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Flame Retardancy Enhancement of Jute Fabric Using Chemical Treatment

Izboljšanje ognjevarnosti jutne tkanine s kemično obdelavo

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Abstract
This work aims to improve the flame retardancy of jute fabric. Raw and bleached plain weave jute fabric was used in this work. Flame retardants borax, diammonium phosphate and thiourea were applied in different concentrations in a raw and bleached jute fabric with the padding method. The influences of flame retardant finishing on the vertical flammability behaviour and tensile properties as well as wash resistance were investigated. Flame spread time was found to significantly increase when these simple flame retardant finishing agents were used. It was found that the borax-treated raw and bleached specimens exhibited higher flame spread time among all. The assessment of physical properties such as weight gain percentage and breaking load along warp and weft direction of the control and treated fabrics revealed that the increase of flame retardant finishing weight gain caused a decrease in breaking load. Furthermore, the specimens treated with borax and diammonium phosphate flame retardant showed better results than thiourea for flame retardancy and wash durability. These flame retardant jute fabrics have industrial protective textile applications as brattice cloth in mines and many other potential fields of application, e.g. flame retardant kitchen apron, furnishings for public hall, theatre and hospital, etc.
Keywords: flame retardant, jute fabric, finishing, wash durability, breaking load

Izvleček
Namen raziskave je bil izboljšati ognjevarnost jutne tkanine. Surova in beljena jutna tkanina sta bili impregnirani z zaviralci gorenja boraksom, diamonijevim fosfatom in tiosečnino v različnih koncentracijah. Z vertikalnim testom gorljivosti je bil proučevan učinek ognjevarne obdelave na gorljivost, prav tako pa tudi njen vpliv na natezne lastnosti in odpornost pri pranju. Ugotovljeno je bilo, da se je z uporabo teh preprostih ognjevarnih sredstev čas širjenja plamena znatno podaljšal. Najdaljši čas širjenja plamena so imeli surovi in beljeni vzorci, obdelani z boraksom. Ocena fizikalnih lastnosti, kot sta odstotek povečanja mase in pretržna obremenitev v smeri osnove in votka, kontrolne in obdelane tkanine so pokazali, da se je pri povečani količini ognjevarnega sredstva zmanjšala pretržna obremenitev. Pri obdelavi

z boraksom in diamonijevim fosfatom so bili doseženi boljši rezultati zaviranja gorenja in obstojnosti na pranje kot s tiosečnino. Tako obdelane jutne tkanine so primerne za industrijske tekstilne pregrade v rudnikih in na številnih drugih področjih, kot so ognjevarni kuhinjski predpasniki, ognjevarne dekorativne tekstilije za notranjo opremo javnih prostorov, v gledališčih in bolnišnicah ipd.
Ključne besede: zaviralec gorenja, juta, plemenitenje, obstojnost pri pranju

1 Introduction

Jute is a lignocellulosic fibre with a different percentage of hemicellulose (22–24%), α-cellulose (58–60%) and lignin (12–14%) as the key constituents with other elements as well [1]. Despite jute being one of the most important biodegradable, eco-friendly, anti-statistic and annually renewable agro products, it is nowadays facing tough competition with synthetic fibres both home and abroad. Therefore, for the competitiveness of this environment friendly fibre, it is necessary to diversify its uses and develop new products for domestic and industrial purposes that can at least partially overcome the present unfavourable situation of jute [2–5]. In South Asia, jute is the most versatile natural fibre gifted to man by nature. At present, jute can be defined as an eco-friendly natural fibre with multipurpose application prospects ranging from low value geotextiles to high value products, e.g. fancy bags, carpets, home furnishings, composites, papers, particle boards, car components, fashion accessories and gift articles [6]. Apart from its conventional use as packaging material, jute fabrics are now extensively used in furnishing clothes and home textiles as this fibre has good spinnability [7–10]. Due to its versatility, jute is the second most important bast fibre after cotton. However, it ignites easily and is frequently involved in fire. Jute cellulose undergoes decomposition upon ignition, forming highly explosive volatile compounds, mainly laevoglucose with the spread of fire causing injuries and fatalities

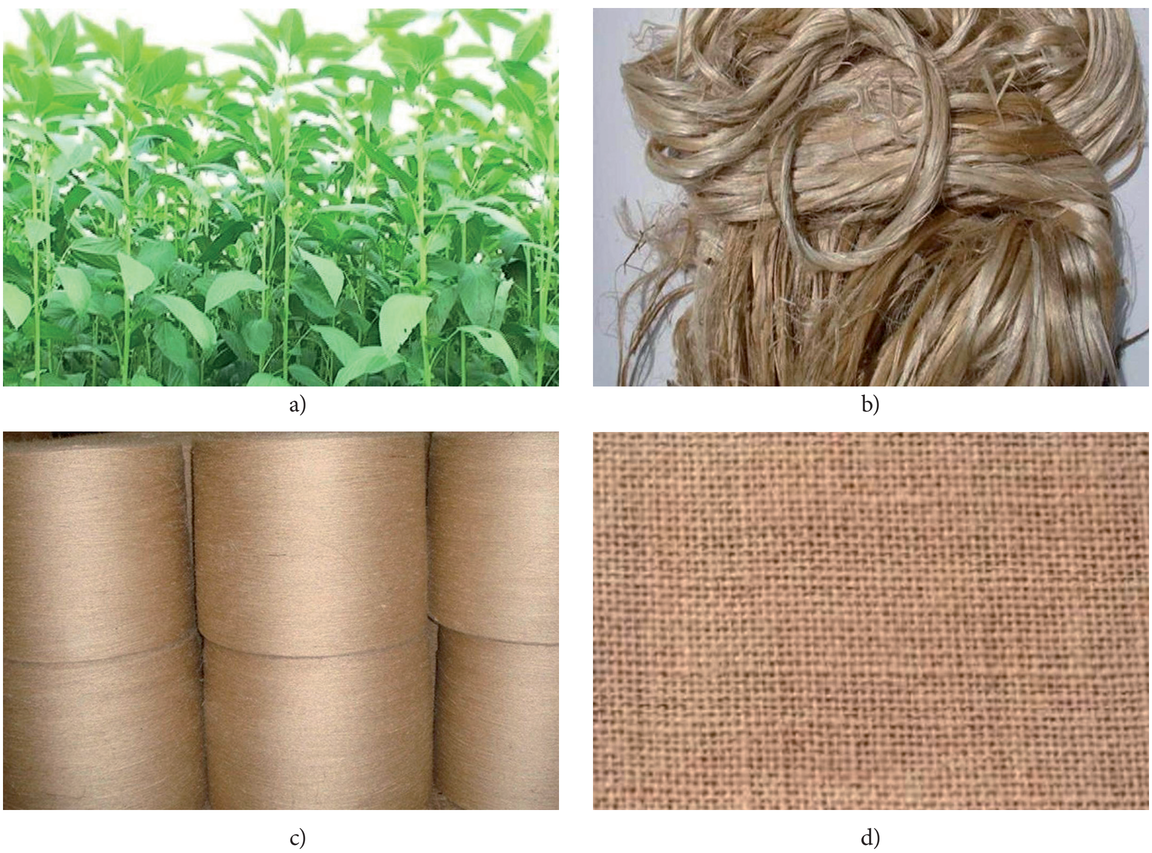


Figure 1: Jute: a) plant, b) fibre, c) yarn and d) fabric

in fire accidents [11, 12]. Since consumers are now increasingly becoming aware of a safe lifestyle, expectations and demand for diversified value-added flame retardant jute products are steadily increasing. The flame retardant jute product demand is also on an increase due to its prolonged life cycle and boosted application for home textile and furnishing purposes [13].
Different chemical formulations have been reported for preparing flame retardant jute fabrics. It has been found that different inorganic salts, borax-boric acid composition, hydrated metal oxide like sodium silicate, different phosphorous and nitrogenous compounds and their combinations have been mostly used to make fire-retardant jute [12–16]. Studies also have been reported on the application of nitrogen and sulphur based thiourea on jute fabric, and their flame retardancy properties have been evaluated [17, 18].
This study reports on the application of borax, diammonium phosphate and thiourea for developing flame retardant functionality on a jute fabric (cf. Figure 1). The thermal behaviour in terms of vertical flammability was investigated, and the weight gain and breaking load changes of the jute fabric were reported.

2 Experimental

2.1 Materials

A raw and bleached plain weave jute fabric commonly known as a hessian cloth with mass per unit area of 241 g/m^2 was fabricated for this research. The fabric construction is shown in Table 1 and its breaking load is stated in Table 2. After the bleaching, fabric mass per unit area became 232 g/m^2.

2.2 Chemicals

Flame retardant finishes such as borax ($Na_2B_4O_7 \times 10\ H_2O$, white solid), diammonium phosphate ($(NH_4)_2HPO_4$, white powder) and thiourea (CH_4N_2S, white solid) were obtained from Tradesia International Pvt. Ltd., Singapore. Other essential chemicals particularly hydrogen peroxide (H_2O_2), sodium silicate (Na_2SiO_3) and sodium carbonate (Na_2CO_3) were procured from Redox Chemical Industries Ltd., Sri Lanka. All reagents were laboratory grade and were used without further purification.

2.3 Methods

2.3.1 Bleaching process

The bleaching was conducted according to the exhaust method using an infrared lab dyeing machine (Xiamen Rapid, China) at 85 °C for 60 min. Then, the bleaching bath was cooled to 40 °C. Samples were washed at room temperature and neutralised with 0.5 g/L acetic acid for 10 min. The specimens were air-dried in a flat dryer machine (Mesdan, Italy). For both the bleaching and neutralising, the material to liquor ratio was 1 : 40. The recipe for bleaching the jute fabric is tabulated in Table 3.

Table 3: Recipe of bleaching of jute fabric

Chemicals/Parameters	Amount
Hydrogen peroxide, 35% (g/L)	1.5
Sodium silicate (g/L)	3
Sodium carbonate (g/L)	3
Wetting agent (g/L)	1
pH	11
Material : liquor	1 : 40
Temperature (°C)	85
Time (min)	60

Table 1: Raw jute fabric specifications

Fabric structure	Yarn count (tex)		Fabric density (cm^{-1})		Mass per unit area (g/m^2)
	Ends	Picks	Ends	Picks	
Plain weave	210.54	210.54	6.2 ± 0.2	5.2 ± 0.2	241

Table 2: Jute fabric breaking load

Fabric type	Breaking load (kg)	
	Warp	Weft
Raw jute	32	30
Bleached jute	25	23

2.3.2 Padding process

All single chemicals with different concentrations were applied to both raw and bleached jute fabrics. The prepared solution was poured into the padding bath of a two-bowl horizontal padding machine (Switzerland Mathis shares technology Ltd., China) and the fabric was impregnated to yield a 95% wet pick up. The pressure was set to 0.3 MPa and the bowl rotation was 20 m^{-1} to get the 95% pick up. Each sample was passed two times through the padding bath for better results. The nip pressure was controlled to ensure the required pick-up percentage. The latter can be calculated by using Equation 1. After the padding, the samples were dried using a stenter machine at 100 °C for 2 min.

$$\text{Pick up} = \frac{\text{Wet weight of sample (g)} - \text{Dry weight of sample (g)}}{\text{Dry weight of sample (g)}} \times 100\ (\%) \quad (1)$$

2.4 Characterisation

2.4.1 Weight gain measurement

Weight gain can be determined by using the oven-dry weight method, taking the oven-dry weight of a sample before and after the treatments, expressing the results as a percentage of the initial oven-dry weight of the material taken. Weight gain was calculated with Equation 2.

$$\text{Wet gain} = \frac{W_2\ (g) - W_1 (g)}{W_1\ (g)} \times 100\ (\%) \quad (2)$$

where W_1 and W_2 indicate the oven-dry weight of the untreated and treated fabric samples, respectively.

2.4.2 Tensile strength

Warp and weft breaking strength of untreated and treated jute fabric samples was determined according to the EN ISO 13934-2 standard test method [19] by using a universal strength tester (Titan 3, James Heal, England). The sample size was 20 cm × 10 cm for the breaking strength measurement.

2.4.3 Vertical flammability test

Raw and chemical-treated bleached jute fabric samples with 30.48 cm × 7.62 cm (12 inch × 3 inch) in size were prepared and placed in a specimen holder for the measurement. Afterwards, the specimens were exposed to a standard flame at 90° angle for 12 s ± 0.2 s and left for burning. The flame spread time after the burning was measured in line with the ASTM D6413 standard test method [20].

2.4.4 Wash durability of fabrics

The wash durability of the chemical-treated samples (sample size 30.48 cm × 7.62 cm) was tested by washing the samples in a bowl taking 500 ml of water. Each wash cycle was performed for 30 min at 45 °C followed by drying at 80 °C for 10 min to simulate the Samsung auto (WF8500NHS) laundering machine. The flame spread time of fabrics was repeatedly measured after different wash cycles and the average value was reported.

2.4.5 Sampling

The samples are identified as stated in Table 3.

Table 3: Sample identification of jute fabric

Fabric type	Flame retardant finish	Amount (%)	Sample identification code
Raw jute fabric	–	–	RR
	Borax	4	RB1
		6	RB2
		8	RB3
		12	RB4
	Diammonium phosphate (DAP)	4	RD1
		6	RD2
		8	RD3
		12	RD4
	Thiourea	4	RU1
		6	RU2
		8	RU3
		12	RU4

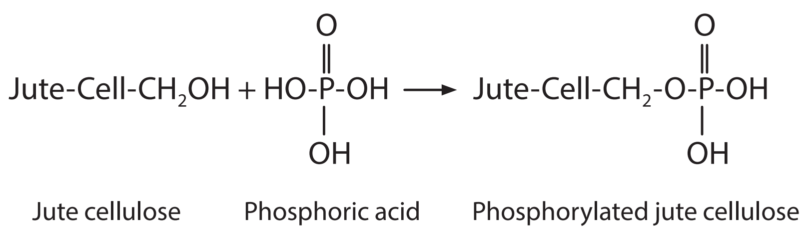
Fabric type	Flame retardant finish	Amount (%)	Sample identification code
Bleached jute fabric	–	–	BR
	Borax	4	BB1
		6	BB2
		8	BB3
		12	BB4
	Diammonium phosphate (DAP)	4	BD1
		6	BD2
		8	BD3
		12	BD4
	Thiourea	4	BU1
		6	BU2
		8	BU3
		12	BU4

2.4.6 Atmospheric conditioning

All physical properties of raw, bleached chemical-treated jute fabrics were evaluated after the conditioning in a standard testing atmosphere, i.e. 65% ± 2% relative humidity (RH) and 27 °C ± 2 °C temperature for 48 hours [21].

2.4.7 Probable reactions mechanism

H_3PO_4 reacts with the hydroxyl groups in jute fibres at high temperature. The following reactions illustrate the postulated mechanism leading to the configuration of phosphorylated jute.



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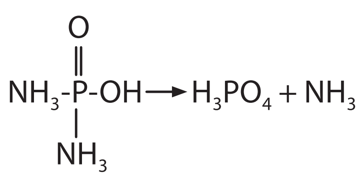

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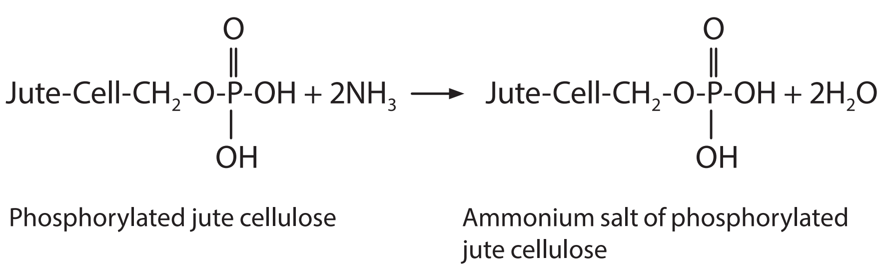

c)

3 Results and discussion

3.1 Weight gain percentage

Raw and bleached jute fabrics were subjected to a treatment with three different flame retardant formulations under specific treatment conditions and the weight gain percentage of the treated fabrics was evaluated. The results of the weight gain percentage are reported in Figures 2 and 3.

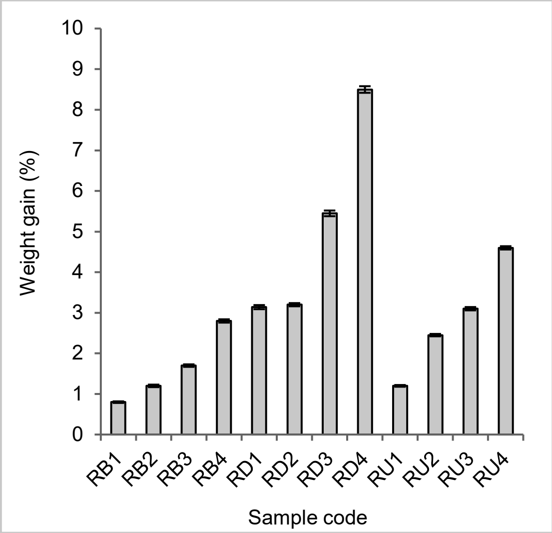

Figure 2: Weight gain changes of raw jute fabric during application of different concentrations of flame retardant finish

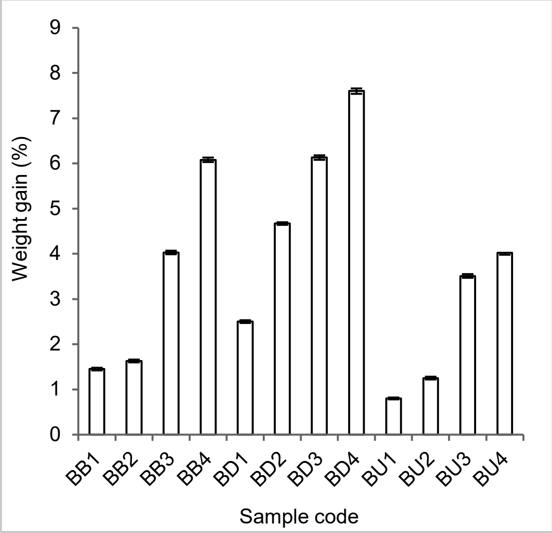

Figure 3: Weight gain changes of bleached jute fabric during application of different concentrations of flame retardant finish

From Figures 2 and 3, it can be observed that with increased loading percentage of chemicals in all formulations, the weight gain gradually increased in jute fabric as well. The DAP-treated samples showed higher weight gain compared to the borax- and thiourea-treated samples. Both raw and bleached jute fabrics showed similar behaviour after the treatment with flame retardant chemicals. A probable reason for this strength gain may lie in the formation of additional binder film on the substrate.

Regarding raw jute fabrics, the sample order of weight gain was RB4 > RB3 > RB2 > RB1 after being treated with borax in a different amount of chemical loading, RD4 > RD3 > RD2 > RD1 for the samples treated with DAP and RU4 > RU3 > RU2 > RU1 for the samples treated with thiourea (cf. Figure 2). Due to the 2%, 6%, 8% and 12% borax concentration treatment of the raw jute fabric, the weight gain increased by 0.08%, 1.20%, 1.70% and 2.80% for the samples RB1, RB2, RB3 and RB4. The weight gain showed a 3.14%, 3.20%, 5.45% and 8.50% increase for the samples RD1, RD2, RD3 and RD4 compared to the raw jute fabric. The flame spread time increased by 1.20%, 2.45%, 3.10% and 4.60% for the samples RU1, RU2, RU3 and RU4 compared to the raw jute fabric. The same results were recorded for RB2 and RU1, despite the fact that RB2 was treated with 6% and RU1 with 2% chemical concentration (cf. Figure 2).

Regarding the bleached jute fabrics, the weight gain of samples followed in the order BB1 < BB2 < BB3 < BB4 after being treated with borax in a different amount of chemical loading, BD1 < BD2 < BD3 < BD4 for the samples treated with DAP and BU1 < BU2 < BU3 < BU4 for the samples treated with thiourea (cf. Figure 3). Due to the 2%, 6%, 8% and 12% borax concentration treatment of bleached jute fabric, the weight gain was by 1.45%, 1.63%, 4.03% and 6.08% higher for the samples BB1, BB2, BB3 and BB4. The weight gain was by 2.50%, 4.67%, 6.13% and 7.60% higher for the samples BD1, BD2, BD3 and BD4 compared to the bleached jute fabric. The weight gain showed a 0.80, 1.25%, 3.51% and 4.02% increase for the samples BU1, BU2, BU3 and BU4 compared to the bleached jute fabric (cf. Figure 3). The same results were observed for RB1 and BU1 at 2% chemical concentration, RB1 being the sample of raw jute fabric treated with borax and BU1 the sample of bleached jute fabric treated with thiourea (cf. Figures 2 and 3). At 2% chemical concentration, the weight gain was by 0.08%, 3.14% and 1.20% higher for the samples RB1, RD1 and RU1 compared to the raw jute fabric, and by 1.45%, 2.50% and 0.80 higher for the samples BB1, BD1 and BU1 compared to the bleached jute fabric (cf. Figures 2 and 3). At 6% chemical concentration, the flame spread time showed a 1.20%, 3.20% and 2.45% increase for the samples RB2, RD2 and RU2 compared to the raw jute fabric, and a 1.63%, 4.67% and 1.25% increase for the samples BB2, BD2 and BU2 compared to the bleached jute fabric (cf. Figures 2 and 3). At 8% chemical concentration, the flame spread time grew by 1.70%, 5.45% and 3.10% for the samples RB3, RD3 and RU3 if compared to the raw jute fabric, and by 4.03%, 6.13% and 3.51% for the samples BB3, BD3 and BU3 if compared to the bleached jute fabric (cf. Figures 2 and 3). At 12% chemical concentration, the flame spread time increased by 2.80%, 8.50% and 4.60% for the samples RB4, RD4 and RU4 if compared to the raw jute fabric, and by 6.08%, 7.60% and 4.02% for the samples BB4, BD4 and BU4 compared to the bleached jute fabric (cf. Figures 2 and 3). Finally, it was concluded that the weight gain percentage of raw and bleached jute fabrics increased together with increased chemical concentration. The highest value was observed at DAP treated samples.

3.2 Flammability properties

The flame spread times of raw and bleached jute fabric were tested after using a different flame retardant finish in different concentrations. The results are presented in Figures 4 and 5.

It was found that the raw jute fabric without the treatment with a flame retardant finish catches fire and burns continuously within 18 s, while the bleached jute fabric catches fire and burns continuously within 21 s. It became evident that the flame spread time of the jute fabric increased due to the bleaching and treatment with a flame retardant finish. Figures 4 and 5 demonstrate that the flame spread time gradually increased in all cases with increased chemical concentration. The borax- and DAP-treated fabrics showed higher flame spread time compared to those treated with thiourea. Both raw and bleached jute fabrics showed similar behaviour after being treated with flame retardant chemicals.

Several chemical reactions are responsible for the flame retardancy effect of the jute fabric treated with a different formulation [7]. The effect of borax on the improvement of the flame retardancy of jute can be explained with the insulating layer theory. Borax acts by the endothermic release of water and melts to form a sodium borate coating. Chemically, borax

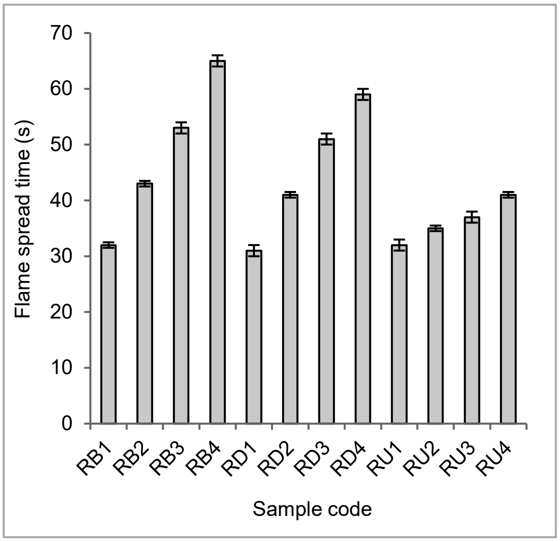

Figure 4: Flame spread time changes of raw jute fabric during application of different concentrations of flame retardant finish

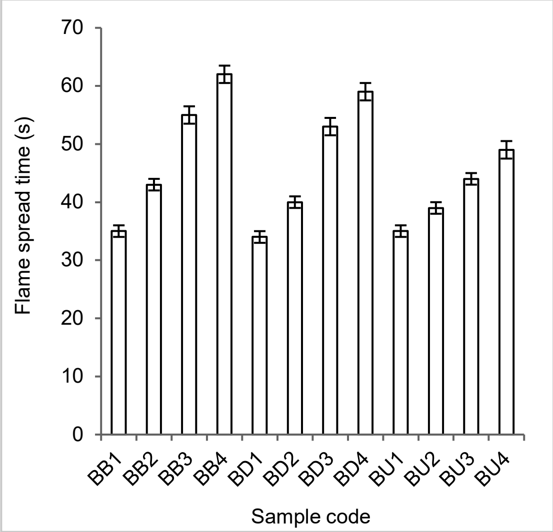

Figure 5: Flame spread time changes of bleached jute fabric during application of different concentrations of flame retardant finish

can also react with the primary hydroxyl group of cellulose polymers to give a borate ester and block the release of flammable gases. In the case of the DAP-treated jute fabric, at high temperature, DAP forms a phosphoric acid, which causes the material to char, forming a thick glassy layer of carbon. This carbonated char stops the decomposition process (pyrolysis) and prevents the release of flammable gases, essentially cutting off fuel to the flame. It also provides a barrier between the material and the heat source. In the case of thiourea-treated jute fabric, at high temperatures, it enables the formation of stable molecular compounds that stop the decomposition process (pyrolysis) and prevent the release of flammable gases. It also releases inert nitrogen gases that inhibit the chain reaction leading to combustion.

Regarding raw jute fabrics, the sample order was RB4 > RB3 > RB2 > RB1 after the treatment with borax in a different amount of chemical loading, RD4 > RD3 > RD2 > RD1 for the samples treated with DAP and RU4 > RU3 > RU2 > RU1 for the samples treated with thiourea (cf. Figure 4). Due to the 2%, 6%, 8% and 12% borax concentration treatment of the raw jute fabric, the flame spread time showed a 77.78%, 138.89%, 194.44% and 261.11% increase for the samples RB1, RB2, RB3 and RB4. The flame spread time was by 72.22%, 127.78%, 183.33% and 227.78% higher for the samples RD1, RD2, RD3 and RD4 if compared to the raw jute fabric. The flame spread time increased by 77.78%, 94.44%, 105.56% and 127.78% for the samples RU1, RU2, RU3 and RU4 in comparison with the raw jute fabric. The same results were observed for RB1 and RU1 at 2% concentration of chemicals. On the other hand, the same results were recorded for RD2 and RU4 even though RD2 was treated at 6% concentration of chemicals, and RU4 at 12% concentration of chemicals (cf. Figure 4).

Regarding bleached jute fabrics, the sample order was BB1 < BB2 < BB3 < BB4 after the treatment with borax in a different amount of chemical loading, BD1 < BD2 < BD3 < BD4 for the samples treated with DAP and BU1 < BU2 < BU3 < BU4 for the samples treated with thiourea (cf. Figure 5). After the bleached jute fabric being treated with 2%, 6%, 8% and 12% borax, the flame spread time was by 66.67%, 104.76%, 161.90% and 195.24% higher for the samples BB1, BB2, BB3 and BB4. The flame spread time showed a 61.90%, 90.48%, 152.38% and 180.95% increase for the samples BD1, BD2, BD3 and BD4 if compared to the bleached jute fabric. The flame spread time increased by 66.67%, 85.71%, 109.52% and 133.33% for the samples BU1, BU2, BU3 and BU4 compared to the bleached jute fabric. The same results were observed for BB1 and BU1 at 2% concentration of chemicals (cf. Figure 5).

At 2% concentration of chemicals, the flame spread time was by 77.78%, 72.22% and 77.78% higher for the samples RB1, RD1 and RU1 in comparison with the raw jute fabric, and by 104.76%, 90.48% and 85.71% higher for the samples BB1, BD1 and BU1 if compared to the bleached jute fabric (cf. Figures 4 and 5). At 6% concentration of chemicals, the flame spread time showed a 138.89%, 127.78% and 94.44% increase for the samples RB2, RD2 and RU2 when compared to the raw jute fabric, and a 66.67%, 61.90% and 66.67% increase for the samples BB2, BD2 and BU2 when compared to the bleached jute fabric (cf. Figures 4 and 5). At 8% chemical concentration, the flame spread time rose by 194.44%, 183.33% and 105.56% for the samples RB3, RD3 and RU3 if compared to the raw jute fabric, and by 161.90%, 152.38% and 109.52% for the samples BB3, BD3 and BU3 if compared to the bleached jute fabric (cf. Figures 4 and 5). At 12% chemical concentration, the flame spread time showed a 261.11%, 227.78% and 127.78% increase for the samples RB4, RD4 and RU4 if compared to the raw jute fabric, and a 195.24%, 180.95% and 133.33% increase for the samples BB4, BD4 and BU4 if compared to the bleached jute fabric (cf. Figures 4 and 5). The flame retardancy of the jute fabric improved after the flame retardant finishing agent was applied. The concentrations of chemicals also had a beneficial effect on flame retardancy. The raw and bleached jute fabrics were shown to improve their flame retardant behaviour.

3.3 Breaking load

Raw and bleached jute fabrics were subjected to a treatment with three different flame retardant formulations under specific treatment conditions, and the changes of the breaking load of the treated samples were evaluated. The results of breaking load both in warp and weft direction are reported in Figures 6 and 7.

Figures 6 and 7 show that both warp and weft direction breaking load values gradually decreased with the increase of loading percentage of chemicals in all formulations. It may be presumed that due to a mild acidic hydrolysis of jute cellulose, the breaking load falls.

Regarding raw jute fabrics, the sample order of breaking load was RB1 > RB2 > RB3 > RB4 after being treated with borax in a different amount of chemical loading, RD1 > RD2 > RD3 > RD4 for the samples treated with DAP and RU1 > RU2 > RU3 > RU4 for the samples treated with thiourea in warp direction. A similar scenario was observed in weft direction (cf. Figure 6). After the raw jute fabric being treated with 2%, 6%, 8% and 12% borax , the breaking load was by 3.12%, 6.25%, 10.93% and 12.50% lower for the samples RB1, RB2, RB3 and RB4 in warp

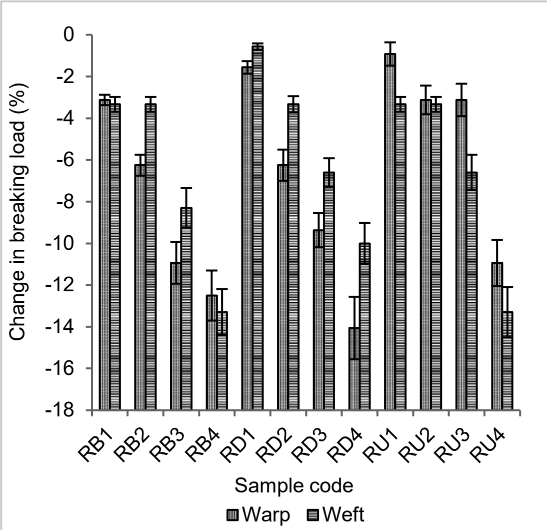

Figure 6: Breaking load changes of raw jute fabric during application of different concentrations of flame retardant finish

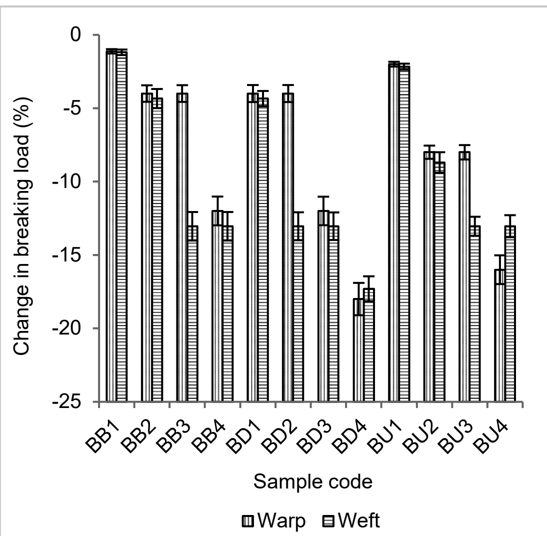

Figure 7: Breaking load changes of bleached jute fabric during application of different concentrations of flame retardant finish

direction, and by 3.33%, 3.33%, 8.30% and 13.30% lower in weft direction. The breaking load showed a 1.56%, 6.25%, 9.37% and 14.06% decrease for the samples RD1, RD2, RD3 and RD4 in warp direction, and a 0.56%, 3.33%, 6.60% and 10.0% decrease in weft direction if compared to the raw jute fabric. The breaking load fell by 0.92%, 3.12%, 3.12% and 10.93% for the samples RU1, RU2, RU3 and RU4 in warp direction, and by 3.33%, 3.33%, 6.60% and 13.30% in weft direction when compared to the raw jute fabric. Under the same amount of breaking load, a 6.25% decrease in warp direction was recorded for RB2 and RD2, a 3.33% decrease for RB1, RB2, RD2, RU1 and RU2, a 6.60% decrease for RD3 and RU3, and a 13.30% decrease for RB4 and RU4 in weft direction (cf. Figure 6).

Regarding bleached jute fabrics, the sample order of breaking load was RB1 > RB2 = RB3 > RB4 after being treated with borax in a different amount of chemical loading, RD1 = RD2 > RD3 > RD4 for the samples treated with DAP and RU1 > RU2 = RU3 > RU4 for the samples treated with thiourea in warp direction. A regular decreasing scenario was observed in weft direction for all samples (cf. Figure 7). The breaking load was by 1.120%, 4.0%, 4.0% and 12.0% lower for the samples BB1, BB2, BB3 and BB4 in warp direction, and by 1.19%, 3.34%, 13.04% and 13.04% lower in weft direction after treating the bleached jute fabric with 2%, 6%, 8% and 12% concentration borax (cf. Figure 7). The breaking load showed a 4.0%, 4.0%, 12.0% and 16.0% fall for the samples BD1, BD2, BD3 and BD4 in warp direction, and a 4.34%, 13.04%, 13.04% and 17.30% fall in weft direction compared to the bleached jute fabric (cf. Figure 7). The breaking load decreased by 2.0%, 8.0%, 8.0% and 16.0% for the samples BU1, BU2, BU3 and BU4 in warp direction, and by 2.17%, 8.69%, 13.04% and 13.04% in weft direction if compared to the bleached jute fabric (cf. Figure 7). Under the same amount of breaking load, there was a 4.0% decrease recorded for BB2, BB3, BD1 and BD2, and an 8.0% decrease for BU2 and BU3 in warp direction, and a 13.04% decrease for BB3, BB4, BD2, BD3, BU3 and BU4 in weft direction (cf. Figure 7). At 2% concentration of chemicals, the breaking load showed a 3.12%, 1.56% and 0.92% fall for the samples RB1, RD1 and RU1 in warp direction, and a 3.33%, 0.56% and 3.33 fall for the same samples in weft direction when compared to the raw jute fabric, and a 1.12%, 4.0% and 2.0% fall for the samples BB1, BD1 and BU1 in warp direction, and a 1.19%, 4.34% and 2.17% fall for the same samples in weft direction in comparison with the bleached jute fabric (cf. Figures 6 and 7). At 6% chemical concentration, the breaking load showed a 6.25%, 6.25% and 3.12% increase for the samples RB2, RD2 and RU2 in warp direction, and a 3.33%, 3.33% and 3.33 decrease for the same samples in weft direction if compared to the raw jute fabric. The breaking load was by 4.0%, 4.0% and 8.0% lower for the samples BB2, BD2 and BU2 in warp direction, and by 4.34%, 13.04% and 8.89% lower for the same samples in weft direction compared to the bleached jute fabric (cf. Figures 6 and 7). At 8% chemical concentration, the breaking load was by 10.93%, 9.37% and 3.12% lower for the samples RB3, RD3 and RU3 in warp direction, and by 8.30%, 6.60% and 6.60% lower for the same samples in weft direction if compared to the raw jute fabric. For the samples BB3, BD3 and BU3, it was lower by 4.0%, 12.0% and 8.0% in warp direction, and by 13.04%, 13.04% and 13.04% in weft direction in comparison with the bleached jute fabric (cf. Figures 6 and 7). At 12% chemical concentration, the breaking load showed a 12.50%, 14.06% and 10.93% fall for the samples RB4, RD4 and RU4 in warp direction, and a 13.30%, 10.0% and 13.30% fall for the same samples in weft direction if compared to the raw jute fabric. It was by 12.0%, 18.0% and 16.0% lower for the samples BB4, BD4 and BU4 in warp direction, and by 13.04%, 17.30% and 13.04 for the same samples in weft direction compared to the bleached jute fabric (cf. Figures 6 and 7). A lower breaking load in weft direction is responsible for a lower density of picks compared to the density of ends.

3.4 Wash durability

The washability of the chemical-treated samples after several wash cycles (1–5) was evaluated and the results are shown in Figure 8.

After wash cycle 1, the treated samples experienced a slight decrease in flame spread time compared to the unwashed samples. This was probably due to

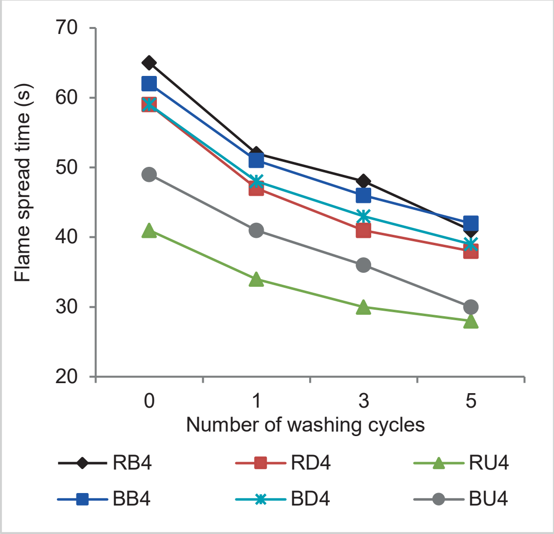

Figure 8: Effect of wash performance on flame spread time of jute fabric treated with flame retardant finish

the removal of unfixed chemical substances from the fabric surface after the washing. Furthermore, increasing the number of wash cycles to 3 and 5 resulted in a decrease of flame spread time. The latter can be attributed to the surface damage of coated layers caused by rigorous stirring during the washing [1]. Nevertheless, a moderate decrease in the flame spread time pattern was observed after the wash cycle 5, which is comparable to the raw and chemical-bleached unwashed jute samples, suggesting that the chemical-treated jute samples have moderate wash durability.

4 Conclusion

This study describes the added value of a jute fabric by imparting flame retardancy by using borax, diammonium phosphate and thiourea. It was found that the flame spread time of a jute fabric significantly improved through the application of these simple flame retardant agents. The weight gain percentage increased with the increase of concentration of chemicals whereas the breaking load decreased. It was also established that the specimens treated with borax and diammonium phosphate flame retardant showed better results than those treated with thiourea. Since borax, diammonium phosphate and thiourea are abundantly available and the application process is simple, the scope of applying these flame retardant finishes to impart flame retardancy in jute fabrics is appealing, better wash durability further reinforcing the use in wearable textile applications.

Declaration of conflict of interest

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