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Potential Utilization of Solid Wastes Generated from Tannery, Garments and Jute Industries for the Production of Composite Board

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Article

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ABSTRACT

Solid wastes generated during the tanning process are an unavoidable byproduct that is typically disposed of through dumping or incineration. These processes pose serious environmental threats. Among various tannery solid wastes, leather shaving dust contributes a large portion. Its reuse is a burning issue for sustainable tannery solid waste management. There are several possible ways to reuse this waste product. For example, leather shaving dust can be converted into useful products such as leather boards, biofuel, and compost. In this research, various composite boards were made using leather shaving dust in combination with other industrial wastes, including cotton and jute waste from the garment and jute sectors. The highest 8.90 MPa tensile strength was obtained for the leather dust-cotton-jute board compared to 7.89 MPa for the control leather dust board. The addition of cotton and jute materials lowered the hardness. The highest 81.2 hardness was found for the leather dust-cotton-jute board compared to 85.0 for the control leather dust board. These boards were used as various reinforcement components in leather products. Hardness, water absorption, mechanical properties, scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and thermogravimetric analysis (TGA) were used to characterize and evaluate the performance of the resulting composite board.

KEYWORDS

composite board, solid waste, physical properties, environmental pollution

INTRODUCTION

In Bangladesh, the economy greatly relies on the leather and garment industry. These industries generate a significant amount of solid waste, which is usually disposed of in the environment. The dominant methods of tanning in Bangladesh are chrome and vegetable tanning, with most tanneries producing chrome-tanned leather, resulting in a large amount of chromium being discharged with the wastewater. Despite this, Bangladesh is known for exporting excellent tanning products worldwide. Currently, 220 tanneries are operating in Bangladesh, which accounts for as much as 6% of the country's total exports of manufactured goods. Annually, this industry produces 180 million square feet of hide, along with approximately 20,000 cubic meters of tannery effluent and 232 tons of solid waste [1]. However, only 20% of the hides and skins are transformed into commercial leather, while 25% become chromium-containing leather waste (CCLW), and the remaining 80% are lost in the wastewater as fat, soluble protein, and suspended solid contaminants [2]. These pollutants contribute significantly to the environmental issues in the country.

Bangladesh, which is one of the world's top three producers and exporters of clothing, produces a significant amount of solid waste in the form of buttons, zippers, thread, and unused garments. The unused garments are locally called Jhoot which are mainly composed of cotton fibres. A typical RMG factory can produce 25,000 pieces per day, resulting in 500–750 kilograms of Jhoot, while solid knit fabric waste can reach 11,200 tons per day. Improper disposal of these garment and knitting wastes (Jhoot) poses a significant risk to public health and the environment [3].

Effective recycling of these wastes can help conserve resources and energy. Several waste management solutions aim to add value to waste by developing new materials and processes [4]. For instance, Ghosh and Pan made handmade paper from jute waste, using resin, gum, and other materials, and found it to have adequate strength and other properties [5]. Saikia et al. worked on creating flexible composites from dyed trimmings of leather waste and natural fibre wastes like jute and cotton, with the maximum tensile strength and breaking loads found at a 50:50 blend ratio of dyed trimmings and natural fibres [6]. Kumar et al. made leather polymer composites using leather buffing dust, polyvinyl butyral (PVB), and milk pouches, while another study showed the use of wet blue leather residue and recycled polyvinyl butyral to make PVB/leather composites, with the shore hardness of the composites increasing with the weight percentage of leather while the abrasion resistance decreased [7,8]. PVC blended with chrome-tanned leather waste can be used to make PVC-leather fibre composites for various applications [9]. Additionally, cotton and polyester fibres can be combined with leather waste fibres to make reconstituted fibre composite materials [10]. Madera et al. produced a leather-like composite by integrating chemically modified short leather fibres into a plasticized polyvinyl chloride (PVC) matrix [11]. Tejyan et al. studied the bagasse and jute fibres reinforced epoxy composites and found that the addition of fibres increases the tensile strength as well as flexural strength of epoxy composites [12]. They also examined epoxy-based hybrid polymer composites with wooden dust and nonwoven fabric mats made of cotton fibres. The authors discovered that increasing the amount of fibre loading by 5 to 15 wt% improved the mechanical strengths [13]. Some researchers investigated needle-punched nonwoven reinforced epoxy composites made of polypropylene. The composites that contain between 30 and 40 wt% of nonwoven materials have correspondingly shown the highest and lowest rates of erosion. They also found that adding more fibre to a composite material increases its load-bearing capacity and bending resistance [14,15].

The purpose of this research is to use chrome shaving dust and combine it with other materials, such as Jhoot cotton and waste jute ropes, to make composite sheets. The natural rubber (latex) was added as a binder to enhance the reinforcing effect, with the base material accounting for 94–98 wt% and the blended materials only accounting for 2-4 wt% [16]. The mechanical properties of the composite sheets, including tensile strength, elongation at break, and shore hardness, were analysed. The morphology of the samples was examined using a scanning electron microscope (SEM), and Fourier-transform infrared (FT-IR) analysis was conducted to assess the effectiveness of the process in forming uniform sheets.

EXPERIMENTAL

Sample Collection

The researchers obtained chrome shaving dust from the BSCIC Chamra Shilpa Nagori (BSCIC Leather Industrial Area) outer fields in Hemayetpur, Savar, Dhaka. Jute fibre was purchased from the local market in Savar, Dhaka, while Jhoot cotton was collected from Sterling Denim Limited. Chrome shaving dust was transformed into leather fibre using a Pulverize machine. Table 1 contains a breakdown of the mixing ratios of the raw materials used to improve the quality of the composite.

Table 1. Composition of Raw Material

Sl. No.	Sample code	Materials	Proportion (%)
01	LD	Leather Dust	100
02	LC2	Leather Dust +Cotton	98:2
03	LC3	Leather Dust +Cotton	97:3
04	LC4	Leather Dust +Cotton	96:4
05	LJ2	Leather Dust + Jute	98:2
06	LJ3	Leather Dust + Jute	97:3
07	LJ4	Leather Dust + Jute	96:4
08	LC4J2	Leather Dust +Cotton + Jute	94: 4: 2
09	LC3J3	Leather Dust +Cotton + Jute	94 :3: 3
10	LC2J4	Leather Dust +Cotton + Jute	94 :2: 4

a)

b)

c)

Figure 1. Raw materials: a) Chrome shaving dust; b) Jhoot cotton; and c) Jute fibre

Chemicals

The main chemicals used in making composites are listed in Table 2. All chemicals are taken based on the raw materials' weight.

Table 2. List of Major chemicals

Chemicals	%	Function
Water	600	Solvent
Busan 30 L	0.01	Preservative
Quebracho	7.3	Vegetable tanning agent to impart stiffness
Glycerin	6	For flexibility
Latex	32	Binding material
Aluminium sulphate	5.8	Protect swelling

Preparation of Leather Board Composite (LBC)

The LBC was made by combining natural rubber latex as the binding agent with leather shaving dust fibre, jute fibre, and cotton Jhoot fibre. These substances were mixed in various ratios with water and additional chemicals, and the resulting pulp was then poured onto a steel plate that was 2 feet by 1 foot in size. The pulp was then covered with another plate and pressed using a hydraulic press machine to eliminate excess water. The resulting composite materials were subsequently dried in an oven at 50-60 ^{o}C for 7-8 hours.

Mechanical Properties

The SATRA STM 566 Universal Tensile Testing Machine was employed following the TM 43:2021 standard to determine the tensile strength (TS) and percentage of elongation (PE) of the prepared samples. To measure the tensile strength (in MPa), the samples were cut into dumbbell-shaped specimens with a width of 4 mm and a length of 110 mm.

Water absorption

For examining the water intake or absorption properties of the samples, 5 cm x 5 cm pieces were cut and weighed before being immersed in 500 ml of distilled water at 25 °C. After 4 hours of immersion, the samples were removed, weighed again, and the process was repeated for a total of 24 hours. The amount of water absorbed was calculated by subtracting the final weight from the initial weight, and water absorption was determined using the following equation [17].

$$W_{A\,(\%)} = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100 \tag{1}$$

Where W_A is the water absorption, W_{wet} is the wet weight of the sample and W_{dry} is the dry weight of the sample.

Hardness Test

The hardness of different composite boards was determined using Shore D hardness measurement.

RESULTS AND DISCUSSION

Tensile Strength (TS)

The tensile strength and percentage of elongation for the composite boards made with leather dust and other composite materials are shown in Figure 2. The LC composite boards exhibited a decrease in tensile strength as the percentage of cotton increased and the highest 6.8 % of tensile strength was increased at LC2 composite board from the control one.

The LJ and LCJ composite boards demonstrated similar patterns. But all the LJ composite boards exhibited lower tensile strength than the control. While the highest 12.8 % tensile strength was achieved at LC4J2 composite board. The control leather dust board had a tensile strength of 7.89 MPa, while the highest strength of 8.90 MPa was achieved in the LC4J2 composite board, which had a leather dust-cotton-jute proportion of 94:4:2.

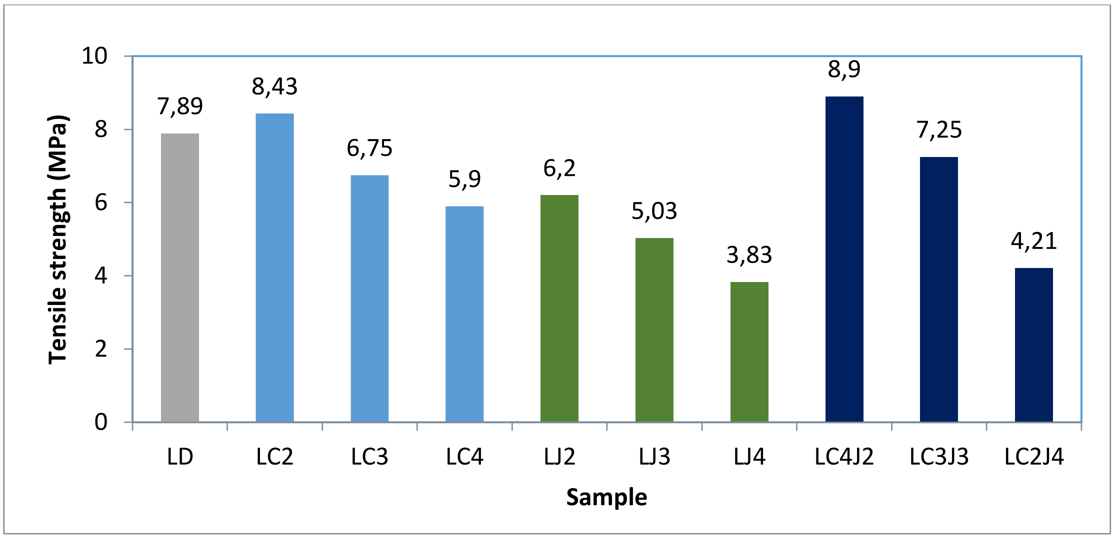


Figure 2. Tensile strength of different leather composite boards

Water Absorption

Figure 3 displays the water absorption values for the leather board composites with the highest tensile strength. The leather dust-cotton-jute (LCJ) composite had the highest water absorption after 24 hours of immersion. It is worth noting that leather shaving dust had the lowest moisture content, whereas jute had the highest moisture content compared to cotton [18,19]. Therefore, the addition of cotton and jute fibres to the shaving dust resulted in an increased water absorption capacity due to their higher tendency to absorb water. Figure 4 provides a visual representation of water absorption after 1 minute.

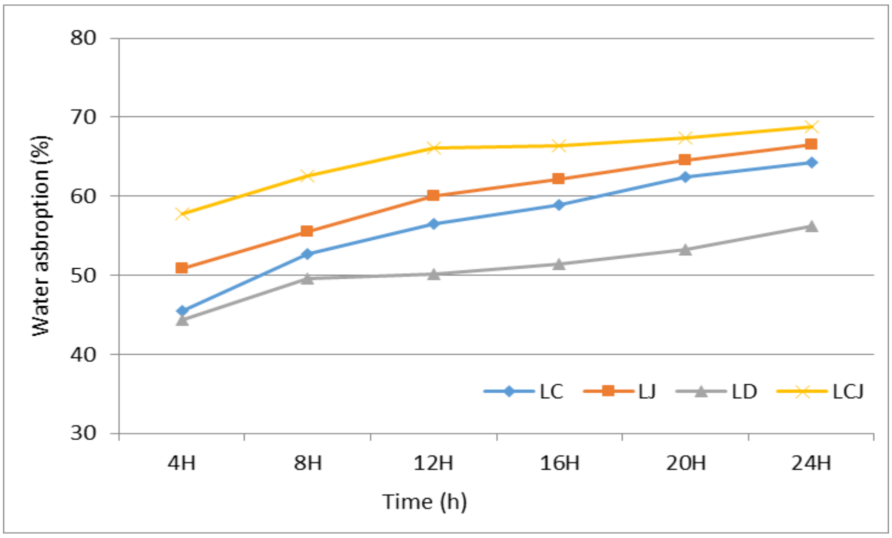
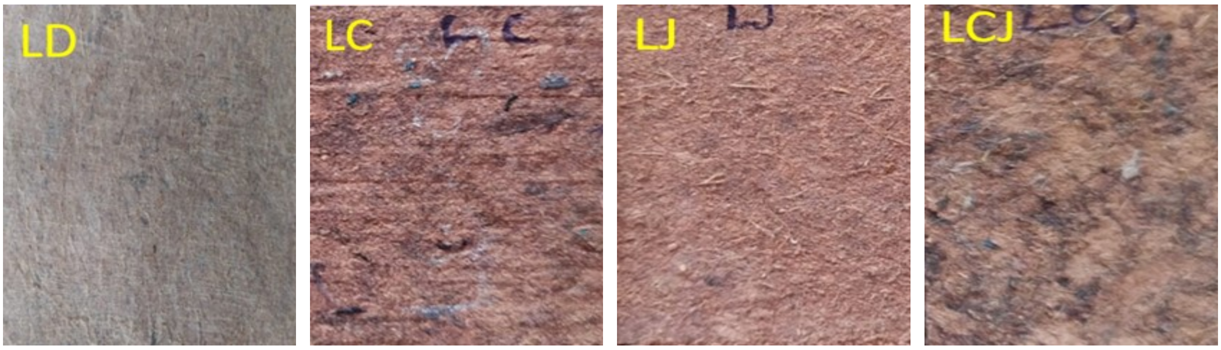
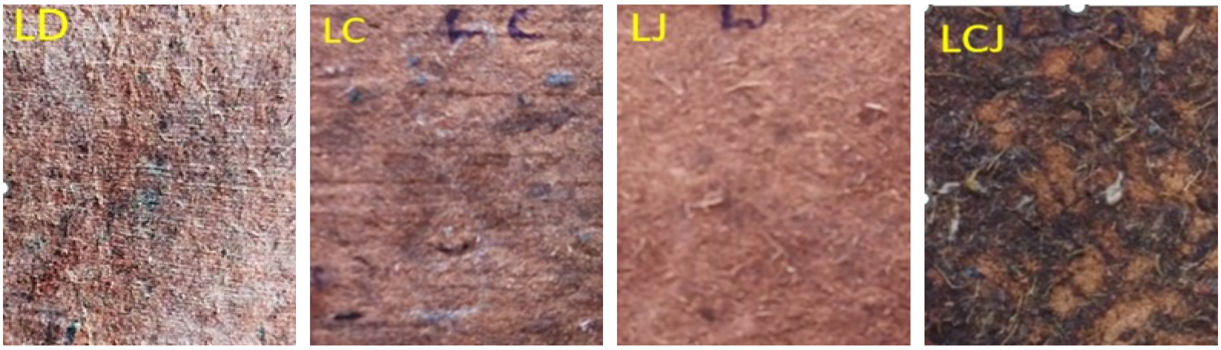


Figure 3. Water absorption of various composite boards



Before water absorption



After water absorption

Figure 4. Pictorial view of water absorption property (after 1 min)

Hardness Test

The Shore D hardness of several leather board composites is shown in Figure 5. The hardness of composite boards was reduced as a result of the addition of cotton and jute fibres. The lowest hardness value of 70.4 was achieved in the leather dust-cotton composite at a ratio of 96:6 in the LC4 composite board. However, in leather dust-cotton-jute composites (LCJ), increasing the percentage of jute fibre leads to an increase in the composite's hardness.

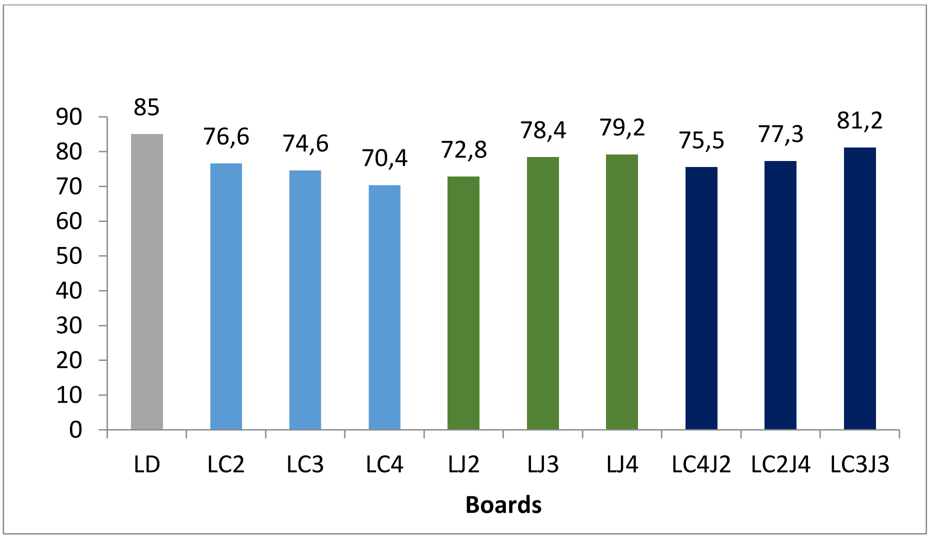


Figure 5. The hardness of leather board composites

The overall physical properties of composite boards are tabulated in Table 3.

Table 3. Statistical analysis of the physical properties of the Prepared composite

Composition	CODE	Tensile (MPa)	Hardness
Leather dust + Cotton	LC2	8.43	76.6
	LC3	6.75	74.6
	LC4	5.9	70.4
	Average	7.03	73.87
	SD	1.29	3.16
Leather dust + Jute	LJ2	6.2	72.8
	LJ3	5.03	78.4
	LJ4	3.83	79.2
	Average	5.02	76.8
	SD	1.19	3.49
Leather dust + Cotton+ Jute	LC4J2	8.9	75.5
	LC3J3	7.25	77.3
	LC2J4	4.21	81.2
	Average	6.79	78
	SD	2.38	2.91
Leather shaving dust	LD	7.89	85

Fourier Transform Infrared (FTIR) Spectroscopy Analysis

Figure 6 displays the FTIR spectra of various leather board composites (LBCs) and leather dust (LD) alone (a-d). The absorption bands observed at 3250 cm^{-1} in the spectra of LD, LJ, LC, and LCJ were due to the stretching vibration of O-H groups in water, alcohol, and phenol, as well as N-H stretching in amines. The peak observed at 2889-2881 cm^{-1} in LC, LJ, and LCJ composite boards was due to C-H stretching in cellulose and hemicellulose in cotton and jute fibres, as well as aliphatic chains in leather fibre. In the LC board, the characteristic peaks at 1637 and 1026 cm^{-1} were attributed to the C=O and C-O-C stretching of cellulose [20]. Peaks at 1240, 1107, and 1026 cm^{-1} in LJ composite corresponded to C-O of acetyl (lignin), O-H of cellulose and hemicellulose, and C-O of cellulose, hemicellulose, and lignin [21].

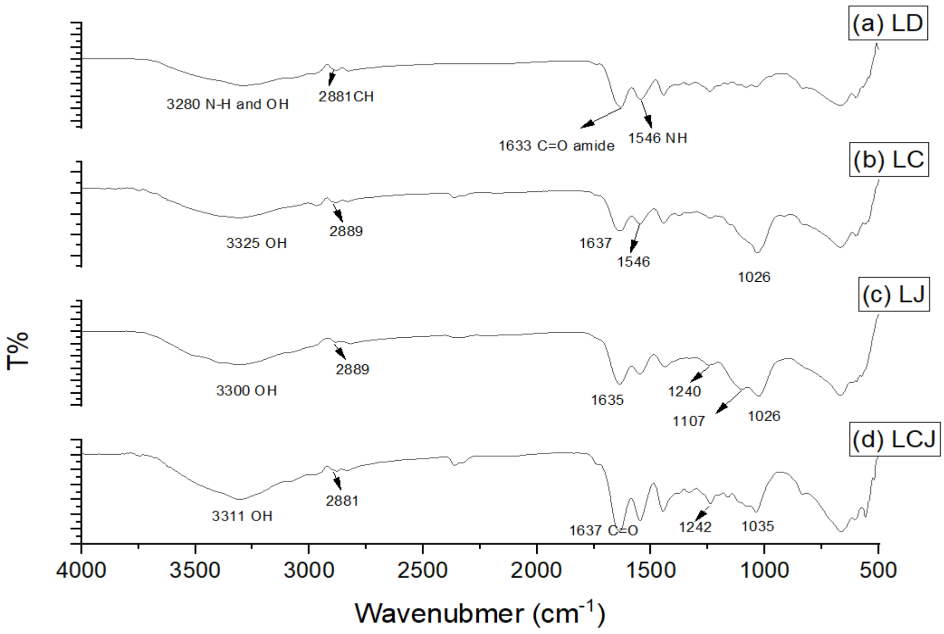
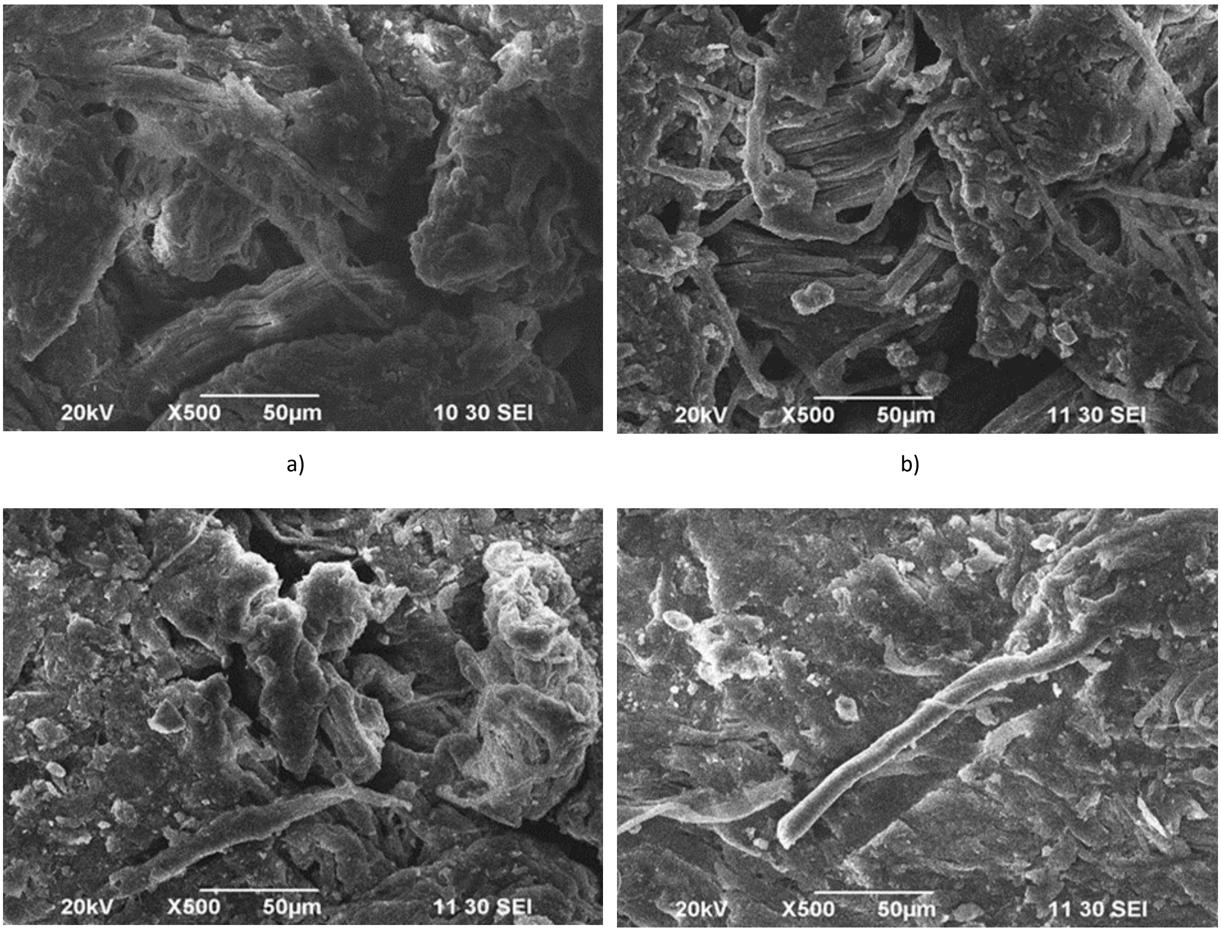


Figure 6. FTIR of (a) LD; (b) LDJ; (c) LDC; (d) LDCJ

Scanning Electron Microscope (SEM)

The SEM images of leather board composites of leather, jute, and jhoot cotton fibre are shown in Figure 7. The images were captured at 500 times magnification with a resolution of 50 nm. A noticeable number of fibre bundles are present in all the composite compositions, which may be due to the flexible fibres' ability to coil and bend during processing to prevent alignment. These fibre bundles may have originated from the initial fibre bundles that were not dispersed during processing, possibly due to shear stress flow or the presence of long, flexible leather fibres in the polymer matrix. The visible surface examination of the sheets also indicates that the fibres are evenly distributed throughout the composite, up to the content found in LDC.



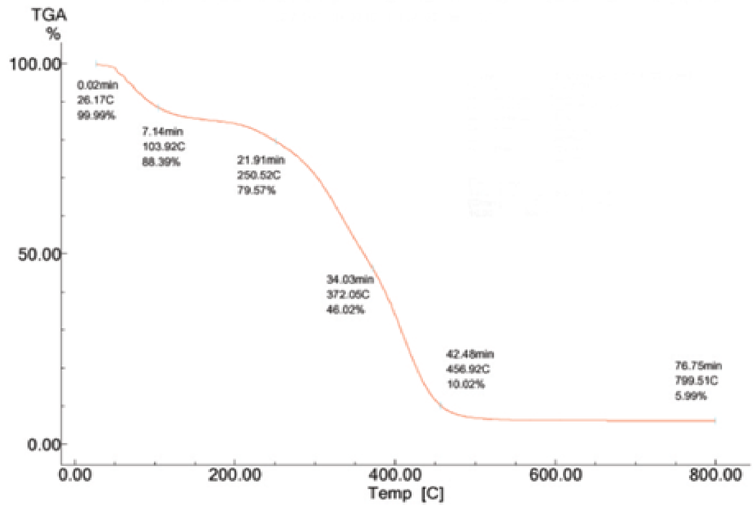
a) b)

c) d)

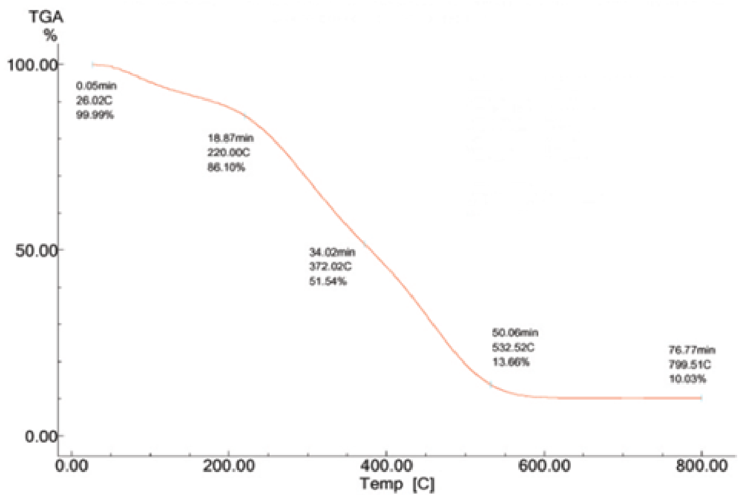
Figure 7. SEM image of a) Leather Dust (LD); b) Leather Dust + Jute (LDJ); c) Leather Dust + Cotton (LDC); d) Leather Dust + Jute + Cotton (LDJC)

Thermogravimetric Analysis (TGA)

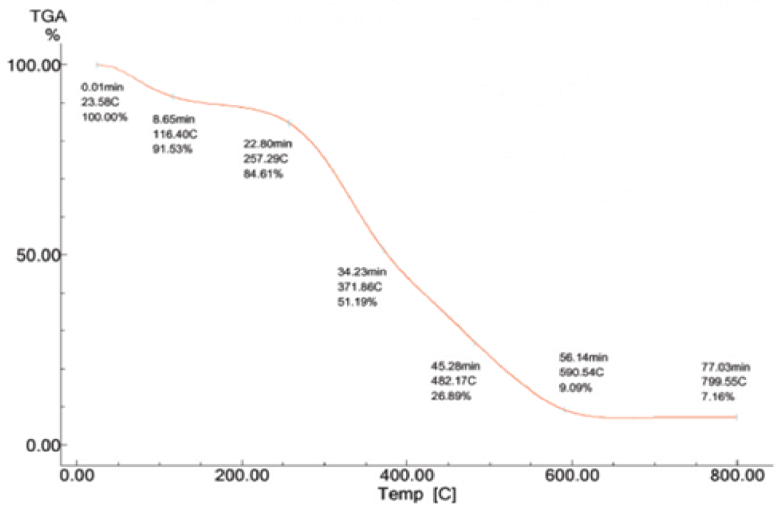
The TGA curves of the samples designated LD, LDJ, LDC, and LDCJ are depicted in figure 8. All samples exhibited a weight loss below 100-200 °C, which is possibly due to the evaporation of adherent moisture, including volatile compounds. A gradual mass loss was observed up to 250 °C, indicating the beginning of degradation. The LD board had a distinctive stepwise mass loss pattern compared to the other samples. LDC, LDJ, and LDCJ boards exhibited a slower rate of degradation up to 600 °C than the LD board. At 800 °C, LD had the least remaining mass (5.99 %), whereas LDC had the highest (10.03 %), with the other two falling in between.


TGA
%
100.00
50.00
0.00
0.00
200.00
400.00
600.00
800.00
Temp [C]
0.02min
26.17C
99.99%
7.14min
103.92C
88.39%
21.91min
250.52C
79.57%
34.03min
372.05C
46.02%
42.48min
456.92C
10.02%
76.75min
799.51C
5.99%

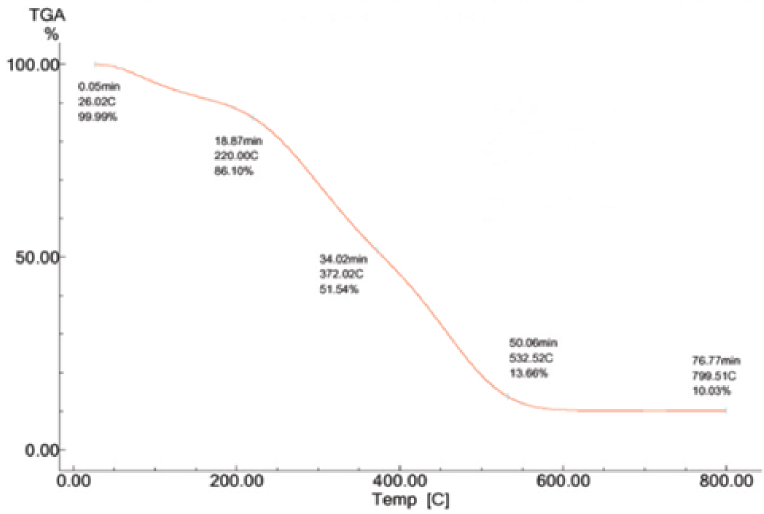
a)


TGA
%
100.00
50.00
0.00
0.00
200.00
400.00
600.00
800.00
Temp [C]
0.05min
26.02C
99.99%
18.87min
220.00C
86.10%
34.02min
372.02C
51.54%
50.06min
532.52C
13.66%
76.77min
799.51C
10.03%

b)


TGA
%
100.00
50.00
0.00
0.00
200.00
400.00
600.00
800.00
Temp [C]
0.01min
23.58C
100.00%
8.65min
116.40C
91.53%
22.80min
257.29C
84.61%
34.23min
371.86C
51.19%
45.28min
482.17C
26.89%
56.14min
590.54C
9.09%
77.03min
799.55C
7.16%

c)



d)

Figure 8. TGA of a) Leather dust board (LD); b) Leather dust-cotton composite board (LDC); c) Leather dust-jute composite board (LDJ); d) Leather dust-cotton-jute composite board (LDCJ)

Uses of Developed Boards

The leather board composites possess favourable mechanical and nailing characteristics appropriate for crafting leather products such as shoe counter stiffeners, insoles, reinforcement of waist belts and bags, wallets, key chain holders, sandal insoles, suitcase lining supports, etc. Typically, synthetic reinforcements are used in leather products, but replacing them with natural materials like leather shaving dust blended with cotton and jute wastes can help preserve virgin synthetic raw materials and prevent the landfilling of leather, cotton, and jute wastes. Utilizing leather-shaving dust offers environmental advantages, cost savings, and the opportunity to use renewable resources. Figure 9 displays actual images of the leather board and leather board composites.

a)

b)

c)

d)

Figure 9. Images of a) Leather dust board, b) Leather dust-cotton board, c) Leather dust-jute board, and d) Leather dust-cotton-jute board

Some products made of leather composite boards are shown in Figure 10.

a)

b)

c)

d)

Figure 10. Used of developed composite boards a) Keyrings, b) Footwear insole board and covered with leather, c) Waist belt reinforcement and complete belt, d) Toe puff and counter stiffener

CONCLUSION

Dumping and burning leather shaving dust creates an environmental issue due to exposure to harmful substances. Instead, recycling or reusing this waste can be a better option. The shaving dust was combined with cotton and jute materials to investigate their properties. It was found that the addition of cotton and cotton-jute combinations increased the tensile strength up to 6.8 % and 12.8 % respectively while using jute alone decreased it. The hardness of composite boards was reduced by adding cotton and jute materials. All the boards produced had similar thermal stability. By serving as reinforcement elements in leather goods, these composite boards can lessen the demand for brand-new synthetic materials and open up new possibilities for the management of solid waste in the leather sector.

Author Contributions

Conceptualization – Alam-E-Nur M; methodology – Alam-E-Nur M and Chakma S; formal analysis – Alam-E-Nur M and Chakma S; investigation - Alam-E-Nur M, Chakma S and Fatama K; writing-original draft preparation – Alam-E-Nur M and Chakma S; writing-review and editing – Akter N; visualization - Alam-E-Nur M and Chakma S; supervision – Alam-E-Nur M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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