction [17].
- Glass Fiber-Reinforced Polymer (GFRP): Cost-effective textile material with tensile strength ranging from 1000 to 1500 N/mm², commonly used in structural applications [18].
- Hybrid Composites: A blend of carbon and glass fiber textiles, combining the high performance of carbon fibers with the affordability of glass fibers, providing a balanced solution for cost and performance.

3.3 Manufacturing Process for Textile-Based Composites

The hand lay-up method was utilized for fabricating textile-reinforced composite components. This method involved layering carbon fiber, glass fiber, and hybrid textiles, which were bonded with epoxy resin. The components were cured to ensure structural integrity before testing [19].

Overall Procedure for Manufacturing Textile-Reinforced Composites:

a) Trim the textile fiber sheets (carbon, glass, or hybrid) to the required dimensions.

b) Prepare a resin mixture tailored to the fiber type (e.g., polyester or epoxy resin with cobalt and hardener for glass fibers).

c) Use a die for shaping the bumper bracket components.

d) Apply a gel coat to the die to ensure a smooth release and improved surface finish.

e) Place the textile fiber sheet in the die cavity.

f) Cover the fiber sheet with resin, ensuring complete impregnation.

g) Repeat steps 5 and 6 to build up layers until the desired thickness is achieved.

h) Remove trapped air and distribute the resin uniformly between layers using rollers or vacuum methods.

i) Allow the component to soak and cure for the specified duration to achieve optimal mechanical properties.

j) After curing, the component is ready for further machining and finishing operations.

This process emphasizes the integration of textile materials into composite manufacturing, ensuring lightweight, strong, and cost-efficient structural components [20].

3.4 Finite Element Analysis (FEA) with Textile Composites

Stress and deformation analyses were performed using ANSYS Workbench to evaluate the performance of textile-reinforced composite materials under operational conditions. The analysis focused on the bumper bracket's response to real-world loads, considering the unique properties of textile composites, such as fiber orientation and matrix interaction. [21]

Boundary and Loading Conditions

The boundary conditions were defined to simulate the real-world loads experienced by the bumper bracket. Fixed support was applied at the mounting points, and a force of 500 N was applied to simulate impact loading (Fig. 5 and Fig. 6). These conditions were chosen to replicate typical operational stresses encountered in automotive applications.

Constitutive Material Model

The material behavior was modeled using a linear elastic constitutive model, which is appropriate for the small deformations and stresses expected in the bumper bracket under normal operating conditions. The material properties for CFRP, GFRP, and hybrid composites were input based on experimental data from tensile tests.

Geometry Discretization

The geometry was discretized using 3D solid elements (SOLID185) with a mesh size of 2 mm. The total number of elements used for the steel bracket was 12,345, while the CFRP, GFRP, and hybrid composites had 10,987, 11,234, and 11,567 elements, respectively. This mesh size ensured accurate stress and deformation predictions while maintaining computational efficiency.

Observations from FEA Results

- Steel Bracket (Fig. 7 and Fig. 8): The steel bracket exhibited a maximum stress of 33 MPa and a deformation of 0.12 mm. The stress was concentrated at the mounting points, indicating potential failure zones under high loads.
- Carbon Fiber Composite (CFRP) (Fig. 9 and Fig. 10): The CFRP bracket showed a maximum stress of 52 MPa and a deformation of 1.3 mm. The stress distribution was more uniform compared to steel, with no significant stress concentrations, highlighting the material's superior load-bearing capacity.

- Glass Fiber Composite (GFRP) (Fig. 11 and Fig. 12): The GFRP bracket exhibited a maximum stress of 45 MPa and a deformation of 1.9 mm. The higher deformation compared to CFRP indicates a trade-off between strength and flexibility.
- Hybrid Composite (Fig. 13 and Fig. 14): The hybrid composite showed a maximum stress of 46 MPa and a deformation of 1.7 mm. The stress distribution was similar to CFRP, but with slightly higher deformation, making it a cost-effective alternative for applications requiring moderate performance.

Boundary conditions

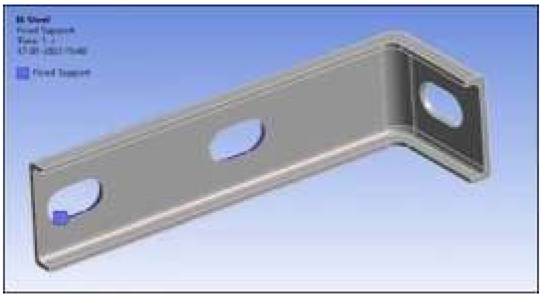


Figure 5 - BC fixed Support

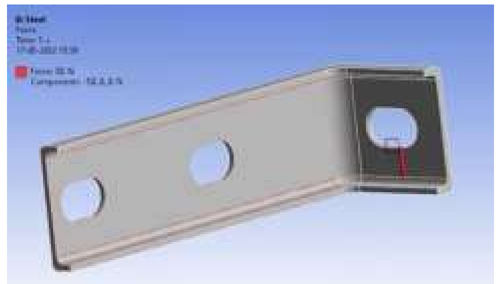


Figure 6 - BC Force Plot

Steel Component

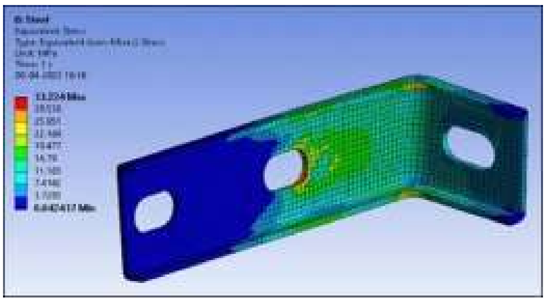


Figure 7 - Stress Plot

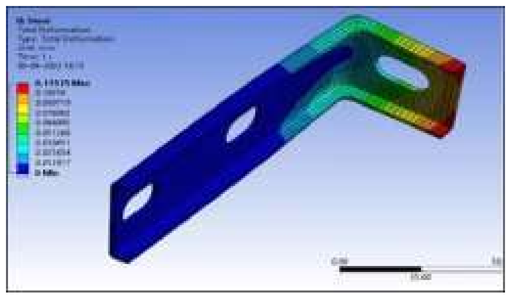


Figure 8 - Deformation Plot

Carbon Fiber Composite

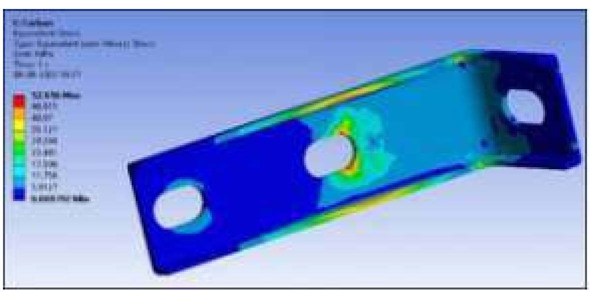


Figure 9 - Stress Plot

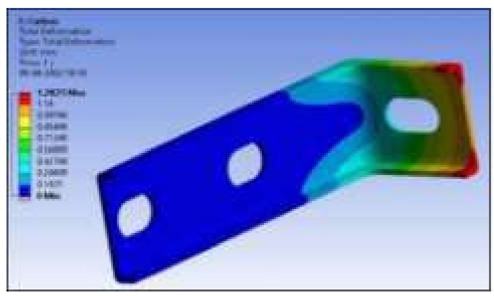


Figure 10 - Deformation Plot

Glass Fiber Composite

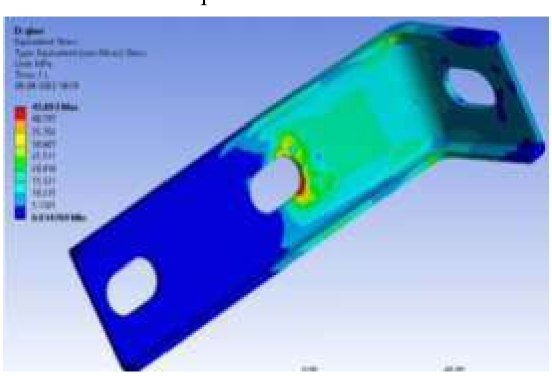


Figure 11 - Stress Plot

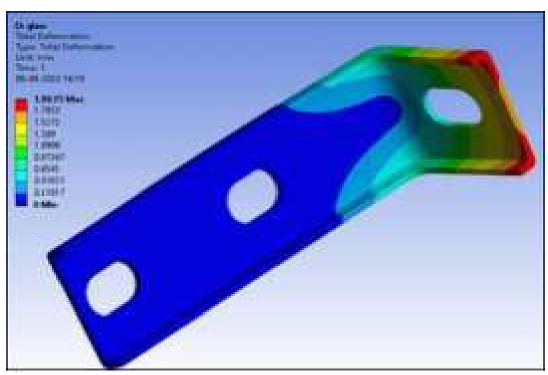


Figure 12 - Deformation Plot

Analysis Visualization

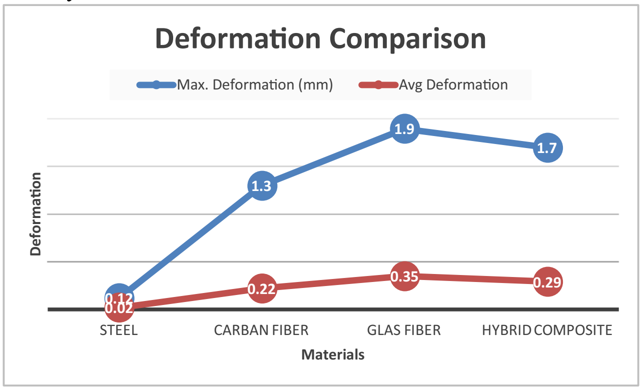


Figure 13 - Deformation Analysis Chart

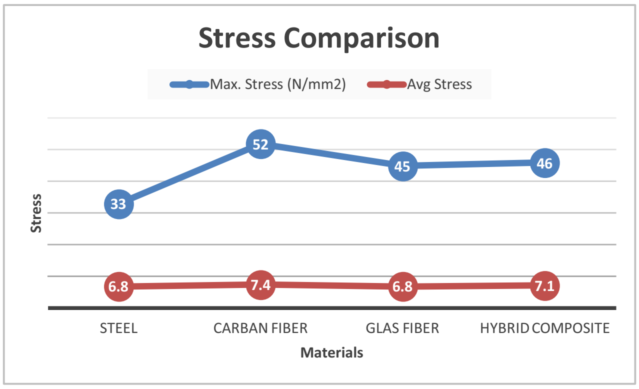


Figure 14 - Stress Analysis Chart

3.5 Tensile Testing of Textile Composites

Tensile tests were conducted on textile-reinforced composite samples using a universal testing machine (UTM) to assess their mechanical performance. The specimens were prepared according to ASTM D3039, the standard test method for tensile properties of polymer matrix composite materials. This standard ensures consistent and reliable measurement of tensile strength, modulus, and elongation. The specimens, sized 20 mm × 170 mm × 5 mm, were prepared with fibers oriented according to design specifications. The tests aimed to measure the tensile strength and elongation of carbon fiber, glass fiber, and hybrid composite materials.

- Fiber Orientation: The unidirectional (0°) fiber orientation was chosen to align with the primary loading direction in the bumper bracket application. This orientation maximizes the tensile strength and stiffness of the composite in the direction of the applied load.
- Testing Standard (ASTM D3039): This standard was selected because it is widely recognized for evaluating the tensile properties of polymer matrix composites. It provides detailed guidelines for specimen preparation, testing procedures, and data analysis, ensuring consistent and reliable results.

Failure Phenomena in Composites

- Steel (Fig. 16): The steel specimen exhibited a classic ductile failure, with significant elongation before fracture. The failure occurred at a stress of 33 MPa, consistent with the FEA predictions.
- Carbon Fiber Composite (CFRP) (Fig. 17): The CFRP specimen failed in a brittle manner, with minimal elongation and a clean fracture at 1330 N/mm². The failure was sudden, indicating the material's high stiffness and low ductility.
- Glass Fiber Composite (GFRP) (Fig. 18): The GFRP specimen showed a combination of brittle and ductile failure, with some fiber pull-out observed. The failure occurred at 1000 N/mm², with higher elongation compared to CFRP.
- Hybrid Composite (Fig. 19): The hybrid composite exhibited a mixed failure mode, with partial fiber pull-out and matrix cracking. The failure stress was 1100 N/mm², demonstrating a balance between the properties of carbon and glass fibers.

The tensile testing results validated the FEA predictions, confirming the accuracy of the stress distribution and deformation analyses. This experimental approach ensured that the textile composite materials could withstand the expected loads and perform as anticipated in real-world applications.

Figure 15 - Test Specimens

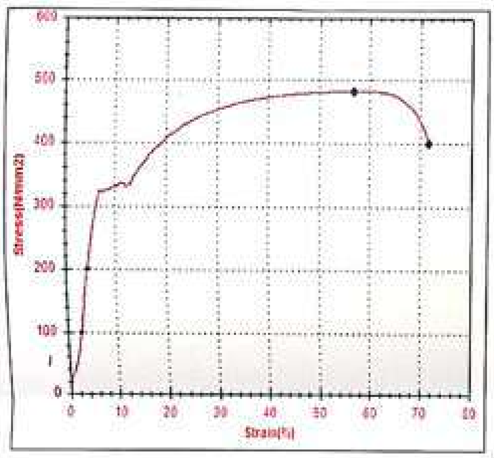
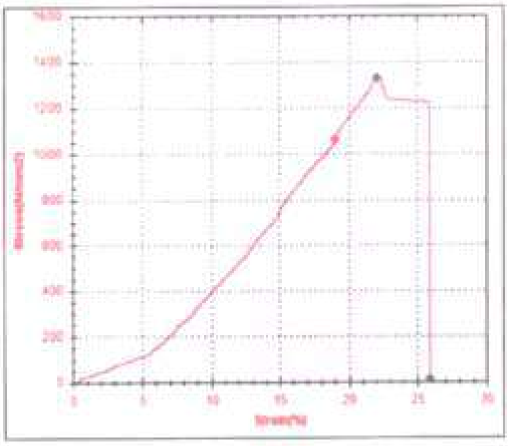


Figure 16 - Tensile Testing Report – Steel



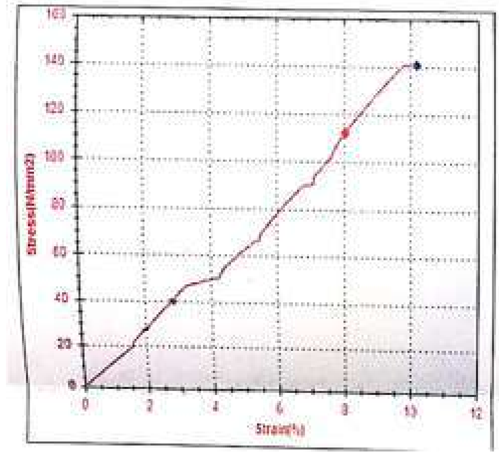


Figure 17 - Tensile Testing – Carbon Fiber Composite   *Figure 18 - Tensile Testing – Glass Fiber Composite*

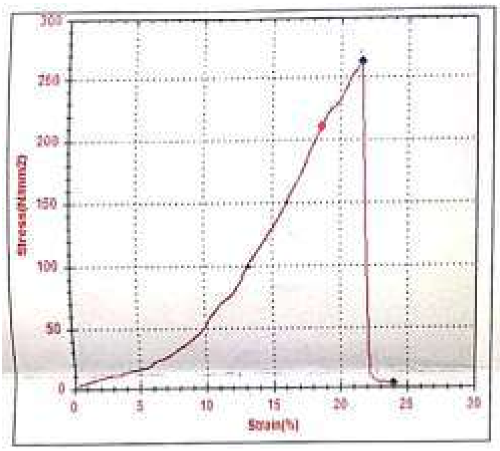
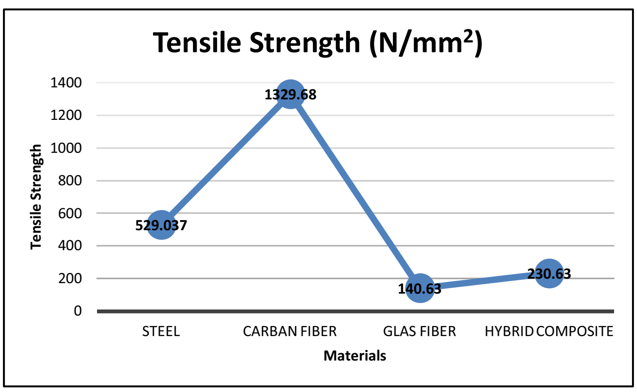


Figure 19 - Tensile Testing Report – Hybrid Composite (Carbon-Glass)



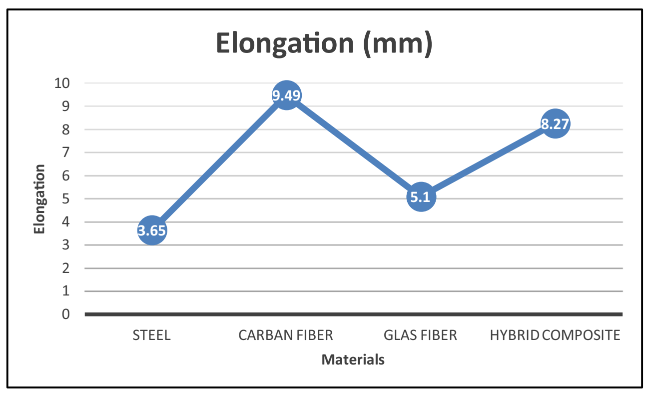


Figure 20 - Tensile Strength Result Comparison

Figure 21 - Elongation Result Comparison

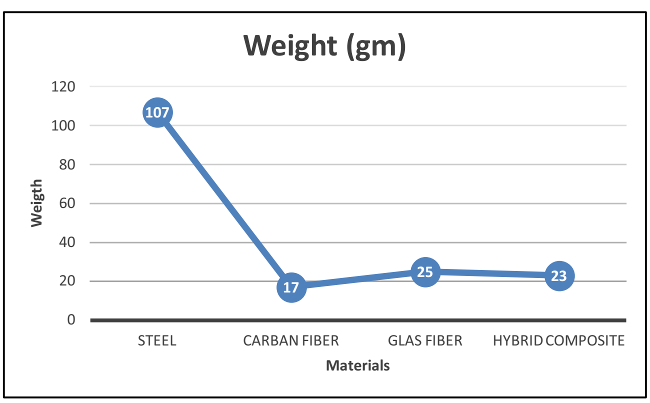


Figure 22 - Actual Weight Comparison Chart

3. Results and Discussion

The results from the FEA and tensile testing are summarized in Table 1 and Figures 23-24. The key findings are as follows:

- CFRP (Carbon Fiber-Reinforced Polymer): Demonstrated the highest tensile strength (1330 N/mm²) and the lowest weight (17 g), making it ideal for high-performance, weight-sensitive applications.
- Hybrid Composites: Provided a cost-effective alternative, balancing structural integrity and affordability, suitable for applications requiring moderate performance at a reduced cost.
- Weight Optimization: The carbon fiber composite bracket achieved an 84% reduction in weight compared to the steel bracket, highlighting its potential for lightweight structural applications.

Table 1 - Material Property Comparison

Materials	Weight (gm)	Stress (MPa)	Deformation (mm)
Steel	107	33	0.12
Carbon Fiber Composite	17	52	1.3
Glass Fiber Composite	23	45	1.9
Hybrid Composite	25	46	1.7

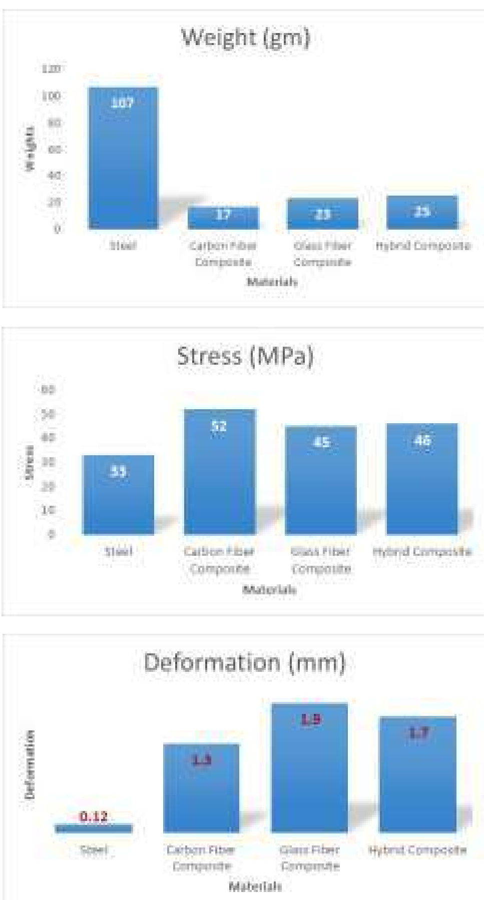


Figure 23 - Charts comparing the properties of the materials

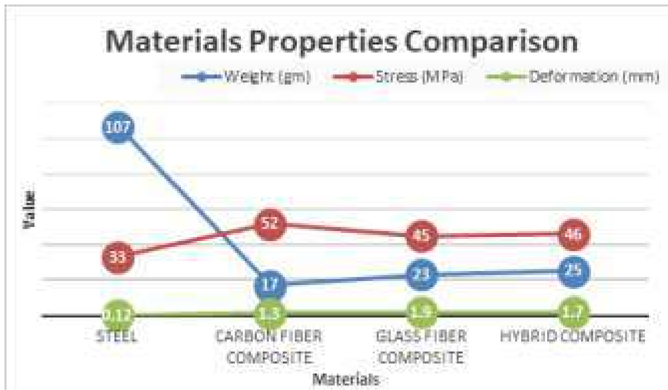


Figure 24 - A combined lines and scatter plot representing the material properties

4.1 Stress and Deformation Analysis of Textile Composites

- Steel Bracket: While steel demonstrated high stress resistance (33 MPa) and minimal deformation (0.12 mm), its substantial weight (107 g) was a significant disadvantage for lightweight applications.
- Carbon Fiber Composite (CFRP): The carbon fiber composite was the lightest at 17 g, offering excellent stress tolerance (52 MPa) and moderate deformation (1.3 mm), making it ideal for high-performance, weight-sensitive applications.
- Glass Fiber Composite (GFRP): The glass fiber composite exhibited adequate stress tolerance (45 MPa) but experienced higher deformation (1.9 mm), indicating a trade-off between strength and flexibility.
- Hybrid Composite: The hybrid composite, combining carbon and glass fibers, provided a balanced performance with stress tolerance (46 MPa) and moderate deformation (1.7 mm), offering a compromise between cost and mechanical properties.

4.2 Tensile Testing Results for Textile Composites

- CFRP demonstrated the highest tensile strength (1330 N/mm²), outperforming GFRP and hybrid composites in terms of overall mechanical performance.
- Hybrid composites offered a cost-performance balance, showing satisfactory mechanical properties suitable for secondary applications or cost-sensitive designs.

4.3 Weight Optimization in Textile Composites

The carbon fiber composite bracket achieved an impressive 84% reduction in weight compared to the steel bracket, highlighting its potential for lightweight structural applications where performance and weight reduction are critical.

This study highlights the benefits of textile-reinforced composite materials for bumper brackets, achieving significant weight reduction while maintaining excellent mechanical performance.

- CFRP (Carbon Fiber-Reinforced Polymer) emerged as the most effective material, offering superior strength-to-weight ratios and significant weight savings, making it ideal for high-performance applications.

- Hybrid composites, combining carbon and glass fibers, provided a cost-effective alternative while maintaining adequate structural integrity, suitable for applications requiring a balance of performance and cost.

The findings underscore the potential of composite textiles for lightweight, high-strength applications, particularly in industries such as automotive and aerospace. Future research could focus on exploring advanced manufacturing techniques, such as textile-based fabrication methods, to improve scalability and cost-effectiveness in large-scale production.

5. Conclusion

This study highlights the significant advantages of textile-reinforced composite materials for bumper brackets, showcasing their ability to achieve substantial weight reduction while maintaining excellent mechanical performance.

- CFRP (Carbon Fiber-Reinforced Polymer): Demonstrated exceptional strength-to-weight performance, making it the most effective material for lightweight and high-performance applications.
- Hybrid Composites: Provided a cost-effective alternative, balancing structural integrity and affordability, suitable for applications requiring moderate performance at a reduced cost.

The findings emphasize the potential of textile composites in advancing lightweight, high-strength designs, particularly in industries such as automotive and aerospace, where material efficiency is critical. Future research could investigate advanced textile-based manufacturing methods, enabling improved scalability and cost-effectiveness for large-scale production.

References

[1] N. Shama Rao, T. G. A. Simha, K. P. Rao, and G. V. V. Ravi Kumar, “Carbon Composites are Becoming Competitive and Cost Effective,” Infosys Ltd., pp. 1–12, 2018

[2] A. R. Bunsell and B. Harris, “Hybrid carbon and glass fibre composites,” Composites, vol. 5, no. 4, pp. 157–164, 1974, doi: 10.1016/0010-4361(74)90107-4

[3] A. Muhammad, M. R. Rahman, R. Baini, and M. K. Bin Bakri, Applications of sustainable polymer composites in automobile and aerospace industry. LTD, 2020. doi: 10.1016/B978-0-12-820338-5.00008-4

[4] M. K. Gupta and R. K. Srivastava, “Mechanical Properties of Hybrid Fibers-Reinforced Polymer Composite: A Review,” Polym. - Plast. Technol. Eng., vol. 55, no. 6, pp. 626–642, 2016, doi: 10.1080/03602559.2015.1098694

[5] J. Zhang, J. Chen, Z. Li, M. Ji, and T. Sang, “Optimisation design of CFRP passenger car seat backplane based on impact characteristics,” Int. J. Crashworthiness, vol. 26, no. 4, pp. 355–367, 2021, doi: 10.1080/13588265.2020.1717919

[6] J. Marzbanrad, M. Alijanpour, and M. S. Kiasat, “Design and analysis of an automotive bumper beam in low-speed frontal crashes,” Thin-Walled Struct., vol. 47, no. 8–9, pp. 902–911, 2009, doi: 10.1016/j.tws.2009.02.007

[7] M. Deshmukh and R. K. Sontakke, “www.ijser.in Analysis and Optimization of Engine Mounting Bracket,” Int. J. Sci. Eng. Res. ISSN (Online Impact Factor, vol. 3, no. 5, pp. 2347–3878, 2014

[8] M. S. Ummah, No, vol. 11, no. 1. 2019. [Online]. Available: http://scioteca.caf.com/bitstream/handle/123456789/1091/RED2017 Eng8ene.pdf?sequence =12&isAllowed=y%0A http://dx.doi.org/10.1016/j.regsciurbeco.2008.06.005%0Ahttps://www.resear hgate.net/publication/305320484_SISTEM_PEMBETUNGAN_TERPUSAT_STRATEGI_MELESTARI

[9] F. Khan et al., “Advances of composite materials in automobile applications – A review,” J. Eng. Res., no. February, 2024, doi: 10.1016/j.jer.2024.02.017

[10] Q. Fan, H. Duan, and X. Xing, “A review of composite materials for enhancing support, flexibility and strength in exercise,” Alexandria Eng. J., vol. 94, no. February, pp. 90–103, 2024, doi: 10.1016/j.aej.2024.03.048

[11] K. G. Prakash, “Characterization and Applications of Natural Fiber Reinforced Polymer Hybrid Composites - A Review,” Int. J. Res. Appl. Sci. Eng. Technol., vol. 7, no. 7, pp. 145–156, 2019, doi: 10.22214/ijraset.2019.7022

[12] J. Obradovic, S. Boria, and G. Belingardi, “Lightweight design and crash analysis of composite frontal impact energy absorbing structures,” Compos. Struct., vol. 94, no. 2, pp. 423–430, 2012, doi: 10.1016/j.compstruct.2011.08.005

[13] P. Sharma, P. Priyanka, H. S. Mali, and A. Dixit, “Geometric modeling and finite element analysis of kevlar monolithic and carbon-kevlar hybrid woven fabric unit cell,” Mater. Today Proc., vol. 26, no. xxxx, pp. 766–774, 2019, doi:10.1016/j.matpr.2020.01.023

[14] H. S. Ashrith, T. P. Jeevan, and J. Xu, “A Review on the Fabrication and Mechanical Characterization of Fibrous Composites for Engineering Applications,” J. Compos. Sci., vol. 7, no. 6, 2023, doi: 10.3390/jcs7060252

[15] D. K. Rajak, D. D. Pagar, P. L. Menezes, and E. Linul, “Fiber-reinforced polymer composites: Manufacturing, properties, and applications,” Polymers (Basel)., vol. 11, no. 10, 2019, doi: 10.3390/polym11101667

[16] William, “Materials Science and Eng.,” Mater. Sci. Eng. A, vol. 42, no. 1, p. 181, 1980 [17] S. Rao, T. G. A. Simha, K. P. Rao, and G. V. V. Ravikumar, “Carbon Composites Are Becoming Competitive And Cost Effective. Infosys Report,” Infosys Rep., pp. 2–3, 2015, [Online]. Available: https://www.infosys.com/engineeringservices/white-papers/Documents/carbon-composites-cost-effective.pdf

[18] A. Al-Nini et al., “Flexural behavior of double-skin steel tube beams filled with fiber-reinforced cementitious composite and strengthened with CFRP sheets,” Materials (Basel)., vol. 13, no. 14, 2020, doi: 10.3390/ma13143064.

[19] R. Tetlow, “Design With Composites.,” p. 125, 1982, doi: 10.1002/9781118097298.weoc067[20] M. A. Bennaceur, Y. M. Xu, and H. Layachi, “Wing Rib Stress Analysis and Design Optimization Using Constrained Natural Element Method,” IOP Conf. Ser. Mater. Sci. Eng., vol. 234, no. 1, 2017, doi: 10.1088/1757-899X/234/1/012018

[21] M. Karthikeyan, M. P. Jenarthanan, R. Giridharan, and K. Shunmugesh, “Investigation on Crash Analysis of a Frontal Car Bumper,” Trans. Indian Inst. Met., vol. 72, no. 10, pp. 2699–2709, 2019, doi: 10.1007/s12666-019-01741-w

Designer Aarti Vijay Gupta and Liva Reviva at London

Designer Aarti Vijay Gupta and Liva Reviva Redefine Sustainable Luxury at London Fashion Week FW'25 with 'Kalighat Stories".

Renowned designer Aarti Vijay Gupta once again pushed the boundaries of sustainable fashion at London Fashion Week, unveiling her latest collection, Kalighat Stories, for FW25 in collaboration with Liva's sustainable fabrics. Rooted in heritage yet executed with a contemporary touch, the collection honored India's artistic traditions through Gupta's signature modern lens while embracing innovation in both design and fabric.

Crafted using Liva Reviva Fabrics, made from up to 30% recycled textile waste blended with FSC-certified wood pulp, the collection championed eco-conscious luxury without compromising fluidity or versatility. The lightweight and breathable nature of the fabric allowed Gupta to bring intricate artistry to life, inspired by India's rich cultural heritage, all while reinforcing the importance of responsible fashion.

For Kalighat Stories, Gupta worked closely with artisans from Kolkata's famed Kalighat and Patua traditions, transforming age-old storytelling into modern fashion. Midnapore's renowned scroll paintings were integrated alongside "Patua Feet" a vivid artistic depiction of music, mythology, and daily life. The designs merged tradition with contemporary aesthetics, showcasing a seamless blend of history and modernity.

The runway featured 35 distinct looks across menswear and womenswear, presenting a diverse range of styles. Flowing drapes and structured layering highlighted the versatility of Liva's sustainable fabrics while earthy hues and muted pastels formed the base for intricate prints with handcrafted details adding depth to each piece.

Commenting on the collaboration, Mr. Sree Charan, VP Marketing, Global Head – Brands, Birla Cellulose, Aditya Birla Group, said, "We are proud to partner with Aarti Vijay Gupta in this journey towards sustainable fashion. Her ability to integrate traditional art forms with contemporary design using Liva's sustainable fabrics perfectly embodies our commitment to responsible fashion. Together, we continue to redefine luxury in a way that is both innovative and environmentally conscious."

Designer Aarti Vijay Gupta shared her vision for the collection, "Traditional artists are often overshadowed in the global fashion conversation, and so bringing their work to an international stage is incredibly special to me. With this collection, I wanted to reframe the narrative around Indian art by using the old to create something new. Working with Liva Reviva, a sustainable fabric, provided the perfect canvas to honour these traditions while embracing innovation. This is the future of fashion where heritage and sustainability come together with purpose."

Liva's collaboration with Aarti Vijay Gupta aligns with its mission to drive change in the fashion industry through conscious design and advanced fabrics that minimize waste. By supporting designers in merging artistry with sustainability, Liva continues to shape a future where fashion is both meaningful and responsible.

Jakob Müller Group (JMG) announced the acquisition of 100% of the shares of MEI

Jakob Müller Group Acquires MEI International, Expanding Narrow Fabric Weaving Solutions

Jakob Müller Group (JMG), a global leader in narrow fabric weaving machinery, today announced the acquisition of 100% of the shares of MEI International, effective January 1, 2025. With a history spanning over 50 years, MEI is a renowned Italian manufacturer of wide label weaving machines. This strategic acquisition combines the strengths of two industry pioneers, creating a comprehensive portfolio of solutions for woven label production.

JMG, known for its high-quality rapier and air-jet weaving machines, expands its offerings with MEI's specialized air-jet technology and broad product range. As part of this integration, JMG will discontinue its Müjet air-jet weaving machine, fully endorsing MEI's advanced air-jet technology, which will continue to be strengthened thanks to the mutual cooperation.

MEI team with Andreas Conzelmann (CEO JMG, center left) and Paolo Mazzucchelli (CEO MEI, center right)

Key benefits of the acquisition:

- Comprehensive product portfolio: Customers gain access to a wider range of label weaving machines, catering to diverse production needs.
- Enhanced innovation: The combined expertise of JMG and MEI will accelerate the development of new products and services.
- Stronger financial foundation: The acquisition reinforces the financial strength of both companies, enabling increased investment in innovation and customer support.
- Continued customer focus: Existing sales and service structures of both companies will remain in place, ensuring continuity for customers.

"This acquisition is a significant step forward in our JMG 2030 strategy," said Andreas Conzelmann, CEO of Jakob Müller Group. "I really appreciate the entire MEI team for their values, attitude, and spirit. Together, we can offer our customers an outstanding range of solutions and services, while continuing to provide the highest quality, productivity, and reliability they expect from both JMG and MEI."

Paolo Mazzucchelli, CEO of MEI, added, "Joining forces with JMG is an exciting opportunity for MEI. This alliance will enable us to develop new products and services more quickly and professionally, ultimately benefiting our customers' growth. We are committed to maintaining our separate sales forces to preserve the long-standing relationships we have built with our customers."

MEI will continue to operate as an independent company, retaining its location in Gallarate, Italy, with Paolo Mazzucchelli remaining as CEO. Both brands will maintain their separate market presence, leveraging their individual strengths to serve customers in a demanding market environment.

Media contact Jakob Müller Group
Luca Guarda
Marketing & Communications Manager,
Jakob Müller Holding AG
luca.guarda@jmh.swiss
+41 62 865 56 00

T-SCAN: Indian customers confirm impressive performance

Removing foreign parts from cotton is a challenging task. That's why our T-SCAN technology features multiple modules that detect contaminations and reliably eject them as part of our blowroom process. After establishing T-SCAN in cotton ring lines, our Indian customers are now enjoying the benefits of our intelligent solutions in rotor applications.

When cotton travels out of fields and into spinning mills, it sometimes carries a few unwelcome passengers. Leaves, stems, stones, plastic or jute particles from transport bags, bits of metal or shreds of paper can find their way into cotton bales. Some of these foreign parts sneak past the first cleaning steps in the blow room. Colored parts and plastics like polypropylene create particularly big problems for spinners: They can cause yarn breaks during spinning and weaving, take dye in a different way than the raw material and therefore show up on the surface of the final textile product.

And if that happens, the yarn might get rejected or returned to the spinner! In ring spinning, sophisticated yarn clearers with an option to detect and cut polypropylene and colored

Ashish Raval, Vice President Spinning, Nandam Terry

contaminants are the main solution to this problem. However, the usage of such a yarn clearer in rotor spinning is in practice very limited, especially the detection of polypropylene.

L to R: Ganesh Bansal (Chairman), Sawant Singh Kulhari (General Manager of the plant), Ashwani Garg (Managing Director) and Vikas Bansal (Managing Director)

The answer? T-SCAN! Our state-of- the-art system ejects foreign parts out of cotton via its comprehensive range of sensor modules for detecting contamination. The TS-T3 and TS-T5 are the latest versions of this market-proven technology.

They empower spinners to maximize quality and avoid costly rejections – even when dealing with low-contrast, small or thread-like foreign parts. This technology detects and removes a wide variety of polypropylene types, such as transparent or glossy polypropylene, or polypropylene that reacts to different UV light intensities.

Especially in the rotor and recycling segments, these foreign part separators can be a good solution to effectively deal with contaminants.

Proven performance in the rotor and recycling segment

Real-world tests from Trützschler customers, particularly in rotor applications, are confirming the impressive capacity to kick out contaminations, boost quality and avoid rejections with our TS-T5 and TS-T3 systems. Nandam Terry and Nandam Denim are among those pioneering customers. The companies are one of the biggest denim manufacturers based in Ahmedabad, India. They make 45 tons per day of denim and 10 tons per day of terry towel products. “Since installing TS-T3 and TS-T5 technologies, we have drastically reduced color contaminations with minimum ejection of cotton,” says Ashish Raval, Vice President Spinning. “The appearance of our fabric has improved very much and we are now selling contaminationcontrolled yarn to high-end brands. Our end users are really happy.”

Thiagarajar Mills Ltd. in Madurai, India, is a vertically integrated group in South India known for quality fine yarns and fabrics. The company runs 25 Trützschler machines to produce 250 tons of yarn per month for denim products. After successfully establishing TS-T5 in ring spinning, the customer continued with our foreign part separator in rotor spinning. “The quality of our yarn, in terms of contamination, is much improved with the TS-T5,” says Muthupalaniappa M, Senior Vice President (Technical). “It is easy to operate and maintain, with improved cleaning for polypropylene. Along with great support from the Trützschler team, we are making excellent progress with the various challenges related to contamination.”

Further positive feedback recently arrived from Blue Rose Cotspin LLP. This company based in northern India produces 20 tons of yarn per day, mainly for hosiery and weaving customers. “We have not received any complaints about contamination since installing the TS-T3 from Trützschler,” says Ashwani Garg, Managing Director. “The performance is excellent and it's capable of ejecting all types of contamination while protecting good fibers. The auto-calibration is really valuable for us.”

Kamal Kumar, owner of Patiala Gold LLP, is enthusiastic about the user-friendly cleaning and maintenance of the TS-T3: “This reduces downtime to an absolute minimum without any loss of performance. Based in Samana, Punjab, the company operates twelve Trützschler cards with IDF, producing up to 30 tons of rotor yarn per day, mainly for bottomweight and bed sheets. “Compared to other foreign part separators, the production efficiency of our blow room and card lines is significantly higher with the TS-T3,” says Kamal Kumar. Blue Rose Cotspin and Patiala Gold are using the TS-T3 in rotor recycling applications, even for polycotton blends. They have also placed repeat orders for their new units based on the performance of the TS-T3.

Info: Minimal Maintenance, Maximum Efficiency

The TS-T5 and TS-T3 achieve maximum foreign part separation with very low levels of good fiber loss. They are energy-efficient solutions that use up to 80 % less compressed air than comparable systems. The TS-T5 and TS-T3 also have minimal requirements for cleaning and maintenance, which customers value highly. Their range of functions and detection modules are unique in the market.

Benefits of SUPERTIP

SUPERTIP stands for enormous durability, great versatility and the highest precision. These benefits have been achieved through a new, unique manufacturing process that builds on TCC's long technological expertise in the market.

Paramount Instruments Unveils AI-Powered "Make in India" Textile Testing Innovation – THE GSM AI

In the ever-evolving textile industry, where precision and efficiency are paramount, the integration of Artificial Intelligence (AI) in Quality Control is transforming Global Standards. Paramount Instruments, a trusted name with six decades of expertise in manufacturing reliable textile testing equipment in India, continues to lead this transformation with cutting-edge solutions designed to enhance accuracy and efficiency.

At GTE & GTTES 2025, Paramount Instruments showcased its premier range of textile testing equipment's, reinforcing its commitment to helping Indian textiles meet global quality benchmarks. A key highlight was the unveiling of GSM AI, The World's first AI powered GSM Testing System, developed under the leadership of Mr. Manjit Singh Saini. This revolutionary device measures the grams per square meter (GSM) of woven, knitted, and non-woven fabrics with unparalleled precision. By eliminating traditional methods involving cutters, blades, and weighing balance prone to human error and inefficiencies, The GSM AI delivers instant, highly accurate results using high resolution cameras and advanced image processing algorithms.

Image of GSM AI with Mr. Manjit Singh Saini

Hon'ble Minister of Textiles, Shri Giriraj Singh Ji visited the stall

The company's vision for innovation was further recognized when Honourable Minister of Textiles, Shri Giriraj Singh Ji, visited the Paramount Instruments stall at GTE'25. Witnessing India's Make in India vision come to life, he expressed enthusiasm for the company's IIoT & AI-powered solutions, reinforcing GSM AI's status as a groundbreaking industry advancement.

Paramount Instruments recognizes that while the initial investment in AI-based technology may be higher the long-term benefits like reduced material waste, lower maintenance costs, and enhanced operational efficiency far outweigh the costs.

With GSM AI, the company reaffirms its strong commitment to: Make in India | Made for the World

As the textile industry pivots towards greater efficiency and sustainability post pandemic, Mr. Saini's dedication to integrating AI into textile testing aligns perfectly with this shift. With continuous innovation, Paramount Instruments is shaping a future where quality control is not just a requirement but a seamless, intelligent part of the production process paving the way for smarter, safer, and more efficient textile testing.

For more detail, please contact:
E-mail : haransh@paramountinstruments.com
M.: 9999663300

Oerlikon Manmade Fibers Solutions hosted Innovation and Technology Day Successfully in Daman

Oerlikon Manmade Fibers Solutions recently hosted its highly anticipated Innovation and Technology Day on 31-01-2025 in Daman. The event attracted over 300 participants, including industry experts, partners, and stakeholders, who gathered to explore the latest advancements and trends in the manmade fibers industry in India.

The Innovation and Technology Day commenced with a warm welcome and introduction by Wolfgang Ernst, Chief Sales Officer (CSO) at Oerlikon Manmade Fibers Solutions, and Debabrata Ghosh, Head of Sales at Oerlikon Textile India. They provided an overview of the Indian market and its challenges.

"The Indian textile industry, particularly the chemical fiber sector, is experiencing significant growth and transformation. This development is driven by increasing production capacities, strategic investments, and a shift in global consumption patterns", said Ghosh. India's production of manmade fibers (MMF) is robust, with annual outputs of 4.8 million tons of Polyester Filament Yarn (PFY), 1.7 million tons of Polyester Staple Fiber (PSF), 0.7 million tons of viscose, 0.2 million tons of Polyamide 6 (PA 6), and 25 thousand tons of acrylic.

Additionally, the country boasts substantial capacities for PET bottles and films, growing at rates of 7% and 15% per

annum, respectively. The Indian market is witnessing significant expansions in PTA (Purified Terephthalic Acid) capacity, with major projects underway by Indian Oil Corporation, GAIL, MCPI, Reliance Industries, and the Adani-Indorama joint venture. These expansions are set to increase the PTA capacity from the current 6.296 million tons to over 14 million tons by 2030.

Market Dynamics and strategic investments

"The global consumption landscape is shifting towards India and emerging Asia, driven by rising incomes and changing demographics. By 2050, India and emerging Asia are expected to account for 30% of global consumption at purchasing-power parity (PPP), up from 12% in 1997. This shift underscores the growing importance of these regions in the global economic landscape", Ghosh continuous. Significant investments are being made to enhance production capacities and integrate advanced technologies. Indian Oil Corporation, in a joint venture with MCPI, is establishing a 900 TPD continuous polymerization unit in Odisha, supported by substantial government subsidies. Similarly, the Adani Group, in partnership with Indorama, is entering the petrochemical sector with a $3 billion PTA plant in Maharashtra.

Challenges and Opportunities

Despite the positive outlook, the industry faces challenges such as ensuring cost efficiency, scalability, and the seamless integration of new technologies into existing production processes. However, the sector is optimistic about improving profitability, driven by favorable supply-demand dynamics and strategic investments. "The Indian textile and chemical fiber industry is poised for significant growth, supported by strategic investments, capacity expansions, and a favorable global consumption shift. These developments position India as a key player in the global textile market, driving towards a sustainable and prosperous future", said Ernst.

After the introduction about the current market situation, the event continued with numerous technical presentations in which Oerlikon and its partners presented their technological and solution expertise along the textile value production chain "From Melt to Yarn, Fibers and Nonwovens".

"To spin an excellent yarn, you need the prefect melt", said Moderator André Wissenberg, Head of Marketing, Corporate Communications, and Public Affairs at Oerlikon Manmade Fibers Solutions. How this can be produced using extrusion or continuous polycondensation technology was demonstrated by the keynote speakers Sven Streiber, Regional Sales Director at Oerlikon Barmag, Deepak Lokre, Head of Engineering at Oerlikon Textile India, and Matthias Schmitz, Head of Engineering Recycling Technology at BB Engineering (BBE).

The second session focused on Oerlikons technology partner for manmade fiber spinning mills. Presentations covered topics such as enhancing manmade fiber production with innovative air engineering, automatic handling solutions and quality inspections, as well as air texturizing solutions. Notable speakers included Praveen Kumar Singh, Managing Director of Luwa India, and Luca Lacitignola, Sales Director at Irico Gualchierani Handling (IGH), Simone Ducceschi, Sales & Project Manager at Thema Systems, as well as Ralf Morgenroth, Head of Engineering Textile Machinery at BBE.

The third session delved into solutions for producing the perfect fibers and yarns, with a focus on Oerlikon Barmag POY/DTY, FDY, IDY technologies as well as Oerlikon Neumag BCF and staple fiber line plants. Presentations were delivered by Philip Jungbecker, Head of R&D, and Guido Dresen, Regional Sales Director, both at Oerlikon Barmag, as well Chetan Bhagat, General Manager Sales, and Sameer Mehrotra, General Manager Service at Oerlikon Textile India. Ralf Morgenroth added further insights of the compact spinning solution VarioFil from BBE.

Environmentally Friendly Recycling solutions

The fourth session highlighted environmentally friendly recycling solutions, featuring insights from Sven Streiber and Sudipto Mandal, Sales and Marketing Manager at Oerlikon Textile India, and again Matthias Schmitz, BBE.

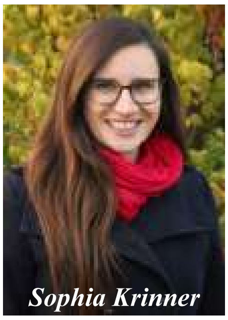
They provided a detailed portfolio overview in the field of mechanical and chemical recycling. The new partnership between Oerlikon Barmag and Evonik was also presented to the audience. Finally, this was followed by a session on customer services and digital solutions, where Michael Ruebenhagen, Head of Global Service Sales and Ivan Gallo, Digital Solutions, both at Oerlikon Manmade Fibers Solutions discussed current upgrade and retrofit options, the Digital Academy, and the future of digitalization in manmade fiber spinning mills. Shared Kulkarnie, General Manager Service Sales & Workshops, as well as Chandru Gurbaxani, Digital Solutions, performed together with their German colleagues.

The event concluded with closing remarks again from Wolfgang Ernst, who provided a global market overview and outlook for 2025. Final remarks were given by Atul Vaidya, Managing Director of Oerlikon Textile India. Finaly the event ended with a gala evening with more than 500 participants featuring a fashion show, music, dancing, and excellent food, supported by Decathlon and Garden Vareli.

The Oerlikon Manmade Fibers Solutions Innovation and Technology Day 2025 was a resounding success, fostering collaboration and knowledge sharing among industry leaders and setting the stage for future advancements in the manmade fibers sector. Participants had the opportunity to network during the event, engaging with experts from Oerlikon, Luwa, IGA/IGH, Them
a, and BBE at various marketplaces.

KARL MAYER Learning for Working Life

A positive look back at 2024, an optimistic start to 2025 - the KARL MAYER Academy


Sophia Krinner

KARL MAYER supports its customers not only with top products and the best service, but also with valuable specialist knowledge, and has done so for decades. The company's own trainings for customers have been providing know-how for entry into warp knitting or business development since 1960 and are still in great demand in the industry today. In 2024, there were a total of 104 courses for the warp knitting sector with 432 learners at the KARL MAYER academies in Germany, China, India, Japan and Turkey.

The online offerings of the company's own training hub are also gaining in importance. The online training platform has been available to customers in the Western Markets region since summer 2022. In December 2024, the Academy already had 564 active accounts with users from 50 countries, including many company owners and managers, as well as textile engineers, product developers and machine operators.

“We are seeing a shift from on-site training to digital alternatives. The online courses are sufficient for many professional groups and make a trip to Obertshausen no longer necessary,” says Sophia Krinner, Product Owner Academy at KARL MAYER. She is looking forward to receiving the first registrations for the 2025 course program at the beginning of January.

Early bookers can look forward to a New Year's special: there is a 25% discount on the “Introduction to warp knitting” e-learning course in February.

Specialist knowledge with high practical relevance

Just over half of last year's courses corresponded to the standard program. However, there were also many special trainings in which customers specifically chose individual topics from the course program to intensify their knowledge. In addition, there was an increase in inquiries about the production of fishing nets, optimizing production processes and improving product quality. These trainings were held at the customer's premises during ongoing production.

Whatever format the courses took, they were always a success for the participants. The close practical relevance was particularly well received.

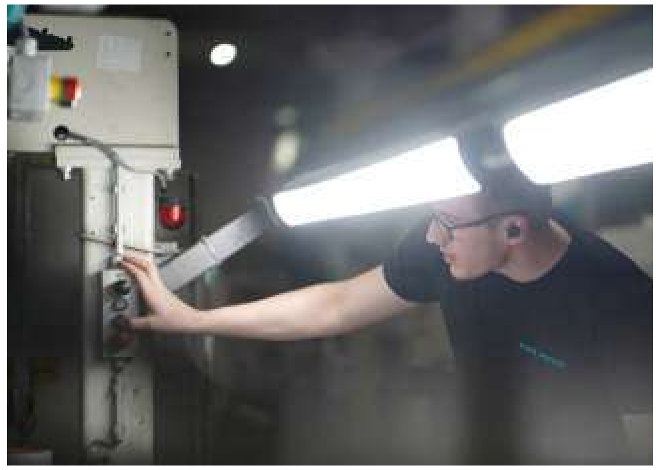
“I have much better view of the correlation between machine parts and product property now. I think the basic mechanism of lapping and needle motion will guide me on common quality issues in my work. And the practice I did in this training will be influencing me a lot in the future," says Fang of Shawmut Corp., USA, about the training "Practical introduction to warp knitting".

“What I learned will help me develop new functionalities for the company I work for. I will use it every day. My new knowledge will help me to develop new patterns and realize new design. By doing a training here you can eliminate many doubts and everything will be much clearer afterwards," explains Valentina, American Specialized Textiles, Mexico, who had attended the same training.

„An excellent time spent learning and expanding my knowledge which I can now implement in my day-to-day job. The facilities and staff have been wonderful, and I look forward to returning to KARL MAYER to further my education with another course soon," concludes Ashley, Baltex, United Kingdom, after attending the advanced course on warp knitting machines.

An introduction to warp knitting - already available in five languages - and various free tutorials are available in e-

Academy Obertshausen



Working live Warp Knitting Mill

learning format. In 2024, the new topics "Energy Efficiency Solution" and "Basics of Textile Analysis" were added to the range and were very well received. 117 trainees have already taken advantage of the additional offerings. This year has already started with new additions.

"In January, we published our new knowledge check for warp knitting. We want to help customers to self-assess their knowledge and make it easier for them to choose the right academy course," explains Sophia Krinner.

For more details, please contact:

Press Release
Postanschrift / post address: KARL MAYER GROUP
Industriestraße 1, 63179 Obertshausen

Media Contact
Ulrike Schlenker
Tel.: +49 6104/402-274
E-Mail: ulrike.schlenker@karlmayer.com

ITAMMA's Mega Product-Cum-Catalogue Show at Surat

More Time –More space for Exhibitors for interaction with Buyers in ITAMMA's Mega Product-Cum-Catalogue Show at Surat International Exhibition and Convention Centre (Platinum Hall), Surat on 23rd & 24th December '24 to promote the Growth of Textile Industry of Surat.

factory/machine set-up. The support received from Members' participation and the response from the user industry was overwhelming during all the previous shows.

Welcome address by Mr. Bhavesh Patel, President, ITAMMA

Lamp lighting ceremony by dignitaries

Mr. Bhavesh Patel, President, ITAMMA said that ITAMMA had organized until now Twenty Six Product-cum-Catalogue Shows at various Textile clusters of India, giving a platform to our members to explore new customers as well as to connect with their old customers to understand their problems/suggestions for improving the process and product quality in order to suit their customer's present

Now as per the demand of our Members and their Customers from User Industry, in order to make it possible to attend our shows by everyone as per their availability during the day, ITAMMA Management has decided to extend the interaction period of the Product Catalogue show for 2 days and also to allot a stall of bigger size so that the Member participants can comfortable display their products (machine spares/components/accessories) along with Catalogues.

Welcoming Shri Mukeshkumar Chandrakant Dalal, M.P., Bharatiya Janata Party, Surat, Gujarat

The event was inaugurated by the Chief Guest Smt. Darshana Jardosh, Former, Minister of State for Textiles, New Delhi & Honorable, Shri Mukeshkumar Chandrakaant Dalal , MP, Bharatiya Janata Party, Surat , Gujarat, as the Guest of Honour by Mr. Ketan Sanghvi, Chairman, India ITME Society and Mr. Manubhai Patel, MLA, Udhana, Gujarat and Mr. Ashok Jirawala, President, FOGWA as the Special Guest and thereafter all the dignitaries released "ITAMMA Voice" Volume No. 14 based on the theme 'Technology and Innovations the strength of Atma Nirbhar Bharat taking it towards ' Viksit Bharat".

Smt. Darshana Jardosh, Former, Minister of State for Textiles, New Delhi said that there is a need for textile machinery development whereby innovation in textile machinery can add value to the industry. She added that this event will encourage students to become entrepreneurs and innovate new textile products as they will get an opportunity to interact with many stakeholders along with their products in this show. Smt. Jardosh said that the future of Indian Technical Textiles is very promising with National Technical Textiles Mission (NTTM) encouraging cutting-edge innovations.

Welcoming Smt. Darshana Jardosh, former Minister of State for Textiles, New Delhi

Mr. Manubhai Patel, MLA, Udhana, Gujarat and Mr. Ashok Jirawala, President, FOGWA said that FOGWA members

Welcoming Mr. Manubhai Patel, MLA, Udhana

Welcoming Mr. Ashok Jirawala, President, FOGWA

will be getting a very good opportunity to interact with the stakeholders of textile engineering industry to know the latest developed /innovated textile machines and spares/components available to deliver high quality of textiles at high productivity.

Speech by Mr. Ketan Sanghvi, Chairman, India ITME Society

While Summing –up the session Mr. Omprakash Mantry, Vice-President, said that Surat is the largest synthetic textile industry cluster in India where about 65 % of India's manmade fabric production is done whereby about 30 million metres of raw fabric and 25 million metres of processed fabric are produced daily.

It calls for Quality Accessories and Spares helping these machines to sustain their performance at low maintenance cost considering high abrasion of machine parts due to Man-Made Fibres when compared with cotton. This event has led appropriate platform for Exhibitors to understand the need of the buyers and the Buyers to explore the new innovations and technological developments in spare parts and accessories.

At the same time ITAMMA has transformed digitally and has created a marketplace and ecosystem with the support of Sambuq.com to help our members to grow in the today's challenging GLOBAL Market of Sustainability and Responsible manufacturing.

Vote of thanks by Mr. Omprakash Mantry, Vice President, ITAMMA

Felicitation of Mr. Vijay Mevawala, President, SGCCI

Release of ITAMMA Voice issue

View of the Audience

Rieter – Significant Increase in Order Intake in Financial Year 2024

- **Order intake of CHF 725.5 million**
- **Sales of CHF 859.1 million**
- **Order backlog of around CHF 530 million at December 31, 2024**
- **EBIT margin expected to be in the upper half of the guidance range**

At CHF 725.5 million, order intake was significantly higher than in the same period of the previous year (2023: CHF 541.8 million), representing an increase of 34%. This was the fourth consecutive quarter of year-on-year growth. As expected, the Rieter Group ended financial year 2024 with lower sales than in the previous year. According to preliminary, unaudited figures, total sales amounted to CHF 859.1 million, which is around 39% down on the previous year (2023: CHF 1 418.6 million). For the full year 2024, Rieter expects an EBIT margin in the upper half of the guidance range of 2% to 4% communicated in October 2024 (2023: 7.2%).

Order intake

Order intake in 2024 was 34% higher than in the previous year at CHF 725.5 million (2023: CHF 541.8 million). Rieter thus succeeded in strengthening its competitive position in a challenging market environment. Compared with the previous year, there were signs of an initial market recovery.

Sales by division

The Machines & Systems Division posted sales of CHF 424.9 million, a decrease of 56% compared with the previous year (2023: CHF 965.0 million). In the Components Division, sales declined to CHF 247.6 million, down 7% from the same period of the previous year (2023: CHF 266.2 million).

The After Sales

Division reported sales of CHF 186.6 million, comparable to the previous year (2023: CHF 187.4 million). Order backlog At the end of 2024, the company had an order backlog of about CHF 530 million (December 31, 2023: CHF 650 million).

EBIT margin

Rieter successfully implemented the measures of the "Next Level" performance program. Despite significantly lower sales, a solid EBIT margin is expected in the upper half of the 2% to 4% guidance range, as communicated in October 2024.

Results Press Conference 2025

Rieter will provide further details on the financial year on March 13, 2025. The Group will also publish its Annual Report 2024 and hold an annual results press conference.

Annual General Meeting of April 24, 2025

The next Annual General Meeting of Rieter Holding Ltd. will take place on Wednesday, April 24, 2025. Proposals regarding the agenda must be submitted in writing to Rieter Holding Ltd., Office of the Company Secretary, Klosterstrasse 20, CH-8406 Winterthur (Switzerland) by no later than February 28, 2025, accompanied by information concerning the relevant motions and evidence of the necessary shareholdings (with a par value of CHF 0.5 million as stipulated by §9 of the Articles of Association).

Forthcoming dates

Deadline for proposals regarding the agenda of the

• Annual General Meeting	February 28, 2025
• Results press conference 2025	March 13, 2025
• Annual General Meeting 2025	April 24, 2025
• Semi-Annual Report 2025	July 18, 2025
• Investor Update 2025	October 22, 2025

For further information, please contact:

Rieter Holding Ltd.	Rieter Ltd.
Oliver Streuli	Relindis Wieser
Chief Financial Officer	Head Group Communication & Marketing
T +41 52 208 70 15	T +41 52 208 70 45
investor@rieter.com	media@rieter.com
www.rieter.com	www.rieter.com

USTER® Think quality

Subscription package with Uster FiberQ drives top quality

Uster FiberQ automated raw material management generated more than 2,000 laydowns in a year for Sagar, one of India's leading spinners. The results delivered consistent yarn quality and optimized process efficiency – giving a payback period of three months.

Sagar is convinced of the benefits from the full FiberQ package, taking advantage of the new annual subscription format, which includes the software solution plus valuable advisory services from Uster expert technologists. Renewing the subscription is proof of Sagar's faith in FiberQ.

A. K. Saini_Chief General Manager perations_Sagar

After one year using FiberQ, A. K. Saini, Chief General Manager, Operations at Sagar Manufacturers Pvt. Ltd., reported: "We have seen better fiber utilization, significantly improved yarn quality consistency and elimination of seldom-occurring faults such as white specks and barré. The overall outstanding results convinced our management about the value of FiberQ and we confirmed the renewal of the subscription services of FiberQ and the 360Q platform."

High and higher

Expectations were high, as Sagar insists on consistently high standards in yarn quality and performance. The company wanted to go even further, by optimizing its manufacturing operations and achieving maximum fiber yield. "Uster FiberQ is a game-changer in terms of high-quality consistency with minimal production cost," says Saini.

Sagar Manufacturers Pvt. is renowned for excellence, in both its home country of India and the global textile marketplace, as a producer and supplier of top-class cotton yarns and knitted greige fabric. Saini says: "Our strategic focus is on integrating advanced technology and eco-friendly practices, for creative solutions which drive excellence in manufacturing performance and ensure customer satisfaction."

Before FiberQ, the company was already proud of the excellent raw material management processes in its spinning

Sagar plant - aerial view

operation. It was a determination to improve still further in both production efficiency and consistent quality which led to the decision to implement the Uster FiberQ raw material management solution.

Sagar has always embraced new technologies – especially those focused on innovation and automation – and it was naturally one of the first adopters of the FiberQ raw material management solution. FiberQ combines advanced technology and textile expertise to automate many tasks previously done manually. So it became a very interesting value proposition for progressive spinners like Sagar.

The automated, intelligent, reliable and easy-to-use system minimized manual efforts but also provided consistent results. "I can safely say that FiberQ has ticked all the boxes! We have seen an improvement in quality consistency and a reduction in important quality characteristics such as yarn imperfections, Classimat faults and yarn alarms," Saini says. "At the same time, we have achieved zero quality complaints from our customers." Uster's end-to-end solution also offers access to continuous improvements such as supplier statistics and fiber-to-yarn correlation, which will add even more value in future.

Impact on production – and more

Sagar figures show that yarn realization has increased by 0.3% to 0.5% on average and it has eliminated the need for 'cut and creel' – a big advantage in terms of efficiency and fewer changes in production. During the year, FiberQ generated more than 2,000 laydowns for all production units in a very efficient, fast and easy way. Another plus was the easily accessible laydown history and the visibility of the impact of different cotton lots in use.

Customer feedback has also been strong. Sagar's improved quality consistency was said to have resulted in better fabric appearance. And since Sagar can now provide customers with bigger yarn lot sizes with the same quality and color properties, they can produce larger, uniform batches of knitted and dyed fabrics and save manufacturing costs.

Advisory service benefits

FiberQ is not only a software solution. It comes with advisory services from expert Uster textile technologists. "The advisory services have been extremely beneficial. We have gained insights from best practices, proven in mills worldwide, for greater optimization opportunities," says Saini.

The FiberQ advisory services ensure there is always a textile engineer with mill experience and deep knowledge available to support the spinners. As well as taking care of all aspects of installation, there are periodic assessments to track quality status from fiber to yarn, which is a unique competence of Uster and a highly appreciated element of the service.

FiberQ is offered as a yearly subscription service. For the industry, the idea of subscribing to a software service for raw material management is quite new, although it has been established for many years in other fields. "At Sagar, we are convinced that the value we get from this solution completely justifies the recurring investment," states Saini. For Sagar, the opportunities presented by Uster FiberQ and 360Q were clear – and quickly proven in practice.

For more details, please contact:
Ms. Edith Aepli
Phone +41 43 366 38 80
Mobile +41 79 91 602 91
E-mail : edith.aepli@uster.com

KARL MAYER

Using warp knitting technology to create high-quality sportswear for everyone in India

Successful joint open house event organised by TechnoSport, KARL MAYER and A.T.E. to present innovative jersey machine technology

First in South India: TechnoSport Leverages KARL MAYER tricot machines for Active and Sportswear Production at its new Mega Factory in Perundurai. The state-of-the-art HKS 3-M high-performance warp knitting machines complete the capacities of the recently opened Perundurai mega-facility of the leading Indian activewear brand. TechnoSport has invested in cutting-edge machines to further this mission and expand its market reach. The company is committed to delivering high-quality, accessible apparel while prioritizing sustainability and global recognition.

As a first step, TechnoSport has realised its innovative "DuraCool+" product line on the HKS-3M machines from KARL MAYER and successfully launched it on the market. Building on this advancement, the brand plans to introduce versatile, functional, and durable all-day pants, combining the robustness of woven trousers with the comfort and flexibility of knitwear.

Mark Smith

TechnoSport KARL MAYER ATE Open house 1

There was also a joint event as part of the new collaboration. In mid-February 2025, TechnoSport joined forces with KARL MAYER and A.T.E. to host an in-house exhibition at its Mega Factory.

Joint open house event

KARL MAYER is proud of the partnership with its first tricot machine customer in the activewear and sportswear sector in South India and was delighted with the participation in the open house event. It was a complete success. Over 100 industry professionals from Tirupur, Erode, Coimbatore, and other regions attended the event and gained a lot of inspiration for their business from its extensive program.

Attendees witnessed live demonstrations of three HKS 3-M machines, coupled with a DS-Warper, showcasing the production of specialized warp-knitted fabrics for active and sportswear. Dynamic demonstration of all three tricot machines operating at speeds up to 2,800 rpm was a real highlight. There were also contributions from speakers. The event featured a welcome address by Navin Agrawal, Senior Vice President der A.T.E. Enterprises Private Limited, followed by an insightful presentation on warp knitting technology by Mark Smith, Deputy Vice President Sales of KARL MAYER's warp knitting business unit. Franziska Guth, product developer at KARL MAYER, and the A.T.E. sales team further engaged the audience with displays of warp-knitted fabric samples and finished garments.

Talking about the significance of the event, Mr. Sunil Jhunjhunwala, Co-founder of TechnoSport commented. "We are very proud to partner with KARL MAYER and bring such technology to India. Given the growing demand for synthetic materials in both domestic and export markets, we expect interest in warp knitting technology to gain significant momentum in the next few years. By partnering with A.T.E. and KARL MAYER and hosting such events, we hope to further solidify that interest."

Mark Smith supports this concern. "We hope to conduct more such events in the future to expand warp knitting capabilities in India."

He extended his sincere appreciation to Mr. Sunil Jhunjhunwala and the entire TechnoSport team for their invaluable support in making this Open House a resounding success. He also commended the A.T.E. Coimbatore team for their dedicated efforts in organizing and executing this impactful event.

By embracing cutting-edge technology and focusing on sustainability, TechnoSport is poised to redefine the standards of activewear globally. As the brand continues to expand its market reach and product offerings, it remains committed to making high-quality sportswear accessible to everyone, inspiring a healthier and more active lifestyle for all.

Please contact;

Press release
Post address:
KARL MAYER GROUP
Industriestraße 1
63179 Obertshausen

Media contact:
Ulrike Schlenker
Tel.: +49 6104/402-274
E-Mail: ulrike.schlenker@karlmayer.com

Liva Protégé Shapes the Future of Sustainable Fashion

The Liva Protégé Textiles Design Competition, a pioneering initiative by Birla Cellulose in collaboration with the National Institute of Fashion Technology (NIFT), culminated in a grand finale at the Jio World Convention Centre, Mumbai. The event celebrated the creativity and innovation of 15 student finalists from NIFT centres across India, showcasing their designs in Surface Design, Woven Design, and Print Design categories.

Liva Protégé is a fashion competition in India that helps young designers showcase their creativity and get noticed in the fashion industry. Guided by renowned mentor and designer Karishma Shahani Khan, the students infused sustainability at the core of their creations. Their innovative designs utilized eco-friendly materials such as Livaeco fabrics and recycled yarns, employing zero-waste techniques and dead stock materials to craft their collections. This initiative reflects Birla Cellulose's commitment to promoting sustainable practices within the textile industry.

The esteemed jury panel comprised industry leaders Narendra Kumar, Ekta Saran, and Dr. Deepa Chandran, alongside members of the Birla Cellulose executive committee, Ms. Anupama Mohan and Dr. Aspi Patel.

They evaluated the finalists' innovative works, emphasizing creativity, sustainability, and design innovation. Senior leaders from Aditya Birla-Grasim Industries, including Mr. Manmohan Singh, Mr. Suraj Bahirwani, and Mr. Murugan Thenkondar, presented the awards to the winners.
Representing NIFT centres in Patna, Delhi, Bengaluru, and Hyderabad, the winners were lauded for their exceptional talent and awarded certificates, trophies, and cash prizes.

The event featured an inspiring speaker session with industry leaders, including Karishma Shahani Khan, Chief Sustainability Officer at Birla Cellulose- Mr. Surya Vallari, and NIFT Mumbai Director- Prof. Dr. Sharmila Dua. They shared valuable insights on sustainability, innovation, and the importance of nurturing young talent in the textile industry.

Mr. Manmohan Singh, Chief Marketing Officer at Birla Cellulose, remarked, “The Liva Protégé Textiles Design Competition exemplifies our dedication to fostering innovation and sustainability in the textile industry. It's incredible to witness the talent and creativity of these young designers, who are paving the way for a more sustainable future. We are proud to support initiatives that not only celebrate creativity but also emphasize the importance of responsible design practices.”

Attended by prominent industry figures and NIFT officials, the event underscored the transformative journey of Gen Next designers and the future of sustainable textile design

Call for Manuscripts

Journal of the Textile Association

Journal of the Textile Association (JTA), is an open access bimonthly prestigious Peer Reviewed Textile Technology Journal, published by the Textile Association (India) since 1940. **JTA** invites for the original Research & Review Manuscripts from the Researchers, Academicians and Business Experts, within the scope of our journal which covers **Textile Chemical Engineering, Material Science, Technical Textile Technology, Clothing & Fashion Science, Textile Digitalization** and **Textile Manufacturing Engineering** categories.

Blind Review Process is followed to ensure the integrity for submission to this journal. Authors should suggest 3 reviewers with their detailed full address and contacts, those are prompt, responsible in reviewing the manuscripts in time.

JTA is listed with Scopus, UGC, & Google Scholar etc. and has DOI Nos. to each published manuscripts. For improving journal Citations and Impact Factor, maximum JTA References / Citations are to be referred in work.

Your contribution of manuscripts in JTA is an honor for us.

Manuscripts should be sent to
Hon. Editor on e-mail to jtaeditor@textileassociationindia.org

For more details, please visit
www.textileassociationindia.org

ADVERTISEMENT INDEX

Regd. No. R. N. 11386/57 (Formally Textile Digest)