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ORIGINAL PAPER

Latex reinforced waste buffing dust-jeans cotton composites and its characterization

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Abstract

This study aims to fabricate flexible composite sheets from waste buffing dust and post-consumer cotton waste through a simple solution casting technique. Natural rubber latex (NRL) was used as a binder material in different mixing ratios. To validate the chemical bonding between buffing dust and cotton fiber, FTIR was performed. Thermal stability of as-prepared composites was confirmed through TGA and DTA studies., The surface tropology of fabricated composites, were examined by FESEM analysis. From the results of oxygen gas transmittance rates, it was found that prepared composites possess enhanced gas barrier properties as compared to pure buffing dust. The physical and mechanical properties such as tensile strength, elongation, hardness, and density of prepared composites with optimum NRL content were augmented by 58, 48, 35, and 21%, respectively, as compared to pure buffing dust sheets. Thereby, these simple, low cost and flexible composite sheets would be a promising material for packaging as well as interior decoration industries.

Keywords Composite · Latex · Solid waste · Cotton · Buffing dust

Introduction

The increasing demand for leather and associated goods are compelling the expansion of tanning units every year. During the conversion of raw hides/skins to finished leather, various organic and inorganic pollutants are generated as byproducts and pose a significant challenge to the surrounding environments and ultimately in bionetwork [1]. Specifically, the tannery wastes contain a wide range of solid wastes from trimming, shaving, and splitting, which poses with mineral components as well as animal fats, while liquid wastes comprising highly polluted wastewater and sludge with organic compounds [2–4]. The leather tanning process generates a substantial amount of solid waste since only a small portion of raw materials (20–25%) is converted to finished leather, while the remaining 75–80% is released into the environment as trash [5, 6]. In consequence, safe disposal of these solid wastes are imperative, and several waste management strategies such as anaerobic digestion, landfilling, and thermal incineration are widely employed. But these techniques encounter numerous environmental safeties like massive pollution of landfill sites, extensive workforce engagement provoking unhygienic situations, and a high chance to convert trivalent chromium (nontoxic) into carcinogenic hexavalent chromium (toxic) during thermal incineration at high temperature [7].

Similarly, a significant quantity of wastes is generated from the textile and garments industry, while a large percentage is from cotton and blended synthetic fibers. Uprising demand for clothing outfits results in large quantities of clipping, cloth scrap, and loose pieces, which are the prime factors for solid waste in the textile industry [8, 9]. In

Highlights:
1. The cellulose content of fiber is mainly responsible for the strength of composite
2. The collagen content of leather fiber is crucial for the flexibility of composite
3. Uniformity of network between collagen and cotton fiber is essential to consider
4. Excess fiber ends in the composite is resulting in the decrement of mechanical properties

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recent years, the safe disposal of bulk waste material creates a pathetic issue in the environment because conventional landfilling can't degrade synthetic fibers naturally, and in turn, it has a hazardous impact on living soil organisms [9]. As a result, environmentally sustainable and commercially feasible waste management techniques are emergent to mitigate this problem.

To handle both leather and textile wastes efficiently, recycling solid wastes as value-added composite material could be an effective strategy in these processes [10]. In recent years, several research works were carried out to fabricate leather and textile-based composites. Teklay et al. [11] used finished leather waste with natural plant fibers to prepare polymeric composites, while Yılmaz et al. [12] prepared composite adsorbent from leather wastes. On-trend, Sekaran et al. [13] considered waste buffing dusts to produce activated carbon as a green strategy for solid waste management. Moreover, Saikia et al. [4] converted leather trimming to the flexible composite material. Teklay et al. [14] investigated the potentiality of conversion of leather waste into commercial graded composite sheets. Senthil et al. [15] fabricate composite using leather-based solid wastes, but as prepared composite possess poor physio-mechanical strength [16]. Numerous research works have been carried out by researchers for the preparation of textile waste-based green composite material, which mitigates the impact of environmental pollution caused by garment wastes [9]. Todor et al. [17] utilized textile wastes from packing industry as reinforcement materials in composite sheets. In addition, Sivakumar et al. [10] recently reported a review regarding the prospects of composite preparation in combination with the textile and leather wastes as solid wastes were characterized with high strength, stiffness, and fatigue resistance during their commercial applications. Their study reported the prime attributes of leather-textile waste composite sheets that can be unprecedented in the field of composite materials. Their review also states that the adopted waste containment strategy can be seen as a versatile approach for composite preparation rather than the concept of solid waste management. Various research efforts have been made to reduce solid waste from the textile and leather industry environment by utilizing them as composite materials.

Hence, an attempt has been initiated in this work to develop a composite material from buffing dust of the leather industry and post-consumer cotton waste (PCCW). NRL was considered as a binder for the preparation of composite materials that can be suitable for packing and interior garnishing industries. Different buffing dust with various concentrations of PCCW were employed and optimized for improved mechanical, thermal, and gas barrier properties along with higher interfacial adhesion of composite materials.

Materials and methods

Materials

Buffing dust was collected from "SAF" Leather Industry Ltd., Noapara, Jessore, Bangladesh. Cotton waste was procured from the local area of Khulna, Bangladesh. Analytical graded NRL, polyethylene glycol (PEG), aluminum sulfate ($Al_2(SO_4)_3$), and sulfuric acid (H_2SO_4) were purchased from Sigma Aldrich, Bangladesh.

Sample preparation

Preparation of composite

About 130 g of fiberized buffing dust was soaked in 1L distilled water for 12 h. Then mincing was carried out to prepare a fine paste. Around 160 mL of NRL, 10 mL of PEG, and 4% of $Al_2(SO_4)_3$ were added as binders, plasticizers, and stabilizers, respectively, and mixed thoroughly with the prepared paste. After that, 10 mL of H_2SO_4 with a 1:3 ratio was added slowly to adjust pH to 5 and diluted with 4L of di-ionized water. At next, prepared PCCW was added at different proportions (%w/w), like sample 1(S1): 100% buffing dust, sample 2(S2): 90% buffing dust with 10% PCCW, sample 3(S3): 80% buffing dust with 20% PCCW, and sample 4(S4): 70% buffing dust with 30% PCCW. Then, the mixtures were processed with fiberize machine (SDL868, USA). Finally, the samples were poured into a sheet-making mold (30 cm × 30 cm) and pressed with a pressure of 140 bar at 90 ºC for 10 s.

Characterization

Different physical and chemical analyses were carried out to check the properties of the newly developed composite. Regarding physical testing, tensile strength (SATRA TM137), flexing endurance (SATRA STM 465), density, and hardness (ASTM D2240) tests were carried out. On the other hand, chemical analysis including Fourier Transform Infrared (FTIR) (between 4000 and 500 cm^{-1} spectral range with a resolution of 4 cm^{-1}) by using Nicolet 6700 spectrometer (Thermo Scientific, USA). Moreover, Differential Thermal Analysis (DTA) was done by DTG-60 series (Shimadzu, Japan), Thermogravimetric Analysis (TGA) was conducted in High Resolution 2950 TGA thermogravimetric analyzer

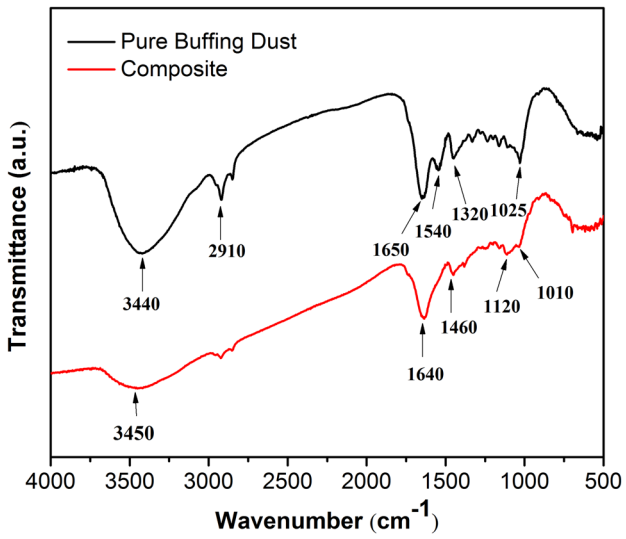

Fig. 1 FTIR analysis of pure buffing dust and composite

(TA Instrument). Field Emission Scanning Electron Microscope (FESEM) and Oxygen Transmission Rate (OTR) were carried out using JSM-7800F, JEOL, and ASTM D3985, respectively.

Results and discussion

FTIR analysis

FTIR analysis of pure buffing dust and newly fabricated composite (80% buffing dust with 20% PCCW) are representing in Fig. 1. Here, a broad peak in the range of 3200 to 3500 cm^{-1} was attributed to the hydroxyl group (possible from COOH and H_2O) of pure buffing dust. A small peak range of 2750 to 3000 cm^{-1} indicates C-H group presence from the materials protein chain [18]. In addition, typical peaks at ~ 1650, ~ 1540, and ~ 1320 cm^{-1} are generating from stretching vibration of C-O, C = N, and N–H, respectively, which may come from protein and amino acid [19]. Hence, it is worth mentioning that characteristic peaks intensity of newly developed composite is significantly remarkable than buffing dust. It is also important to note that few new peaks are approached with minute intensities at the range of ~ 1100 to 1300 cm^{-1} due to the hybridized C = C (in-plane stretching) of buffing dust.

Moreover, a peak at ~ 1460 cm^{-1} has been attributed to the presence of the C = O group in composite material. In addition, a new peak with higher intensity was emerged at around ~ 1000 cm^{-1} and highlight the presence of di-substituted alkene groups [19]. These observations confirm the strong chemical bonding between buffing dust and cotton fiber with NRL as a binder.

Thermogravimetric (TGA) analysis

Figure 2a highlights the TGA analysis of pure buffing dust and composite material (80% buffing dust with 20% PCCW). As shown in the figure, weight degradation occurs in three steps. At first, 5% weight loss of buffing dust was noticed at 100 °C. It was due to the rapid loss of moisture during heating [16]. In the second step, degradation was comparatively faster compare to the start. During this phase, hydrophilic organic compounds of buffing dust including protein, fatty substrate, tanning materials were slowly degraded into the intermediate compounds up to 25% at 200–500 °C.

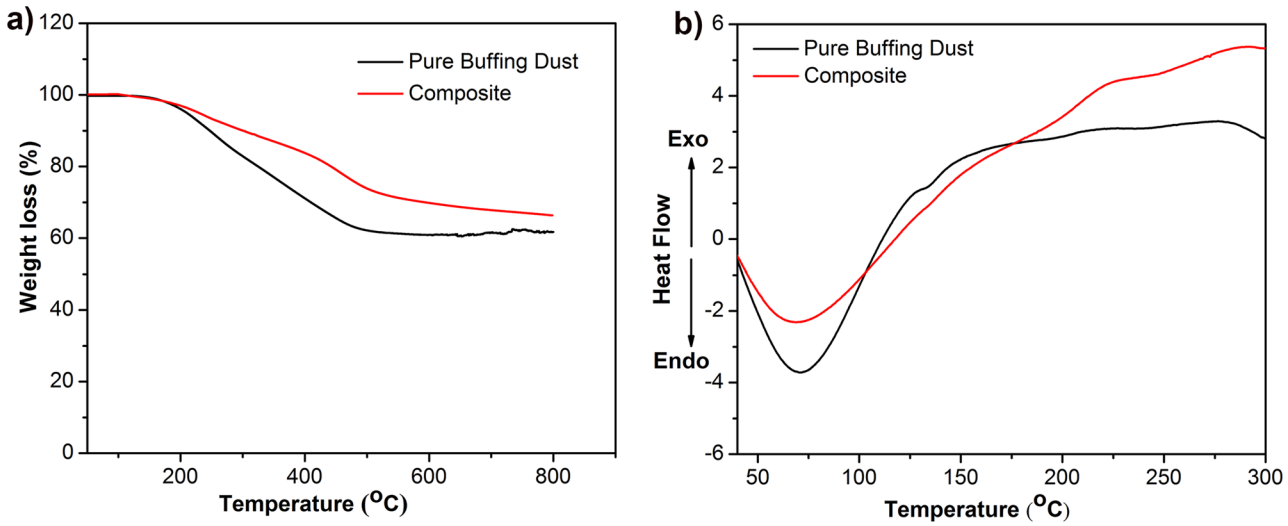

Fig. 2 Thermal analysis of pure buffing dust and composite **a**) TGA **b**) DTA

Further decomposition was continued due to the breakdown of NRL within this range of temperature. In the final stage, the residual matter of buffing dust was exhausted entirely at 800 ºC [20]. Regarding the prepared composites, 2% weight loss was noticed at 100 ºC due to the slow evaporation of absorbed crystal water molecules associated with the fibres [21]. Then, the subsequent 20% degradation continued linearly up to 200–500 ºC because of the solid chemical bonding of interfacial fibers [22]; and it sharply exhausted within 800 ºC due to the cellular decomposition [21]. The results found that the thermal stability of composite is comparatively higher than buffing dust.

Differential thermal analysis (DTA)

Figure 2b represents the DTA analysis of pure and blended composite sheets (80% buffing dust with 20% PCCW). Regarding pure buffing dust, the endothermic peak was found at 64 ºC, while the peak for the composite sheet at 72.5 ºC. Hence, the heat resistivity of pure buffing dust is comparatively lower than a composite sheet. In general, this phenomenon attributes to the higher uniformity of interfacial fibers bonding that fabricated in the composites with the increase in temperature [23, 24].

FESEM study

The morphology of both pure buffing dust and composite (80% buffing dust with 20% PCCW) were characterized via cross-sectional field emission transmission electron microscopy (FESEM), and the respective images are shown in Fig. 3a and b. From analysis, it was observed that pure buffing dust demonstrates a typically irregular layer and a long ribbon structure, which resembles a fibril with a certain degree of orientation on the surface [25]. The composite film showed relatively rough surfaces with homogenous dispersion. These phenomena may attribute to the low molecular weight of NRL with high chain mobility and increment of matrix chain mobility. The irregular and flake-like cotton fiber disappeared in the matrix, and new uniform morphology was infused due to the strong interfacial interaction between buffing dust and cotton fiber. Hence, the fabricated composite sheet confirms the molecular-level dispersion with cotton fiber into the buffing dust matrix.

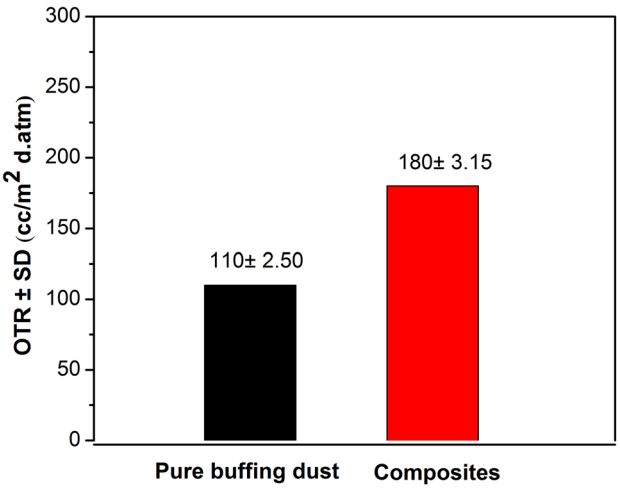

Fig. 4 Oxygen gas transmittance rates (OTR) of pure buffing dust and composite film

Oxygen gas barrier properties

The oxygen gas transmittance rates (OTR) of pure buffing dust and composite film (80% buffing dust with 20% PCCW) at ambient temperature are presented in Fig. 4. In general, fibrous materials possess poor oxygen barrier capability and moisture content in a dry state with relative humidity. But, the addition of impermeable fillers with proper dispersion and orientation into the polymer matrix can significantly enhance this properties [26]. OTR of buffing dust is comparatively lower (110 ± 2.50 cc/m^2.d.atm) compare to composite films (180 ± 3.15 cc/m^2.d.atm). The barrier properties were dramatically enhanced due to the homogeneous dispersion

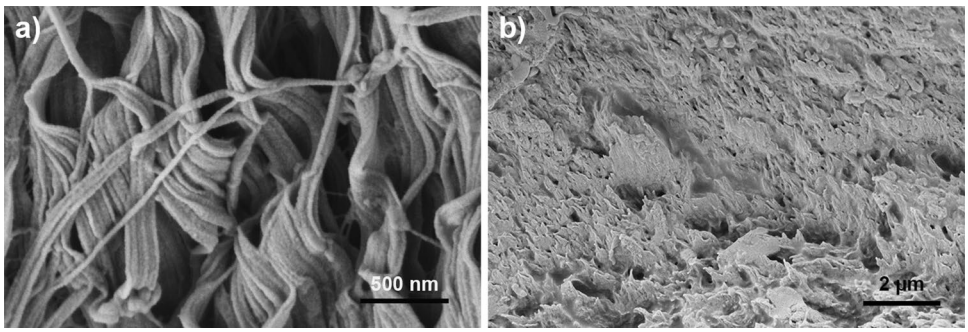

Fig. 3 FESEM analysis of **a**) pure buffing dust and **b**) composite

and strong interfacial adsorption between the cotton fiber and matrix. In addition, the related crystallinity of the composite film was also responsible for this phenomenon.

Tensile strength test

Tensile strength of pure buffing, as well as cotton fiber, blended sheets are represented in Table 1. Initially, pure buffing dust imparts tensile strength of 4.15 MPa, and the result is in line with the experimental study of Senthil et al. [16]. The addition of 20% cotton fibers as reinforcement simultaneously increases the strength of the material. The authors El-Shekeil et al. [27] and Prasad et al. [28] achieved the highest tensile strength at 20% fiber content in composites. Hence, 20% of fiber reinforcement was considered as an optimum value. The uniform fiber distribution and better dispersion may facilitate the strength of composites. Moreover, potential surface interaction between fiber and matrix with minimum agglomeration is also responsible for the higher strength. Hence, the entanglement of cotton fiber plays a vital role in the strong bonding of matrix with reinforcement [29–31]. It was observed that the additional incorporation of natural fibers (at 30%) significantly degrades the tensile strength of material. It is owing to the increase in chance of fiber pull out with increase in fiber content [28, 31–33].

Percentage of elongation

The percentage of elongation for pure buffing dust and cotton reinforced materials are highlighted in Table 1. It is observed that buffing dust imparting 20% elongation at the initial stage, while Ugbaja et al. [34] also mentioned a similar elongation percentage for such material. During experiments, successive addition of cotton slightly increasing the elongation percentage but sharply decreased at 30% cotton content. This can be ascribed that more fiber ends could cause fast crack initiation during the loading of composites [35, 36]. So considering this factor, the optimum range was considered as 80% buffing dust with 20% PCCW. Moreover, elongation is a salient parameter of composite and also related to the impact strength, which determines the brittleness or ductility of any composites in field applications [37, 38].

Hardness test

In this study, Table 1 represents the hardness of pure and blended composite materials. Here, the initial hardness of pure buffing dust was 82.88 Pascal, which is quite similar to the analysis of Moses et al. [39]. Initially, the gradual addition of cotton uprising the composite hardness due to the higher modulus and rigidity of fibers while fiber percentage more than 20 reducing the hardness simultaneously. This may indicate the poor boning of fiber-matrix due to the lower dispersion and higher agglomeration of incorporated fibers [31, 40]. As a result, 80% buffing dust with 20% PCCW was considered as the optimum ratio.

Density test

A density test was carried out and represented in Table 1. From the table, it is clear that the density of composites is slowly increasing with the increment of fiber percentage. The same phenomena were also mentioned by Bodur et al. [30], where cotton was used as reinforcement in glass fiber-based hybrid composite materials. So due to the slow development of density in terms of experimental values, 80% buffing dust with 20% PCCW was considered as the optimum level to minimize additional fiber consumption. Here, density is a significant parameter to consider when the lightness of composite is a concerning issue [41].

From Table 2, it is clear to mention that leather fiber reinforced with natural plant fiber has higher tensile strength than individual utilization of leather fiber with a significant percentage into the composite. This may be attributed that more cellulose content in plant fiber is directly responsible for composite strength [15]. On the contrary, decrement of cellulose percentage is causing lower strength of fabricated composite [43]. Moreover, uniform networking between natural fiber and collagen is also fortifying the ultimate tensile strength of composite [4]. In our experiment, the significant percentage of composite is posses with buffing dust, and this may attribute the highest elongation percentage (about 30%) due to the wide availability of collagen

Table 1 Mechanical properties of buffing dust and composites

Sample	Tensile strength (MPa)	% of Elongation	Hardness (Pascal)	Density (g/cm^3)
S1	4.15 ± 3.12	20.30 ± 4.05	82.88 ± 3.22	0.90 ± 2.21
S2	5.76 ± 2.50	27.50 ± 3.25	93.00 ± 2.33	0.97 ± 4.16
S3	6.56 ± 2.45	29.98 ± 3.11	109.75 ± 3.14	1.03 ± 3.25
S4	5.69 ± 3.10	25.33 ± 2.21	94.52 ± 4.10	1.10 ± 3.34

Table 2 Comparison of mechanical properties of various composite materials

Name of the composites	Tensile strength (MPa)	% of Elongation	Hardness (Pascal)	Density (g/cm^3)	References
Latex with buffing dust and jeans cotton (80:20)	6.56 ± 2.45	29.98 ± 3.11	109.75 ± 3.14	1.03 ± 3.25	(This work)
Buffing dust with natural rubber with (90:10)	6.80	21.00	-	-	[34]
Dyed trimmings with jute fiber (50:50)	52.67	13.89	-	0.698	[4]
Finished leather fiber with coconut fiber (50:40)	5.88 ± 0.09	5.62 ± 0.07	-	-	[15]
Finished leather fiber with sisal fiber (60:40)	9.08 ± 0.91	7.73 ± 1.34	-	-	[11]
Finished leather scraps with palm fiber (70:30)	8.30 ± 0.06	3.66 ± 0.88	-	-	[42]
Finished waste leather fiber with enset fiber (80:20)	2.78 ± 0.24	19.12 ± 2.07	-	-	[14]

content in buffing dust, where the minute content of cellulose is causing comparatively lower tensile [4]. The same phenomena are also prominent in other experimental analyses represented in Table 2, where the elongation property increased with the increment of leather fiber-based collagen content, and higher tensile strength is prominent for more cellulose in plant fibers. In terms of flexibility, the infusion of latex increased the ductility of fabricated composite, and these phenomena are also experimented with by Ahmad et al. [44]. The density of the composite was also increased with the uprising of jeans cotton fiber during experimentation, and similar behavior of the composite was studied by Saikia et al. [4]. Until date, several natural plant fiber-based composites have been researched, but the use of jeans cotton with buffing dust will open up a new dimension for composite fabrication, allowing for higher tensile strength and percentage of elongation at the same time, as well as other features.

Conclusion

Eco-friendly and high-performance composites were prepared and characterized by FTIR, DTA, TGA, and FESEM to confirm chemical bonding, thermal stability, and surface analysis, respectively. Then, further physical analysis was conducted to check the mechanical stability of fabricated composites. Among them, sample 3 (S3) with 80:20 (buffing dust: cotton fiber) ratio showed enhancement in properties of tensile strength, percentage of elongation, hardness, and density by 58, 48, 35, and 21%, respectively in comparison to pure buffing dust sheet. It was also noticed that composite performance was sharply degraded at 30% cotton content due to the more fiber ends and the higher agglomeration of incorporated cotton. Moreover, the cellulose content, as well as collagen percentage, were also responsible for the tuning of ultimate tensile strength, density, elongation at break, and hardness of the composite. The oxygen gas barrier properties of the composite film were significantly increased compared to pure film due to the even dispersion of fillers with proper orientation into the polymer matrix. Plant fiber-based composites have the highest tensile strength due to the significant cellulose percentage with lower elongation. But elongation is the salient property of composite to ensure proper bending and shaping without breaking. As a result, this newly developed approach could be vital for managing both leather and textile waste as low-cost packaging material and interior designing rather than landfilling and may reduce environmental pollution significantly.

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Authors' contributions MAI and MYM both conducted experimentation in laboratory. TKD analyzed and interpreted the experimental data. RR, MAI and MYM characterized the sample. MJ reviewed the manuscript. MEU performed the idea generation, evaluation, and interpreted of overall experimentation. All authors participated in writing the manuscript; read and approved the final manuscript.

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Declarations

Competing interests We (all the six authors) do not have any competing interests.

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