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Flame Retardant Jute-based Fabrics & Floor Coverings for Home Textile Application

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Abstract

Jute is a ligno-cellulosic fiber composed primarily of hemicellulose (22-24%), cellulose (58-60%), and lignin (12-14%), and it has an LOI of 20.5%. The woolenization process on jute fiber removes lignin content from the structure of jute fibre, hence jute fibre shows the changes in the physical properties such as crispiness, and bulkiness and develops a wool-like appearance. Woollenised jute has been blended with wool and other natural fibers like Bamboo, Mohair, Banana, etc. to develop yarn for floor covering applications. On the other hand, Woollenised jute can also be utilized heterogeneously with fibers like Cotton, Hemp, and Viscose, etc. to develop home furnishing fabrics.

In the current work, developed jute-based fabrics and carpets have been subjected to flame-retardant treatment to obtain flame-retardant jute-based fabrics and floor coverings for the stated purpose, and research has been conducted to investigate the physical parameters of flame-retardant jute fabrics and floor coverings. An eco-friendly organo phosphorous compound was used to add flame retardancy at different concentrations and found an LOI % value of more than 25 in each case. After FR finish on Jute-based Fabrics and floor coverings, the physio-mechanical properties were also examined. According to Fourier Transform Infrared Spectroscopy (FTIR) analysis, the flame-retardant chemical did not affect the inherent properties of the fiber.

Keywords: Flame Retardant Fabrics; Floor Coverings; Home Textile; Woollenised Jute; Eco-Friendly

Abbreviations: FTIR: Fourier Transform Infrared; LOI: Limiting Oxygen Index; FR: Flame-Retardant; N: Newtons; PSI: Pounds Per Square Inch; MVSS: Motor Vehicles Safety Standards

Introduction

A ligno-cellulosic fiber valued for its adaptability and environmental friendliness, jute has a complex composition made up mostly of hemicellulose (22-24%), cellulose (58–60%), and lignin (12-14%), with a little amount of other minor ingredients. Because of its complex chemical composition, which determines its various thermal behaviors, each component has unique properties under different circumstances [1]. Prior studies have attempted to comprehend the thermal behavior of jute and investigate ways to improve its fire resistance. Notably, improvements have been made to make jute items fire-resistant, including brattice cloth for mines, carpet backings, and fabrics for decorative furnishings. The goal of these initiatives is to lessen the increasing number of fire-related fatalities and injuries by reducing the dangers associated with fire accidents [2].

In contemporary home interiors, the quest for safety and sustainability has become paramount, driving innovation in material science and design. In response to this demand, flame retardant jute-based fabrics and floor coverings have emerged as a compelling solution, seamlessly blending safety with sustainability [3]. Jute, a natural fiber renowned for its eco-friendly properties, serves as the foundation for these products, offering inherent biodegradability and renewability. By integrating flame retardant additives into jute-based textiles and floor coverings, manufacturers achieve a crucial synergy: enhancing fire resistance without compromising environmental responsibility. This unique blend not only safeguards homes against fire hazards but also aligns with the growing emphasis on eco-conscious living [4]. Furthermore, the utilization of jute contributes to sustainable agriculture practices, fostering socio-economic development in regions where it is cultivated. As consumers increasingly prioritize both safety and environmental stewardship in their living spaces, flame retardant jute-based fabrics and floor coverings emerge as a compelling choice, embodying a harmonious fusion of safety, sustainability, and style in modern home interiors [5].

Material

Developed Fabric

The fabrics development was carried out on the shuttle less dornier loom (Rigid rapier type). The fabrics developed were coded from serial HF 1 to HF 10. Table 1 below gives the details of construction parameters.

Table 1: Details of construction parameters of developed fabrics. HF- Home Furnishing.

Sample Code	Sample Description	Warp	Weft	Blend %		GSM	Weave	EPI	PPI
				Jute	Cotton				
H1	Jute/Cotton	Cotton	Jute	40	60	383	Mat weave	36	14
H2	Jute/Cotton	Cotton	Jute	40	60	357	Diagonal twill	36	18
H3	Jute (natural bleached strip)	Jute	Jute	100	-	330	Plain (strip)	10	8
H4	Jute Cotton (dyed bleach)	Cotton	Jute	40	60	261	Plain	33	21
H5	Jute/Cotton	Cotton	Jute	75	25	222	Plain	48	20
H6	Jute	Jute	Jute	100	-	250	Plain	16	14
H7	Bleached jute	Jute	Jute	100	-	279	Plain	15	13
H8	Jute/Cotton	Cotton	Jute	43	57	291	Herringb-one	56	24
H9	Hemp Cotton/Jute	Hemp/Cotton	Jute	76.47	23.53	251	Plain	10	21
H10	Jute /Viscose	Jute	Viscose	33.33	66.67	211	Plain	10	85

Developed Floor Coverings

Wool/Jute/Mohair and Wool/Jute/Banana-based developed floor coverings were made by using hand tufting and hand knotting technique in Bhadohi, UP.

Chemical Used

Below chemical was procured from LN chemical industries, Mumbai (Table 2).

Table 2: Details of chemical used in flame retardant application.

Sr. No.	Product Name	Purpose
1	Glogard-CP-NEW	Flame retardant material
2	Mod finish-HDNI	Softener
3	Allenol-RW	Wetting agent
4	Tristar-RCT	Resin

Methodology

Flame Retardant Finishing

FR finishing was given to the home furnishing fabrics using organo phosphorous compound by using pad-dry-cure method. Padding was done at 70% expression followed by drying at 120°C for 30 minutes and curing at 150°C for 2-3 minutes. On the other hand, spray method was used for floor covering to impart flame retardancy at room temperature followed by sun drying (Figure 1,2).

Testing

The following tests were conducted for home furnishing fabrics coded as HF1 to HF 10.

a) FTIR Analysis

b) Vertical flame test

c) Horizontal flame test

d) LOI

e) Washing fastness

The following tests were conducted for floor coverings.

a) Carpet flammability test

b) Methamine Tablet -Test Method- 16 CFR 1631

c) Hot Metal Nut Method -Test Method-BS- 4790

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Figure 1: Flame Retardancy application by spray method.

Figure 2: Flame Retardancy application by pad-dry-cure method.

Result & Discussion

The studies carried out on fabrics used for home furnishings (designated as HF1 to HF10) show variable performance across several criteria. Tests of resistance of fabric to ignition and flame propagation were conducted in both vertical and horizontal configurations, revealing differing degrees of fabric resistance. The flammability of fabrics in various oxygen conditions was shown by the Limiting Oxygen Index (LOI) test. In order to evaluate wear resistance and durability, tests for fabric abrasion and pilling were also carried out, which revealed variations in the capacity of material to tolerate friction and repetitive usage.

Furthermore, the results of the fastness tests provided important information on how well the materials retained their color and held up against outside influences including washing,

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rubbing, and light exposure. The capacity of the materials to retain color brightness and integrity over time and under different settings varies, according to the results.

In order to assess flammability for floor covering applications, particular tests were carried out. The carpet flammability test shed light on the ignition of material and fire resistance characteristics by using techniques including the Hot Metal Nut Method (BS-4790) and the Methamine Tablet Test (ASTM-D 2859). The results of these tests showed differences in the capacity of textiles to withstand flame propagation and prevent ignition- two essential elements in floor covering applications safety.

Fabric Test

FTIR Analysis

The chemical composition changes of Untreated and FR treated woollenised Jute and Jute- Cotton fabrics are illustrated in Figure 3. ATR-FTIR analysis was used to determine the surface chemical composition of the substrate. These spectra are concentrated in the 4000 to 500 cm^{-1} spectral range. The peaks at 3292-3500 cm^{-1} in the case of untreated Jute & Jute-Cotton fabric, represent hydrogen-bonded (OH) stretching; this is one of the distinctive bands of the spectrum associated with the-cellulose in fiber. Additionally, the enlarged peak areas at 3327-3331 cm^{-1} for the vibration of the CH-OH stretching, the stretching vibration of cross-linking agent and organo phosphorous compound, as well as the holding H_2O molecules in FR treated fabrics, are responsible for the increased hydrophilicity of FR treated fabrics. along with. Like this, the peaks for C-H stretching vibrations of aliphatic methylene groups were found at 2897 and 2919 cm^{-1} for both untreated and FR-treated Jute and Jute-Cotton fabrics, respectively. These peaks represent the presence of the aldehyde group; the existence of CH and CH_2 in cellulose and hemicellulose was shown by stretching and bending C-H at 2897–2919 cm^{-1} and for increased C-H and CH_2 stretch vibrations for cross linking agent along with organo phosphorous compound also merged with C-H and CH_2 stretch vibrations of cellulose in Jute and Jute-Cotton in the same wave numbers at 3330-3338 cm^{-1}. The peak was apparent at 2363 cm^{-1} and was associated with the stretching of C-H in polysaccharide chains. The gradual increase in the height of the peak at 2320-2378 cm^{-1} is due to the additional vibration of the amide group (-CO-NH) present in organo phosphorous compound as obtained after FR treatment and also due to -C-N- stretching for amino group of cross-linking agent molecules added in FR treatment. Furthermore, the increase in peak height at 1019-1026 cm^{-1} can be viewed as the increase in -OH and CH-OH wagging cellulose intensifies with the stretching vibration of H_2O (water) molecules held by amide-ester of phosphate as FR chemical applied to Jute and Jute-Cotton fabrics.

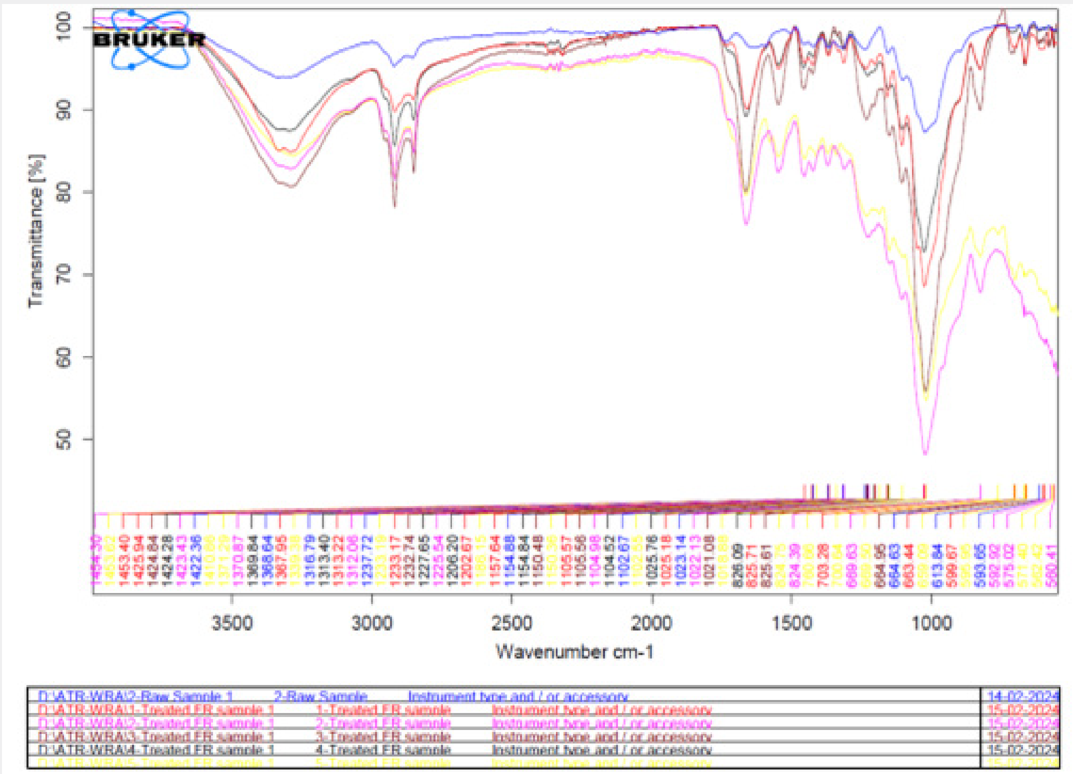

Figure 3: FTIR Analysis of Untreated and FR treated woollenised Jute and Jute- Cotton based fabrics.

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Vertical Flame Test

The produced specimens were subjected to thorough evaluation using the IS11871-A standard vertical flame test. This test is essential for determining a material's fire resistance, particularly when it comes to home furnishings where safety is of the utmost importance. The characteristics that were looked at were char length, after flame time, and afterglow time; these all show how well a material can resist burning and ignition. Interestingly, the treated Woollenised jute-based furnishings, which consisted of multiple blends with a GSM range of 211-383, performed excellently in the vertical flame test. This result demonstrates how well the treatment procedure worked to improve the fire-resistant qualities of materials, increasing safety in households. After flame retardant finishing; all the fabric (HF1 to HF10) successfully passed the vertical flame test (Table 3) (Figure 4).

Table 3: Details of Vertical flame test on different jute-based fabric.

Sample code	UNTREATED SAMPLES			TREATED SAMPLES			Char Length (in mm)
	Direc-tion	After Flame Time (in sec.)	After Glow Time (in sec.)	Char Length (in mm)	After Flame Time (in sec.)	After Glow Time (in sec.)	
HF 1	Warp	30	121	Whole Sample burnt	0	0	85
	Weft	33	130	Whole Sample burnt	0	0	79
HF 2	Warp	30	110	Whole Sample burnt	0	0	92
	Weft	31	103	Whole Sample burnt	0	0	89
HF 3	Warp	28	90	Whole Sample burnt	0	0	66
	Weft	34	87	Whole Sample burnt	0	0	71
HF 4	Warp	21	99	Whole Sample burnt	0	0	110
	Weft	22	102	Whole Sample burnt	0	0	108
HF 5	Warp	25	84	Whole Sample burnt	0	0	94
	Weft	30	104	Whole Sample burnt	0	0	83
HF 6	Warp	33	86	Whole Sample burnt	0	0	36
	Weft	32	90	Whole Sample burnt	0	0	33
HF 7	Warp	29	101	Whole Sample burnt	0	0	61
	Weft	33	96	Whole Sample burnt	0	0	73
HF 8	Warp	34	135	Whole Sample burnt	0	0	44
	Weft	32	131	Whole Sample burnt	0	0	42
HF 9	Warp	35	107	Whole Sample burnt	0	0	53
	Weft	33	97	Whole Sample burnt	0	0	62
HF 10	Warp	30	99	Whole Sample burnt	0	0	58
	Weft	31	87	Whole Sample burnt	0	0	63

Horizontal Flame Test

The test was conducted according to motor vehicles safety standards (MVSS 302) & the rate of burning was measured. The results of tests carried out in compliance with Motor Vehicle Safety Standards (MVSS 302) to assess the flammability properties of fabric samples designated by codes HF1 through HF10- differentiating between untreated and treated variants-are summarized in the data that is supplied. Notably, flames did not extend above the specified scribe lines for treated or untreated samples of any fabric code, indicating compliance with flame resistance standards. According to the standard burn rate should be less than 4 inches/min. All the untreated & treated samples (FR 1 to FR 10) passed the test (Table 4) (Figure 5).

LOI % Test

Limiting Oxygen Index (LOI) tests conducted using Test Method IS 13501 on different fabric samples, categorized by fabric code HF1 to HF10. The LOI % indicates the minimum concentration of oxygen required to sustain combustion in a material. For each fabric code, two types of samples were tested: untreated and treated. The untreated samples showed LOI % ranging from 19% to 21%, while the FR treated samples exhibited

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higher LOI %, ranging from 27% to 34%. This indicates that the treatment process has effectively increased the fire resistance of the fabrics, as evidenced by the higher LOI values. Overall, the data suggests that the treatment method applied to the fabrics has resulted in significant improvements in their fire-retardant properties, as demonstrated by the increase in LOI % compared to the untreated samples (Figure 6).

Figure 4: Vertical flame test of Untreated and FR treated woollenised Jute and Jute- Cotton fabrics.

Carpet Flammability Test

Methenamine Tablet Test

Carpet flammability test employing the Methenamine Tablet Test Method, outlined in 16 CFR-1930, serves as a critical safety measure to assess the fire resistance of small carpets or rugs. The test criterion, which dictates the parameters for determining a pass or fail result, is defined by the charred portion of the tested specimen. According to the criterion, the charred area must not extend closer than 2.54 cm (1.0 in.) to the edge of the hole in the flattening frame at any point. Application duration of 112 seconds with methenamine tablet on untreated sample was found a radius of 17 mm, no smoldering and no hole formation. On the other hand, the treated sample, which had a 16 mm radius and was likewise exposed with methenamine tablet for 109 seconds, showed signs of no smoldering and no hole formation same as untreated. These results indicate that both the treated and untreated samples meet the criteria for passing the flammability test, suggesting a satisfactory level of fire resistance for the carpets or rugs under examination (Figure 7).

Hot Metal Nut Method

The Hot Metal Nut Method described in BS 4790 is used to conduct a carpet flammability test that evaluates the ignition resistance of wool/jute/mohair and wool/jute/banana-based carpet samples. Two samples one treated and one untreated are examined using this methodology. A hot metal nut heated to 900ºC is applied to the samples for a predetermined amount of time, and

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observations are made throughout. A result of over 75 mm, which can be described as "high radius of effect of ignition" indicates that the material will ignite and may continue to spread flame. The nut application duration of 30 seconds caused the untreated sample, with a radius of 17 mm, to smoldering for 5 seconds. On the other hand, the treated sample, which had a 15 mm radius and was likewise exposed to the nut for 30 seconds, showed signs of smoldering for a longer period of time 9 seconds. These findings imply that, in contrast to the untreated sample, the treated sample showed greater resistance to ignition despite having a smaller radius (Figure 8).

Figure 5: Horizontal flame test of Untreated and FR treated woollenised Jute and Jute- Cotton fabrics.

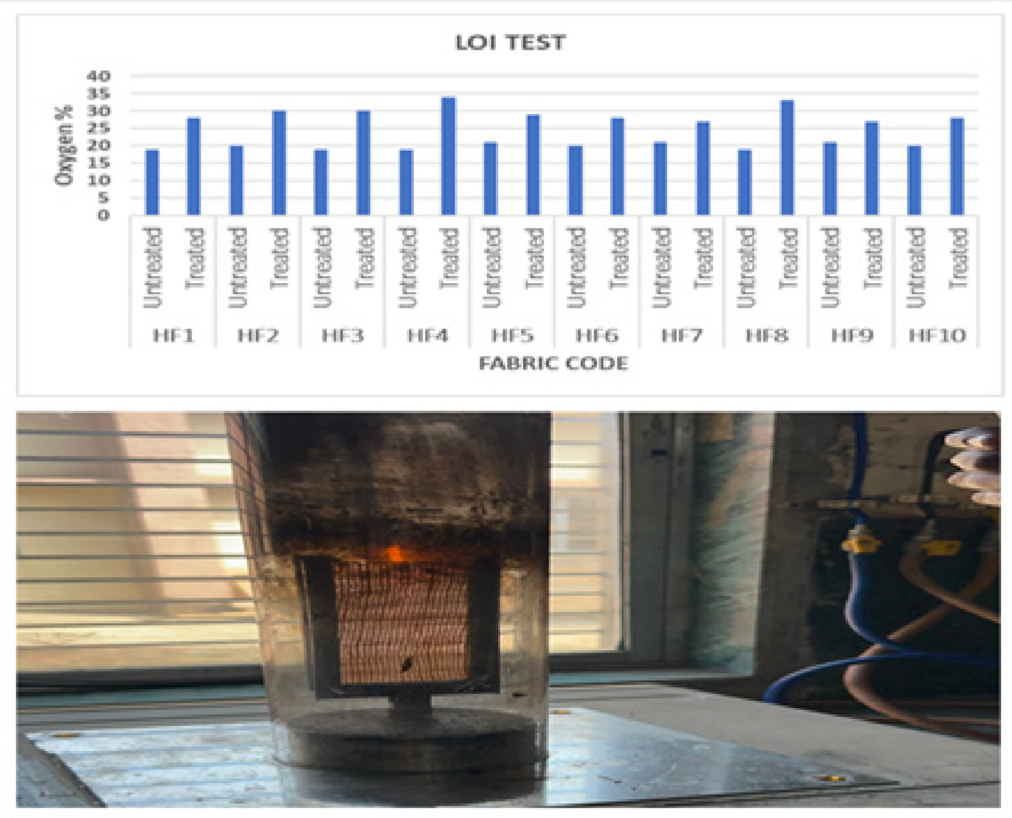

Figure 6: LOI % test of Untreated and FR treated woollenised Jute and Jute- Cotton fabrics.

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Figure 7: Carpet flammability test with Methenamine tablet test on treated woollenised Jute based carpet.

Figure 8: Carpet flammability test with Hot metal nut method on treated woollenised Jute based carpet.

Physio-Mechanical Test of FR Fabrics

Add on % Analysis

The chemicals add-on% on the FR treated samples (HF1 to HF10) was found in range of 35-45%. This indicates the excellent bonding between the organo phosphorous compound and the cellulose structure.

Tensile Strength Test of Treated and Untreated Fabric

Tensile testing is an essential process for evaluating the robustness and longevity of textiles, particularly those used in flame-retardant (FR) applications [6]. The fabric samples in this collection are denoted by their unique codes (HF1-HF10), and measurements of their tensile strength are given for both the pre and post-FR finishing treatments. Tensile strength is expressed as force per unit area, commonly expressed as Newtons per square meter (N/m^2) or pounds per square inch (PSI). values for the warp (lengthwise) and weft (width wise) directions are included in the measurements [7]. The fabric often has lower tensile strengths prior to the FR finish; but, following the treatment, the strength typically increases as seen by the increasing values for both warp and weft directions throughout the fabrics.

The graph presents data regarding the strength of fabric samples tested using ASTM D 5035 -06 method on both fabrics, before and after applying a flame-retardant (FR) finish. The fabric is analyzed in terms of warp-wise and weft-wise strength, measured in Newtons (N). Before the FR finish application, the

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fabric exhibits varying levels of strength across different samples, with HF2 showing the highest warp-wise strength at 1088.839N and HF5 displaying the lowest at 197.512N. After the application of the FR finish, there is a noticeable increase in strength for most samples, indicating the effectiveness of the flame-retardant treatment. HF4 demonstrates the most significant improvement in warp-wise strength, rising from 376.84N to 1151.33N, while HF5 sees the most considerable increase in weft-wise strength, from 197.512N to 278.512N (Figure 9 & 10).

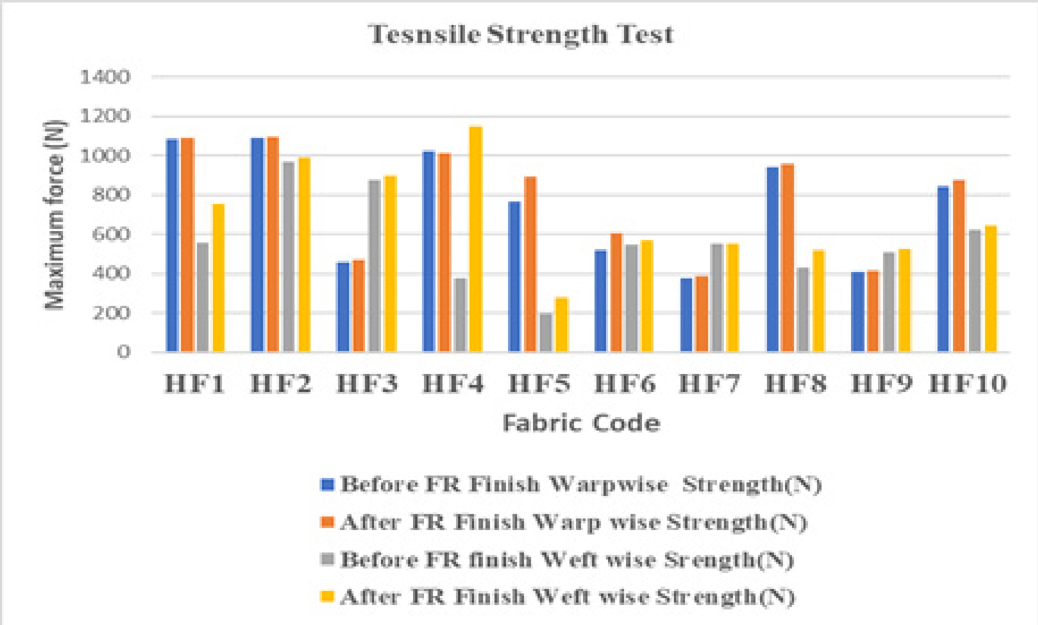

Figure 9: Graph representation of Tensile strength test of treated and untreated fabric.

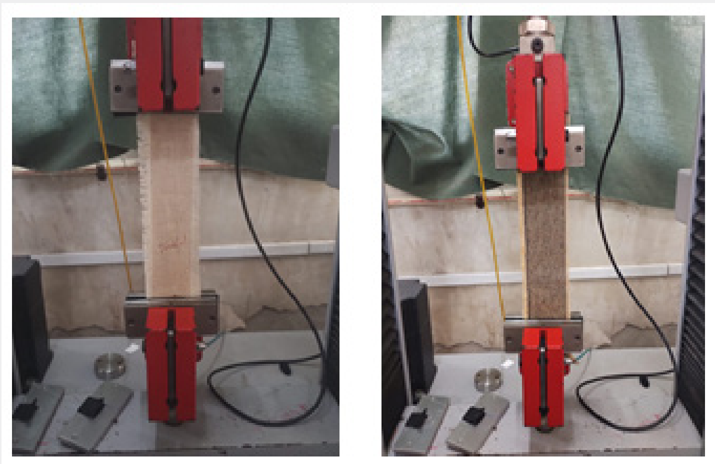

Figure 10: Tensile strength of treated and untreated fabric.

Washing Fastness to Dry Cleaning using Perchloroethylene Solvent

Washing fastness to dry cleaning, assessed using perchloroethylene solvent, is a crucial aspect of evaluating fabric durability and performance. Following ISO 105-D01:2010(E) standards, fabric samples were subjected to dry cleaning at 30°C using perchloroethylene solvent, a common method in textile care. After cleaning, the samples were air-dried, and the LOI %

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was measured once again. A significant finding is that in each case of the developed fabric samples, the LOI % exceeds 25, indicating robust washing fastness. This suggests that the fabrics exhibit remarkable resistance to flame.

Table 4: Details of Horizontal flame test of Untreated and FR treated woollenised Jute and Jute- Cotton fabrics.

Fabric Code	Type of Sample	Whether Flame Crosses 1st Scribe Line	Whether Flame Crosses 2nd Scribe Line	Burn Distance (mm)	Burn Time (sec)	Burn Rate (mm/sec)	Pass/Fail
HF1	Untreated	Yes	Yes	291	210	1.38	Pass
	Treated	No	No	0	0	0	Pass
HF2	Untreated	Yes	Yes	290	246	1.17	Pass
	Treated	No	No	0	0	0	Pass
HF3	Untreated	Yes	Yes	290	191	1.51	Pass
	Treated	No	No	0	0	0	Pass
HF4	Untreated	Yes	Yes	290	190	1.52	Pass
	Treated	No	No	0	0	0	Pass
HF5	Untreated	Yes	Yes	290	190	1.52	Pass
	Treated	No	No	0	0	0	Pass
HF6	Untreated	Yes	Yes	290	208	1.39	Pass
	Treated	No	No	0	0	0	Pass
HF7	Untreated	Yes	Yes	294	195	1.5	Pass
	Treated	No	No	0	0	0	Pass
HF9	Untreated	Yes	Yes	298	224	1.33	Pass
	Treated	No	No	0	0	0	Pass
HF10	Untreated	Yes	Yes	298	224	1.33	Pass
	Treated	No	No	0	0	0	Pass

Applications

Flame retardant finished fabrics play a crucial role in enhancing safety within home interiors, especially in items like pillow covers, carpets, wall hangings, apparel wear, cushion and mattress covers, and curtains [8]. These fabrics are treated with chemical compounds that inhibit or delay the spread of fire, thereby reducing the risk of accidents and providing valuable time for evacuation in case of emergencies. In pillow covers and mattresses, flame retardant finishes offer peace of mind, ensuring that even in the event of a fire, these items are less likely to ignite or contribute to the flames. Carpets, wall hangings, and curtains often adorn various spaces in homes, making them susceptible to accidental fires; hence, employing flame retardant fabrics adds an extra layer of protection. Additionally, apparel wear treated with flame retardant finishes offers safety benefits, particularly for garments worn during cooking or in proximity to heat sources. Overall, integrating flame retardant finished fabrics into these home interior applications not only prioritizes safety but also fosters a secure and comfortable living environment for occupants.

Conclusion

In summary, jute is a ligno-cellulosic fiber that has changed physical characteristics and looks similar to wool through the process of woolenization. Its unique composition consists of hemicellulose, cellulose, and lignin. This alteration creates opportunities for its use in a variety of applications, including as floor coverings and fabrics for home furnishings, both on their own and in combination with other natural fibers.

Building upon this versatility, current research has focused on enhancing the fire-retardant properties of jute-based fabrics and floor coverings. Through the application of an eco-friendly organophosphorus compound, significant improvements in flame-retardancy have been achieved, as evidenced by an increase in the Limiting Oxygen Index (LOI) to more than 25%. Importantly, the flame-retardant treatment has been found not to compromise the intrinsic properties of the jute fiber, as confirmed by Fourier Transform Infrared Spectroscopy (FTIR) analysis.

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This advancement holds promise for the development of safer and more sustainable textiles and floor coverings, catering to both functional and environmental concerns. By combining the natural attributes of jute with enhanced fire-retardant properties, the research underscores the potential of jute as a viable alternative in various industries, contributing to the ongoing pursuit of eco-friendly and safer materials.

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