

ANNUAL REPORT

2025-26



**The Bombay Textile Research
Association**



ANNUAL REPORT
[2025-2026]

THE BOMBAY TEXTILE RESEARCH ASSOCIATION
Lal Bahadur Shastri Marg, Ghatkopar (W)
Mumbai – 400 086

Telephones: 022 6202 3636

E-mail: director@btraindia.com

Fax: 91-22-2500 0459

Website: www.btraindia.com

This page is intentionally left blank

**MEMBERS OF THE
GOVERNING COUNCIL**

- ♣ Mr. Sharad K. Saraf, ***Chairman***
- ♣ Mr. Narendra Dalmia, ***Deputy Chairman***
- ♣ Mr. S. K. Tyagi
- ♣ Mr. R. D. Udeshi
- ♣ Dr. Vikas B. Thakare
- ♣ Mr. Pramod Khosla
- ♣ Mr. Rajendra K. Dalmia
- ♣ Mr. Sunil Patwari
- ♣ Mr. L. Saravanan
- ♣ Mr. Mohan M. Kavrie
- ♣ Dr. Anoop Anand
- ♣ Dr. Anand Katti
- ♣ Mr. Kailash R. Lalpuria
- ♣ Mr. Pragnesh Shah
- ♣ Dr. Prakash Vasudevan
- ♣ Dr. M. S. Parmar
- ♣ Dr. T.V. Sreekumar, ***Director, BTRA***

	<u>CONTENTS</u>
5	(1) INTRODUCTION
6	(2) ON-GOING SPONSORED PROJECTS
45	(3) IN-HOUSE PROJECTS
48	(4) CENTRE OF EXCELLENCE FOR GEOTECH
51	(5) CALIBRATION LABORATORY
51	(6) ACCREDITED PROFICIENCY TESTING PROVIDER
53	(7) TECHNICAL SERVICES
53	(8) TESTING SERVICES
66	(9) INFORMATION DISSEMINATION / INDUSTRY INTERACTION
72	(10) EXHIBITION PARTICIPATION
74	ACKNOWLEDGEMENTS
75-86	APPENDICES [1 TO 11]
87	FINANCIAL STATEMENTS
104	INDEPENDENT AUDITOR'S REPORT

Details of Appendices

Particulars	Appendix No.	Page No.
Research Projects	1	75
Papers Published	2	76
Papers Presented	3	81
Others ♣ Products / Chemicals / Instruments / Gadgets Sold on Reimbursable Basis ♣ Instruments / Gadgets Calibrated ♣ Instruments Serviced	4	82
Patents Details	5	82
Members of the General Advisory Committee for Research and Liaison	6	82
BIS Membership	7	84
Staff Details	8	85
List of Members	9	87
Vishakha Certificate	10	88

BTRA Annual Report (2025-2026)

We have great pleasure in presenting the 72nd Annual Report of The Bombay Textile Research Association (BTRA). It highlights the R & D and other activities of BTRA and also presents the Audited Statement of Accounts for the year ending 31st March 2026.

1. Introduction

The global textile industry is going through an upheaval, and the Indian textile sector has had a particularly challenging year due to a number of issues. However, because the National Technical Textile Mission is concentrating on research, innovation, and development, the technical textile and synthetic fiber industries are going to flourish. More efforts will be made to create qualified personnel and achieve sustainability and traceability in manufacturing processes and products.

Recently, the textile sector has concentrated on developing high-tech, value-added products, with a focus on technical and medical textiles that are currently best suited to the market. At BTRA, significant efforts are being made to create new goods and procedures as well as diversify into more technology-based items. At our Center of Excellence, Geo-synthetics, we have strengthened several testing facilities. At our electro-spinning facility, we are even accepting assignments from DRDOs and other private organizations. With assistance from the Government of India (GOI), the Ministry of Textiles (MOT), and other funding agencies including DRDO, BARC, IREL, KVIC, and RGSTC, among others, BTRA has made major R&D developments to expand knowledge and provide services to the textile sectors.

At BTRA, we understand the importance of research and development, particularly in the development of innovative products and processes. Additionally, increasing productivity and reducing expenses in textile mill operations are prioritized. The two main goals of BTRA's R&D efforts are to: (i) improve, expedite, and lower the cost of current products; and (ii) develop new products in a sustainable way to lessen their negative effects on the environment and ecosystem. Last year, three patents from various projects were filed, and one technology was transferred. BTRA is also scaling up its training programs to provide need-based training at the technical/supervisory and operator levels. In this regard, in collaboration with M/S Austro Water Technologies, Pvt Ltd, Tirupur, BTRA also started a training program on sustainable technology, water recycling, and wastewater treatment facilities. Below is a quick summary of some of the work finished during the period under consideration.

❖ Product Development Assistance to the industry

- Waterless dyeing equipment Consultancy to QC, BASF, Mumbai
- Plasma Treatment and testing of industry (VIJTI, CIRCOT and Saint gabion)
- WVTR, CA, Antistatic Testing
- Malvern Panalytical Empyrean XRD (X-ray diffraction) and Epsilon 1 XRF (X-ray fluorescence) systems

❖ Calibration, Technical Services, and Training

- ✓ BTRA calibration laboratory received accreditation from NABL as per ISO/IEC 17043:2023 standards for Mass, Balance, Volume. BTRA is ready to provide calibration services to other NABL-accredited testing laboratories for Mass, Balance and Volume parameters.

BTRA Annual Report (2025-2026)

- ✓ BTRA undertakes extensive liaison and consultancy services to solve problems of quality, maintenance, productivity, water/energy conservation, etc., at various levels from time to time. Also, special studies such as vendor selection, valuation of fixed assets, manpower planning, etc. are undertaken for the mills. For the period under review, BTRA provided services in the areas of accredited partner audits, boiler efficiency audits, and fabric inspection.
- ✓ BTRA conducted several training programs at the mills' premises covering subjects such as Technology Upgradation, Quality Control and Value Addition for Chaddar manufacturers, Fabric Inspection, Size Application, and Evaluation, Cuprammonium fluidity test, and Good Work Practices & Utility Conservation. BTRA imparted training (theory and practical) at the testing laboratories/pilot plants covering subjects such as Technical Textiles (Geotech), Textile Terminology and Processing, Yarn testing and sizing, Sizing and Testing, Mechanical & Chemical Testing, and General elements of textiles. A total of 207 industry personnel were trained during the period under review, in line with specific industry requirements and subject demand.

❖ Other

In a nutshell, research and development and consultancy activities at BTRA have been directed towards innovative product/process or test method development and providing an essential database for the industry. In the years ahead, BTRA will strive to make its mark in the area of technical textiles, utility conservation, effluent load reduction, chemical management systems, and eco-management for process houses.

2. ON-GOING RESEARCH PROJECTS

2.1 Development of Carbon Nanotubes Reinforced Acrylic Precursor for Carbon Fibre

Abstract

Residual solvent content in PAN precursor fibers critically influences the mechanical performance of the resulting carbon fibers, yet the effect of precursor tow size on solvent removal kinetics remains underexplored. This study presents a MATLAB-based computational model employing the finite difference method to solve Fick's second law of diffusion for multifilament PAN tows modeled with cylindrical geometry and hexagonal close packing. Simulations for 1K, 2K, and 3K tows along a wet-spinning line were validated using GC-MS data. Results show decreasing solvent removal efficiency with increasing tow size, with the washing unit being the most effective due to longer residence times. The model provides a robust framework for optimizing spinning line design and producing high-quality PAN precursors.

Introduction

The residual solvent content in PAN fiber is a very crucial parameter for the high-strength Carbon fiber production process. The high-solvent content severely affects the morphology of the PAN precursor, which results in microvoids in the carbon fiber. Thus, an optimal quantity of solvent is desirable in the PAN precursor fiber for optimal strength and modulus in carbon fibers. Various spinning parameters, such as tow size (number of filaments), spinning bath concentrations, spinning line design, and spinning speed, have a direct influence on the solvent content in PAN precursor fibers. As reported by Gao et al, the higher spinning line speed resulted in higher PAN precursor strength, but due to the presence of higher solvent content (~820 ppm), it resulted in lower strength

in carbon fiber. However, the PAN fibers spun at a lower spinning speed resulted in comparatively lower strength in the PAN precursor along with lower solvent content (~ 493 ppm) in it, resulting in higher strength in the Carbon fibers. This study shows the great significance of solvent content in PAN precursor that significantly affects the carbon fiber properties, where higher solvent content results in a higher number of microvoids in carbon during the heat treatment process. Though the importance of solvent content can be observed, the minor increase in it from ~500 ppm to 820ppm drastically reduces the strength in carbon fibers, but this study is only limited to the effect of one influential factor. However, the influence of other factors is yet to be known, which can help researchers and industry professionals to further improve the properties of the carbon fiber. Thus, this literature gap opens up an opportunity for further research in the related field.

In this work, a MATLAB-based study is performed along with experimental verification to understand the effect of tow size and spinning unit components on the solvent content present in PAN precursor fibers during the spinning process. The effectiveness of the different types of unit and their effect on solvent extraction capability is also studied through the model. Further, the predicted values from the program were compared with the experimental values of the solvent content obtained through GC/MS. Based on the predicted values & experimental values, an optimized spinning line design is also applied and verified.

Experimental

Polyacrylonitrile (PAN) copolymer and commercial-grade DMAc solvent were used to prepare PAN fibers via wet spinning with three tow sizes: 1K, 2K, and 3K, using identical processing parameters to ensure consistency. Fibers were produced at a 20% dope concentration with fixed jet ratio, draw ratio, take-up speed, and bath temperature. A MATLAB-based finite difference method (FDM) model was developed to simulate solvent diffusion within multifilament tows by solving Fick's second law, assuming cylindrical geometry with hexagonal close packing. Experimental validation was performed using GC–MS headspace analysis on processed fibers, with solvent content normalized against pure DMAc values to verify the model predictions.

Results and Discussion

The tow geometry model is developed using hexagonal close packing (HCP) theory, which provides the highest packing efficiency (74%) and represents the tendency of multifilament tows under tension to minimize surface area (as shown in Figure 1). In this configuration, filaments form multiple concentric layers, limiting direct exposure of inner layers to the surrounding medium. Based on HCP theory, the number of filament layers increases with tow size, yielding 18, 26, and 32 layers for 1K, 2K, and 3K tows, respectively. Correspondingly, the calculated effective tow radii before jet and draw ratio effects are 3.16 mm for 1K, 4.47 mm for 2K, and 5.47 mm for 3K, forming the basis for diffusion modeling.

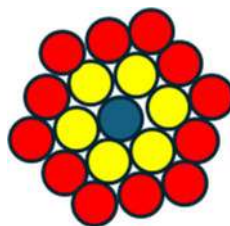


Figure 1: Schematic of the Hexagonal pack structure formed by multifilaments

$$R_{\text{eff}} = r \times \sqrt{N} \dots (1)$$

Where, R_{eff} is the effective radius of the Tow,
 r is the radius of the single filament, and
 N is the number of filaments

For efficient and faster calculation of the concentration reduction during the various processes, Fick's second law of mass diffusion from a cylindrical geometry system is employed, due to its ability to link concentration with time and spatial dimension. The law states that the rate of change of concentration with respect to time can be determined from the double spatial derivative of the concentration. The governing equation for the same for cylindrical geometry is represented in equation 2.

$$\frac{\partial C}{\partial T} = D \left(\frac{\partial^2 C}{\partial x^2} + \frac{1}{x} \frac{\partial C}{\partial x} \right) \dots (2)$$

Where, C is the solvent concentration,
 x is the spatial dimension,
 D is the diffusion coefficient of the solvent in the outside medium, and
 T is the time.

Although the governing equation suits cylindrical geometry, it assumes a homogeneous system, whereas multifilament tows exhibit voids due to 74% packing efficiency. Larger geometries also demand higher time steps, reducing accuracy or increasing computation time. To improve efficiency, the cylindrical system is discretized along the radial direction only, as expressed in Equation 3.

Governing equation:

$$C_i^{m+1} = C_i^m + \frac{D\Delta t}{(\Delta r)^2} \left[\left(1 + \frac{\Delta r}{2r_i}\right) C_{i+1}^m - 2C_i^m + \left(1 - \frac{\Delta r}{2r_i}\right) C_{i-1}^m \right] \dots (3)$$

Where, C_i^m is Concentration at radial position $r_i = i\Delta r$ and time $t_n = n\Delta t$,
 D is the Diffusion coefficient of the DMAc solvent in the water ($1.41 \times 10^{-9} \text{ m}^2/\text{s}$),
 Δr is the Spatial step size,
 Δt is the Time step size, and
 r_i is Radial position, $r_i = i\Delta r$.
 m is a step for time, and
 i is the spatial step.

Initial conditions:

$$C = C_i^m \text{ at } 0 < r \leq R_{eff} \dots (4)$$

$$C = 0 \text{ at } r > R_{eff} \dots (5)$$

Boundary conditions:

$$C = 0 \text{ at } r > R_{eff} \text{ for } 0 < \Delta t < T \dots (6)$$

Solvent diffusion profiles were computed as functions of time and radial position for 1K, 2K, and 3K PAN tows to assess solvent removal across wet-spinning units. An identical spinning line with two coagulation baths, two stretching units, and one washing unit was modeled to enable normalized comparison, with details shown in Figure 2 and Table 1.



Figure 2: Hypothetically designed wet-spinning line for solvent extraction

Table 1: Parameters of wet-spinning line for solvent extraction

S. No.	Unit	Parameters		
		Temperature (°C)	DMAc Concentration (%)	Residence time (s)
1	Coagulation Bath-1	30	70	120
2	Coagulation Bath-2	30	0	41.63
3	Washing unit	90	0	570
4	Stretch Bath-1	90	0	24.27
5	Stretch Bath-2	90	0	17.65

Solvent extraction from PAN precursor tows of different sizes (1K, 2K, and 3K) was evaluated using the FDM model under appropriate initial and boundary conditions. Figure 3 illustrates solvent reduction at various stages of the wet-spinning line, revealing a strong influence of filament layering on diffusion behavior throughout the process. After the coagulation bath, solvent reduction values of 71.5%, 74.1%, and 75.3% were obtained for 1K, 2K, and 3K tows, respectively, consistent with coagulation theory involving double diffusion and gel fiber formation. At this stage, residual solvent contents in 2K and 3K tows were similar, while 1K exhibited lower values, highlighting the limiting effect of increased layering on solvent extraction efficiency. These results indicate that differences between 2K and 3K tows arise mainly in downstream spinning units. Subsequent stages show more pronounced solvent reduction, particularly in the washing unit. Notably, no further solvent decrease was observed for 1K tows after washing, indicating near-complete extraction. Although stretching units reduce fiber diameter and expose fresh surfaces, their shorter residence times limit solvent removal. In contrast, the washing unit, despite no size reduction, achieves effective solvent extraction due to extended residence time. Comparative simulation videos further illustrate these effects.

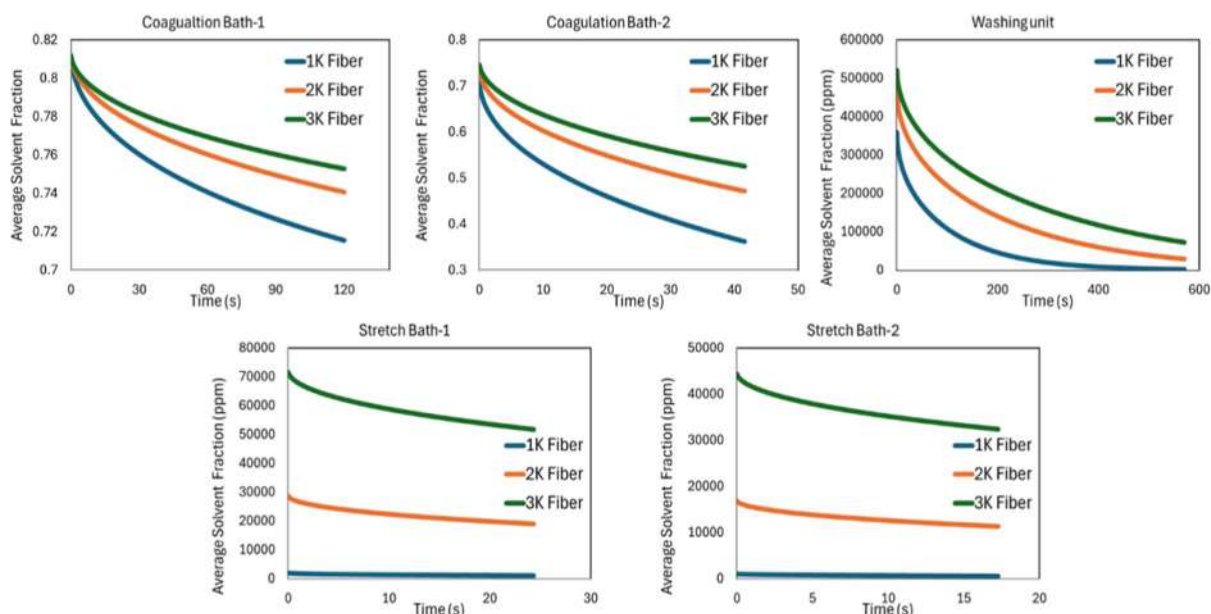


Figure 3: Solvent extraction profile for 1K, 2K, and 3K filaments at various stages

The FDM study demonstrates the effectiveness of individual wet-spinning units and highlights the strong influence of parameters such as tow size, effective tow radius, and residence time on residual solvent content in PAN fibers. However, experimental validation is essential to substantiate these

computational trends. Accordingly, solvent content in PAN fibers was quantified using GC/MS analysis. The characteristic DMAc solvent peak at a retention time of 7–7.3 minutes, identified using pure DMAc as a reference standard, was used to determine solvent levels in the fiber samples. Residual solvent contents for 1K, 2K, and 3K tows were measured and are presented in Table 2, enabling direct validation of the FDM predictions against experimental results.

Table 2: Residual solvent content in the fibers with different tow sizes

S. No.	Tow size	FDM predicted value (ppm)	Experimental value (ppm)	Difference (ppm)
1	1K	327.1	122.6	204.5
2	2K	11,258.1	10,889.5	368.9
3	3K	32578.5	26005.2	6573.7
4	2K-modified line	897.2	2597.8	-1700.6
5	3K-modified line	5464.4	5983.4	-519

Comparison of the FDM-predicted solvent contents with GC/MS experimental data (Table 2) demonstrates good agreement, confirming the validity of the developed model. The solvent reduction trends are accurately captured for 1K and 2K tows using the hexagonal close-packed (HCP) geometry. However, deviations observed for 3K tows suggest that larger filament bundles may adopt alternative packing arrangements due to self-weight effects, leading to increased surface area, additional water contact points, and fewer effective layers. These findings highlight the practical relevance of the model for PAN wet-spinning, where unit selection and placement directly affect both solvent content and mechanical performance. Based on these insights, a revised spinning line incorporating two washing units operating at identical speeds was proposed, as washing was identified as the most effective solvent extraction stage. Both FDM predictions and GC/MS measurements for rewashing 2K and 3K tows showed further solvent reduction and strong agreement. Overall, the framework enables rational spinning line design for producing high-strength PAN precursors and improved carbon fibers with reduced microvoid formation.

Conclusion

An FDM-based computational model was developed to simulate the effect of tow size on solvent removal from PAN precursor fibers during wet spinning. The results demonstrate that smaller 1K tows exhibit significantly higher solvent removal efficiency than 2K and 3K tows, achieving solvent contents as low as 327 ppm due to shorter diffusion paths associated with smaller effective radii and fewer filament layers. The study identifies the washing unit as the most critical stage for solvent extraction, as its longer residence time enables effective removal from the tow core, unlike short-duration stretching baths. Model predictions showed strong agreement with GC/MS experimental data, validating the model's reliability. Overall, the model offers a cost-effective and practical tool for optimizing spinning line design and tailoring PAN precursor properties for high-strength carbon fiber production.

Acknowledgements

The authors would like to express their sincere thanks to the National Technical Textile Mission (NTTM) for granting the opportunity and financial support for this work.

2.2 Preparation of Lyocell CNT Composite High-Strength Carbon Fiber.

Introduction

Carbon fibers are of much interest due to their higher strength and light weight. These are extensively used as reinforced materials for aerospace applications, sports equipments, wind-turbine blades etc. The precursors for carbon fibres (based on their source of availability) are polyacrylonitrile (PAN), petroleum pitch and cellulose. Out of all these, PAN is the extensively used precursor for the synthesis of carbon fiber. But because of its high cost, finding of an alternative precursor to replace PAN has been intensified and the target is not only to reduce the cost of obtained carbon fiber, but also to use a biobased feedstock. Cellulose can be a suitable option in view of its high carbon content and oldest known precursor of carbon fibers. However, the tensile strength and yield of fibers developed from this precursor tend to be low. Despite of these disadvantages, cellulose based carbon fibers can be chosen over PAN-based fibers because of its abundance in availability, biodegradability and the processing is free of any environmental pollutants. Lyocell is an eco-friendly fiber based on cellulose obtained by dry-jet-wet-spinning method from direct dissolution of cellulose in N-methylmorpholine N-oxide (NMMO). Lyocell fibers exhibit higher mechanical and lower shrinkage properties than any other rayon-based fibers. Also, addition of flame resistant salts before stabilization of lyocell fibers helps to improve the yield as well as the strength of the resulting fiber.

Carbon nanotube (CNT) has received much attention due to its high strength, high modulus and higher electrical conductivity. It has been reported in literatures that incorporation of CNT to carbon fiber exhibits much reduction in shrinkage during carbonization process. So to enhance the tensile strength of the carbon fiber, CNT can be a good option. Treatment of lyocell fiber with flame retardant molecules helps to improve the carbon yield by preventing the process of combustion during carbonization step.

So in this work, we will be focusing on producing carbon fibers from lyocell-SWCNT composite along with the incorporation of the suitable flame retardant molecule to improve both mechanical strength and carbon yields.

Materials and Methods

Materials

Cellulose Pulp, N-methylmorpholine-N-oxide (NMMO), n-propyl gallate, SWCNT.

Methods

Optimization of the dispersion of CNT

Dispersion of CNT in 60% NMMO solution has been checked by using probe sonication. Optimization of % of CNT and dispersion time was varied and observed that 25-30 min. of dispersion is sufficient to separate the aggregated CNT bundles.

Dissolution of cellulose in NMMO-CNT slurry

76% NMMO solution is the requirement for the dissolution of cellulose. So, 60% NMMO solution was concentrated to 76% by removing extra water from it. Then dispersion of CNT has been carried out followed by the dissolution of cellulose in it. Dissolution of cellulose (10-12%) in CNT-NMMO slurry has been done in sigma mixer at 120-125 °C followed by removal of extra water by using vacuum. Finally the dope was prepared and taken out and kept in vacuum container.

Synthesis of fiber

CNT dispersed dope was allowed for filtration using 200 µm and 50 µm mesh in order to avoid any kind of blockage or jam because of any larger undissolved or agglomerated particles during spinning. Then the filtered dope was melted at 120 °C for 2-3 h and then allowed for spinning through the spinneret using 100 µm mesh.

Treatment of FR

Diammonium hydrogen phosphate (DAP) was taken as FR agent and it is treated to the obtained fiber in different concentrations (w.r.t. water as solvent). 50 mL of DAP solution at different concentrations like 3%, 5% and 10% were prepared at 60 °C (stirred for 30 min.). 10g of fiber was immersed in the above solution for 30 min., taken out and dried overnight at 70 °C. Then stability of the fibers were checked by TGA.

Carbonization

Carbonization of the fibers was carried out to get the carbon fiber. The conditions for carbonization is mentioned in Table-1.

Table-1: Conditions for carbonization of lyocell fiber

Temperature (°C)	Gas flow	Heating rate	Retention time at Max. Temperature
25-250	Air	1°C/min.	10 min.
300-400	N ₂ /Argon	3°C/min.	17 min.
400-800	N ₂ /Argon	3°C/min.	17 min.
800-1000	N ₂ /Argon	3°C/min.	17 min.

Characterizations

The obtained fibers were characterized using different characterization techniques such as physical testing, mechanical testing, analytical testing etc. to check the CNT content, strength, denier, tenacity etc. of the fiber.

Results and Discussion

Clear dispersion of CNT in NMMO has been observed through optical microscopy as depicted in Fig. 1.

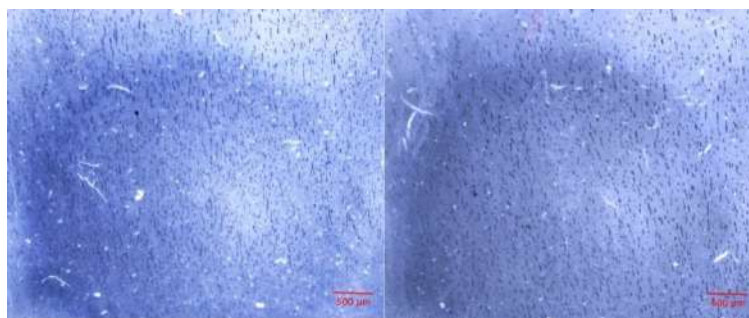


Fig. 1: Optical microscopic image of CNT dispersed NMMO solution after sonication with 0.35 wt% CNT content w.r.t cellulose

After that cellulose was allowed to dissolve in the above slurry in a sigma mixer to get a dope. Finally a black color dope was obtained after removal of requisite amount of water. Then the dope was filtered to get rid of undissolved cellulose as well as agglomerated CNTs.

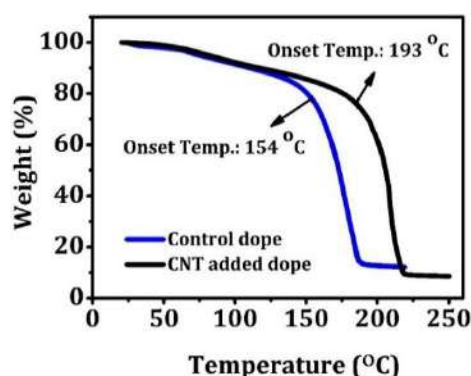


Fig. 2: Thermal analysis of the dope

Fig. 2 represents the thermal stability of the CNT incorporated dope. It can be seen that the onset temperature of the CNT added dope is higher than that of the control dope. Thereafter spinning of the dope has been carried out to get fibers. Fig. 3 illustrates the SEM image of the obtained fibers, where both surface and cross-section can be seen clearly. The lyocell-CNT fiber shows a quite smooth surface, round cross-sections along with dense fibrillar structure.

Trials have been taken with variation of % of CNT w.r.t. cellulose and up to 0.45% of CNT, fiber drawing is smooth without any blockage. After that, continuous breaking of fiber was observed during spinning irrespective of the size of CNT.

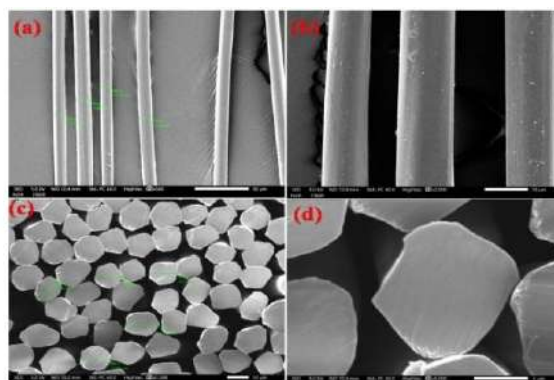


Fig. 3: SEM image fiber samples; (a) and (b) surface morphology; (c) and (d) cross-section morphology

Then flame retardant molecule is treated with the fiber to get rid of char formation during stabilization and carbonization of the fiber. There is no shrinkage of the fiber observed after stabilization. Also, the tenacity of the fiber has not decreased after stabilization. The stability of the fibers after treating with FR were checked by TGA. The results are given in Fig. 4. It can be seen that with increase in % of FR, % of residual carbon increases. Compared to untreated fiber, increase in char residue at higher temperature was observed after treating the fibers with DAP. The carbon yield for 10% FR treated fiber is 38% and in case of untreated one, it is 10%. So, the % of carbon yield is increasing with increase in FR.

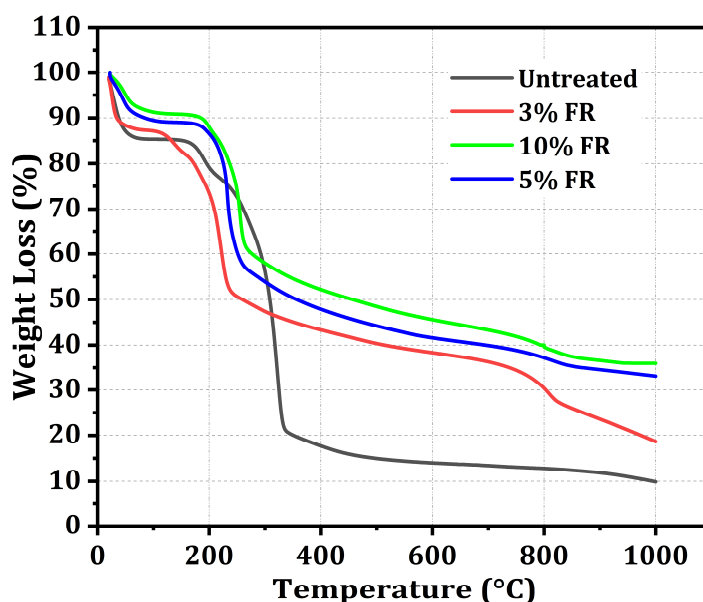


Fig. 4: TGA of untreated and FR treated fibers

After the carbonization, tensile strength and modulus of the precursor and carbonized fibers were checked. The results obtained are given in Table-2.

Table-2: Mechanical properties of lyocell precursor and the corresponding carbon fiber

Samples	Tensile Strength (GPa)	Modulus (GPa)	% of carbon yield
Carbon fiber	2.602	187.1	38
Precursor	0.68	5.94	10

Conclusion

Clear dispersion of CNT in NMMO has need observed and the fibers obtained from lyocell-CNT composite are having similar morphology and other physical properties. Further modification of the fibers with variation of CNT content has also carried out and treatment of FR to the fiber before stabilization has been done. Carbonization of the fiber has also been done.

2.3 Development of Alkaline Resistance Polyester for the Geosynthetic Application

Abstract

Polyester-based geosynthetics are extensively used in civil engineering due to their superior mechanical properties and economic advantages. Nevertheless, prolonged exposure to highly alkaline environments, including high-pH soils and groundwater, can substantially compromise their long-term durability. In the present study, polyvinyl alcohol (PVA) was selected as a coating material for polyester yarns because of its inherent resistance to alkaline conditions and its water solubility, which eliminates the need for organic solvents and supports environmentally sustainable processing. To enhance water resistance and mechanical integrity, the PVA coating was chemically crosslinked using suitable crosslinking agents. The crosslinked PVA was applied to polyester yarns using a padding mangle technique, followed by drying under controlled conditions. The coated yarns exhibited excellent resistance to alkaline environments up to pH 12.5 at 50 °C, showing minimal physical degradation even after extended exposure. Gravimetric evaluations, including GSM measurements, verified uniform coating distribution and improved mechanical stability. Overall, this study presents a cost-effective, scalable, and environmentally friendly approach for extending the service life of polyester geosynthetics in aggressive alkaline conditions.

Introduction

Polyester-based geosynthetics are widely used in civil engineering applications because of their excellent mechanical strength and cost-effectiveness. However, their susceptibility to alkaline hydrolysis in aggressive environments such as high-pH soils and groundwater significantly limits their long-term durability. This study investigates a surface-coating strategy to improve the alkaline resistance of polyester materials. Among the available approaches, coating with alkaline-resistant polymers was identified as a practical and scalable method that enhances chemical stability without demanding high energy consumption or complex processing. Consequently, this approach offers a cost-effective and industrially viable solution for extending the service life of polyester-based materials exposed to severe alkaline conditions.

Polyvinyl alcohol (PVA) was selected as the coating material due to its inherent resistance to alkaline environments and its water solubility, which reduces reliance on organic solvents and supports environmentally sustainable processing. PVA is a versatile synthetic polymer characterized by a carbon-carbon (C-C) backbone with pendant hydroxyl (-OH) groups, which impart unique properties such as water solubility. Owing to this characteristic, PVA has gained increasing use in packaging and other industrial applications. Additionally, PVA exhibits excellent film-forming ability, strong adhesion, and high thermal stability. It is a white, odorless, and tasteless powder widely employed in industries including paper, textiles, adhesives, coatings, films and packaging, pharmaceuticals, construction, and cosmetics. Despite its advantages, the high water solubility and crystallinity of PVA can limit its performance in humid environments or applications requiring enhanced water resistance. To mitigate this drawback, various crosslinking agents such as cyanuric acid, citric acid, formaldehyde, glutaraldehyde, glyoxal, acetic acid, and maleic acid are commonly used. However, inadequately modified or plasticized crosslinked PVA films may exhibit brittleness, underscoring the need for careful optimization, particularly for coating applications.

To address these challenges, a novel approach has been developed that enables effective crosslinking within a few minutes. This advancement significantly improves process efficiency and

expands the applicability of PVA in industries requiring rapid processing. The optimized coating technique achieves fast crosslinking while maintaining or enhancing the mechanical strength and stability of PVA. Overall, this development presents a promising, efficient, and sustainable solution for industrial applications involving PVA-based coatings.

Materials and Methods

Materials

PVA (Molecular weight = Approx. 1,15,000, Hydrolysis degree = 98 - 99%), Calcium Hydroxide 94 %, Sodium Hydroxide pellets 98%, Sulphuric Acid (AR) 98%, Sodium Sulphate Anhydrous 99%, 40% Crosslinker -1(CL-1), 37% Crosslinker -2 (CL-2), were buy from Loba Chemie Pvt Ltd, 07, Wodehouse Rd, near Bank of India, Cuffe Parade, Mumbai, Maharashtra, India, 400005. Crosslinker -3 (CL-3), purchased from Tokyo Chemical Industry Co. Ltd, 6-15-9 Toshima, Kiti-Ku, Tokyo, Japan. Shanghai Lingfeng chemical reagents co. LTD (Shanghai, China),

Methods

Preparation of crosslinked films PVA / Crosslinker -1, Crosslinker -2, and Crosslinker -3

This two-step procedure was designed to ensure effective crosslinking of the polymer. In the first step, a polymer solution was prepared and processed into thin films using the solution-casting technique. In the second step, the formed films were crosslinked by immersion in an acidic bath composed of sulfuric acid and sodium sulfate dissolved in distilled water. The detailed preparation procedure for crosslinked PVA films containing different crosslinker formulations, designated as PVA/(CL-1), PVA/(CL-2), and PVA/(CL-3), is described below.

Initially, a 5% (w/v) PVA solution was prepared by dissolving PVA in distilled water at 85 °C under continuous magnetic stirring at 800 rpm for 30 minutes to achieve complete dissolution. The solution was subsequently cooled to ambient temperature (30 °C), after which the crosslinking agents were introduced in predetermined ratios as listed in Table 1. The mixture was stirred for an additional 10 minutes to ensure uniform dispersion. The homogeneous solution was then cast into Petri dishes to form thin films and dried in an oven at 70 °C until complete solvent evaporation. After drying, the films were carefully peeled from the Petri dishes for further processing.

In the second step, the dried films were immersed in a crosslinking bath containing 5% (v/v) sulfuric acid and 20% (w/v) sodium sulfate at 50 °C for 5 minutes. Following crosslinking, the films were thoroughly rinsed with distilled water to remove residual acid and subsequently dried in an oven at 70 °C for 10 minutes.

CL-1/PVA	CL-2/PVA	CL-3/PVA
1.0	1.0	1.0
0.8	0.8	0.8
0.6	0.6	0.6
0.4	0.4	0.4
0.2	0.2	0.2

Table1 composition ratio of crosslinking agents and PVA

Water-swelling degree

The water swelling degree was determined by immersing a 3 × 5 cm film sample (Figure 3c) in distilled water for 72 hours. After swelling, the dimensions (l_s) and weight of the swollen film were recorded. The film was then placed in a desiccator at room temperature for three days to dry completely, after which the dried film dimensions (l_d) were measured. The water swelling degree was calculated using the following equation:

$$DS = [(l_s - l_d)/l_d] \times 100 \dots\dots\dots 1$$

Degree of Cross – Linking

The degree of crosslinking was evaluated based on the weight loss of the films before and after immersion in water. All prepared films were initially dried to a constant weight and recorded as m_0 . After immersion in water for 72 hours, the films were assumed to have reached solubility equilibrium. The remaining insoluble portions were then dried in an oven at 85°C until a constant weight was achieved and recorded as m_d . The degree of crosslinking was calculated using the following equation:

$$DC = m_0/m_d \times 100 \dots\dots\dots 2$$

Evaluation of Alkaline Resistance property of PVA- coated Polyester

The alkaline resistance of the coated polyester samples was assessed in accordance with DIN EN 14030:2003, "Screening test method for determining the resistance to acid and alkaline solutions Geotextiles and geotextile-related products." This standard outlines a procedure for evaluating the chemical stability of geosynthetic materials when exposed to aggressive alkaline environments. As specified, the test specimens were fully immersed in an alkaline solution with a pH of 12.5 and maintained at 60 °C for duration of three days (72 hours). After the exposure period, the samples were removed from the solution, thoroughly rinsed with distilled water to remove any residual alkali, and subsequently dried under controlled conditions before further characterization.

Result and Discussion

Water-swelling degree

Because PVA is inherently water soluble, evaluating its water solubility after crosslinking serves as an important indicator of crosslinking efficiency. Accordingly, solubility and swelling tests were employed to quantify both the degree of swelling and the extent of crosslinking achieved. PVA films were crosslinked using progressively increasing crosslinker-to-PVA ratios of 0.2, 0.4, 0.6, 0.8, and 1.0 under identical experimental conditions, as summarized in Table 2. All experiments were conducted in triplicate, yielding films with an average thickness of approximately 100 μm .

Figure 1 illustrates the relationship between swelling degree (%) and the crosslinker-to-PVA ratio, with the corresponding numerical values provided in Table 2. Among the crosslinking agents evaluated, CL-3 exhibited the most significant effect on the swelling behavior of the PVA films. At a

CL-3/PVA ratio of 0.2, the swelling degree was measured at 18% ($\pm 4\%$). With increasing CL-3 content, the swelling degree progressively decreased to approximately 9%, 7%, and 6% ($\pm 4\%$) at ratios of 0.6, 0.8, and 1.0, respectively. This trend can be attributed to the increased crosslinking density resulting from higher CL-3 concentrations, which promote reactions at both ends of the CL-3 molecule. The resulting denser polymer network reduces free volume within the matrix, thereby significantly enhancing the water resistance of the PVA films.

Crosslinker / PVA ratio	CL-1	CL-2	CL-3
1.0	Gel formation	20	6
0.8	Gel formation	18	7
0.6	Gel formation	15	9
0.4	265	26	15
0.2	300	40	18

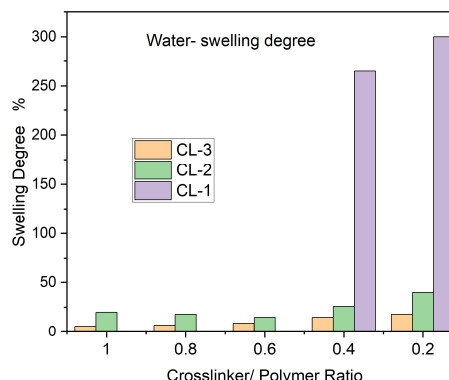


Table2 water swelling degree Figure 1 water swelling degree

Degree of Cross — Linking:

Figure 2 illustrates the relationship between the degree of crosslinking and the crosslinker-to-PVA ratio, with the corresponding data summarized in Table 3. The degree of crosslinking was evaluated using the weight loss method following water immersion. Among the crosslinkers investigated, CL-3 demonstrated consistently high crosslinking efficiency, with values ranging from 96% to 99% across CL-3/PVA ratios between 0.2 and 1.0. CL-2 exhibited a crosslinking degree of 93% at a CL-2/PVA ratio of 0.2, reaching a maximum of 97% at a ratio of 0.8. In contrast, CL-1 achieved a crosslinking degree of 90.2% at the lowest CL-1/PVA ratio, which gradually decreased as the crosslinker concentration increased.

This inverse trend for CL-1 may be attributed to the availability of reactive hydroxyl groups on the PVA chains. At lower CL-1 concentrations, a greater number of accessible active sites facilitate effective crosslinking, whereas higher concentrations may impede optimal molecular interactions, thereby reducing crosslinking efficiency. These findings highlight the importance of optimizing crosslinker concentration to achieve an appropriate balance between reactivity and material performance in PVA-based systems. Additionally, the observed variations may be influenced by insufficient activation energy for effective reaction initiation at the relatively low experimental temperature employed.

Crosslinker / PVA ratio	CL-1	CL-2	CL-3
1.0	64.4	96	98
0.8	66.5	97	99
0.6	68.2	94	99
0.4	76.9	94	97
0.2	90.2	93	96

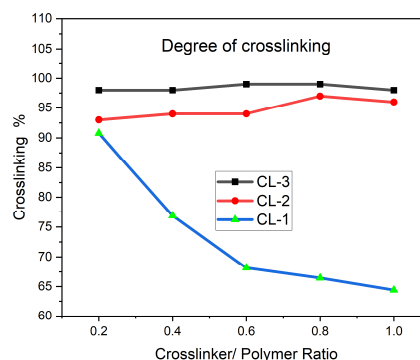


Table3 Degree of Cross- linking

Figure 2 Degree of cross - linking

Coating of Polyester Yarn, geotextile, and geogrid with Crosslinked PVA

Initially, a PVA-based emulsion was prepared by dissolving PVA in distilled water under continuous stirring and controlled heating to obtain a homogeneous solution. Selected additives and crosslinking agents were then incorporated to improve coating adhesion, flexibility, and resistance to alkaline environments. The resulting emulsion exhibited appropriate viscosity and stability for application via the padding process.

The formulated PVA emulsion was applied to polyester yarns, geotextiles, and geogrids using a padding mangle unit operated at a nip pressure of 2 bar and a roller speed of 120 rpm. These operating conditions were optimized to achieve uniform coating pick-up and sufficient penetration into the yarn structure while preventing fiber deformation or excessive material loss. Following application, the coated substrates were dried in a hot-air oven at 150 °C for 4 minutes to remove moisture and initiate the crosslinking reaction between PVA and the crosslinking agents. This treatment produced a thin, uniform, and well-adhered crosslinked PVA layer on the polyester surfaces.

The controlled drying and curing conditions facilitated the formation of a stable three-dimensional polymer network, thereby enhancing the chemical resistance and mechanical durability of the coated yarns. Finally, the coated materials were conditioned under standard atmospheric conditions ($65 \pm 2\%$ relative humidity and 25 ± 2 °C) prior to subsequent characterization and performance evaluation.

Evaluation of Alkaline Resistance property of coated Polyester

The grams per square meter (GSM) of each specimen namely virgin polyester textile coated polyester textile, virgin polyester geogrid, and coated polyester geogrid was measured both before and after alkaline exposure to assess the effect of the PVA coating on material mass and surface coverage. All specimens were prepared with a uniform dimension of 20 cm × 20 cm (400 cm²), and their weights were recorded using a precision balance. GSM values were calculated using the standard formula, providing a normalized measurement independent of sample size. This normalization enabled direct and reliable comparison between coated and uncoated materials, as well as evaluation of mass changes resulting from coating application and alkaline exposure.

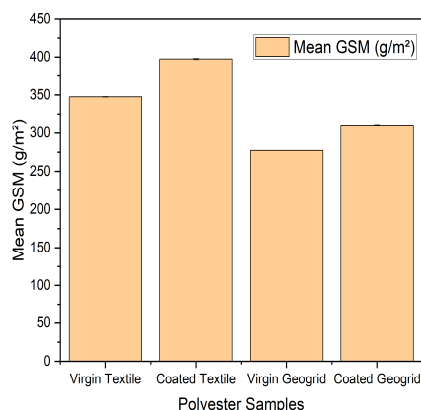


Figure 3 GSM for Coating uptake Assessment

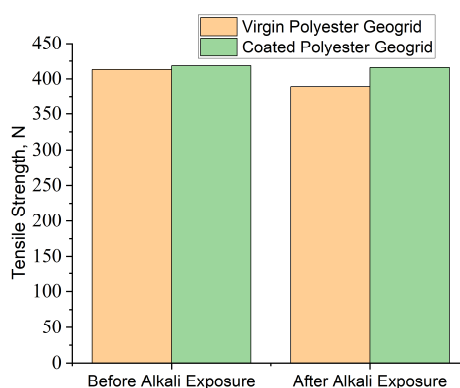


Figure 4 TS for evaluation of Alkaline Resistance

Each GSM value represents the average of five independent measurements, ensuring statistical reliability. The corresponding standard deviations were minimal for all samples, indicating excellent repeatability and uniformity of the coating process. Figure 3 illustrates the relationship between GSM values for the different materials. The virgin polyester textile exhibited a mean GSM of 347.575 g/m², which increased to 397.305 g/m² after coating, corresponding to an approximate mass gain of 14.3%. This increase is attributed to the uniform deposition of the crosslinked PVA coating on the textile fibers, reflecting effective wet pick-up and strong adhesion of the coating layer.

Similarly, the virgin polyester geogrid showed a mean GSM of 277.145 g/m², which increased to 310.655 g/m² following coating, representing a mass increase of approximately 12.1%. The comparatively lower percentage increase in GSM for the geogrid suggests that its more open structure retains fewer polymers than the denser textile substrate.

Effect of Alkaline Exposure on GSM Retention

Post-exposure GSM values were compared with the corresponding pre-exposure measurements to quantify percentage mass loss. The virgin polyester textile exhibited a GSM reduction of 3.20%, whereas the coated textile showed a minimal loss of only 0.10% under the same alkaline conditions. Similarly, the virgin polyester geogrid experienced a 3.61% decrease in GSM, while the coated geogrid demonstrated a negligible reduction of 0.20%. This pronounced contrast clearly demonstrates the protective effectiveness of the crosslinked PVA coating against alkaline-induced degradation. The substantial mass loss observed in uncoated polyester samples is attributed to hydrolytic cleavage of ester bonds within the polymer backbone, a process that is significantly accelerated in highly alkaline environments. In contrast, the coated specimens retained nearly their original mass, indicating that the crosslinked PVA layer functioned as an efficient diffusion barrier, limiting direct exposure of the polyester substrate to the aggressive alkaline medium.

Tensile Strength Evaluation Before and After Alkaline Exposure

Figure 4 illustrates the tensile strength behavior of virgin and coated polyester geogrids. Tensile testing was conducted to evaluate the effect of the crosslinked PVA coating on mechanical integrity and durability, both before and after alkaline exposure. Each reported value represents the average of five independent measurements, ensuring statistical reliability and reproducibility. Prior to alkaline exposure, the virgin polyester geogrid exhibited a mean tensile strength of 413.24 N, whereas the coated geogrid showed a slightly higher value of 418.42 N. This modest increase of approximately 1.25% indicates that the PVA coating does not compromise the inherent mechanical properties of the polyester substrate. Instead, the coating appears to provide a minor reinforcement effect, likely due to the formation of a thin crosslinked polymer layer that enhances fiber–fiber friction and promotes more uniform load transfer during tensile loading.

Following exposure to the alkaline environment, pronounced differences were observed between the coated and uncoated samples. The tensile strength of the virgin polyester geogrid decreased significantly to 389.02 N, representing a 5.86% reduction from its initial value. This loss in strength is attributed to alkaline hydrolysis of the ester bonds in the polyester backbone, leading to chain scission, reduced molecular weight, and surface degradation, all of which weaken the fiber structure. In contrast, the coated polyester geogrid retained a tensile strength of 416.46 N after alkaline exposure, corresponding to a minimal reduction of only 0.47% relative to its pre-exposure strength.

This negligible decrease clearly demonstrates the effective barrier protection provided by the crosslinked PVA coating, which restricts the diffusion of alkaline species into the polyester matrix and thereby mitigates hydrolytic degradation.

These findings are consistent with the GSM retention results, where coated specimens exhibited minimal mass loss ($<0.2\%$) under identical test conditions. Collectively, the results confirm that the crosslinked PVA coating effectively preserves both the dimensional stability and mechanical strength of polyester geogrids in high-pH environments. The combination of high tensile strength retention and negligible GSM variation after exposure underscores the chemical stability, structural integrity, and long-term performance reliability of the coated material.

Conclusion

In this study, we successfully developed and applied a crosslinked PVA-based coating to enhance the alkaline resistance of polyester-based geosynthetics. The coating was applied using a padding mangle technique and thermally cured at $150\text{ }^{\circ}\text{C}$ for 4 minutes, resulting in uniform, continuous, and well-adhered films on both polyester textiles and geogrids. Through GSM analysis, we confirmed effective coating deposition, evidenced by increased areal weight and consistent coating uniformity across all treated samples. Following exposure to alkaline conditions, we observed negligible GSM loss ($<0.2\%$) in the coated materials, while the uncoated polyester samples exhibited a weight reduction of approximately 3–4%, demonstrating the strong chemical resistance imparted by the crosslinked PVA layer. Mechanical performance evaluation further confirmed the effectiveness of the coating, as the coated geogrids retained more than 99% of their original tensile strength after alkaline exposure, in contrast to a 5–6% reduction observed in uncoated specimens.

These findings clearly demonstrate that the crosslinked PVA coating effectively inhibits alkaline hydrolysis and preserves both the structural integrity and mechanical performance of polyester substrates. Overall, this study establishes a durable, environmentally sustainable, and easily scalable coating strategy for improving the long-term chemical stability of polyester geosynthetics. The compatibility of the developed process with existing industrial coating techniques highlights its strong potential for practical implementation in civil and geotechnical applications where alkaline exposure is a critical concern.

2.4 Preparation of cellulose/silica based aerogels and its composite for thermal insulation application

Introduction

The amount of energy required for environmental comfort in a building is governed by the thermal performance of the building envelope such as walls and roofs which separates the indoor from outdoor. With the proper application of thermal insulation material in building envelope, the rate of heat transmission and energy consumption for heating and cooling of building internal environment can be reduced. Thermal insulation can be measured in terms of R-value and for the clothing material; it can be expressed as a clo value. Higher the R-value and clo value, higher is the insulation. Polystyrene, polyurethane forms and aerogels are such type of thermal insulation material.

Experimental

In it cellulose was first dissolved in N methyl morpholine oxide at an appropriate temperature, solidifying in mould along with batting. The composite was then repeatedly washed with distilled water and freeze dried to obtain aerogel composite. Density and porosity of the aerogel composite was calculated. Thermal insulation of composite was then evaluated.

Results and discussion

Density and porosity of the prepared composite is calculated as 0.05 g/cm³ and 96.5% respectively. The targeted property of the prepared composite related to thermal insulation is found 0.86 clo compared to 0.58 for batting. This is because of porous structure formed by the aerogel in between the batting cause air entrapped and avoids the heat loss through conduction and radiation process.

Conclusion

Cellulose aerogel composite was successfully prepared with cellulose aerogel and polyester batting by dissolving cellulose in N-methyl morpholine N-oxide solvent. Cellulose solution was then converted into gel by sol-gel process, moulded with batting and then regenerated with water and freeze dried. The prepared composite has three-dimensional porous structure. Density of the prepared composite is 0.05 g/cm³. Porosity of prepared composite is 96.5%. The thermal insulation of prepared composite is 48.27% higher than the batting. This material has potential application in providing heat insulation to the building envelope, aerospace interiors and clothing.

2.5 Atmospheric Plasma Assisted Dyeing of Polypropylene with Graphene Nanomaterial to Impart Antistatic and Conductive Properties

Introduction:

Nitrene functionalization is an important approach for modifying graphene because it enables the formation of strong and stable covalent C-N bonds directly on the graphene lattice. Nitrenes are highly reactive nitrogen-centred species that can insert into the C=C bonds of graphene, providing robust chemical anchoring that is far more durable than non-covalent interactions. This method allows controlled introduction of nitrogen-containing functional groups without extensive oxidation or severe disruption of the graphene structure, thereby preserving much of its intrinsic electrical and mechanical properties. The presence of C-N functionalities enhance surface polarity and chemical affinity, significantly improving interfacial binding with polymers such as polypropylene and enabling improved coating adhesion and wash durability. Additionally, nitrene-functionalized graphene exhibits better dispersion and processability, reducing agglomeration and facilitating uniform surface coverage. The introduced nitrogen sites also act as reactive anchors for further chemical modifications or crosslinking reactions, making nitrene functionalization a versatile and effective strategy for developing durable graphene-based coatings, composites, and functional surfaces.

EXPERIMENTAL SECTION

SYNTHESIS OF 3-AZIDO PROPAN-1-OL FROM 3-CHLORO PROPAN-1-OL

3-Azidopropan-1-ol was synthesized following the reported method by S. Depaifev et al. In a typical procedure, 20.16 g of 3-chloropropan-1-ol was dissolved in 213.5 mL of deionized water, followed by

the addition of sodium azide (19.44 g). The reaction mixture was refluxed at 50 °C under vigorous stirring for 24 h. After cooling to room temperature, the product was extracted with diethyl ether (3 × 50 mL). The combined organic layers were dried over anhydrous MgSO₄, filtered, and concentrated under reduced pressure to obtain a pale-yellow azido-functionalized intermediate.

FUNCTIONALIZATION OF GRAPHENE WITH 3 AZIDO PROPAN-1-OL USING NITRENE CHEMISTRY

In a typical procedure, 1.2 g of graphene was dispersed in 240 mL of ortho-dichlorobenzene in a 250 mL two-necked round-bottom flask fitted with a reflux condenser. The system was purged with argon and heated to 150 °C. A solution of 3-azidopropan-1-ol (2.02 g) in 10 mL ortho-dichlorobenzene was added dropwise, and the reaction was stirred at 150 °C for 48 h. After cooling to room temperature, the black solid was vacuum-filtered through a 0.45 µm polyamide membrane, washed successively with acetone, dichloromethane, and ethanol, and dried under vacuum at 60 °C for 48 h.

Reaction mechanism

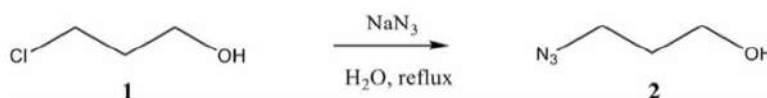


Fig: schematic way of synthesis of 3-azido-1-propanol from 3-chloro-1-propanol – Part A

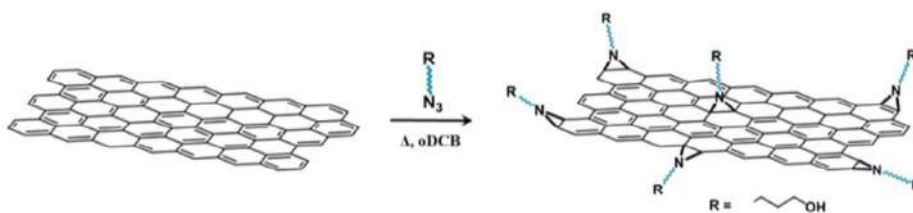


Fig: schematic way of functionalization of Graphene with 3 Azido-1-propanol

Fig.1.Reaction mechanism

NITROGEN PLASMA TREATMENT OVER PP

Atmospheric plasma treatment was carried out using a dielectric barrier discharge (DBD) system operating at 20 kHz with a roll-to-roll configuration. Ready-to-dye PP spun-woven fabric was fed into the plasma chamber with an electrode gap of 0.5 mm. Nitrogen was used as the working gas at a flow rate of 0.5 L·min⁻¹, with helium as the carrier gas at 5 L·min⁻¹. Plasma was generated at different power levels (2, 2.5, 3, and 3.5 kW), and the treatment time was fixed at 60 s to avoid thermal degradation of the polypropylene fibers. After treatment, the samples were removed and stored in zip-lock bags to minimize surface aging before further functionalization.

GLUTARALDEHYDE TREATMENT OVER FABRIC

Plasma-treated polypropylene fabrics were functionalized with glutaraldehyde to introduce surface aldehyde groups. In a typical procedure, 100 mL of deionized water was heated to 50 °C under continuous stirring, followed by the addition of 1 mL of glutaraldehyde (50 wt.%). The solution pH was adjusted to 7-8 using dilute NaOH. The plasma-treated fabric was immersed in the solution and

maintained at 50 °C for 3 h. After treatment, the fabric was thoroughly rinsed with deionized water to remove unreacted glutaraldehyde and air-dried overnight at ambient conditions.

FIXATION OF N-GRAPHENE OVER PP

N-graphene dispersions were prepared by probe sonication using an ethylene glycol/DI water mixture (80:20, v/v) as the solvent. N-graphene was added at concentrations ranging from 0.05 to 0.25 wt.% and sonicated for 2 h to obtain a homogeneous dispersion. The dispersion was directly used for treating polypropylene fabric by a standard high-temperature beaker dyeing method at 130 °C for 3 h. After dyeing, the bath was cooled to room temperature, and the fabric was rinsed thoroughly with DI water and cured at 158 °C to fix N-graphene onto the fiber surface. The same solvent system was also employed for the pad-dry-cure method.

RESULTS AND DISCUSSION

SEM MORPHOLOGICAL ANALYSIS

SEM analysis for Fig.2. reveals a clear transformation of PP spun-woven fibers after functional treatment. While pristine PP fibers exhibit smooth, clean surfaces typical of untreated polypropylene, the treated fibers show a markedly roughened morphology with flake-like and particulate deposits. High-magnification images confirm the presence of surface defects and adhered fragments, indicating successful chemical activation and strong interfacial interactions. These morphological changes increase surface area and available binding sites, supporting enhanced adhesion and improved coating durability compared to untreated PP.

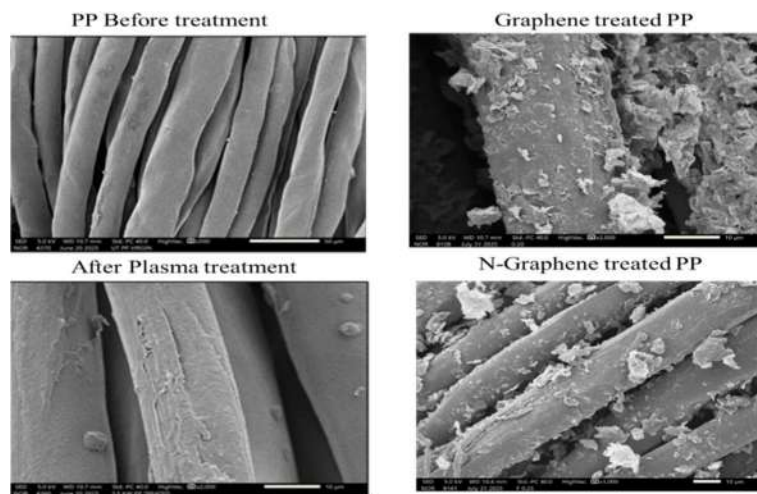


Fig.2. SEM Images of PP Before and after treatment with plasma and Graphen& N-Graphene

XPS ANALYSIS

XPS analysis confirms the successful nitrogen functionalization of graphene. The survey spectrum of N-graphene shows the presence of C 1s, O 1s, and a distinct N 1s signal, indicating the incorporation of nitrogen into the graphene framework. High-resolution spectra reveal a dominant C 1s peak corresponding to sp² C-C bonding, confirming the preservation of the graphitic structure after functionalization. Deconvolution of the C 1s spectrum demonstrates additional components associated with sp³ C-C, C-O, and C-N bonds in N-graphene, evidencing chemical modification of the

graphene surface. The appearance of the N 1s peak further validates nitrogen incorporation, while the O 1s peak suggests the presence of oxygen-containing functional groups. Overall, the XPS results indicate that nitrogen functionalization introduces new chemically active sites on graphene without significantly disrupting its sp^2 carbon network.

RAMAN SPECTROSCOPY ANALYSIS

Raman spectroscopy reveals clear differences between pristine graphene and N-graphene, confirming successful nitrogen functionalization. Both samples exhibit the characteristic D (1341 cm^{-1}) and G (1580 cm^{-1}) bands of graphene, associated with structural disorder and in-plane sp^2 carbon vibrations, respectively. Compared to pristine graphene, N-graphene shows an increased D-band intensity, indicating a higher defect density arising from nitrogen incorporation into the graphene lattice. Additional Raman features observed in N-graphene, including bands attributed to C-N/C-O vibrations, further support chemical functionalization. The presence of second-order bands in the higher wavenumber region confirms the retention of the graphitic framework. Overall, the Raman results demonstrate that nitrogen doping introduces controlled defects and functional groups while preserving the fundamental sp^2 carbon structure of graphene.

SURFACE RESISTIVITY MEASUREMENT

The surface resistivity of N-graphene-coated PP fabrics as a function of N-graphene loading and plasma power. At lower graphene concentrations (0.05-0.10 wt.%), the samples exhibit high surface resistivity (1010 ohm sq^{-1}), indicating insufficient formation of conductive pathways. With increasing graphene content ($\geq 0.15\text{ wt.}\%$), a pronounced reduction in surface resistivity (106 ohm sq^{-1}) is observed, suggesting the establishment of a percolation network across the fabric surface. Plasma power plays a critical role in modulating electrical performance. At moderate plasma powers (2-3 kW), surface resistivity decreases below 106 ohm sq^{-1} significantly with increasing graphene content, reflecting improved graphene dispersion and stronger interfacial bonding. At higher plasma power (3.5 kW), the resistivity shows slight increase, likely due to excessive surface etching or damage to conductive pathways. Overall, the results demonstrate that an optimal combination of plasma power and N-graphene loading is essential to achieve low surface resistivity, highlighting the importance of controlled surface activation for developing electrically conductive PP-based textiles.

THERMAL CONDUCTIVITY MEASUREMENT ANALYSIS

The thermal conductivity and insulation performance of pristine and N-graphene-treated PP spunwoven fabrics were analysed. The untreated PP fabric exhibits a low thermal conductivity of $0.005\text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ corresponding to an R value of $0.043\text{ m}^2\cdot\text{K}\cdot\text{W}^{-1}$, confirming its inherently insulating nature. After N-graphene functionalization, the thermal conductivity increases to $0.012\text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, accompanied by a higher R value of $0.089\text{ m}^2\cdot\text{K}\cdot\text{W}^{-1}$. The increase in thermal conductivity indicates enhanced heat transport pathways introduced by the N-graphene coating, likely due to the formation of interconnected conductive networks on the fiber surface. Simultaneously, the increased R value suggests that the treated fabric maintains effective thermal insulation, possibly due to the porous fabric structure and air entrapment combined with controlled graphene loading. These results demonstrate that N-graphene functionalization allows modulation of thermal properties

while preserving the insulating characteristics of PP spun-woven fabrics, making them suitable for advanced thermal management textile applications.

Conclusion

In last year, PP spun-woven fabric was successfully functionalized using N-graphene through controlled surface activation, resulting in significant improvements in surface, electrical, and thermal properties. SEM analysis confirmed a clear transformation from a smooth, inert PP surface to a roughened and textured morphology with firmly anchored graphene features, supporting enhanced interfacial adhesion and durability. XPS and Raman analyses verified the successful incorporation of nitrogen-containing functional groups while preserving the sp^2 carbon framework of graphene, indicating effective chemical functionalization without structural degradation. The treated fabrics exhibited a substantial reduction in surface resistivity with increasing graphene loading and optimized plasma power, demonstrating the formation of conductive pathways across the fabric surface. Additionally, thermal studies showed tuneable thermal conductivity with maintained insulation performance. Overall, these results highlight the effectiveness of N-graphene functionalization in imparting multifunctional properties to PP spun-woven fabrics, making them promising candidates for advanced conductive and thermal textile applications.

2.6 Plasma Assisted Waterless Dyeing Of High-Performance Textiles Using Supercritical Fluid for Application in Technical Textiles

Comparative analysis of thermosol and exhaust dyeing process on plasma surface modified nylon fabric

Abstract

Helium and oxygen gasses are used to generate the low-temperature atmospheric pressure plasma that modifies nylon fabric. The changes in nylon fabric with respect to plasma exposure duration are studied while keeping the power used to generate the plasma (2000W) and the distance between the electrodes (0.5mm) constant. The treated nylon fabric is dyed with acid dyes using thermosol and exhaust dyeing process. Analysis of color uptake of the dyed fabric is done by K/S measurement. It is observed that thermosol process results in higher colour depth as compared to exhaust method. Surface changes after plasma treatment is analyzed by Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD). Performance of both the methods for dyeing is evaluated by the colour fastness to light, rubbing and washing.

Easy desizing of the cotton fabric using plasma technology

Abstract

The issue of environmental pollution is a major drawback of wet processing in textile industries. One significant cleaning technology with potential applications in the textile sector is Atmospheric Pressure Plasma (APP). It can be used to treat the surface of the majority of textile materials. Plasma has the ability to enhance wettability, hydrophobicity, adhesion, dyeability, and utility in textiles without changing the material's intrinsic qualities. The goal of this study is to determine the effect of plasma surface modification on the plain woven greige cotton fabric on the preparatory process

focused on desizing and combined desizing, scouring and bleaching (CDSB). The greige cotton fabric was treated with low temperature atmospheric plasma using helium and oxygen gasses. Enzymatic desizing and CDSB of the untreated and plasma treated greige cotton fabric was performed and comparative analysis was carried out by measuring the desizing efficiency and whiteness index. Plasma-treated samples showed a notable increase in desizing and CDSB efficiency.

2.7 Development of Spinnable grade Meta- and Para-Aramid polymers and their Fibre Spinning

Introduction

Rapid advances in modern ammunition and weapon systems have intensified the demand for lightweight, high-performance protective materials, driving extensive use of para- and meta-aramid fibres in ballistic, thermal, and high-temperature applications. Para-aramid fibres such as PPTA provide exceptional tensile strength and modulus, enabling their use in antiballistic composites and impact-resistant structures, while meta-aramid fibres such as PMIA offer outstanding flame resistance and thermal stability for protective clothing, insulation, and technical textiles. Beyond conventional macrofibres, aramid nanofibres and nanofibrous assemblies have enabled aerogel fibres, thermally insulating fabrics, flexible thermal-management media, and advanced composites with tailored mechanical and thermal responses. Lin et. al. investigated the application of meta-aramid nanofibrous membranes to water purification, showing that the intrinsic thermal and chemical stability of aramid structures can be effectively combined with nanofibrous architectures to deliver high permeability and efficient contaminant removal in liquid filtration, underscoring the versatility of aramid systems across defence, environmental, and industrial domains.

The performance of aramid fibres is governed strongly by polymer structure, solvent system, and spinning conditions. For high-performance para-aramids, dry-jet wet spinning from concentrated sulphuric acid or oleum produces highly oriented, crystalline filaments with superior mechanical properties suitable for ballistic and extreme-environment protection. Meta-aramids, which can be dissolved in polar aprotic solvents with inorganic salts (e.g., LiCl/DMAc), are likewise processed by wet or dry-jet wet spinning; optimization of dope concentration, temperature, and coagulation critically controls skin-core morphology, porosity, and fibre strength. Globally, most high-performance aramid fibres and associated technologies are produced by a limited number of international manufacturers, leading to strategic dependence on imports for defence, ballistic, and high-temperature applications. In this context, establishing an indigenous, scalable dry-jet wet spinning process for both PMIA and PPTA, using solvent systems such as LiCl/DMAc for meta-aramid and H₂SO₄/H₂S₂O₇ for para-aramid, is crucial for enabling domestic production of high-performance aramid fibres tailored for antiballistic and protective textile applications.

Materials and Methods:

Materials

(Poly (meta-phenylene isophthalamide), PMIA; Nomex®) Meta and (Poly (para-phenylene terephthalate), PPTA; Kevlar®) Para aramid polymers were obtained from NCL, Pune. LiCl (Lithium chloride) and DMAc (N, N-Dimethyl acetamide) were purchased from Merck Specialities Pvt. Ltd. and Loba Chemie Pvt. Ltd., respectively, whereas H₂SO₄ (sulphuric acid) and H₂S₂O₇ (oleum) were purchased from Loba Chemie Pvt. Ltd. and Spectrochem Pvt. Ltd., respectively. All the materials

received were used without any further purification. The IKA Overhead stirrer was used for stirring purposes.

Method

The dope solution of meta- and para- aramid polymer was prepared by dissolving in the LiCl/DMAc and H₂SO₄/H₂S₂O₇ solvent system, respectively at 70–80°C for 5h using different w/w% concentrations of both the polymers. The prepared dope was filtered via vacuum filtration and was further degassed before subjecting to the dry-jet wet spinning process. The solution was spun through 100 µm spinneret in a coagulating bath.

Results & Discussions

POM

The para aramid polymer is known to form lyotropic liquid crystalline phase above a concentration of 10 wt % in concentrated sulfuric acid. The formation of these phases under the polarized microscope is an indication of high molecular weight for the polymer. Figure 5 shows the birefringent images obtained for 15 weight percent solution of Kevlar in Oleum at 100 °C.

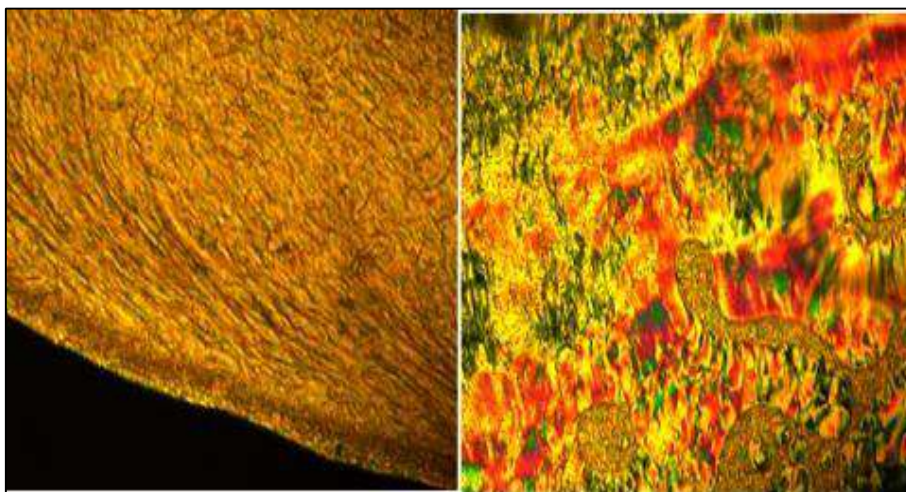


Fig. 1. Polarizing optical microscope (POM) images of the 15 weight percent solution of Kevlar in Oleum at 100 °C.

SEM

The FE-SEM images in Figures 2. (a) and (b) showed that the meta-aramid fibres produced by dry-jet wet spinning have a relatively smooth outer surface but a porous, non-uniform internal structure with significant variability in filament diameter. Similarly, longitudinal views revealed a distinctly rough, ribbed surface of para-aramid fibres in Figure 2. (c), indicating pronounced skin fibrillation, and the bundle cross sections in Figure 2. (d) showed a solid, compact interior, possibly due to rapid and successful coagulation in the bath.

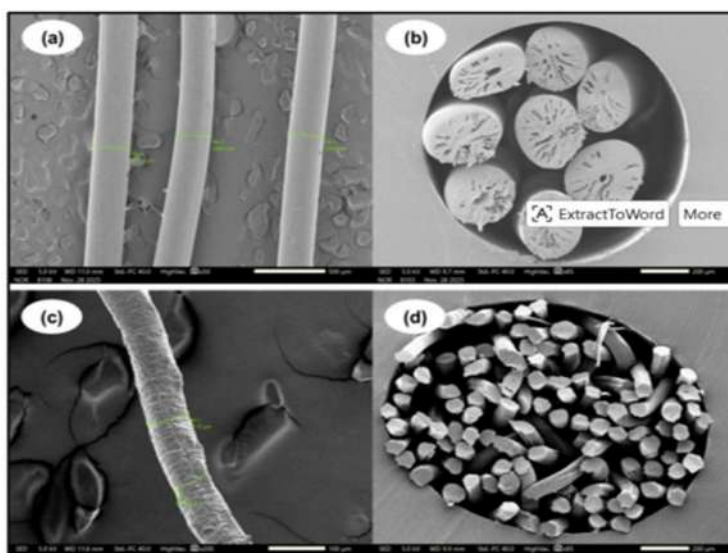


Fig. 2. (a) Meta–aramid fibres longitudinal view, (b) Cross section of the meta– aramid fibres, (c) Longitudinal view of Para–aramid fibre and (d) Cross section of the fibres bundle of para– aramid fibres

Conclusion

The present work demonstrates the feasibility of formulating and spinning meta and para–aramid dopes using LiCl/DMAc and H₂SO₄/H₂S₂O₇ solvent systems respectively, via a dry–jet wet spinning process tailored for indigenous production.

2.8 Development of high-performance gel spun UHMWPE fibers and tapes for bullet proof and geo-girds/ geo-composites applications

Abstract

Ultra-high-molecular-weight polyethylene (UHMWPE) fibres have high applicability in advanced engineering applications because they have high mechanical strength, low density, and chemical resistance. The current update outlines the progress made during the current reporting period pertaining to the development of gel-spun UHMWPE fibres using a laboratory-scale setup for gel spinning. The current study involves the preparation and rheological investigation of the prepared solutions of UHMWPE, process attempts for gel spinning, subsequent processes for fibre drawing, and detailed investigation of the prepared fibres. The current study also focuses on fibre preparation, orientation, and subsequent mechanical properties, indicating the applicability of the developed UHMWPE fibres for protection and geotechnical purposes.

Introduction

High molecular weight polyethylene, which is otherwise known as ultra-high molecular weight polyethylene (UHMWPE), is a linear polyethylene type. It possesses an exceptionally high molecular weight, often greater than a few million g/mol. This high molecular weight of polyethylene results in a high molecular chain, which, in turn, is responsible for excellent mechanical properties of polyethylene, like high tensile strength, a high Young's modulus of elasticity, high impact strength, high abrasive resistance, as well as low density. Moreover, it is chemically inactive.

In the past few decades, UHMWPE fibres have received widespread attention in the high-performance industry in regions like the United States of America for their applications in ballistic protective gear and equipment, high-strength ropes/cables, aircraft components, and advanced composite systems. In the field of civil and geotechnical engineering, UHMWPE-based geo-grids and geo-composites have also attracted attention for their high load-carrying capability and stability toward environmental factors.

Although such benefits exist, there remain considerable challenges for making high-performance fibres from UHMWPE. This arises due to its high melt viscosity, making melt spinning impossible. As such, solution-based processing and gel spinning have become recognised as effective for preparing highly oriented UHMWPE fibres. The solution rheology of UHMWPE was systematically studied, and a gel spinning facility was successfully constructed. This has created a solid foundation for efficient facility operation and controlled fibre development in subsequent stages.

Materials and Methods

Materials

The UHMWPE powder of molecular weight 3.5 million grams/mole was purchased from Mitsui Chemicals Inc. Pvt. Ltd. The primary solvent, paraffin oil with a density of 0.86 gm/cc was purchased from the local market. The n-hexane of 99% concentration was procured from LobaChemiePvt. Ltd.

Methods

Rheological analysis of UHMWPE solution

The gel fibre was converted into disks by compression moulding at 170°C. Rheological tests were performed on a Smart Pave 102e Rheometer using a 25 mm parallel plate geometry. The viscoelastic properties, such as storage modulus (G') and loss modulus (G''), were obtained from oscillation frequency sweeps in the frequency range of 0.6 to 100 rad/s in the temperature range of 180,190°C.

Design and fabrication of lab-scale gel spinning line

The gel spinning line has been designed and manufactured in collaboration with E-spin, Kanpur, UP, and Steer World, Bengaluru, Karnataka. A twin-screw extruder is incorporated into the spinning line, where the UHMWPE polymer mixes directly with solvent (liquid paraffin or decalin) to form a UHMWPE gel solution. The gel spinning line was installed in BTRA

Gel spinning of UHMWPE solutions

Several spinning trials were conducted, varying the concentration of UHMWPE between 4% and 10% wt/vol. Along with the concentration, the temperature of extrusion and take up roller speed were optimised. A single as well as multi holesspinneret was used for the trials.

Drawing of UHMWPE gel fibres

The collected gel filament of the aforementioned concentrations was drawn at temperatures ranging from 80°C to 145°C using a hot roller and a hot air duct to achieve different finenesses of UHMWPE filaments.

Characterisation of UHMWPE filaments

The prepared UHMWPE fibres are characterised based on their mechanical and thermal properties, such as tenacity, elongation, melting point, degree of crystallinity and orientation, etc. For the aforesaid characterization UTM, SEM, XRD and DSC have been used.

Results and discussion

Rheological analysis

The rheological behaviour of the UHMWPE solution of 6% concentrations. The Han plots show overlapping curves at different temperatures, indicating thermo-rheological simplicity, and it can be an indication that the processing profile led to the formation of a homogeneous melt.

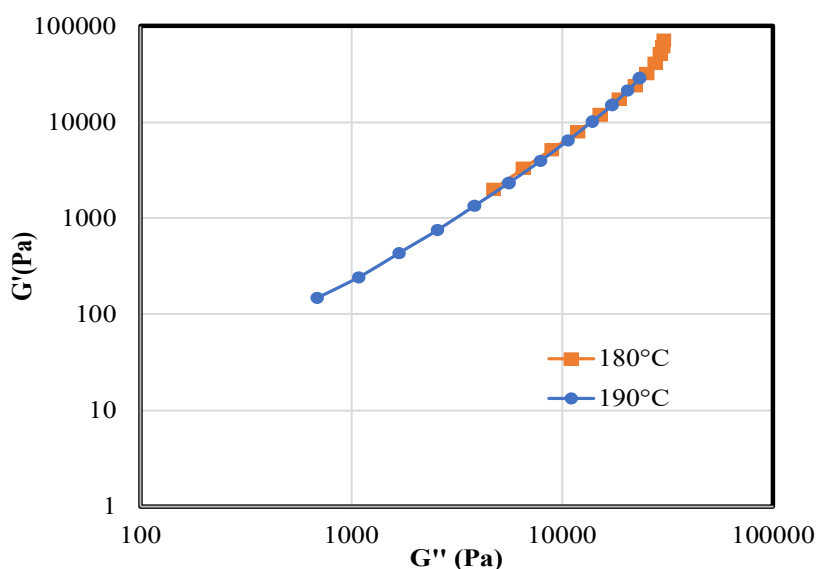


Figure 1: Han plot of 6% UHMWPE solution

Drawing and Characterisation of UHMWPE fibre

The 6% concentration filaments were drawn in two stages low temperature stage and a high temperature stage to achieve a fibre strength of 32.76 gpd and a fineness of 31.5 denier. The longitudinal cross-section SEM micrographs show smooth fibrillary morphology. The X-ray diffraction studies show 89.19% crystallinity, which was confirmed from DSC, which yielded crystallinity of 89.49%. The orientation order taken from the azimuthal scan for the 21.5 was determined from the formula $(180^\circ - \text{FWHM}) / \text{FWHM}$ to be 0.95, which is indicative of high degree of orientation of the fibres.

Table 1: Drawing and mechanical parameters of UHMWPE fibre

Polymer conc. (%)	Heating Media	Stage	Temperature (°C)	Final fineness (denier)	Maximum tenacity (g/d)	Average elongation (%)
6	Hot roller and Hot air duct	1 st	30 °C	27.9	32.76	14.86
		2 nd	80 - 145 °C			

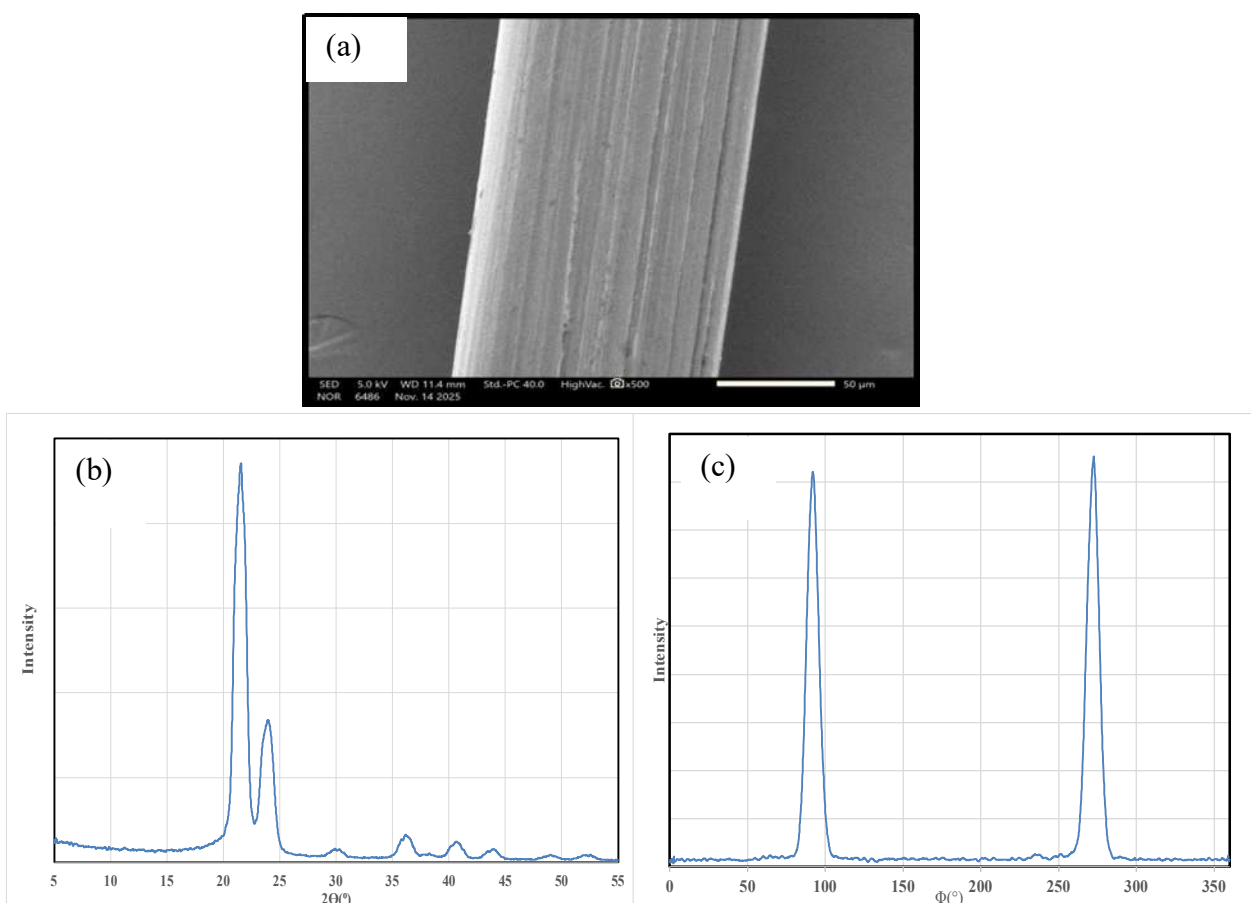


Figure 2: SEM analysis showing a) longitudinal section, XRD curve showing b) crystallinity, and c) orientation angle of UHMWPE fibre

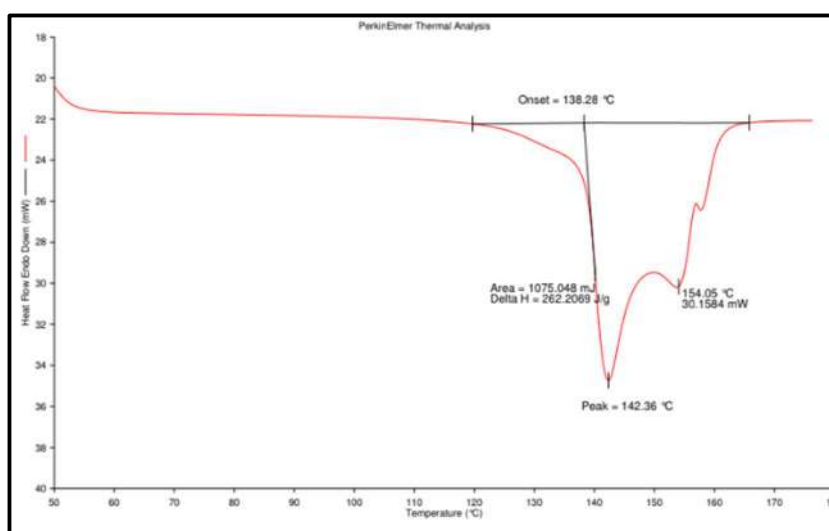


Figure 3: DSC thermogram showing melting behaviour of UHMWPE fibre

Conclusions

The rheological study was used to validate the extrusion processing parameters that resulted in homogeneous solutions. An optimal concentration of 6% was determined, where good mechanical and thermal properties were observed. Production for rope application is to be undertaken.

2.9 Development of Flame Retardant Aircraft Interior Fabrics by Plasma Assisted Chemical Treatment

Cotton fabric was treated with commercially available 3-hydroxyphenyl phosphinyl propanoic acid (3HPP) as a flame-retardant agent, in combination with 1,2,3,4-butanetetracarboxylic acid (BTCA) as a cross-linking agent and dicyandiamide (DCDA) as a catalyst for esterification. The phosphorus moiety successfully bonded with both the cotton fibers and the cross-linking agent, as confirmed by FTIR and XPS analyses. The concentration of 3HPP in the padding bath was varied from 1% to 10%. With optimization of 3HPP concentration and pH, the limiting oxygen index (LOI) of untreated cotton increased from 17.4% to 29.5%, and further improved to 31.5% following atmospheric plasma treatment. Thermal degradation studies demonstrated a significant enhancement in stability: while virgin cotton exhibited approximately 80% weight loss at 350 °C, treated samples showed only 40% reduction at the same temperature. Cone calorimetry further indicated reductions in both the heat release rate and total heat release, along with delayed ignition. Additionally, the treatment showed good wash durability, with an LOI of 28.1% retained even after 20 laundering cycles. This study addresses the key durability challenges of flame-retardant treatments for cotton fabrics and highlights the potential of this system for improving both safety and performance.

Introduction

Flame-retardant (FR) cotton is essential for enhancing safety in textiles used for clothing, furnishings, and technical applications. Despite its versatility, cotton is highly flammable, igniting at oxygen levels as low as 17–18%, which limits its use in fire-safe materials. The recent California wildfire tragedy underscored the need for effective FR treatments, as many cellulose-based fabrics and wooden furnishings could have been protected through proper flame-retardant applications. In a recent study, we reported the application of 3-HPP in enhancing polyester flame retardancy through impregnation using a high-temperature, high-pressure (HTHP) treatment, followed by plasma treatment. The novelty of the present work lies in the exploration of 3-HPP—a commonly used flame retardant (FR) for polyester—for use in cotton flame retardancy. We have effectively applied 3-HPP to cotton via esterification, cross-linking, and plasma treatment. In our previous research, we also observed that plasma treatment following chemical processing improved the washing fastness of polyester fabrics. Atmospheric plasma can ionize surface molecules, enabling the formation of strong covalent bonds with the cellulose backbone. In this study, we present a detailed investigation into the effect of higher concentrations of 3-HPP on cotton fabrics, using DCDA as a catalyst and 1,2,3,4-butane tetracarboxylic acid (BTCA) as a cross-linking agent. Importantly, the process described can be readily adopted by downstream cotton fabric manufacturers to impart flame-retardant properties to their products.

Experimental

Materials

Ready-for-dyeing (RFD) cotton fabric (Table 1a) was purchased from the local market and washed according to AATCC 135. 3HPP, Alfa Chem Laboratories, India served as the flame retardant, while BTCA, Sigma Aldrich, India acted as the cross-linker. DCDA, obtained locally, was used as the esterification catalyst. All other chemicals were of LR grade.

Table 1a : Technical characteristics of the cotton fabric.

GSM	Count (Ne)		Thread Density		Weave
	Warp	Weft	Ends/inch	Picks/inch	
152.6	21.78	20.61	67	59	Plain

Table 1b : Sample abbreviations

VC	Virgin Cotton
VTR	Virgin Cotton Treated with 3HPP+BTCA+DCDA
VTR-PTR	Virgin cotton Treated with 3HPP+BTCA+DCDA and then subjected to five Plasma Treatment
VTR-PTR _{w10}	VTR-PTR subjected to 10 washing cycle
VTR-PTR _{w20}	VTR-PTR subjected to 20 washing cycle
VTR-PTR _{w30}	VTR-PTR subjected to 30 washing cycle
VTR-PTR _{w40}	VTR-PTR subjected to 40 washing cycle
CRA	Crease Recovery Angle

Flame retardant treatment for cotton fabric

Cotton fabric was pre-washed and cut into 30 × 30 cm samples. The samples were immersed in the finishing bath (Table 3) at 60 °C for 10 min; a parallel set was treated by boiling under identical conditions. After treatment, fabrics underwent two dips and two nips at 1 bar pressure, achieving a wet pick-up of 120–180%. The samples were then dried at 105 °C for 5 min and cured at 160 °C for 3 min using a thermosetting machine.

Plasma treatment

Plasma treatment was performed using a Platex 600 atmospheric-pressure plasma reactor (Grip S.R.L., Torino, Italy). Fabric strips (~50 cm wide) were passed continuously between upper and lower electrodes, where a dielectric barrier discharge (DBD) was generated using helium. Treatment was conducted at 2500 W for 1 min with a helium flow rate of 5 L/min, while atmospheric air was allowed to enter the chamber

Characterizations

Flame retardancy was evaluated using the Limiting Oxygen Index (LOI) test (ASTM D2863) with an oxygen index tester (Fire Testing Technology Ltd., India). FTIR spectra of virgin, treated, and washed fabrics were obtained on a Perkin Elmer System 2000 spectrophotometer within the 4000–650 cm⁻¹ range. Thermogravimetric analysis (TGA) was carried out using an SDT Q600 (USA) on ~5 mg samples under air flow (100 mL/min) from 30 to 700 °C at a heating rate of 10 °C/min. Vertical flammability was assessed following ASTM D6413 using an in-house chamber, where 12 × 3-inch specimens were exposed to a 38 mm methane flame for 12 s, and average results from five replicates were reported. Cone calorimetry (ISO 5660-1) was performed using a Testech instrument at a heat flux of 35 kW/m² on 100 × 100 mm samples to determine combustion characteristics. Wash durability and LOI retention were tested after up to 40 washing cycles following ISO 105 C10 (option B) at 40 °C for 30 min. Mechanical properties, including tensile (ASTM D5035), tear (ASTM D1424), crease recovery (IS

4681), bending length (IS 6490), water permeability (ASTM D4491), air permeability (ASTM D737), and abrasion resistance (ASTM D4966), were evaluated for both virgin and treated fabrics. Surface morphology and elemental composition were analyzed using SEM (JEOL JSM-IT200) equipped with an EDX detector after gold sputtering. X-ray photoelectron spectroscopy (XPS) was performed using a Kratos AXIS Supra system with monochromatic Al K α radiation (75 W) at a resolution of ~ 2 eV.

Results and discussion

Limiting oxygen index (LOI)/ Flame retardancy

The Limiting Oxygen Index (LOI) represents the minimum oxygen concentration (%) required to sustain material combustion in an O₂-N₂ mixture and serves as a quantitative measure of flammability. In the LOI test (ASTM D2863), a vertically mounted specimen is exposed to controlled O₂/N₂ flows, and the minimum O₂ level that supports continuous burning (≥ 5 cm) is recorded. Higher LOI values denote lower flammability.

As shown in Table 2, untreated cotton exhibited an LOI of 17.4%, indicating high flammability. Treatment with 2 wt.% 3HPP increased the LOI to 20.4%, while 7 wt.% 3HPP yielded 23.9%, rendering the fabric self-extinguishing since ambient air ($\sim 21\%$ O₂) cannot sustain combustion. Further increases (8–10 wt.%) slightly enhanced LOI but caused surface crystallization of 3HPP, as confirmed by SEM (Fig. 3). At 7 wt.% 3HPP, the additive remained soluble with no visible deposits, establishing this as the optimal concentration.

BTCA, a well-known crosslinking agent for cellulose, was used to link cotton and 3HPP within the fibre matrix. Incorporating 14 wt.% BTCA slightly improved the LOI to 24.2% (Table 2, Sl. No. 5), but this remained below the $\sim 28\%$ LOI threshold typically required for effective flame-retardant fabrics.

Table 2 : Optimization of 3HPP concentration in the cotton fabric.

Sl. No	Sample	3 HPP (wt.%)	Weight gain (%)	LOI (%)
1	VC	0	0	17.4
2	VC	2	35.5	20.4
3	VC	4	35.7	21.3
4	VC	6	36.2	22.5
5	VC	7	40.1	23.9 (24.2**)
6	VC	8	41.3	26.1*
7	VC	10	39.2	26.6*

*Chemical deposition was found on the fabric surface.

** VC treated in beaker containing 7 wt.% 3HPP and 14 wt.% BTCA

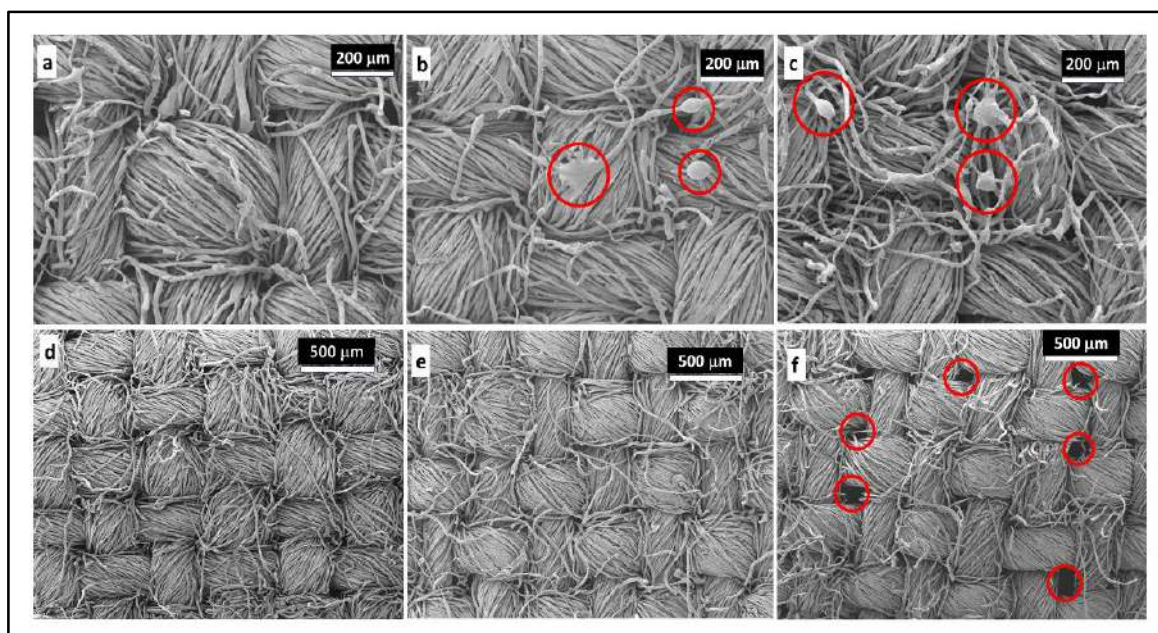


Fig. 1. SEM images of cotton sample treated with: a) 7 wt.% 3HPP, b) 8 wt.% 3HPP, c) 10 wt.% 3HPP, effect of plasma treatment on surface topology of cotton fabric: d) virgin cotton fabric, e) cotton fabric with five-time plasma exposure, f) cotton fabric with six times plasma exposure.

Table 3 summarizes the effect of cross-linking and esterification on the flammability of cotton fabrics. Esterification markedly improved LOI values across all formulations. While 7 wt.% 3HPP with 14 wt.% BTCA yielded an LOI of 24.2%, the addition of 2 wt.% DCDA increased it to 26.2%, and 4 wt.% DCDA further raised it to 29.4%. Higher DCDA levels provided no additional benefit and caused surface deposition above 7 wt.%. Therefore, the optimal formulation for achieving maximum flame retardancy comprises 7 wt.% 3HPP, 14 wt.% BTCA, and 4 wt.% DCDA.

Table 3 : Effect of esterification agent on limiting oxygen index.

Sample	3 HPP (wt.%)	BTCA (wt.%)	Dicyandiamide (wt.%)	Weight gain (%)	LOI (%)
1	7	14	2	44.9	26.2
2	7	14	4	45.6	29.4
3	7	14	6	46.7	29.7
4	7	14	7	48.1	29.5
5	7	14	9	47.3	32.0***

***Chemical deposition observed in the fabric surface.

Table 4 summarizes the formulations and their effects on the flammability of cotton fabrics. Untreated cotton (VC) exhibited an LOI of 17.4%, while treatment with 14 wt.% BTCA increased the LOI to 18.4%. Incorporation of DCDA further enhanced the LOI to 21.8%, likely due to nitrogen-containing functional groups contributing to char formation. The addition of 7 wt.% 3HPP with BTCA raised the LOI to 24.2%, as phosphorus from 3HPP promoted early char development that restricted oxygen diffusion; the corresponding phosphorus content was 1820 ppm. The esterification efficiency was strongly pH-dependent: at pH 1.6, the LOI reached 26.4%, increasing to 29.5% at pH 3.0, consistent with previous findings that the optimal pH range for DCDA-catalyzed esterification lies between 3.0 and 3.5.

Plasma treatment further improved flame retardancy. SEM images (Fig. 1) showed that up to five plasma cycles caused no visible fiber damage, whereas six cycles led to pinhole formation, indicating overexposure. Thus, five cycles were selected as optimal. When the chemically treated fabric was subsequently exposed to plasma (VTR–PTR), the LOI increased to 31.5% (Table 4, Sr. No. 9). This enhancement likely results from plasma-induced activation of surface –OH and –COOH groups, which facilitated stronger bonding between 3HPP and cellulose, improving phosphorus–carbon interactions and char formation. Achieving an LOI of 31.5% in cotton is significant; by comparison, Li et al. reported only 26% LOI using a liginosulfonate/chitosan layer-by-layer system. The present method is simpler, more effective, and compatible with continuous processing.

Table 4 : Effect of 3HPP, BTCA and DCDA on the limiting oxygen index of the treated cotton fabric.

Sr. No	Sample	3 HPP (wt.%)	BTCA (wt.%)	DCDA (wt.%)	pH	Add On %	LOI (%)	Phosphorous (ppm)
1	VC	-	-	-	-	0	17.4	0
2	VTR1	-	14	-	-	123	18.4	
3	VTR2			4			21.8	
4	VTR3	7	-	-	-	142	23.9	
5	VTR4	7	14	-	-	158	24.2	
6	VTR5	7		4			25.7	
7	VTR6	7	14	4	1.6		26.4	
8	VTR7	7	14	4	3.0	160	29.5	1820
9	VTR7-PTR	7	14	4	3.0		31.5	
10	VTR7-PTR _{W10}	Sr. No.9- Washed 10 times					29.2	1818
11	VTR7-PTR _{W20}	Sr. No.9- Washed 20 times					28.1	
12	VTR7-PTR _{W30}	Sr. No.9- Washed 30 times					27.8	
13	VTR7-PTR _{W40}	Sr. No.9- Washed 40 times					27.5	

#in rest of the paper VTR indicates VTR7

The washing fastness of Sample 9 was evaluated after 10–40 laundering cycles (Table 4, Sr. No. 10–13). Wash durability is critical for FR textiles, as it determines the retention of flame-retardant performance after repeated cleaning. The LOI decreased slightly from 29.2% after 10 washes to 28.1% after 20 and 27.5% after 40 cycles (Fig. 2), demonstrating good durability and sustained flame resistance even after extensive laundering.

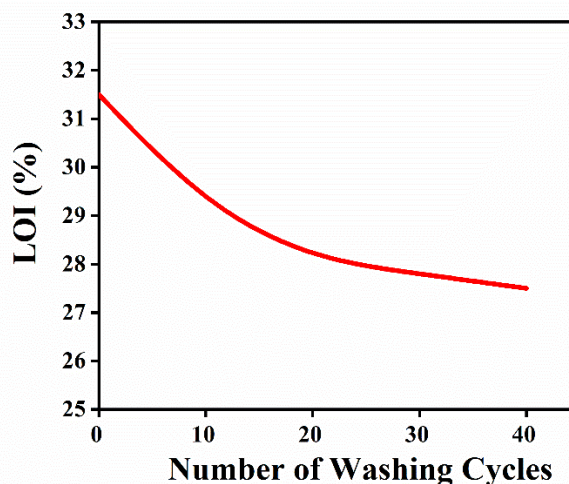


Fig. 2. Effect of washing cycles on LOI values of FR treated cotton fabrics.

To further assess the flame-retardant performance of treated cotton fabrics (VC, VTR, VTR–PTR, and VTR–PTRW20), combustion times during LOI testing were recorded (Fig. 3). Unlike previous studies on PET fabrics that used bottom ignition, the present work followed the LOI protocol employing top ignition. Untreated cotton (VC) burned completely within 97 s without forming any char, confirming its high flammability. In contrast, the 3HPP-treated sample (VTR) self-extinguished within 21 s, forming a compact black intumescent char that limited oxygen access. The plasma-treated fabric (VTR–PTR) showed further improvement, extinguishing within 11 s, indicating enhanced adhesion and reactivity of 3HPP with cellulose fibers. Even after 20 wash cycles (VTR–PTRW20), the fabric retained an LOI of 28.1% and self-extinguished within 25 s, demonstrating excellent durability and sustained flame retardancy.

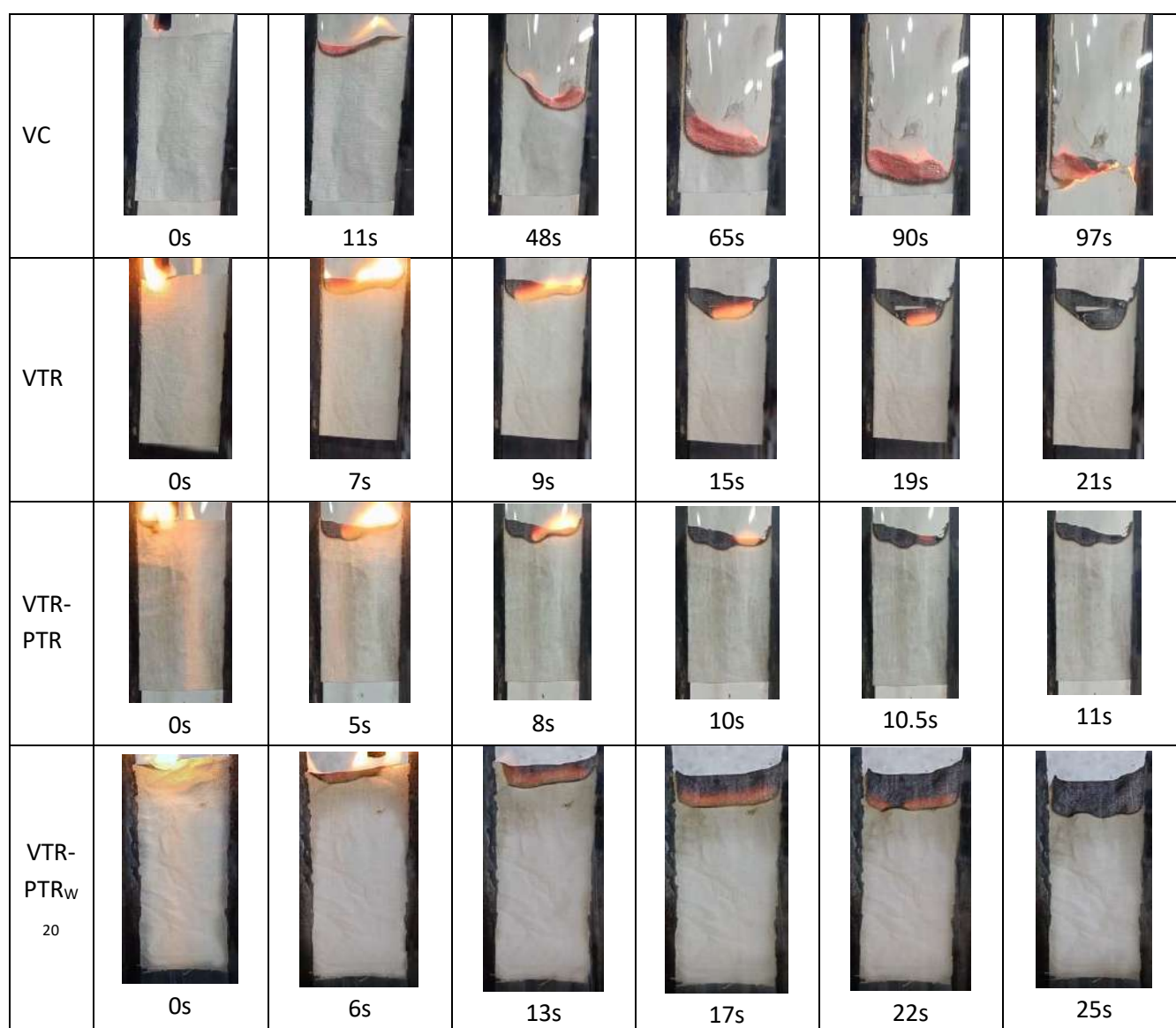


Fig.3. Photographs of burning behaviour of virgin and treated cotton fabric samples.

Vertical Flammability

In addition to LOI testing, vertical flammability testing was conducted to assess combustion behavior, recording parameters such as after-flame duration, char length, and overall burning response. Virgin cotton (VC) exhibited rapid combustion with a 9 s after-flame and a 30 cm char length (Fig. 6). In contrast, 3HPP-treated (VTR) and plasma-assisted (VTR–PTR) fabrics ignited only under direct flame

and self-extinguished immediately, showing no after-flame (0s) and reduced char lengths of 13 cm and 11.3 cm, respectively (Table 5). The VTR–PTRW10 sample (after 10 wash cycles) maintained these characteristics, with only a slight increase in char length but no after-flame or after-glow. These results confirm enhanced and durable flame retardancy, consistent with the reported inverse relation between LOI and char length .

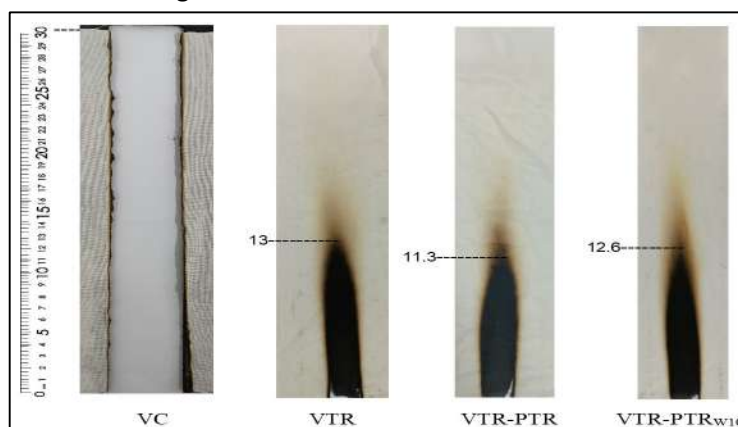


Fig.6 : Vertical flammability and char length of various cotton samples.

Table 5 : Vertical flammability data of various cotton fabrics.

Sample	After-flame Time (s)	After-glow Time (s)	Char length (cm)
VC	9	21	30
VTR	0	0	13
VTR-PTR	0	0	11.3
VTR-PTR _{W10}	0	0	12.6

Cone Calorimetric Studies

Table 6 summarizes key fire parameters—TTI, MARHE, PHRR, THR, and total smoke. The TTI increased from 7 s for untreated cotton to 11 s after FR treatment and 15 s after combined FR + plasma treatment, while the washed sample (VTR–PTRW10) showed 9 s. TTI, representing the time to sustained ignition, reflects material resistance to heat flux. The observed TTI enhancement confirms the synergistic flame-retardant effect of chemical and plasma treatments, demonstrating improved fire resistance and potential for safer bio-based textiles.

Table 6 : Cone calorimeter parameters of various cotton fabrics

	TTI (s)	MARHE (kW/m ²)	Peak HRR (kW/m ²)	THR (MJ/m ²)	Total Smoke Production (m ²)
VC	7	127.3	284.8	5.6	4.4
VTR	11	106.7	219.6	4	5.8
VTR-PTR	15	100.8	210.5	3.7	6.3
VTR-PTR _{W10}	9	113.4	249.8	4.1	4.7

Virgin cotton (VC) showed the highest heat release, with a MARHE of 127.3 kW/m², compared to 106.7 kW/m² for FR-treated cotton and 100.8 kW/m² for plasma-treated fabric (VTR-PTR). After 10 washes, MARHE increased to 113.4 kW/m². Similar trends were seen for PHRR and THR. The

reductions stem from phosphorus-based FR compounds that suppress combustion. However, total smoke production rose from 4.4 m² (VC) to 5.8 m² (FR) and 6.3 m² (VTR-PTR), likely due to char-layer formation causing incomplete combustion.

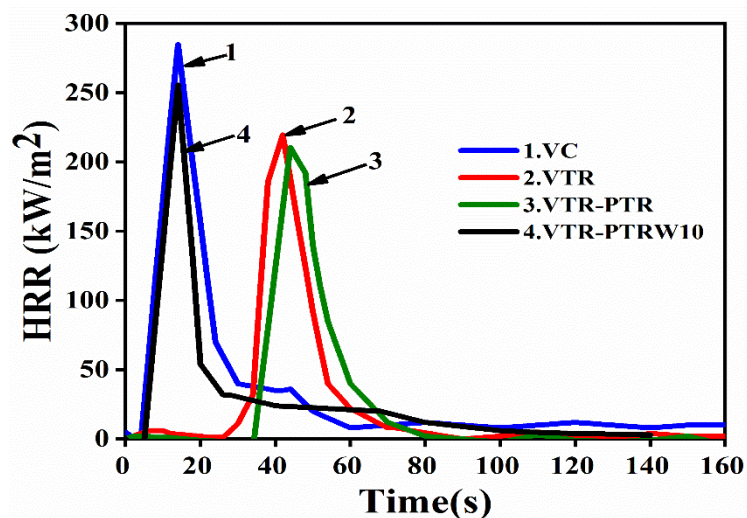


Fig. 7 : Heat release rate vs.time curves of virgin and treated cotton fabrics.

Fig. 7 shows HRR–time curves, where untreated cotton (VC) ignites rapidly, while FR-treated (VTR) and plasma-assisted (VTR-PTR) samples display delayed ignition and slower combustion. The marked reduction in peak HRR confirms effective heat-release suppression and improved flame resistance. Plasma treatment following FR application further enhances ignition resistance and overall fire safety.

FTIR Analysis

Fig. 8a–b show the FTIR spectra of cotton samples. Characteristic peaks of –OH, C=O (acids, esters, anhydrides), C–H, and C–C bonds are evident. Broad bands at 3000–3600 cm⁻¹ correspond to –OH and C–H stretching, common to all samples due to the cellulose backbone. Overlapping peak shapes and positions indicate similar chemical structures, while absorption between 1670–1800 cm⁻¹ confirms carbonyl functionalities.

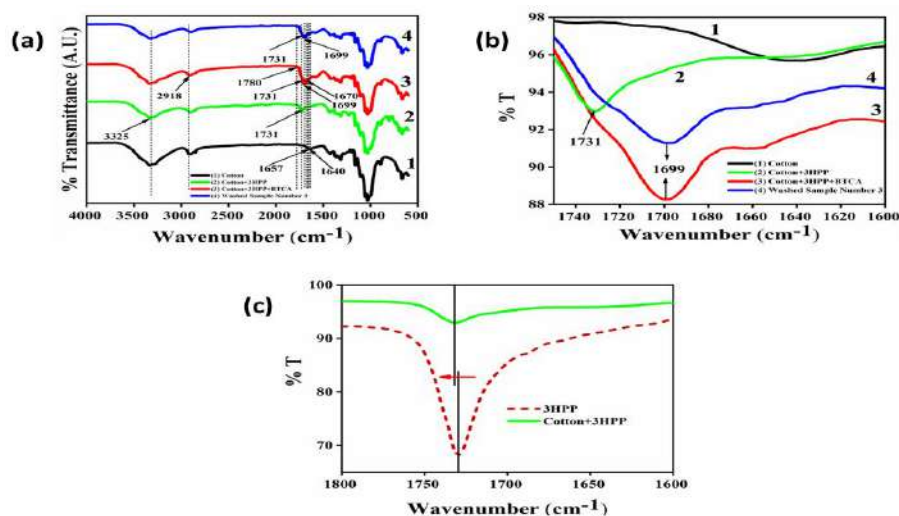


Fig. 8 : FTIR spectra of various cotton fabrics (a), expanded region of carbonyl frequency range (b), overlay of carbonyl stretching frequencies of pure 3HPP and cotton fabric treated with 3HPP (c).

Fig. 8b expands the carbonyl region to illustrate treatment effects. Virgin cotton shows no carbonyl peak, confirming the absence of C=O groups. In contrast, 3HPP-treated cotton (Sample 2) displays a peak at 1731 cm^{-1} , assigned to C=O stretching of carboxylic acids. Sample 3 (3HPP + BTCA) shows dual bands at 1731 and 1699 cm^{-1} , corresponding to 3HPP and BTCA carbonyls, respectively. After washing (Sample 4), both peaks remain but with reduced intensity, indicating partial loss of unbound chemicals while esterified species persist. Fig. 8c compares pure 3HPP and treated cotton: the 3HPP carbonyl band at 1729 cm^{-1} shifts to 1731 cm^{-1} upon treatment, suggesting ester bond formation between 3HPP and cellulose –OH groups.

Studies on thermal stability

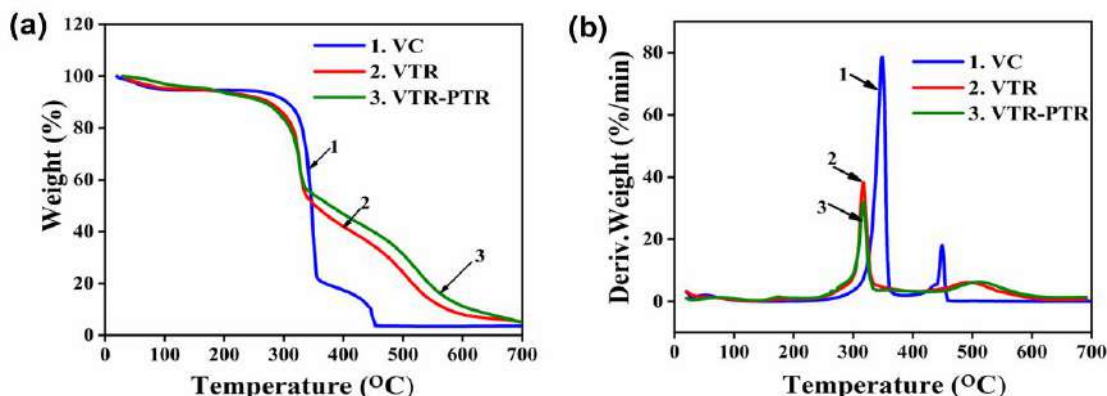


Fig. 11 : Thermogravimetric (TG) curves of the cotton fabrics in air (a), Differential curves of thermogravimetric analysis (TGA) of the various cotton fabrics in air (b).

The thermal stability of untreated and treated cotton fabrics was analyzed via TGA (Figs. 11a–b). Both control and treated samples showed minor initial weight loss due to moisture evaporation, followed by major cellulose degradation. Virgin cotton exhibited rapid mass loss between 300–350 °C with a peak at ~320 °C, leaving ~20 % residue at 350 °C. In contrast, FR-treated cotton began degrading near 280 °C but retained ~55 % residue, indicating enhanced char formation and combustion suppression.

The plasma-assisted FR fabric (VTR-PTR) demonstrated the greatest thermal stability and highest char yield, attributed to additional P–C bond formation and intumescent char development that limited oxygen diffusion.

DTG curves (Fig. 11b) further confirmed reduced peak intensity and smaller degradation areas for treated fabrics. The main decomposition peak shifted from 350 °C (VC) to 330 °C (VTR), while the secondary peak moved from 450 °C to 510 °C (VTR) and 530 °C (VTR-PTR), evidencing slower degradation kinetics and superior flame resistance.

Surface Morphology and Elemental Analysis:

SEM and EDX analyses revealed distinct morphological changes after FR and plasma treatments (Fig. 12). Virgin cotton (Fig. 12a) showed a smooth, defect-free surface, while 3HPP-treated cotton (Fig. 12b) exhibited surface irregularities and deposits. Plasma-assisted FR cotton (Fig. 12c) displayed pronounced fibre fusion, likely due to 3HPP-induced bonding and plasma-driven surface activation. Although excessive plasma exposure can cause etching or mechanical weakening, moderate

treatment—as applied here—enhanced fibre adhesion and altered surface roughness, consistent with literature reports of improved bending and shear properties.

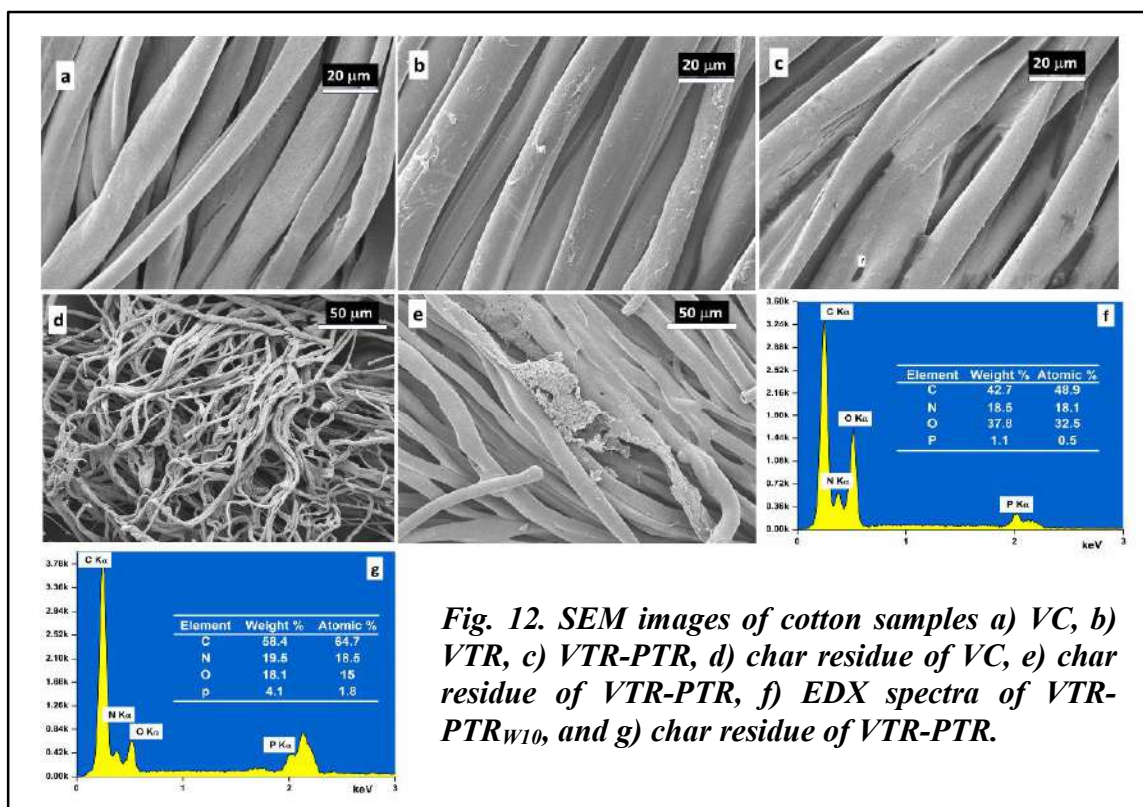


Fig. 12. SEM images of cotton samples a) VC, b) VTR, c) VTR-PTR, d) char residue of VC, e) char residue of VTR-PTR, f) EDX spectra of VTR-PTR_{W10}, and g) char residue of VTR-PTR.

SEM and EDX analyses of char residues (Fig. 12d–g) revealed that untreated cotton (VC) exhibited severe fibril disintegration (~5 μm), whereas FR–plasma-treated cotton (VTR-PTR) retained thicker, more intact fibrils (~10 μm), confirming superior structural protection during combustion. EDX of washed VTR-PTR fabric showed 1.1 wt.% surface phosphorus versus 0.18 wt.% bulk content (Table 4), indicating plasma-induced surface enrichment and strong covalent bonding of P–N species. The char residue contained elevated C, N, and P with reduced O, evidencing an intumescent, oxygen-barrier char that suppresses further oxidation.

Mechanical testing (Tables 7a,b) showed that tensile strength remained unchanged after 3HPP treatment but increased by ~17% following plasma exposure. Bending length and crease recovery were comparable to untreated cotton, confirming that combined FR + plasma treatment enhances flame resistance and preserves textile performance, making it viable for practical applications.

Table 7 : Mechanical properties of cotton fabrics.

Sample	Tensile Strength (N)		Elongation (%)		Tear Strength (N)		Abrasion resistance (Weight loss %)
	Warp	Weft	Warp	Weft	Warp	Weft	
VC	558.1±2.1	438.4±1.5	7.3±0.3	29±1.9	23.2±0.2	22.9±0.1	6.2±0.3
VTR	550.1±1.9	447.4±1.5	6.4±0.5	21.9±1.7	10.7±0.3	8.4±0.3	3.57±0.4
VTR-PTR	644.5±3.3	495.0±2.8	6.9±0.7	22.3±1.4	8.9±0.4	7.36±0.1	1.41±0.4

Average value ± standard error is reported.

Conclusion

This study demonstrated that 3-hydroxyphenyl phosphinyl propanoic acid (3HPP), typically used for polyester, can effectively impart flame retardancy to cotton when combined with 1,2,3,4-butanetetracarboxylic acid (BTCA) and dicyandiamide (DCDA). The simple, scalable treatment yielded excellent results—LOI reached 31.5% and remained 28.1% after 20 washes, confirming high durability. SEM, FTIR, and XPS analyses verified chemical bonding and surface modification, while combustion tests showed rapid self-extinction and substantial reductions in HRR, MARHE, and THR. Plasma treatment (optimal at five cycles) further enhanced bonding but excessive exposure caused surface damage. Although 3HPP lacks strong reactive sites, the synergistic BTCA–plasma system compensated effectively. Future work should focus on cost reduction, alternative polycarboxylic acids, and comparative evaluation with commercial FR systems. Overall, this study presents an efficient and durable phosphorus-based FR approach for safer and sustainable cotton textiles.

2.10 The Development of treated Geosynthetic reinforced Asphalt Pavements

This research investigates the influence of geogrid reinforcement on the fatigue life and permanent deformation resistance of asphalt mixtures. In this research, four geogrids, two polyester-based (G-60, G-50) and two glass fibre-based (GG-100, GB-100) with nominal tensile strengths of 50, 50, and 100 kN/m are incorporated between Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) asphalt mixtures. Performance of the geogrid reinforced asphalt mixtures are evaluated through four-point bending fatigue and cyclic compression tests. Results indicate that geogrid reinforcement significantly improved fatigue performance and resistance to permanent deformation compared to Control Mixture (CM). Among four geogrids, G-60 exhibited the highest performance, attributed to its optimal aperture size and superior load distribution. Polyester geogrids outperformed glass fibre geogrids, due to their energy dissipation and reduced brittleness. At 500 $\mu\epsilon$, the fatigue life of G-60 improved by 2.63 and 6.01 factor at 20 °C and 35 °C, respectively compared to CM. The cyclic compression tests confirmed enhanced rutting resistance across all stress levels, with performance ranking as G-60 > G-50 > GG-100 > GB-100. Post cyclic compression test, geogrids are exhumed and that revealed severe rib damage in glass fibre geogrids on the other hand polyester geogrids showed lesser damage. Overall, these findings showed geogrids, particularly G-60, as more effective reinforcements for long-term asphalt pavement performance.

Introduction

Asphalt pavements are extensively used in transportation infrastructure due to their flexibility, smooth riding quality, and ease of maintenance. However, with increasing traffic and heavier axle loads, asphalt pavements are prone to premature distresses such as fatigue cracking, and permanent deformation, which compromise their service life and performance. Fatigue cracking occurs due to development of the horizontal tensile strains at the bottom of the asphalt layers. This is one of the most commonly found distresses on the pavements, that leads to ravelling and potholes, while the permanent deformation occurs at the surface of the asphalt pavements due to vertical compression stress (Alimohammadi et al., 2021). In order to resist the fatigue cracking and permanent deformation, researchers are started exploring many techniques such as modified binders, higher modulus asphalt mixtures, and fibre additives (Devulapalli et al., 2023; Katla et al., 2021). However, the premature failures are still prevailing in the asphalt pavements. One promising solution for

improving pavement performance is the incorporation of geogrid reinforcements, within the asphalt layers(Shukla et al., 2022; Bhutta et al., 2021). Geogrids are polymeric materials characterized by their high tensile strength and grid-like structure, which enables effective load distribution, crack resistance, and confinement of aggregate particles. These geogrids are made up of polypropylene (PP), polyester (PET), or a glass fibre.

Cyclic Compression test

The cyclic compression test is also known as permanent deformation test, which is conducted to evaluate the rutting resistance of the geogrid reinforced asphalt mixtures as EN 12697-25, Method A1. In this research, cyclic compression test is performed on cylindrical specimens with a diameter of 150 mm and height of 80 mm, compacted to the target air void content and OBC (as presented in Table 5) using a Superpave Gyratory Compactor (SGC) as shown in Fig 7. The specimens are compacted in two layers (i.e., DBM at bottom layer and BC at top layer) and for geogrid reinforced asphalt mixtures a geogrid is placed in between the top and bottom layer with a RS-2 tack coat applied at a rate of 0.8 – 1.0 kg/m². The DBM and BC sample preparation procedure is followed same as presented in Devulapalli et al. (2025).

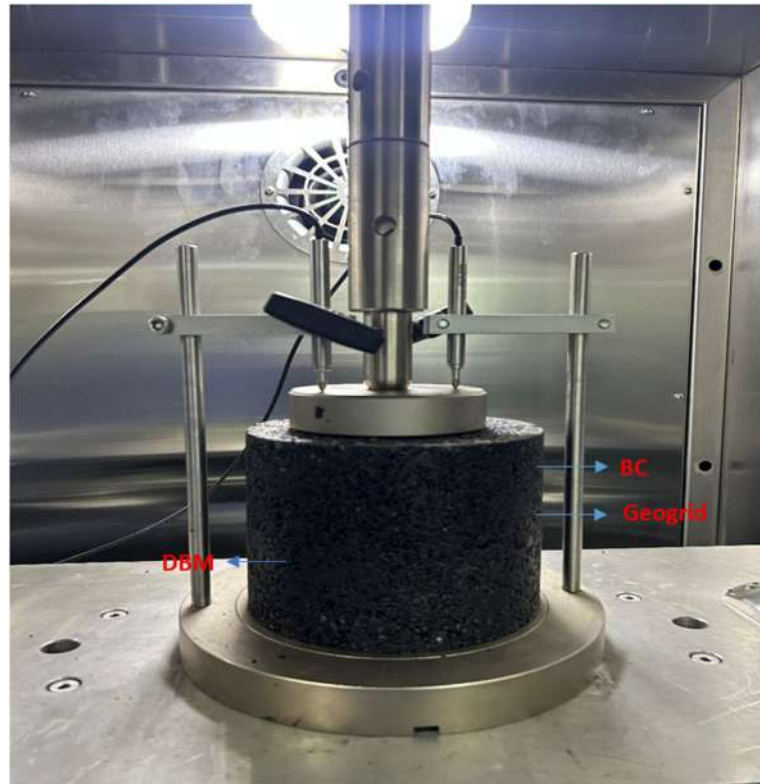


Fig. 8 cyclic compression test

Conclusion

Within the objectives of this research, four-point bending fatigue and cyclic compression tests are conducted to evaluate the performance of geogrid-reinforced asphalt mixtures in terms of fatigue life and resistance to permanent deformation. The test results indicate that the incorporation of geogrids enhanced both fatigue performance and permanent deformation resistance compared to the CM. Among the four geogrids evaluated, G-60 exhibited the highest improvement, which can be attributed to its effective aperture size that facilitates proper load distribution. PET-based geogrids (G-60 and G-50) demonstrated higher performance relative to glass fibre geogrids (GG-100 and GB-

100), likely due to their ability to dissipate energy more efficiently and their less brittle nature. While the fatigue and permanent deformation resistance of the glass fibre are higher than that of the CM. At a strain level of 500 $\mu\epsilon$, the fatigue life of G-60 improved by factors of 2.63 and 6.01 at 20 °C and 35 °C, respectively, confirming its superior reinforcement potential. Cyclic compression test results further validated that geogrid reinforcement enhances resistance to permanent deformation at all stress levels, with the performance ranking in the order: G-60 > G-50 > GG-100 > GB-100. The presence of non-woven backing in G-50 and GB-100 did not contribute to mechanical performance, serving mainly as an aid for installation. The exhumed geogrids after cyclic compression test revealed significant rib damage in glass fibre geogrids, supporting the inference that their brittle nature limits long-term durability.

It is important to note that these findings are based on controlled laboratory testing and constraints of specimen repetitions at each strain levels. Further field-scale investigations are essential to validate the long-term performance, such as measurement of shear bond test (Leutner test) to evaluate the relationship between geogrid bonding and fatigue/permanent deformation performance.

In this research the pavement design analysis is not considered since scope of the research is not to reduce the pavement thickness by geogrid reinforcement. However, the improved FIF values will ultimately reduce the pavements thickness to an extent (if pavement analysis is conducted by considering the design parameters, which is obvious). The aim of the research is to improve the performance and feasibility of geogrids in the asphalt pavements. To increase service life of the pavements and improve the cracking resistance and accommodate higher traffic loads.

3. In-house Project

3.1 Efficient catalytic ozonation and hybrid oxidative techniques for recycling the dyehouse wastewater

Effluents from reactive dyeing vary with shade depth, with dark-shade effluents exhibiting higher chemical oxygen demand (COD), color, and total dissolved solids (TDS). In this work, 20 L of high-shade effluent was treated using ozonation and recycled in exhaust dyeing at two dye concentrations (2% and 6% o.w.f.). The results showed that increasing dye concentration led to an increase in inlet COD from 4100 mg/L (2%) to 5280 mg/L (6%), reflecting higher organic loading. Despite this, the ozonation process maintained a relatively stable COD removal efficiency of ~28–30% over two recycling cycles for both red and blue dyes, with only minor variations observed between cycles.

These findings demonstrate that ozonation provides consistent treatment performance and supports the reuse of high-shade effluent under varying conditions. While further enhancement in COD removal may be required, the process shows promising potential as a pre-treatment strategy for sustainable water reuse in textile dyeing operations.

3.2 Development of a Method to identify Recycled and Virgin Polyester using Advanced Analytical Technique for Quality Assessment and Sustainable Application

This study focuses on the comparative characterization of virgin and recycled polyester. Due to the complexity, time requirements, and process sensitivity involved in laboratory-scale recycling, we

currently collected samples directly from industrial sources with well-established recycling processes. To this end, samples including virgin polyester, post-consumer waste PET (unrecycled), and recycled polyester have been collected from a prominent industry partner. These samples were thoroughly characterized using DSC, GPC, FTIR, and IV. We plan to collect and characterize additional samples from two to three more industries in the next phase.

3.3 Assessing Improvement and Efficiency of Geosynthetics in Flexible Pavements and Associated Embankments

Asphalt pavements are an essential component of transportation infrastructure worldwide, supporting the traffic load and enduring a variety of environmental conditions such as temperature and moisture variations. These pavements are subject to significant mechanical stresses, leading to potential failures such as cracking, rutting, and fatigue. To mitigate these issues and enhance the overall performance and lifespan of asphalt pavements, the use of geosynthetics, including geogrids and geotextiles, has emerged as an effective solution.

The incorporation of geosynthetics into asphalt pavement structures can improve the mechanical properties of the asphalt pavements. They function by providing reinforcement, distributing loads more evenly, and reducing the occurrence of cracking and rutting. The incorporation of geosynthetics into asphalt pavements can help enhance their stiffness, improve their resistance to deformation, and extend the service life of the pavement. However, while the benefits of using geosynthetics in asphalt pavements have been observed, there remains a gap in the quantification of their contribution to key mechanical properties, such as modulus.

The modulus of an asphalt pavements is a critical parameter that defines its stiffness and resistance to deformation under loading conditions. It plays a key role in pavement design, affecting the performance and durability of the pavement under traffic. The Modulus Improvement Factor (MIF) is a parameter used to measure the enhancement in the modulus of an asphalt pavements when reinforced with geosynthetics. It provides a quantitative measure of how much the modulus of a geosynthetic-reinforced asphalt pavements improves compared to an unreinforced mixture. Despite its significance, there is limited research dedicated to understanding the precise impact of geosynthetics on the modulus of asphalt pavements.

This research aims to bridge this knowledge gap by investigating the MIF of various geosynthetics in asphalt pavements. The study will explore how different types of geosynthetics, such as geogrids, geocells and geotextiles, affect the modulus of asphalt pavements under various loading conditions. Understanding the relationship between geosynthetics and modulus will enable engineers to make more informed decisions in pavement design, ensuring that geosynthetics are used effectively to optimize pavement performance. Ultimately, this research provides valuable data for improving the design and longevity of asphalt pavements, contributing to the development of more durable and sustainable transportation infrastructure.

Apart from this, it is necessary to determine the flow characteristics of drainage composite in pavement and embankment applications. Determining flow characteristics of drainage composites (2D and 3D) in pavement and highway embankment requires special testing consideration including different gradient and high surcharge loads. The stability and effectiveness of pavement rely on

efficient water routing from the surface and within its layers. Water infiltration can weaken materials, causing structural damage, erosion, and the formation of cracks and potholes. Effective drainage systems prevent water-related damage, extending the lifespan of pavements and embankments. Drainage composites help remove water from both the surface and subsurface of highway embankments, and testing apparatus is vital for verifying their effectiveness across different gradients.

3.4 Development of Flame Retardant Yarns and Fabrics

Polyester fabric samples were treated in stainless steel high-temperature high-pressure (HTHP) dyeing vessels containing the respective treatment solutions. The fabrics were introduced carefully using a glass rod to ensure complete immersion and to eliminate trapped air, thereby promoting uniform treatment. The vessels were heated to 132 °C and maintained for 30 min, followed by gradual cooling to room temperature over 45 min.

After treatment, the fabrics were removed, air-dried, and subsequently oven-dried prior to curing. Curing was carried out under varying conditions to evaluate the influence of thermal treatment, with temperatures ranging from 120 to 150 °C and durations of 3–7 min. For each formulation, experiments were performed in triplicate to ensure reproducibility.

It was observed that higher curing temperatures (130 and 150 °C) and longer curing durations (5 and 7 min) resulted in noticeable yellowing of the polyester fabric, which may be attributed to thermal degradation or structural alterations within the polymer matrix. In contrast, curing at 120 °C for 3 min provided optimal results, yielding enhanced flame-retardant performance while preserving the visual appearance and structural integrity of the fabric.

3.5 To Study the effect of Woven Geotextile test width and speed on wide width tensile testing

Geosynthetics, including geotextiles and geogrids, are widely utilized in geotechnical and civil engineering applications due to their high strength, durability, and multifunctional performance. Tensile loading governs the in-service behaviour of these materials, making the evaluation of tensile properties essential for design and field performance assessment. In this study, the influence of specimen width on the tensile characteristics of woven geotextiles, non-woven geotextiles, and polymer-coated flexible geogrids was systematically investigated. Tensile tests were conducted across multiple widths, and the results were statistically analysed using ANOVA to determine the significance of width-related variations. The findings reveal that specimen width has a pronounced effect on the tensile strength and elongation behaviour of both woven and non-woven geotextiles, highlighting the importance of adequate width selection during testing. Conversely, the tensile strength of geogrid samples was comparatively insensitive to changes in width, although elongation demonstrated measurable variation. Overall, the study confirms that wider specimens provide a more reliable representation of in-field performance, underscoring the need for appropriate specimen dimensions in tensile testing of geosynthetics.

4. Centre of Excellence for Geotech

BTRA (Bombay Textile Research Association) is recognized as the Centre of Excellence (COE) for Geotech in the year 2008. BTRA has an excellent state of art testing facility for Geosynthetics of International standards, accredited by NABL (India) as per ISO/IEC 17043 and GRI, USA. Earlier manufacturers of geosynthetics and the User Industry were sending their samples to foreign laboratories, spending a lot of money and time. Now they save both money (3 to 5 times) and time. At the same time, they witness the test to get confidence in the test report which is not possible with foreign laboratories. BTRA has an excellent Asphalt and Soil testing laboratory facility.

BTRA is the second commercial Geotech laboratory in Asia accredited by GRI, USA. BTRA has an information resource centre having many publications, Journals, Periodicals, and Research report for the industry people. Details of raw material suppliers and geosynthetic manufacturers are available with contact details.

BTRA has a needle punching nonwoven development facility. Nonwoven manufacturers have used this facility for the development of nonwoven products for technical application. BTRA also has a small loom for the development of woven technical fabrics. BTRA has developed woven products like Geobag, and Geomattress for erosion and flood control applications.

BTRA imparts training to entrepreneurs, students, and industry persons regarding the development of products and testing. Few entrepreneurs have started manufacturing geotextile after taking training in BTRA. BTRA continuously helps the industry resolve its process or product-related issues (especially the nonwoven industry).

BTRA is engaged in the development of test standards and specifications for the Bureau of Indian Standards. BTRA also actively participated in establishing the specifications for Woven / Nonwoven geo bags for the Ganga Flood Control Division, Ministry of Water Resources.

BTRA is involved in standardising the specifications for products like Geogrid, Geocells, Geocomposites, PVD, and Geotextile both made from synthetics and natural fibres (Coiir & Jute) for various applications. Awareness about the use of Geosynthetics has been created by BTRA through awareness programs, Seminars, and Conferences. This awareness resulted in the growth of the use of Geosynthetics in India.

Infrastructure

4.1 Development Facility

Nonwoven

- DILO needle punching pilot plant

Woven

- Local Sizing and Single-end warping machine

Electrospinning Unit:

For nanofibers spinning for different applications.

Plasma Processing Unit:

For imparting various finishes on fabrics (Hydrophobic, Hydrophilic, Antistatic, Antimicrobial, Antibacterial, etc).

Nonwoven Product Developments

*Needle-punched nonwoven geotextiles developed for manufacturers from Synthetic (Polyester and Polypropylene) and Viscose Rayon Fibres Spunlace nonwoven developed from Viscose Rayon Fibres

Various Geotextiles were developed as per the specifications given by the manufacturers.

4.2 Testing Facility

BTRA has fully-fledged testing laboratories. All laboratories are accredited by NABL, India as per ISO 17025. Whereas Geotech Laboratory is accredited by GRI, USA also apart from NABL. BTRA's Geotech Laboratory is the second commercial Laboratory in Asia. This laboratory now full fills the requirements of manufacturers and the user Industry.

Earlier manufacturers were sending their products to Foreign Laboratories and the huge amount paid by them. Due to BTRA Geotech laboratory, now they save a considerable amount in testing (3 to 5 times).

Test Facility at BTRA

Geosynthetics

BTRA is recognized (based on earlier experience, expertise, and facility) as a Centre of Excellence for Geotech by the Ministry of Textiles, Government of India. State-of-Art facilities for testing Geotech are set up at BTRA. The new laboratory has all testing facilities for geosynthetic products like Geotextiles, Geomembranes, Geocomposites, Gabions, Geosynthetic Clay Liner, Geogrids, Prefabricated Vertical Drain, etc. Also, BTRA is strengthening its information resources on Geotech by procuring various books and test methods.

The Geotech Laboratory at BTRA is accredited by the Geosynthetics Institute (GSI), Folsom, Pennsylvania, USA under the GAI – LAP Accreditation Programme for 24 tests of geosynthetics products. It is pertinent to mention that BTRA is the first institute in India and probably only the third institute outside the USA to get this coveted accreditation. What this means to the geosynthetics producers and users is that they can get the products tested in BTRA with utmost confidence that the accuracy of the results is as good as any other GAI-LAP accredited laboratory. They can get the tests done in India, thus saving time and money without compromising on the quality of the results.

The Geotech Laboratory at BTRA is accredited by the Geosynthetics Institute (GSI), Folsom, Pennsylvania, USA under the GAI – LAP Accreditation Programme for 24 tests of geosynthetics products. It is pertinent to mention that BTRA is the first institute in India and probably only the third institute outside the USA to get this coveted accreditation. What this means to the geosynthetics producers and users is that they can get the products tested in BTRA with utmost confidence that the accuracy of the results is as good as any other GAI-LAP accredited laboratory.

They can get the tests done in India, thus saving time and money without compromising on the quality of the results.

For Raw materials: Full fledge Polymer Laboratory accredited by NABL. (Having testing facilities such as DSC, FTIR, X-Ray Diffraction, TGA, etc)

For Yarn and Fabric: Physical Testing Laboratory accredited by NABL for Fibres, Yarns, and all types of Fabrics.

Chemical testing Laboratory: Almost all Chemical tests of geosynthetics are possible. Laboratory accredited by NABL.

Microbiology testing Laboratory: Microbiological Testing Laboratory accredited by NABL.

Soil Mechanics and Asphalt Materials laboratory

The Bombay textile research association (BTRA) has started the soil and asphalt lab and organized to perform tests on soil and pavement materials. During the construction of bridges, buildings, dams, roads highways, and expressways it is necessary to evaluate the physical and mechanical properties of the soil and pavement materials and mixtures. This state-of-the-art laboratory is equipped with all necessary equipment for conducting tests and research in soil mechanics, foundation engineering, and transportation engineering. Research, consultancy, and regular soil testing works are conducted in this laboratory under the supervision of the head of department and laboratory staff specializing in the area of Geotechnical Engineering and Transportation engineering. All the tests are conducted as per the Indian standards (IS), Indian Road Congress (IRC), American Society for Testing Materials (ASTM), and American Association for State Highway and Transportation Officials (AASHTO) standards. The laboratory tests comprise triaxial, direct shear, vane shear, oedometer test, soil classification test, Marshall Stability, wheel rutting, tensile strength ratio, etc. Apart from the laboratory testing, the soil and Asphalt lab can conduct field testing such as static and dynamic cone penetration test, field CBR test, plate bearing test on soil, filed vane shear, filed density of bituminous pavements, lightweight deflector meter, and core cutting of pavements.

4.3 Training

As BTRA has different plants for the manufacturing of Nonwoven, Woven fabrics and processing with Plasma and Nano technology, BTRA can offer practical training on the same. Also, BTRA imparts practical training in the testing of Geosynthetics and other technical Textiles along with chemical and Polymer testing.

4.4 Consultancy

BTRA gives consultancy in the setting up of manufacturing Plants, Setting up of Testing Laboratory, and accreditation of Laboratory, Product development. BTRA also gives consultancy for overcoming problems in nonwoven geotextile manufacturing and improving the quality.

➤ New Test Method

1. Rutting test on Asphalt mixture – ASTM D8292
2. Superpave mix design for asphalt mixtures – Asphalt Institute MS-2

3. Fatigue Four-point bending – ASTM D5
4. Dynamic Shear Rheometer – IS 15462 – 2019
5. Development of Advance Asphalt binder laboratory
6. Concrete lab
7. Resilient modulus - Asphalt
8. Dynamic creep – Asphalt
9. Indirect Fatigue test – Asphalt
10. Semi circular bending test - Asphalt
11. NABL for Asphalt testing
12. BIS approved – IS 73 and IS 15462

➤ **Standards and Specification formulated:**

Test Standard for Geotextile (4), Geomembrane (1), Geogrid (2) & Specification for Geogrids (4), Geotextile (2), Geocomposite (1), Prefabricated Vertical Drain (1).

5. CALIBRATION LABORATORY

BTRA calibration laboratory received NABL accreditation as per 17025:2017 laboratory standards for Mass, Volume, and Balance. BTRA is ready to provide calibration services to their own and other NABL-accredited testing laboratories for Mass, Volume, and Balance parameters for the following ranges.



The parameter to be calibrated	Range
Balance	1 mg to 5 kg
Weights	1 mg to 5 kg
Volumetric glassware	0.5 ml (500 µl) to 1000 ml

The worth equipment available is Balance, Weight– Standard balance 220 g-1 no's, 3kg-2nos & 5kg-1nos. weights 1 mg to 200 g, E2 class, 1 mg to 200 g F1 class and 500g, 1000g, 2000g, 5000g F1 class. The total number of certificates issued for Mass, Volume, and Balance in the last financial year was 103.

6. ACCREDITED PROFICIENCY TESTING PROVIDER

Testing laboratories play a major role in the evaluation of the quality of different products including textiles and geotextiles. The results being reported by the testing laboratories are crucial in deciding the fitness of the purpose of a product manufactured. The results should be reliable, repeatable, and reproducible. The competence of the testing laboratory can be demonstrated by documenting and implementing a laboratory QMS as stipulated in the international standard ISO/IEC 17043:2023. One of the main critical requirements to be demonstrated by a laboratory as stated in this standard is participation in proficiency testing conducted by a third-party accredited agency.

The organization that conducts proficiency testing is called a Proficiency Testing Provider. The International Organization for Standardization has stipulated the QMS to be implemented by such an organization in ISO/IEC 17043:2023. NABL has started accreditation of PT Providers by the standard ISO/IEC 17043:2023 from 2011 onwards. So far, over 35 Proficiency Testing Providers are accredited by NABL for testing/calibration of different products/items.

The five main advantages of participation in PT Schemes are as under:

- a) Evaluation of the performance of the laboratory for specific tests/calibrations;
- b) Providing additional confidence to customers of the laboratory;
- c) Identification of problems in laboratories and initiation of actions for improvement which, for example, maybe related to inadequate test or measurement procedures, the effectiveness of staff training and supervision, or calibration of equipment
- d) Education of participating laboratories based on the outcomes of such comparisons;
- e) Validation of uncertainty claims of laboratories

The deficiencies in the self-organized ILC are as under:

- Impartiality is not maintained as the organizer is also a participant.
- Robust statistical techniques are not used in performance evaluation.
- Confidentiality of the participants is not maintained and consequently, there is a possibility of collusion between the participants and falsification of the results.
- The number of participants is less in ILC (around 5 or 6 only) and hence the uncertainty in the assigned value is too large and the outcome of ILC is not dependable.
- The homogeneity and stability of the samples distributed are not ensured.
- Handling, storage, and transport of PT items are not satisfactory and consequently. The integrity of the sample is compromised.
- The competency of a laboratory to perform testing of any product can be ascertained only through PT participation and not ILC participation.

The above-mentioned deficiencies are rectified in proficiency testing conducted by ISO/IEC 17043:2023. Further, proficiency testing requires robust statistical methods to be used for (i) the determination of assigned value for each measured or characteristic of the proficiency test item (i.e sample), (ii) the determination of evaluation criteria such as Standard Deviation for Proficiency Assessment (SDPA), and (iii) performance evaluation in terms of Z score or Z prime score, etc. All these requirements are stipulated comprehensively in the standard ISO 13528:2018.

To meet the proficiency testing requirements of textile testing laboratories, BTRA has documented and implemented the QMS as per ISO/IEC 17043:2023 and secured accreditation by NABL in 2018. This includes most of the conventional mechanical and chemical tests including eco-parameter tests like banned amines, formaldehyde, and heavy metals, being performed by textile testing laboratories.

First time by any laboratory in India and Asia, we have got accreditation for analytical test parameters (banned amines, formaldehyde, and heavy metals) to our PT scope.

BTRA Annual Report (2025-2026)

From April 2025 to March 2026,

- a. BTRA has completed six PT programs as per ISO/IEC 17043:2023 covering Mechanical, Chemical and Analytical tests. Out of this 2 rounds of PT is done specifically for the Textile Committee covering 11 labs in India, on their request. A total of 38 and 47 textile testing laboratories respectively from different parts of the country and abroad have participated in these PT programs.
- b. We have recently launched another PT program in Mechanical and Chemical tests of Fabric and Yarn recently in Jan 2026.

We have received a good response from the laboratories as well and our reports were well accepted by the users.

7. TECHNICAL SERVICES

BTRA has provided extensive liaison and consultancy services to solve problems of quality, maintenance, and productivity at various levels for the textile units. The details are given below.

7.1 Overview

- | | | |
|--|---|----|
| • Technical investigations carried out | : | 51 |
| • Technical enquires attended | : | 88 |
| • Local mill visits made [man-days] | : | 14 |
| • Outstation mill visits made [man-visits] | : | 56 |

7.2 Type of Assignments Undertaken

- Handbook preparation- BTRA norms for weaving
- LAPF Evaluation and Improvement Program
- Consultancy on venner dyeing
- 3rd party inspection work
- Lab set up work
- Time motion study spg, weaving and processing

8. TESTING SERVICES

Testing activities continued to receive a good response from the industry in the wake of new testing services [microbiology / technical textiles] starting and thrust given on special testing apart from physical/chemical testing.

8.1 Overview

BTRA Test Laboratories has undertaken a range of testing activities such as Fibre Properties, Yarn Properties, Fabric Properties, Fabric Defect Analysis, Chemical Testing (chemicals & auxiliaries), Eco-parameters Testing, Geotextiles Testing, Soil Testing, Technical Textiles Testing (other than Geotech),

BTRA Annual Report (2025-2026)

Microbiology Testing, Scanning Electron Microscope Studies, Special Testing [Flammability, static charge measurement, FT-IR / DSC / TGA / X-ray / GPC analysis, Melt Spinning trials, etc.] and Material Testing (non-textile items such as water, paint, oil, etc.). The total number of tests conducted for the period under review is 49873. Details are as follows.

Test Particulars	Number of Tests
Physical Testing	12532
Chemical Testing and Eco-parameters, Chemicals / Dyes / Auxiliaries Testing and Material Testing (non-textile items, water, oil, etc.)	10494
Eco Testing	1426
Fabric Defect Analysis	391
Geotextile Testing	16906
Soil Testing	550
Microbiology Testing	830
Scanning Electron Microscope	1803
Special Testing (Flammability, static charge, FTIR / DSC / TGA / X-ray / GPC studies, Melt spinning trials, etc.)	4828
Calibration Testing	113
TOTAL TESTS CONDUCTED	49873

8.1.1 Proficiency Testing Programs Participation

During the period under review, BTRA Test Laboratories participated in various proficiency testing programs to maintain its laboratory performance at par with national/international laboratories.

8.1.2 New Machinery / Instruments added

- Compression Testing machine -3000 KN
- Bending Beam Rheometer
- lab scale melt spinning machine line
- Servo Hydraulic Machine with accessories
- Water Impermeability Tester
- Multipurpose X-ray Diffractometer
- Knitting Machine
- Sigma Mixer
- Potentiometric K/F & PH Titrator
- Toc Analyser
- Weighing Balance
- Ozone Generator

8.1.3 New Test Methods Launched

BTRA undertakes the following new test methods as per national and international standards.

1. Rutting test on Asphalt mixture – ASTM D8292
2. Superpave mix design for asphalt mixtures – Asphalt Institute MS-2
3. Fatigue Four-point bending – ASTM D5
4. Dynamic Shear Rheometer – IS 15462 – 2019

5. Development of Advance Asphalt binder laboratory
6. Concrete lab
7. Resilient modulus - Asphalt
8. Dynamic creep – Asphalt
9. Indirect Fatigue test – Asphalt
10. Semi circular bending test - Asphalt
11. NABL for Asphalt testing
12. BIS approved – IS 73 and IS 15462
13. HPLC test method has been developed to distinguish between natural and synthetic indigo dye.
14. Method development for permethrin analysis in mosquito-repellent fabric.
15. During the year, three new GC-MS methods have been developed. Different thinner concentration and purity were developed (Aditya Birla Samples) and consulted them in their R&D work.
16. New method was developed by using headspace GC-MS for identification of component in plant spray (to protect from insects)
17. Some monomer components (ethyl acrylate, Polyurathane etc.) were indentified using modified GC-MS method.

8.2 Technical Textiles Testing

The following types of testing of technical textiles are undertaken at BTRA.

- ❖ FILTER FABRICS - Woven/ Nonwoven
- ❖ GEOTEXTILES – Woven / Nonwoven
- ❖ PVD BAND DRAIN
- ❖ GEO-MEMBRANE LINER
- ❖ GEO-GRID
- ❖ ROPE GABION
- ❖ METAL GABION
- ❖ NONWOVENS – Wadding, Cover Stock, Face Mask, Interlining, Absorbing/Shoulder Pads, Insulation Pad and Carpets [Nonwoven Type]
- ❖ COATED FABRICS
- ❖ AUTOMOTIVE TEXTILES
- ❖ MEDICAL TEXTILES
- ❖ OTHER TECHNICAL TEXTILES - Narrow Fabrics, Conveyor Belts up to 13 Mm Thick [Dumbbell Shape], Nylon Ropes up to 12 Mm, Composites - Glass Composites / Glass Composites/Mats and Glass Roving / Fabrics

Apart from conducting usual tests such as weight per square meter, weight per linear meter, thickness/density, yarn number, etc., certain unique tests are also undertaken. They are as follows.

- ✓ **FILTER FABRICS (Woven and Nonwoven): Tear Resistance (Trapezoid Strength), Grab Strength, Water Permeability, Air Permeability, Pore Size by Porometer, Apparent Opening Size, Bursting Strength, Breaking Strength & Elongation.**
- ✓ **GEOTEXTILES (Woven and Nonwoven): Abrasion Resistance, Apparent Opening Size, Bursting Strength, CBR Puncture Strength, Cone Drop Test (Dynamic Puncture Test), Grab Breaking Load Machine Direction & Cross Direction, Grab Tensile Strength & Elongation, Index Puncture**

Resistance, Mullen Bursting, Pore Size by Porometer, Seam Strength, Static Puncture Strength (CBR Puncture Strength), Tensile Strength & Elongation (Warp and Weft), Tensile Strength (Before & After Exposure UV Xenon Arc), Trapezoid Tear Strength, UV Resistance Exposure to Light, Moisture & Heat in Xenon Arc, Water Permeability, Water Permeability of Filter, Wide Width Tensile Strength Machine Direction & Cross Direction.

- ✓ PVD BAND DRAIN: Tensile Strength & Elongation (Wide Width), Water Permeability of Filter, Tensile Strength of Core, Grab Strength & Elongation at Break for PVD Composite, Trapezoid Tear for Filter Component only.
- ✓ GEO-MEMBRANE LINER: Density, Tensile Strength, Tear Strength, Puncture Resistance, Carbon Black Content, Melt Flow Index, ESCR, 2% Secant Modulus of Polyethylene Geomembrane.
- ✓ GEO-GRID: Tensile Strength & Elongation (Single Rib) / Multi-Rib, Carbon Black Content, Melt Flow Index, Aperture Size & Number of Ribs per meter.
- ✓ ROPE GABION: Size, Tensile Strength, Identification of material [TGA / DSC], UV Resistance Exposure to Light Moisture & Heat in Xenon Arc, Tensile Strength (Before & After Exposure UV Xenon Arc), Tensile Strength of Rope after Thermal Treatment (Heating).
- ✓ METAL GABION: Size, Thickness of Wire, Tensile Strength of Wire.

NONWOVENS

- ❖ **WADDING:** Compressional Recovery, Air Permeability, Thermal Conductivity.
- ❖ **COVER STOCK:** Mass [EDANA], Absorbency [EDANA], Liquid Strike through time [EDANA], Wicking Rate [EDANA], Tensile Strength & Elongation [EDANA].
- ❖ **FACE MASK:** Pore Size, Bacteria Filtration Efficiency [In-house Method].
- ❖ **INTERLINING:** Mass per square metre, Thickness [EDANA], Tensile Strength & Elongation, Heat Shrinkage.
- ❖ **ABSORBING / SHOULDER PADS:** Mass per square metre [EDANA], Thickness [EDANA], Absorbency [EDANA].
- ❖ **INSULATION PAD:** Mass per square metre [EDANA], Thickness [EDANA], Thermal Conductivity.
- ✓ **CARPETS (Nonwoven Type):** Mass per square metre, Thickness, Compressional Recovery, Hexapod Tumbler Test, Lisson Test [Treading Wheel test], Taber Wear Index [up to 300 cycles], Colour Fastness to Light up to 5 Rating, Dimensional Stability – Heat/ Water, Flammability at 450, Horizontal Burning Rate, Pill (Camphor / Methenamine) Test, Tuft Withdrawal Strength (Piled Carpets), Static Charge measurement, Surface Resistivity, Volume Resistivity, Antimicrobial Activity, Antimicrobial Activity, Antifungal Activity.
- ✓ **COATED FABRICS:** Mass per square metre, Thickness, Tensile Strength & Elongation, Tongue Tear Strength, Single Rib Tear Strength, Bonding Strength Bonded / Coated, Application of Adhesive, Water Vapour Transmission [ASTM E: 96 by Gravi Test Instrument], Identification of Coating by FTIR, Taber up to 300 cycles, Hydrostatic Pressure Heat Test, Removal of Coating, Identification of Fibres, Yarn Count, Threads/Inch, Martindale Abrasion Test – 10,000 rubs, Pliability, Blocking Test, Gelling Test, Flexing Test [Dematia Method], Limiting Oxygen Index, Vertical Flame Test, Horizontal Burning Rate.
- ✓ **AUTOMOTIVE TEXTILES:** Mass per square metre, Thickness, Abrasion Resistance: Taber H18 / CS10 [Automotive Std.] up to 300 cycles, Flammability at 450, Horizontal Burning Rate, Pill (Methanamine) Test, Relaxation Shrinkage, Thermal Shrinkage, Odour Test, Tensile Strength

[Automotive Std.], Tear Strength [Automotive Std.], Colour Fastness to Light (up to 6), Colour Fastness to Crocking, Colour Fastness to Shampooing, Colour Fastness to Resistance to Cold - 20°C for 2 hours, Pliability, Blocking Test, Gelling Test, Flexing Test [Dematia Method].

MEDICAL TEXTILES

- ✓ **COTTON WOOL PADS:** Acidity or Alkalinity [Methyl Orange / Phenolphthalein], pH at 26°C, Absorbency Sinking Time, Water Holding Capacity, Water Soluble Substance, Ether Soluble Substance, Sulphated Ash, Fluorescence, Bioburden Test (4 Organisms), Drying Rate [67 + 2% R.H. & 27 + 2°C Temp.].

OTHER TECHNICAL TEXTILES

- ✓ **NARROW FABRIC:** Seat Belt Strength, Tape / Webbing Strength & Elongation, Hot Water Shrinkage of Webbing, Tensile Strength & Elongation, Belt for Lift.
- ✓ **CONVEYOR BELT** up to 13 mm Thick (Dumbbell Shape): Tensile Strength [In-house Method].
- ✓ **NYLON ROPES** up to 12 mm: Tensile Strength, Diameter of Rope, Linear Density.

COMPOSITES

- ➔ **Glass Composites:** Flexural Strength, Lap Shear Strength.
- ➔ **Glass Composites / Mats:** Thermal Conductivity, Mass per square metre, Tensile Strength, Thickness, Density.
- ➔ **Glass Roving / Fabrics:** Mass per square metre, Yarn Number, Thickness, Density, Breaking Strength & Elongation at Break, pH of Aqueous Extract, Glass Content.
- ➔ **Carbon composites:** Strength, Flexural modulus

8.3 Special Testing

Apart from undertaking tests of fibres, yarns, and fabrics (for physical as well as chemical properties), numerous special tests (that are most sought after) are conducted at BTRA. The same are widely availed by the industry. The types of tests conducted here are as follows.

- ✓ Differential Scanning Calorimetry (DSC) Analysis
- ✓ Thermal Gravimetric Analysis (TGA)
- ✓ Gel Permeation Chromatography for Molecular Weight Distribution
- ✓ X-ray Diffraction Analysis (Mineral analysis / Chart diffraction / Fibre orientation angle / Material identification)
- ✓ FT-IR spectroscopy (Material & Finish identification)
- ✓ Dynamic Mechanical Analyzer (DMA)
- ✓ Thermomechanical Analyzer (TMA)

Scanning Electron Microscope

- Longitudinal View of Fibres/Yarns
- Cross-section View of Fibres/Yarns
- Micrographs for Powder Sample

Surface and cross-sectional view of

- Fibers (natural and synthetic)
- Yarns
- Fabrics
- Hair samples
- Powder (Mineral, drug molecule)
- Pharmaceutical formulation powder/Pellets (Thickness/no. of layers)
- Pharmaceutical capsules/tablets
- Metal
- Ceramic
- Polymer films/membranes (Thickness/no. of layers/porosity)
- Medical samples
- Hollowness%, pore diameter/pore density of materials
- Other relevant samples

Elemental composition of all above-mentioned samples by SEM-EDX analysis Automatic capillary viscometer (PET, PVC, Nylon, PS, and other polymers) to measure

- Relative viscosity
 - Specific viscosity
 - Inherent viscosity
 - Intrinsic viscosity
 - Dynamic viscosity
 - K-value
 - Viscosity number
- ✓ Static Charge Measurement
- Total Charge Developed and Half Decay Time [ASTM D:4238]
 - Surface Resistivity [ASTM D:257]
 - Volume Resistivity
- ✓ **Pilot-scale facility for sample preparation**
- Melt spinning for the preparation of filaments
 - Electrospinning for the preparation of nanofiber
 - Melt Compounding for the preparation of the Master batch
- ✓ Other special tests were undertaken
- UV Protection Factor [AATCC-183]
 - Surface Tension – drop volume method (or) contact angle method
 - EMI Shielding Effectiveness [ASTM D 4935]
 - Birefringence measurement by Polarising Microscope
 - Particle Size Analysis
 - Contact Angle
 - Total Organic Carbon (TOC) Analyser
 - Refractive Index of Liquids (Abbe's Refractometer)

✓ **Flammability Tests**

General Apparel

- ➔ Ease of ignition of vertically oriented specimen [BS EN ISO 6940]
- ➔ Flame spread properties of vertically oriented specimen [EN ISO 6941 / BS EN 1103]
- ➔ UK nightwear safety regulation [BS 5438 / BS 5722 Test 1, 2 & 3]

Curtain, Drapes, and Blinds

- ➔ Ignitability of vertically oriented specimen [BS EN 1101]
- ➔ Flame spread properties of vertically oriented specimen [BS EN 1102]

Personal Protective Clothing

- ➔ Limited flame spread [EN 532 / ISO 15025 / BS 5438: 1976 Tests 1, 2 & 3]
- ➔ Limiting Oxygen Index [IS:13501 / ASTM D 2863]
- ➔ Vertical Flammability [IS:11871 / BS:3119 / NFPA 1975 / NFPA 2112]
- ➔ Horizontal Flammability [IS:15061 / ASTM D:5132 / FMVSS / SUZUKI]
- ➔ 45°C Inclined Flammability [16 CFR 1610 / ASTM D:1230 / IS:11871(B)]
- ➔ Carpet Flammability [ASTM D:2863 / 16 CFR 1630 / ISO:6925 / BS : 6307]
- ➔ Vinyl Coated Fabric Flammability [IS:1259]

Flammability of plastics

- ➔ Vertical Burning Test [UL 94 (VO.V1.V2) / ASTM D:3801 / IEC 60695–11–10(B) / ISO:1210(A) / UL 94 (VTM) / ASTM D: 4804 / ISO:9773 (Non Rigid Sample) / UL 94 (5V) / ASTM 5048 / IEC 60695-11-20]
- ➔ Horizontal Burning Test (Wing Top Method) [ASTM D:4986 / ISO:3582 / ISO:9772]
- ➔ Horizontal Burning Test [UL94HB / ISO:1210(A) / ASTM D:635 / IEC:60695–11–10(A)]
- ➔ Determining deterioration of visibility due to smoke released on combustion of materials [using Smoke Visibility Tester] as per UIC 564.2 OR Appendix-15 method
- ➔ Determination of Toxicity Index [Fume Toxicity Tester] as per N.C.D. 1409 method

8.4 Eco-Parameters Testing

The following types of tests are undertaken at BTRA. The following types of tests are undertaken at BTRA.

- Formaldehyde Content in Auxiliaries as per GOTS
- Allergenic Disperse Dyes
- Glyoxal Content in Textiles
- Polycyclic Aromatic Hydrocarbons (PAH)
- Identification & Quantification of Virgin / Recycled Polyester Fibre
- Free Formaldehyde in Textiles and Leather
- Released Formaldehyde in Textiles and Leather
- Chlorophenol - PCP / TECP / OPP
- Pesticides – Organochlorine / Organo phosphorous / Others / Total pesticide residue
- Banned Aryl amines Released from Azo dyes
- Plasticizer/Phthalates
- Chlorinated Organic Carriers (Benzene & Toluene)
- Poly Chlorinated Biphenyls
- Hexachloro benzene

- Organo Tin
- Heavy Metals as per Oekotex 100 and GOTS Specifications.
- Lead in Paints and Surface Coatings.
- Hexavalent chromium (Cr VI) in Textiles/Leather/Dyes
- Spectro photometric Evaluation of Dyes/Optical whitener.
- Analysis of Organic Compounds by - GC-FID /GC-ECD/ GC-MS {NIST library Search Report}
- Perfumery Analysis by GC-MS
- TLC Analysis of Organic Compounds
- HPLC Analysis of Organic Compounds
- Analysis of FAME, Triclosan, BPA, BHT, Solvents.
- Analysis of Mosquito repellents.
- Analysis of free & unreacted monomers
- Analysis of cyclosiloxines (D4,D5,D6)
- Analysis of solvents
- Volatile Organic Carbon (VOC's)...

And many more

8.4.1 New test methods launched :

1. HPLC test method has been developed to distinguish between natural and synthetic indigo dye.
2. Method development for permethrin analysis in mosquito-repellent fabric.
3. During the year, three new GC-MS methods have been developed. Different thinner concentration and purity were developed (Aditya Birla Samples) and consulted them in their R&D work.
4. New method was developed by using headspace GC-MS for identification of component in plant spray (to protect from insects)
5. Some monomer components (ethyl acrylate, Polyurathane etc.) were indentified using modified GC-MS method.

8.4.2 New Instruments Purchased:

- Ecolab has purchased a new Merck Millipore water system.

NABL Activities:

As a PT provider, in 2025-26, Ecolab has initiated to conduct proficiency testing of four analytical parameters (banned amines, free formaldehyde, total metals and leachable metals).Also participated in NABL audit 2025-26.

8.5 Microbiology Testing

Textiles, being an integral part of our everyday life, have been involved in the search for hygienic functional garments with the application of anti-microbial finishes. The types of tests conducted at this laboratory are as follows.

- Antifungal activity, assessment on textile materials: Mildew and Rot Resistance of Textile materials Test-II – Agar Plate, *Chaetomium globosum* [AATCC 30 Test 2]

BTRA Annual Report (2025-2026)

- Antifungal activity, assessment on textile materials: Mildew and Rot Resistance of Textile materials Test-III – Agar Plate, *Aspergillus niger* [AATCC 30 Test 3]
- Antifungal activity, assessment on textiles materials: Mildew and Rot Resistance of Textile materials Test –IV – Humidity Jar, Mixed spore suspension [AATCC 30 Test 4]
- Antibacterial Activity of Fabrics, Detection of Agar Plate Method [AATCC 90]
- Assessment of Antibacterial Finishes on Textile Materials [AATCC:100]
- Antibacterial Activity of Fabrics, assessment of Textile Materials – Parallel Streak Method [AATCC:147]
- Antimicrobial Activity Assessment of New Carpets - qualitative antibacterial assessment / quantitative antibacterial assessment / quantitative antifungal assessment. [AATCC 174 – Parts 1 to 3]
- Determination of a Population of Microorganisms on Products [ISO 11737 – Pt I]
- Textile fabrics – Determination of Antibacterial Activity – Agar Diffusion Plate Test [ISO 20645]
- Textiles – Determination of the Antibacterial Activity of Antibacterial Finished Products [ISO 20743]
- Determination of the Antimicrobial Activity of Immobilized Antimicrobial Agents Under Dynamic Contact Conditions [ASTM E 2149]
- Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi [ASTM G 21]
- Test for Antibacterial Activity and Efficacy on Textile Products [JIS L 1902]
- Antimicrobial products - Test for antimicrobial activity and efficacy for plastics and other antimicrobial-coated hard surfaces. (Film Contact Test Method) [JIS Z 2801]
- Microbiological Examination of Water [IS 1622 & IS 5403]
- Methods for testing Cotton Fabrics for Resistance to Attack by Microorganisms by Humidity Chamber Method [IS 1389]
- Evaluation of Bacterial Filtration Efficiency of Medical Textiles [In-house Test Method]
- Aerobic Plate count & Yeast and Mold count [Bacteriological Analytical Manual] 2021
- Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber (ASTM D 3273)
- Standard Test Method for Evaluating the Bacterial Filtration Efficiency (BFE) of Medical Face Mask Materials, Using a Biological Aerosol of *Staphylococcus aureus* (ASTM F 2101)
- Measurement of antibacterial activity on plastics and other non-porous surfaces (ISO 22196)
- Minimum Inhibitory Concentration (MIC) test by In-house method based on BSCI 424 Method (This is a laboratory-developed method).
- Suspension Time-Kill Test (ASTM E 2315)
- Sterility testing (ISO 11737-2)

BTRA Annual Report (2025-2026)

- AATCC 30 Part 1 is a soil burial test for materials intended to come into direct contact with soil. Standard testing for Part 1 runs for 2 weeks but can last up to 6 weeks.
- EN 12225:2020- Geosynthetics - Method for determining the microbiological resistance by a soil burial test.
- Determination of percent degradation by In-House method.
- IEC 60068-2-10 Environmental testing - Part 2-10: Tests - Test J and guidance: Mould growth.
- ISO 846 – Antimicrobial Test – Plastics
- ASTM D 5511- Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions
- CEN/TS 14416:2014: Geosynthetic barriers- Test method for determining the resistance to roots

... And many more

8.6 Soil Mechanics and Asphalt Testing

- Specific Gravity fine aggregate - IS 2720 (part 3 & sec 1): 1980 (RA 2016)
- Liquid limit IS 2720 (part 5): 1985 (RA 2015)
- Plastic limit IS 270 (part 5): 1985 (RA 2015)
- Shrinkage limit IS 270 (part 6): 1971 (RA 2015)
- Direct shear IS 2729 (part 13): 1986 (RA 2015)
- Swelling pressure IS 2720 (part 41): 1977 (RA 2016)
- CBR IS 2720 (part 16): 1987 (RA 2016)
- Vane shear IS 2720 (part 30): 1980 (RA 2016)
- Free swell index IS 2720 (part 40): 1977 (RA 2016)
- Water content dry density heavy compaction IS 2720 (part 8): 1983 (RA 2015)
- Sieve analysis and hydrometer IS 2720 (part 4): 1985 (RA 2015)
- Consolidation test IS 2720 Part 15: 1973
- Field CBR test IS 2720 part 31
- Rutting test on Asphalt mixture – ASTM D8292
- Superpave mix design for asphalt mixtures – Asphalt Institute MS-2
- Fatigue Four-point bending – ASTM D5
- Dynamic Shear Rheometer – IS 15462 – 2019
- Development of Advance Asphalt binder laboratory

... And many more

8.7 Other Achievements:

- ❖ Accreditation of 30 new tests in the asphalt and bitumen testing
- ❖ BIS approved IS code testing –
 1. IS 73 – 2013
 2. IS 17079 – 2019
 3. IS 15462 – 2019
 4. IS 773 – 2003
- ❖ Associated with the high profile projects like Navi Mumbai Airport, Coastal road project, Mumbai
- ❖ Performed bituminous mix design and conducted asphalt testing for numerous high-profile projects including the Navi Mumbai Airport, Construction of geogrid reinforced Asphalt pavement trial section, Mumbai Pune Missing link.



Advance Asphalt binder testing lab



IRC Annual Session, Bhuvneshwar



MTHL Project – Mumbai



Geogrid Reinforced Asphalt pavement Trial section – Navi Mumbai



Geogrid Reinforced Asphalt pavement Trial section – Navi Mumbai

NABL Scope New Tests Added:

- Absolute Viscosity at 60 °C, Poises
- Kinematic viscosity at 135 °C, cSt
- Flash Point, °C
- Solubility in trichloroethylene
- Softening point (R&B), °C
- Viscosity Ratio at 60 °C
- Ductility
- Elastic recovery of half thread in ductilometer at 15°C, percent
- Complex modulus (G^*) divided by Sin delta ($G^*/\sin \delta$) as Min 1.0 kPa, 25 mm Plate, 1 mm Gap, at 10 rad/s, at a temperature, °C
- Phase Angle (δ), degree, Max
- Separation, difference in softening point (R&B), °C, Max
- FRAASS breaking point, °C,
- Loss in mass - RTFO, percent
- Complex modulus (G^*) divided by Sin delta ($G^*/\sin \delta$) as Min 2.2 kPa, 25 mm Plate, 1 mm Gap, at 10 rad/s at a temperature, °C
- MSCR - Standard Traffic (S) Jnr3.2, Max 4.5 kPa-1 Jnr diff, Max 75 percent Test Temperature, °C)
- MSCR Test - Heavy Traffic (H) Jnr3.2, Max 2 kPa-1 Jnr diff, Max 75 percent Test Temperature, °C
- MSCR Test - Very Heavy Traffic (V) Jnr3.2, Max 1 kPa-1 Jnr diff, Max 75 percent Test Temperature, °C
- MSCR Test - Extremely Heavy Traffic (E) Jnr3.2, Max 0.5 kPa-1 Jnr diff, Max 75 percent Test Temperature, °C
- Complex modulus (G^*) multiplied by Sin delta ($G^*\sin \delta$) as Max 6000 kPa, 8 mm Plate, 2 mm Gap, at 10 rad/s at a temperature, °C
- Theoretical specific gravity of asphalt mixtures
- Bulk Specific gravity of asphalt mixtures
- Marshall Stability and Flow value

BTRA Annual Report (2025-2026)

- Wheel rut test
- Tensile Strength Ratio
- Resilient Modulus of asphalt mixtures
- Cyclic compression test Bituminous Mixtures
- Shear strength of waterproofing membrane
- Bond Strength of waterproofing membrane

8.8 Other Services

BTRA continued the activity of supplying chemicals/gadgets, repairing/calibrating gauges/testing instruments, and testing store accessories for the mills. The details are given in Appendix 4.

8.9 Powerloom Service Centres (PSCs)

BTRA runs three Powerloom Service Centers (PSCs) [at Ichalkaranji, Solapur, and Madhavnagar-Vita]. To improve the quality, operating efficiency, and productivity of the power loom clusters, BTRA PSCs provide technical consultancy, testing services, training in loom working, loom maintenance, and disseminating information through training programs, workshops, demonstrations, and discussions. Liaison visits are made by BTRA staff to have a first-hand view of the problems faced by the power loom weavers/processors and on the spot, suggestions are made. The activities of these centres are given in the following Table 2.

Table 2:Activities of BTRA Powerloom Service Centres

Acetivitis		Ichalkaranji	Solapur	Madhav-Nagar-Vita
Total yarn and fabric samples tested for physical & chemical properties		7320	6388	376
Number of technical assistance/troubleshooting/consultancy given		252	426	22
Total number of persons trained		230	233	73
Total number of trainee man-days		2622	3306	1299
Total seminars/workshops conducted		8	5	4
Survey of the closure of power looms	Units	419	408	342
	Looms	6190	6798	3056
Number of interactive workshops conducted for the TUF scheme and Group Insurance scheme		--	--	--
Group insurance facilitations for power loom workers [number of beneficiaries]		--	--	--
Number of Advisory / PPCICC meetings conducted		1	1	1
Number of samples for design development [non-CAD] / Analysis		--	--	--

9. INFORMATION DISSEMINATION / INDUSTRY INTERACTION

- a) Dr. T V Sreekumar received an award and certification of “Pride of the year 2024” from IIT, Delhi, Textile Department.



- b) Dr. T V Sreekumar invited by ICT-Institute of Chemical Technology for talk on topic of “High Performance Fibres” in April 2025.



- c) The Bombay Textile Research Association (BTRA) enthusiastically celebrated International Yoga Day with a special session led by its esteemed Director, Dr. T.V. Sreekumar. The event brought together staff and researchers for a rejuvenating experience focused on promoting well-being and a healthy lifestyle. Participants engaged in various yoga asanas and breathing exercises, guided by experienced instructors, emphasizing the physical and mental benefits of incorporating yoga into daily life. Dr. Sreekumar addressed the attendees, highlighting the importance of holistic health and the role of yoga in fostering a balanced and productive environment within the organization.

The celebration underscored BTRA's commitment to the health and wellness of its employees, reinforcing the message of unity of mind and body. The event was a grand success, leaving participants refreshed and inspired to continue their journey towards a healthier lifestyle.

BTRA Annual Report (2025-2026)



Celebration of International Day of Yoga (IDY), 2025 by BTRA

- d) BTRA Director, Dr. T. V. Sreekumar, was invited as the Guest of honor at the 15th Annual General Meeting of the Indian Technical Textile Association (ITTA), held on 19th September 2025 at The Orchid Hotel, Mumbai.



Moments from the Event at Indian Technical Textile Association (ITTA)

- e) Mr. Tanaji Kadam - Head Technical services has been considered as member in MPCB committee for State-Academia Environmental Innovation Council.
- f) Mr. Vijay Shirole - nominated for member in CPCB Technical Committee for Textile Products under Ecomark rules.



Joint Textile Commissioner visited to Ichalakranji and Madhavnagar PSC office on 5/12/2025

BTRA Annual Report (2025-2026)

- g) A client delegation from Korea visited the organization on 11th December 2025 to explore business opportunities and strengthen professional collaboration. The visit focused on discussing potential projects, requirements, and future partnerships.



- h) BTRA has developed an innovative plasma and waterless dyeing technology for the dry processing of technical textiles, significantly reducing water consumption while maintaining required performance standards. With support from NTTM and equipment from Deven Supercritical, industrial trial facilities for full-width fabric processing will soon be available. [FEB 2026]



- i) On 19th September 2025, BTRA hosted a Manak Manthan session bringing together industry experts, academia, regulators, and innovators to discuss standards and their adoption in technical textiles and allied sectors. The session emphasized standardization as a key driver of quality, innovation, trust, and sustainable growth in the industry.



- a) BTRA celebrated the "National Safety Week 2026" on 4th to 10th March 2026 at BTRA premises: The event was inaugurated by the esteemed Director Dr. T.V. Sreekumar. The various Safety Awareness Lectures / programs were organised by BTRA.



- b) BTRA participated in the The 63rd Joint Technological Conference (JTC) was officially inaugurated on 16th February 2026 at the J.B. Auditorium, Ahmadabad. The conference was hosted by ATIRA in collaboration with BTRA, SITRA, and NITRA, with support from the Government of India. The event witnessed enthusiastic participation from industry leaders, researchers, academicians, and professionals from the textile value chain. It served as an

BTRA Annual Report (2025-2026)

excellent platform for knowledge exchange, highlighting cutting-edge academic inputs and ongoing research developments in the textile sector. The technical deliberations and interactions were highly enriching and thought-provoking for all attendees. BTRA was privileged and honoured to welcome Smt. Vrunda Desai, IRS, Textile Commissioner, Government of India, at the BTRA stall during the JTC. Her gracious visit, encouragement, and keen interest in the ongoing initiatives were truly motivating for the entire team. We extend our sincere appreciation to the organizers, collaborators, speakers, and participants for making JTC 2026 a meaningful and forward-looking event for the textile industry.



- c) A meeting was held with Shri Nitin Gadkari Ji regarding BTRA's facilities and the Centre of Excellence (CoE) for Geosynthetics testing facility. Discussions focused on strengthening testing capabilities and supporting the technical textile and infrastructure sectors.



- d) A meeting was held with the Director, New Technology for Highway Development, Ministry of Road Transport & Highways (MoRTH), Government of India. Discussions focused on innovative technologies, geosynthetics, and their potential applications in highway development and infrastructure



- e) BTRA visited Indorama in Nagpur to explore opportunities for technical collaboration and industry engagement. Discussions focused on potential applications, technology development, and future areas of cooperation.



- f) BTRA received an award at the **BSL Summit 2025**, held on **July 30–31, 2025**, in recognition of its contribution and participation in the summit



- g) Dr.Shital Palaskar attended the training on Vacuum plasma machine, working, Handling, trouble shooting and maintenance treating at Henniker Plasma, Warrington, UK. During Feb 16th to 20th, 2026.

- h) BTRA was visited by international clients, providing an opportunity to showcase its testing, research, and technical capabilities. The interaction facilitated discussions on potential collaborations, technical services, and opportunities for strengthening BTRA's engagement with international clients.



- ❖ BTRA conducted the training and consultancy services to solve problems of quality, maintenance, and productivity at various levels for the textile units, as follows:
- a. Training on “Machine maintenance weaving and dyeing” at Panipat on 3rd to 15th April 2025.
 - b. Training on “Machine maintenance weaving and dyeing” at Panipat on 5th to 15th May 2025.
 - c. Training on “Lab testing and SOPS” at Navsari on 13th to 16th May 2025.
 - d. Training on “Good manufacturing Practices” at Hosur on 15th and 16th July 2025.
 - e. Training on “Energy Conservation” at Birla Cellulose Tirupur on 18th September 2025.
 - f. Training conducted for Textile Commissioner Office on 22nd September 2025
 - g. Training conducted on Energy conservation for Grasim Industries LIVA partners-Twenty Five person on 20th November 2025.
 - h. Training conducted on Training in Textiles for Textile Commissioner Office-Two persons on 22nd October 2025
 - i. Training conducted on Training Shrinkage Testing for True Colours Limited-Four persons on 15th October 2025
 - j. BTRA organised the A One Day webinar on Energy Efficiency A win –win to your wallet and our planet exclusively for product Developers, Regulatory Manager, Sourcing/Purchasing, Researchers and Academia on 20th January 2026.
 - k. BTRA conducted training on Energy conservation for LAPF partners in Surat zone-Eighteen person on 20th February 2026.

BTRA Annual Report (2025-2026)

- I. BTRA organised the A One Day webinar on Compliance and Beyond: Mastering Life Cycle Assessment(LCA) & Digital Product Passport (DPA) for the Textile Industry by Expert Speaker :Prof. Dr.Kannan Muthu, Chief Sustainability Officer, Green Story, 23rd March 2026.





9.1 Papers Presented & Published

Many research papers of topical interest are presented in various meetings and published in journals. The same are given in Appendix–2 and 3.

9.2 BTRA Publications / Library

BTRA library serves its users and textile units with 'Current Awareness Services' regularly, through the publication of 'BTRA Scan (Quarterly)'.including receives many specialized books, especially in the areas of geotextiles, nonwovens, composites, and nanotechnology also it receives various journals/magazines/newsletters regularly. BTRA updates its website (www.btraindia.com) at regular intervals.

9.3 Academic Activities

BTRA offered an internship to 31 students from various technical education institutes during the period under review.

10. EXHIBITION and CONFERENCE PARTICIPATION

- ❖ BTRA participated in the following exhibitions and various research publications and posters depicting the research and consultancy activities of BTRA were displayed during the occasion.

1. BTRA participated in Non-Woven Tech Asia 2025 during period November 6–8, 2025 and had the opportunity to meet Shri Anil Kumar Sagar, IAS, Principal Secretary, Department of Handloom & Textile, Khadi and Village Industries, and discuss key developments and opportunities in the textile and non-woven sectors.



BTRA Annual Report (2025-2026)

2. BTRA invited by the Utkal Chamber of Commerce & Industry, Odisha, to participate in the Texnova Odisha, 27th and 28th December 2025.
3. Techtextil India 2025 on 19th to 21st November 2025 at Bombay Exhibition Center, Mumbai - During the exhibition, Shri Malhotra Ji, Mission Director, NTTM and other industry partners / delegates visited the BTRA stall. The visit provided an opportunity to showcase BTRA's capabilities, ongoing initiatives, and contributions to the technical textiles sector.



4. BTRA participated in the “Texnova Odisha” at Bhuvneshwar. The event was organized by Maruti Media in association with The Utkal chamber of commerce industry limited; event featured insightful sessions on Odisha’s traditional textiles, building a resilient textile ecosystem,



and technical textiles as a transformation for the future of the textile industry. During the event, BTRA presented its Centre of Excellence (CoE) in Geosynthetics, highlighting opportunities to link this expertise with Odisha's infrastructure development and support the state's future growth.

5. BTRA actively participated in the 84th Annual Session of the Indian Roads Congress (IRC) held in Bhubaneswar during November 7 to 10, 2025, showcasing its research on geosynthetics-reinforced asphalt pavements. The event also highlighted BTRA's Centre of Excellence (CoE) in geotextiles, advanced testing facilities, and its contribution to sustainable road infrastructure.



Acknowledgements

The major portion of R & D's work at BTRA is based on the financial assistance provided by the various sponsoring agencies. The generous support from the sponsors has also enabled BTRA to build a good and useful infrastructure, which efficiently supports the R & D work. Our in-depth gratitude goes to the Ministry of Textiles, Government of India for their generous support and to the Board of Research on Nuclear Science(BRNS), Department of Atomic Energy(DAE), Defence Research and Development Organizations (DRDO), Ministry of Defence(DAF), Government of India. Thanks are also due to members of BTRA for giving constant encouragement to BTRA scientists/technologists to continue their work in uplifting the industry.

RESEARCH PROJECTS

On-going Projects:

Ministry of Textile, Government of India

- ➔ Development of Carbon Nanotube Reinforced Acrylic Precursors for Carbon Fibre
- ➔ Development of Alkaline Resistance Polyester for Geosynthetic Applications
- ➔ Development of High-Performance Gel Spun UHMwPE Fibres and Tapes for Bullet Proof and Geo-Grids/Geo-Composites Application
- ➔ The Development of treated Geosynthetic reinforced Asphalt Pavements
- ➔ Plasma Assisted Waterless Dyeing of High-performance Textiles using Supercritical Fluid for Application in Technical Textiles
- ➔ Development of Flame Retardant Aircraft Interior Fabrics by Plasma Assisted Chemical Treatment
- ➔ Development of Spinnable grade Meta- and para-aramid Polymers and their fibre-spinning
- ➔ Preparation of Lyocell CNT Composite High Strength Carbon Fibers
- ➔ Preparation of cellulose/silica-based aerogels and its composite for thermal insulation application

Defence Research and Development Organisation

- ➔ Atmospheric plasma assisted dyeing of polypropylene with graphene nanomaterial to impart antistatic and conductive properties

On-going In-house Projects:

- ➔ To Study the effect of Woven Geotextile test width and speed on wide width tensile testing
- ➔ Efficient Catalytic Ozonation and hybrid oxidative techniques for recycling the dyehouse wastewater
- ➔ Development of Flame Retardant Yarns and Fabrics
- ➔ Development of a Method to identify Recycled and Virgin Polyester using Advanced Analytical Technique for Quality Assessment and Sustainable Application
- ➔ Assessing Improvement and Efficiency of Geosynthetics in Flexible Pavements and Associated Embankments
- ➔ Centre of Excellence for Geotech
- ➔ BTRA powerloom service centre – Ichalkaranji
- ➔ BTRA powerloom service centre – Solapur
- ➔ BTRA powerloom service centre – Madhavnagar

PAPERS PUBLISHED IN JOURNALS

Authors Name	Title of the Paper	Journal Name
Geetanjali Mishra, Prasanata K Panda	Facile approach for synthesis of glutaraldehyde cross-linked PVA films using layered double hydroxide as fillers for food-packaging applications	Sustainable Chemistry and Pharmacy, https://doi.org/10.1016/j.scp.2025.102043
Vijay Shirole	Comparative Study of Regenerated Cellulosic Fabrics for Chemical Recipe, Process Control Parameters, Utility Consumption, and Cost Per Kg of fabric during Batch & Continuous Wet Processing	BTRA Scan - Vol. LIV No. 2- April 2025, Page no. 5 to 9
Lalit Varshney	Radiation Processing of Municipal Dry Sewage Sludge for Hygienisation and Agricultural Applications	BTRA Scan- Vol. LIV No. 2- April 2025, Page no. 10 to 17
M. P. Sathianarayanan, Shraddha Nitturkar	Development of sustainable hygiene products from sugarcane bagasse	BTRA Scan - Vol. LIV No. 2- April 2025, Page no. 18 to 28
Shreyasi Nandy, T V Sreekumar, Shubham Shinde, P.M.Abhishek, Abhishek Naskar, Arup Bhattacharyya, Neha Mehra	Improved flame retardancy of cotton fabric by crosslinking 3-hydroxy-phenyl phosphinyl propanoic acid using 1,2,3,4-butane tetracarboxylic acid	International Journal of Biological Macromolecules, https://doi.org/10.1016/j.ijbiomac.2025.144774
Shyambabu K.Sainik, Prasanata K Panda, T V Sreekumar	Fast and energy efficient crosslinking of PVA to make water resistant coating using glutaraldehyde	International Journal of Polymer Analysis and Characterization https://doi.org/10.1080/1023666X.2025.2504562 -May 2025
M.Amarnath, Shreyash Mohite, Shital Palaskar	Recent advances and innovations in textile materials for smart sensor applications: A review	Journal of Measurement https://doi.org/10.1016/j.measurement.2025.118057 - June 2025
M. P. Sathianarayanan, Karishma Hemani, Shraddha Nitturkar	Development of sustainable aroma and mosquito repellent finish for textiles	BTRA Scan - Vol. LIV No. 3- July 2025, Page no. 5 to 12. DOI: 10.70225/783640mzvikk
Gyana Ranjan Behera	A Review on Cutting-Edge Utilization of UHMWPE Polymer in Industrial and Medical Applications	BTRA Scan - Vol. LIV No. 3- July 2025, Page no. 13 to 17. DOI: 10.70225/680924rbklag

BTRA Annual Report (2025-2026)

Authors Name	Title of the Paper	Journal Name
Smita Deogaonkar-Baride, Tanushree Tandel, Anupama Chandel	Biosynthesized Silver Nanoparticles as Antimicrobial Finish over Cotton Fabric	BTRA Scan- Vol. LIV No. 3- July 2025, Page no. 18 to 22, DOI: 10.70225/449788xvwcgt
Lek haz Devulapalli , Sajikumar Sreelakshmi, T V Sreekumar	Rutting performance of geogrid reinforced asphalt mixtures	Construction and Building Materials, https://doi.org/10.1016/j.conbuildmat.2025.142560
Smita Deogaonkar Baride, Tanushree Tandel, Anupama Chandel	A Green Method of Developing Copper Nanoparticle-Based Antiviral Textiles	Fibre and Polymers, https://doi.org/10.1007/s12221-025-01171-0
Komal Kukreja, Prasanta K Panda, Shewali Pratihari, Prasanna Kumar S Mrunal	High-performance piezoelectric nanogenerator based on PVDF/2D layered Mo ₃ AlC ₂ composites for sustainable energy harvesting applications	Sensors and Actuators: A. Physical, https://doi.org/10.1016/j.sna.2025.117415
Yogesh Hande	Advances in Spinning Techniques for High-Performance PAN-Based Carbon Fibers	BTRA Scan - Vol. LIV No. 4- October 2025, Page no. 5 to 11, 10.70225/333008wzqaky
Shyambabu K Sainik, Prasanta K.Panda	Development of Alkaline-Resistant Polyester via PVA-Based Coating for Geosynthetic Applications	BTRA Scan - Vol. LIV No. 4- October 2025, Page no. 12 to 16, 10.70225/359927llzdjn
Nishant Chandel, Karishma Hemani, T.V.Sreekumar	Effect of tow size on solvent extraction from PAN fibers during wet spinning- A MATLAB-based FDM study	BTRA Scan - Vol. LIV No. 4- October 2025, Page no. 17 to 21, 10.70225/162575jwdsmm
M. Amarnath, Shreyash Mohite, Omkar Sadalkar, Shital Palaskar	Next-Generation Nanomaterials for Sustainable Engineering	Nanocomposites: From Design to Multifunctionality in Modern Applications Springer Nature Link
M. Amarnath, Shreyash Mohite, Shital Palaskar	Surface modification of polypropylene using atmospheric plasma and graphene adhesion promotion using PECVD for conductive interfaces	Applied Surface Science, https://doi.org/10.1016/j.apsusc.2025.165119
M. Amarnath , Afreen Begum, Supriya Sonawane, Omkar Sadalkar	The plasma-assisted dyeing: A Comparative Study of Exhaust and Pad-Dry-Cure (PDC) Methods with Acid Dye,	Journal of the Indian Chemical Society https://www.sciencedirect.com/science/article/abs/pii/S0019452225006351

BTRA Annual Report (2025-2026)

Authors Name	Title of the Paper	Journal Name
Smita Deogaonkar-Baride, Santosh Ghuge, Mitesh Koli	Recycling textile dyeing effluent through ozonation: An environmentally sustainable approach for reducing freshwater and chemical consumption and lowering operational costs	Journal of Cleaner Production, Volume 510, 2025, 145641, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2025.145641
T. V. Sreekumar, Mahesh Kapurderiya, Akash C Kanse, Yogesh Hande, Rani Rohini, Nishant Chandel	Enhanced drawability and thermo-oxidative stabilization of polyacrylonitrile fibers via oxygenated additive	The Journal of Materials, https://doi.org/10.1007/s10853-026-12275-0
Komal Kukreja, Prasanta K Panda, Prasanna Kumar S Mrunal	Up-scaling of polyvinylidene fluoride electrospun nanofibres with a needleless wire spinneret technique	Indian Journal of Fibre & Textile Research ,Vol. 51, March 2026, pp. 67-73, 10.56042/ijftr.v51i1.18902
Shreyash Mohite, M. Amarnath, Shital Palaskar	Surface functionalization of polypropylene via plasma activation and covalent bonding of N-functionalized graphene for antistatic applications	Surfaces and Interfaces https://doi.org/10.1016/j.surfin.2026.108881
Shreyasi Nandy, T V Sreekumar, Shubham Shinde, P.M.Abhishek, Abhishek Naskar, Arup Bhattacharyya, Neha Mehra	Advanced flame retardant polyester via nitrogen–phosphorus synergism and plasma-driven surface functionalization	Surfaces and Interfaces, https://doi.org/10.1016/j.surfin.2026.108657
Lekha Devulapalli Sajikumar Sreelakshmi, T V Sreekumar, Suraj Vedpathak	Evaluating tack coat compatibility and performance of geogrid reinforced asphalt mixtures	Geotextiles and Geomembranes, https://doi.org/10.1016/j.geotextmem.2026.02.002
Smita Deogaonkar-Baride, Mitesh Koli, Sirisha Majji, Asavari Dhawale, P. Saroj, Santosh Ghuge	Performance enhancement of textile effluent treatment processes using electron beam method	BTRA Scan - Vol. LV No. 1, January, 2026, Page no. 5 to 14 DOI: 10.70225/012716coopmg
Shreyash Mohite, M. Amarnath, Shital Palaskar	Metal Organic Frameworks And Conductive Polymers For Energy Storage	BTRA Scan - Vol. LV No.1 , January, 2026, Page no. 15 to 19, DOI: 10.70225/952330snpiow

BTRA Annual Report (2025-2026)

Authors Name	Title of the Paper	Journal Name
Shreyasi Nandy, T V Sreekumar, Abhishek PM, Shubham Shinde, Neha Mehra	Plasma-Assisted Surface Engineering of Textiles and Polymers for Improved Flame Retardancy: A Comprehensive Review	BTRA Scan - Vol. LV No.1, January, 2026, Page no. 20-34, DOI: 10.70225/943046krpkfq
Tanaji Kadam	Carbon Footprint Awareness and its Importance for the Textile Industry	Colourage , vol LXXIII , March 2026
Snehal Dhamdhare	India's Geotextiles Market 2025: Building Strong Roads While Facing Global Trade Challenges	Technical Textiles Today, January 2026 https://www.technicaltextiles.in/magazines
Sandeep P. Jape, T. V. Sreekumar, Gyana Ranjan Behera, Yogesh Hande, Lekhaz Devulapalli, V. D. Deshpande	Influence of temperature and concentration on the rheology of UHMWPE/paraffin oil solutions	Journal of Elastomers & Plastics, 2026, Vol. 0(0) 1–31, The Author(s) January 2026, DOI: 10.1177/00952443261418104

Appendix–3

POSTER/PAPERS PRESENTED IN CONFERENCE/SEMINAR/LECTURES

Authors Name	Title of the Paper	Occasion/Venue/ Date
Komal Kukreja	Enhancement of thermal insulation behaviour of batting by instituting regeneration of sustainable aerogel material	8 th National conference on “Advanced polymeric materials and applications” by JSS Science and Technology University, Mysore in May 2025.
Shital Palaskar	Plasma - mediated Natural dyeing of Cotton using RE metal salt as a Mordants.	ICAPST 2025 conference during 16 to 18 July, Coimbatore
Shital Palaskar	Hybrid Conductive Fabrics: Atmospheric Plasma and PECVD Functionalization of Polypropylene–Graphene Textiles	ICAPST 2025 conference during 16 to 18 July, Coimbatore
Shital Palaskar	Atmospheric Plasma and Glutaraldehyde Assisted Surface Modification of Polypropylene for Enhanced Conductivity Using Nitrene Functionalized Graphene,	Nano and supramolecular chemistry (NCNSC-25) during 7 -8 August 2025 Srinagar.

BTRA Annual Report (2025-2026)

Authors Name	Title of the Paper	Occasion/Venue/ Date
Shital Palaskar	Plasma Assisted Coupling Of Nitrene Functionalized Graphene On Polypropylene Fabrics For Enhanced ESD Performance	CTAC-2026 at BARC, INDIA on 21-24 January, 2026.
Shital Palaskar	Plasma Applications in Textiles as a Sustainable Technology for Textile Material Processing,	International Conference On Applied Plasma Physics For Sustainable Technologies (ICAPPST-26) Feb 13 and 14 2026
Smita Deogaonkar-Baride	Effluent Treatment Plant (ETP) Management & Operations in Textile Processing	A One-day Webinar on 24th November, 2025, 3.00 pm

Appendix – 4

OTHERS

PRODUCTS / CHEMICALS /INSTRUMENTS / GADGETS SOLD ON A REIMBURSABLE BASIS	• Viscosity cups [29 pieces] • Cuprammonium solution [450ML] • Drave Test Hook [3 nos.]
INSTRUMENTS/ GADGETS CALIBRATED	• Various instruments at BTRA Test Laboratories and 3 BTRA PSCs are calibrated regularly
INSTRUMENTS SERVICED	• Servicing of several types of equipment/ instruments at BTRA Test Laboratories

Appendix – 5

Patents Filed:

- Patent Name`** : A Process For Producing an Alkaline Resistant Polyester-Based Textile Substrate
Application No : 202621016711
Inventors : Prasanta Kumar Panda, Shyam sainik, T V Sreekumar
- Patent Name** : Lyocell Based Carbon Fibre Precursor Composition and Process For Synthesis Of Spun Fibres Comprising
Application No : 202521129806
Inventors : Prasanta Kumar Panda, Geetanjali Mishra
- Patent Name** : A Flame Retardant Fabric and A Method of Treating
Application No : 202621017960
Inventors : Shreyasi Nandy, T V Sreekumar
- Patent Name** : ASustainable hygiene products from sugarcane bagasse.
Application No : 202521047917
Inventors : M.P.Sathianarayanan, Shraddha Nitturkar

MEMBERS OF THE GENERAL ADVISORY COMMITTEE**FOR RESEARCH AND LIAISON****Jan 2024- Dec 2026**

Dr. Lalit Varshney RRF Room No: 209 Electron Beam Centre, Kharghar, Raintree Marg Sector 7, CBD Belapur Navi Mumbai, Maharashtra-410210	Dr. T.M. Kotresh Scientist 'G'/AD, Defence Bioengineering and Electromedical Laboratory, CV Raman Nagar, Bengaluru-560093.	Dr. G.V. Raghunath Reddy Scientist – F, Technology Mission Division (Energy, Water and Others), Department of Science & Technology, Ministry of Science and Technology, Technology Bhavan, New Mehrauli Road, New Delhi – 110016
Mr. Anjani Prasad Vice President South Asia, Global Head of Innovation for dyes and coating, Archroma India Private Limited & Archroma India International Ltd., Co chair Assochem, Chairman SDC EC, Director ITTA, 4th Floor, B Wing, Light Hall, Hiranandani Business Park, Saki Vihar Road, Andheri East, Mumbai- 400 072.	Dr. Debarati Bhattacharjee Sr.DGM 4th Floor, B Wing, Defence Engg Building, Gate No.1 Larsen and Tourbo, Powai Mumbai-400072	Mr. Aniket Bhute Garware Technical Fibres Ltd., Plot No.11, Block D-1, MIDC, Chinchwad, Pune- 411 019.
Dr. Milind Khandwe The Bhor Chemicals & Plastics Pvt Ltd, Plot no. B/18/2/1, MIDC Ambad, Nashik – 422010.	Dr. M.K. Talukdar, M/s. Kusumgar Corporates, 101/102, Manjushree Bldg., Hatkesh Co-op. Society, Corner of N.S. Road No.5, JVPD Scheme, Juhu, Mumbai 400 056.	Prof. Arup R. Bhattacharyya Department of Metallurgical Engineering & Materials Science, Indian Institute of Technology Bombay, Powai, Mumbai-400076
Prof. Asim Tewari Chair Professor Department of Mechanical Engineering Indian Institute of Technology Bombay, Powai, Mumbai- 400076.	Prof. Rajendra R. Deshmukh Institute of Chemical Technology, Nathalal Parekh Marg, Matunga, Mumbai 400 019	Prof. Anirban Guha Department of Mechanical Engineering, Indian Institute of Technology, Bombay, Powai, Mumbai 400 076
Mr. Shahrokh Bagli Technical Advisor Strata Geosystems (India) Pvt Ltd, Sabnam House, Plot No. A- 15/16 Central Cross Road B, MIDC, Andheri (E), Mumbai 400 093	Dr. Nilesh Revagade Reliance Industries Ltd. Reliance Corporate Park, Bldg 8B, First Floor WS-304 Thane Belapur Road, Ghansoli	Dr. Sandip Patil E-Spin Nanotech Pvt. Ltd 406, Third floor, Techno Park IIT, Uttar Pradesh-208016

BTRA Annual Report (2025-2026)

Dr.Prakash Vasudevan Director, The South India Textile Research Association, 13/37, Avinashi Road, Coimbatore Aerodrome Post, Coimbatore – 641 014	Dr. M.S.Parmar Director, Northern India Textile Research Association Sector-23, Raj Nagar, Ghaziabad-201002	Mr. Pragnesh Shah Director, Ahmedabad Textile Industry's Research Association, P.O. AmbawadiVistar, Ahmedabad - 380 015
Dr. T.V.Sreekumar Director The Bombay Textile Research Association Lal Bahadur Shastri Marg, Ghatkopar (West), Mumbai 400 086.		

Appendix – 7

BIS MEMBERSHIP

BTRA staff are involved in the following standard development committees of the Bureau of Indian Standards.

Sectional Committees	Title
TXD 01	Physical methods of test
TXD 05	Chemical methods of test
TXD 07	Textile speciality chemicals and dyestuffs
TXD 14	Textile Machinery and Accessories
TXD 28	Silk and silk products
TXD 30	Geo-textiles and industrial fabrics
TXD 31	Man-made fibres, cotton and their products
TXD 33	Industrial fabrics
TXD 35	Technical Textiles for Agrotech applications
TXD 36	Technical Textiles for Meditech purposes
TXD 38	Technical Textiles for Mobiltech Applications
TXD 39	Technical textiles for Clothtech purposes
TXD 40	High Performance Fibres, Fibrous Structure and Textile Components of Composites Sectional Committee
TXD 41	Smart Textiles Sectional Committee

STAFF DETAILS

The total staff strength of BTRA as of 31st March 2026 was as follows:

Director	1
At BTRA	
◆ Scientific / Technical Officers	23
◆ Scientific / Technical Staff	40
◆ Skilled / Semi-skilled & Maintenance Staff	28
◆ Administrative Staff	19
Sub-total	110
At PSCs	
◆ Scientific / Technical Officers	1
◆ Scientific / Technical Staff	4
◆ Skilled / Semi-skilled & Maintenance Staff	2
◆ Administrative Staff	1
Sub-total	8
TOTAL	119@

@ - Including 31 contractual staff & 7 Trainees

Director : **Dr. T. V. Sreekumar**

Research

Assistant Director : Dr. Prasanta Kumar Panda

("Research"-Chief Scientist)

Advisor : Mr. S. Subramanian

Technical Services Division

Chief Textile Technologist : Mr. Tanaji I. Kadam

Senior Scientific Officer Grade-I : Mr. Vijay. A. Gawde

Senior Scientific Officer Grade-I : Mr. Vijay. R. Shirole

Library, Information & Publication

Senior Assistant-HR and LIB. : Ms. Sharayu Joshi

Electronics

Junior Technical Officer : Mr. Peringeth Jithin

(Electronics & computers)

Junior Engineer : Mr. Kamlesh Desai

BTRA Test Laboratories

Laboratory Manager : Mr. Riyaz.A. Shaikh

(Senior Scientist)

Senior Scientific Officer Grade-II : Mrs. Maria P. D'Souza

BTRA Annual Report (2025-2026)

(i) Physical Testing Division

Senior Scientific Officer Grade-II	: Ms. Shreyasi Nandy
Junior Scientific Officer	: Mr. Dineshkumar.R. Yadav
	: Mrs. Sheetal M. Salunkhe
	: Ms. Nanda G.Vaidya

Scanning Electron Microscope

Senior Scientific Officer Grade-I	: Dr. Amol G. Thite
-----------------------------------	---------------------

Geotech Cell

Senior Scientific Officer Grade-I	: Mr. Rajit. R. Menon
Senior Scientific Officer Grade-II	: Mrs. Komal Kukreja
Junior Scientific Officer	: Mr. Gunwant.R. Mahajan
	Mr. Pramod D. Pandey

(ii) Chemical Testing Lab.

Senior Scientist	: Mrs. Saroj. P. Vairagi
	: Mrs. Chandrakala L.M.
Senior Scientific Officer Grade-I	: Mrs. Smita A.Baride
	Ms. Tejaswini R. Ghadyale
Senior Scientific Officer Grade-II	: Mrs. Shilpa D. Mayekar
Research Officer	: Dr. Geetanjali Mishra
Junior Scientific Officer	: Ms. Karishma Hemani

(iii) Microbiology Lab.

Senior Laboratory Assistant	: Ms. Anupama D.Chandel
Technical Assistant	: Ms. Sonal S. Gupta

(iv) Plasma Lab.

Senior Scientific Officer Grade -I	: Dr. Shital S. Palaskar
Senior Scientific Officer Grade -II	: Ms. Afreen Begum

Engineering Services Section

Junior Technical Officer (Engineering services)	: Mr. Mohan B. Mane
--	---------------------

Administration

Administrative Officer	: Mr.Jignesh S.Jani
Section Officer	: Mrs. Swati P. Wadkar
Accounts Officer	: Mr. Rashmi Ranjan Nayak
Chief Accountant	: Mrs.Vaishali P.Mane
Store-In-Charge	: Ms. Pooja S.Dohale

Marketing

Senior Scientific Officer Grade-I	: Mrs.Snehal B. Dhamdhare
Officer - Marketing Co-ordination	: Mrs. Rohini A. Bantwal Mangalore

Soil Testing Lab.

Senior Scientific Officer Grade-I	: Dr. Devulapalli Lekhaz
Senior Scientific Officer Grade-II	: Ms. Sreelakshmi. S

BTRA Annual Report (2025-2026)

High Performance Fibre

Junior Scientific Officer : Mr. Akash C. Kanse
: Mr. Mahesh Kapurderiya

NTTM Projects

Research Scientist : Mr. Nishant Chandel
Spinning Specialist : Mr. Yogesh Hande

DRDO Projects

Research Associate : Dr. Amarnath Marimuthu
Project Associate : Mr. Shreyash R. Mohite

BTRA PSC, Ichalkaranji

: Mr. Sachin R. Tambe

BTRA PSC, Solapur

: Mr. Amar V. Patil

BTRA PSC, Madhavnagar

: Mr. Namdev A. Chavan

Appendix – 9

LIST OF MEMBERS

- ❖ BanswaraSyntex Ltd., Rajasthan
- ❖ BMD Pvt. Ltd., Banswara
- ❖ BSL Ltd., Bhilwara
- ❖ Aditya Birla Real Estate Limited (Birla Century, Gujarat)
- ❖ Century Rayon, Shahad (under the management & operation of Grasim Ind. Ltd.)
- ❖ Diversey India Hygiene Pvt.Ltd., Mumbai
- ❖ Garware Technical Fibres Limited, Pune
- ❖ Indo Count Industries Ltd., Mumbai
- ❖ Kusumgar Corporates Pvt. Ltd., Mumbai
- ❖ OCM Private Ltd, Punjab
- ❖ Nagreeka Exports Ltd., Kolhapur
- ❖ Pee Vee Textiles Ltd., Wardha
- ❖ Khosla Profil Pvt. Ltd., Mumbai
- ❖ RSWM Ltd., Mumbai
- ❖ Raymond Lifestyle Ltd., Thane
- ❖ Reliance Industries Ltd., Navi Mumbai
- ❖ The Ruby Mills Ltd., Mumbai
- ❖ Siyaram Silk Mills Ltd., Mumbai
- ❖ Strata Geosystems (India) Pvt.Ltd., Mumbai
- ❖ Supreme Nonwoven Ind. Pvt. Ltd., Mumbai
- ❖ Techfab (India) Industries Ltd., Mumbai
- ❖ Technocraft Industries (India) Ltd., Mumbai
- ❖ United Bleachers Ltd., Tamil Nadu
- ❖ Visaka Industries Ltd., Secunderabad
- ❖ Wellknown Polyesters Ltd., Mumbai
- ❖ Terrapro Geosynthetics Pvt. Ltd., Kutch, Gujarat
- ❖ Proto9 Materials Pvt. Ltd., Mumbai
- ❖ Jayatma Industries Ltd., Gujarat
- ❖ Sealed Air Packaging Materials (India) LLP Mumbai
- ❖ Virendera Textiles, Uttarpradesh
- ❖ Geotech Industries Pvt Ltd, Gujarat
- ❖ Kasare Vanya Silk Mill Pvt Ltd, Chhattisgarh
- ❖ Suntech Geotextile Pvt Ltd, Chhattisgarh
- ❖ Indore Composite Pvt Ltd, Mumbai
- ❖ CTM Technical Textiles LTD, Gujarat
- ❖ TWE OBT Private Limited, Uttarakhand
- ❖ Kelvin Plastic Private Limited, Gujarat
- ❖ Precious Alloys Private Limited, Maharashtra
- ❖ Micro Interlinings Private Limited, Maharashtra
- ❖ Eikonoclast India LLP, Maharashtra
- ❖ NEEMCCO, Maharashtra
- ❖ Ten Geosystems, Telangana
- ❖ Amneal Oncology Private Limited, Telangana
- ❖ Camlin Fine Sciences Limited, Maharashtra
- ❖ ADD-ON Safety & Surgicals Private Limited, Maharashtra
- ❖ Texcore Textile Private Limited, Haryana
- ❖ Veer Plastic Private Limited, Gujarat

BTRA Annual Report (2025-2026)



THE BOMBAY TEXTILE RESEARCH ASSOCIATION

Phone : 91-22-6202 3636
Fax : 91-22-2500 0459
E-mail : info@btraindia.com
Website : www.btraindia.com

(Approved Body of the Ministry of Textiles, Govt. of India)

Lal Bahadur Shastri Marg, Near
R-City Mall, Ghatkopar (West),
Mumbai - 400 086.

Date:- 22.07.2026

To,
The Director,
The Bombay Textile Research Association

Subject: Submission of Information Regarding Complaints of Sexual Harassment at the Workplace from April 2025 to March 2026.

Dear Sir,

This is to inform you that the Vishakha Committee of the Bombay Textile Research Association has not received any complaint of sexual harassment at the workplace during the above period.

This information is submitted for your kind information and record.

Thanking You,


(Saroj Vairagi)

Chairman- Vishakha Committee


(Swati Wadkar)

Member- Vishakha Committee


(Chandrakala Madichetty)

Member- Vishakha Committee

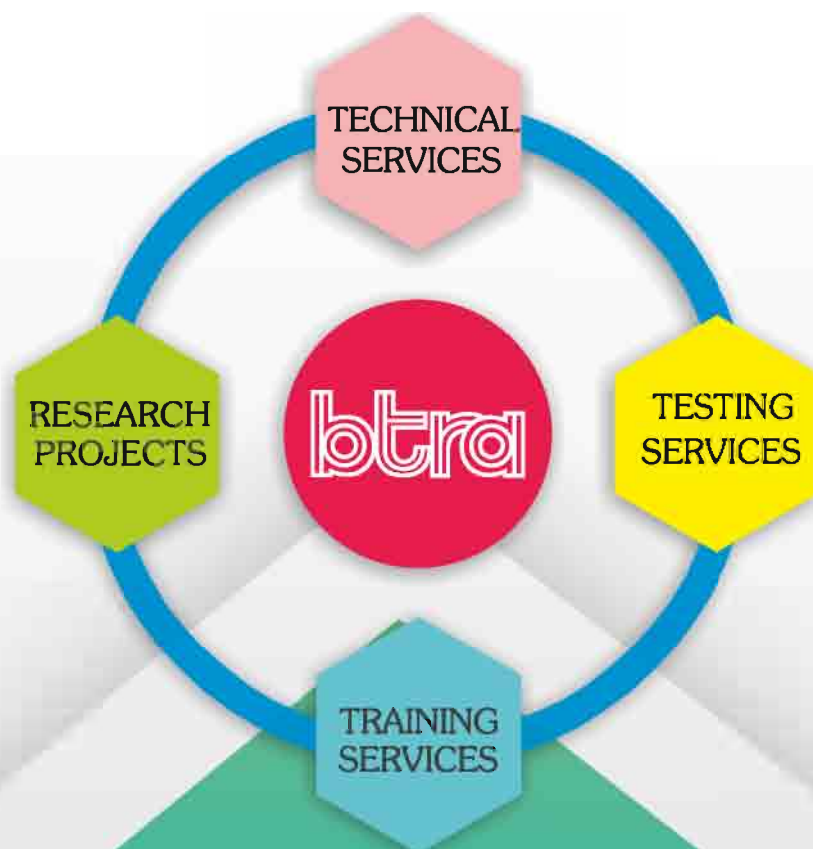

(Jignesh Jani)

(Jignesh Jani)

Member- Vishakha Committee

(Sunita Kulkarni)

Member- Vishakha Committee



**The Bombay Textile Research
Association**

L. B. S. Marg, Ghatkopar(W), Mumbai 400086.

Tel. : 022-62023636

Email : info@btraindia.com



www.btraindia.com