Influence of Surface Treatment and Molding Temperature on Mechanical Properties of Jute/PLA-Based Green Composites

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Abstract In the present study, the main focus is to increase the interfacial bonding between jute fiber with polylactic acid (PLA) with the help of surface modifications of jute fiber using alkali, potassium permanganate, and potassium dichromate treatments. FTIR spectroscopy result confirms the removal of hemicellulose layer which results in an increase in adhesion of jute fiber with polylactic acid. Jute/PLA composites are prepared using hot compression molding process using treated jute fibers and PLA matrix. This study also exposes the effect on the mechanical properties of developed composites of molding temperatures ranging from 160 to 180 °C. Alkali treatments resulted in an increase of 56.1% and 51%, respectively, in the tensile and flexural strength of jute/PLA composites It is so observed that for alkali-treated jute/PLA composite with 170 °C molding temperature, maximum tensile and flexural strength were recorded.

Keywords Jute fibers · Compression molding · Molding temperature · Surface treatment · Green composites

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1 Introduction

Composite material also can be found in our households. For example: concrete is made up of cement, sand, and gravel. It can also be reinforced with steel which improves around 10,000 BC; the houses were made up of straw bricks, and then in around 4000 BC, the writing material was fabricated from the papyrus plant. Egyptians also made fibers by heat treating the glass material to very high temperature. In around 1200 BC, Mongols develop the first modern composite bow. Phenolic resin was used for the first time in the fighter planes by the British Royal Air Force in its mosquito bomber aircraft. Plywood is also a form of good composite used for making furniture. Our bone is also a composite material containing collagen fiber and hydroxyl appetite matrix.

Composite material is nothing but two or more basic materials combining different physical or chemical properties to create a new material, but the individual properties of the material process. The new material may be chosen for many reasons: common examples contain materials which are stronger, lighter, or less expensive when compared to traditional materials. With rise in global temperature, depletion of fossil fuels and a need of sustainable development forced the researchers to develop the green composites [1]. Green composites are materials derived from the natural resource. It consists generally of strengthening as natural fibers and material matrix. Green composites are additional categories in two categories, i.e. partially biodegradable green composites and composites that are fully biodegradable [2, 3]. Partially green composites consist of at least one constituent which should be derived from natural resource such as jute/epoxy composites, carbon fiber/PLA composites. In the case of fully biodegradable green composites, both constituents should be derived from natural resources such as composites of jute/PLA, composites of Jute/PHB.

Lots of research is currently underway to develop green composites. Sareena et al. [4] the biodegradation behavior and its effect on the mechanical properties of natural rubber developed reinforced with natural fillers such as coconut shell and peanut shell powder were studied. The chemical treatment, filler content, and filler size help in improving the durability. The composite containing treated fillers were resistant to soil erosion. The results progressed that after the soil burial testing, the hardness and tensile strength were decreased. Zhong et al. [5] studied to strengthen interfacial adhesion of phenolic resin/cellulose fiber in compound sites consisting of aramid and sisal fiber by surface microfibrillation of cellulose fiber. Sisal fiber's surface microfibrillation to 24 SR surges the internal bonding strength, wear resistance and tensile strength values by 124%, 31%, 93%, respectively [6]. The thermal, morphological and mechanical properties of a bio-composite derived from banana plants were studied, and the results showed that the device decreased at high temperatures. Thermal stability has been enhanced with the increase of glass transition temperature. The mechanical test revealed increase of tensile strength, tensile modules, and flexural modulus by 15%, 12%, and 25%, respectively. Mohanty et al. [7] explored the physicomechanical and inter-phasic properties of "all green composites" acquired from poly-bioresin and kenaf natural fiber. The optimal properties of composites

were accomplished by 20 wt% which results in major increment in flexural strength (48%), tensile strength (310%), and storage modulus (123%). Up to 89% for flexural, 82% for impact, and 83% for tensile strength were absorbed after exposing the composite to boiling water. Bourban et al. [8] Comparison of unidirectional and 2/2 flax fiber damping and mechanical properties including thermoplastic (PP), PLA and thermoset (epoxy) with epoxy composites of glass (GF) and carbon fiber (CF). The best compromise amid damping and stiffness were found with flax fiber-reinforced PLA. The composite with flax fiber showed better damping with respect to carbon fiber and glass fiber-reinforced composite.

Trujillo et al. [9] studied involves a long bamboo fiber and its high end uses as a reinforcement for composite materials. At different gauge lengths, Weibull distribution, which requires only three parameters, explained accurately the fiber strength of fibers. With increasing gauge lengths, the fiber strength decreases. While comparing with natural fibers, Weibull shape parameter had shown low strength variability, indicating high quality.

Singh et al. [10] developed epoxy-based composites reinforced jute fiber and studied the influence of temperature healing on its mechanical properties. Test results showed that at 100 °C, the peak tensile strength was registered at 32.3 MPa. Georgiopoulos et al. [11] developed the unidirectional flax fiber composites, which are exposed to a different dynamic mechanical analysis. It was fabricated by film stacking method. There were different treatment processes used, named as plasticization, silanization, and treatment with maleic anhydride. A strong adhesion between matrix and fibers was observed as a result of these surface treatments. There was also an increase in crystallinity, Young's modulus, processing module, and flexural modulus. Singh et al. [12] studied the effect of surface treatment on jute/epoxy composite mechanical properties. Surface treatment of natural fibers results in the enhancement of tensile and flexural strength; however, impact strength has been tremendously decreased. The literature study clearly reflects that a great deal of work has been done in the field of manufacturing and testing PMC using synthetic fibers and synthetic resins, and the increasing concern for the environment clearly requires the need for environmentally friendly and cost-effective substitute polymer composites. The present initiative is to develop green composites and to study and improve their mechanical properties.

Jute fiber is used as reinforcement and polylactic acid (PLA) as the matrix material derived from the maize starch in this paper. At molding temperatures ranging from 160 to 180 °C, and at fiber volume by weight, all the composites developed 30% fiber volume. Different surface treatments such as sodium hydroxide, potassium dichromate, and potassium permanganate, were employed on jute fiber and studied the effect on their mechanical properties. In order to investigate the chemical interactions between fibers and chemical agents, Fourier transform infrared spectrometry was performed on treated jute fibers.

2 Materials and Method

The matrix material used to develop the composites is polylactic acid (PLA), which in granular form is a commercial grade of 3052D, acquired from Natur-Tec India Pvt Ltd. The reinforcement is selected as jute fiber which is easily available and very economical in nature. Jute fibers consist of alpha cellulose, hemicellulose, lignin, fats, and waxes, pectin, protein/nitrogenic matter, etc., and ash [13].

The optical view of woven jute mat and PLA in granule form is shown in Fig. 1a, b.

2.1 Fiber Surface Treatment

Jute fibers were exposed to three different surface treatments with the motive to the enhancement of mechanical properties.

In alkali treatment, fiber mat was dipped into 5% by weight concentrated NaOH solution for 2 h and then washed away with the acetic acid having 1% concentration by weight to ensure the PH value of the fiber attains 7. Fibers were further washed with water after achieving the 7 PH quality and dried for 2–3 days.

In potassium permanganate and potassium dichromate treatment, fibers were soaked in 0.02% by weight concentrated solution for 2 min at room temperature. Rest same procedure was adopted as used in alkali treatment.

2.2 Spectral Analysis

Using FTIR spectroscopy, both untreated and treated jute fibers were analyzed. It shows the change in molecular fiber structure due to physical and chemical treatments.

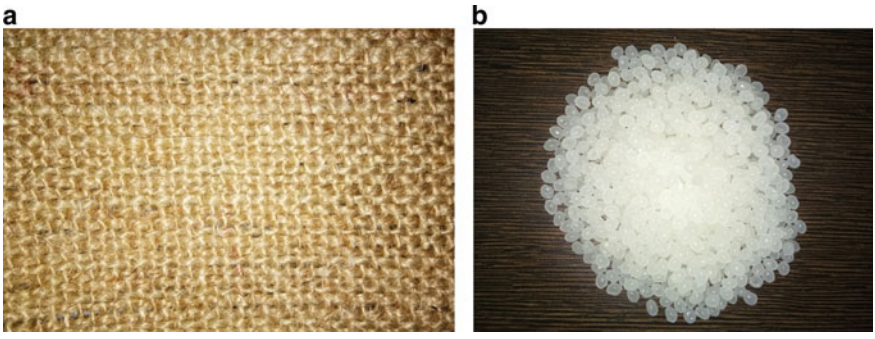

Fig. 1 **a** Of a jute mat woven. **b** Granular PLA

At first, 1 mg of jute fibers were ground into the powder form and then mixed with KBr powder infrared grade. The mixture was then pressed for measurement into a pallet. The spectrum of 500–4000 cm^{-1} was reported.

2.3 Composite Fabrication

Hot pressing and compression molding methods have been introduced for experimental purposes. After chemical fiber treatment, the treated jute mat was cut according to the specific heating die size, and the amount of PLA granules required was measured and placed in the oven at 80 °C for 4 h preheating. Fix the Teflon sheet and strips once the die temperature has reached the required temperature. For the manufacturing process, split the PLA granules into two parts. First, the first half of the granules is spread evenly into the cavity and then the treated jute fabric layers are placed over the PLA granules, and then the remaining PLA granules is distributed into the cavity over the placed jute fabrics. The Teflon sheet is eventually placed on the lower die, and the die is closed later. Eventually, the entire die structure is kept in the molding compression unit. In this fabrication process, the machine molding temperature was kept as operating parameter which ranged from 160 to 180 °C. The selection of the molding temperature parameter was based on the pilot study were temperature range was selected as 160–210 °C and later found that fibers were degraded due to increase in the temperature. That is why, the temperature range was selected as 160–180 °C. The complete composite was kept under the load of 250 KN for 15 min, and then, heaters were stopped and kept at the complete die under the pressure to cool, and finally, the complete die was open at 80 °C, and final composite was kept in desiccator.

2.4 Mechanical Test

1. ***Tensile testing***: On the universal testing machine, the tensile test was carried out in accordance with ASTM standards D3039 [14]. Specimens were cut to 250 mm × 25 mm × 4 mm as required. All tensile tests were conducted at 2 mm/min cross speed. Figure 2a and b shows the specimens fractured during tensile and flexural testing.
2. ***Flexural Testing***: The flexural strength of the formed jute/PLA composites was measured using a three-point bend test conducted on the UTM machine in accordance with the D790-02 [15] ASTM standard with dimensions of 120 mm × 15 mm × 4 mm.

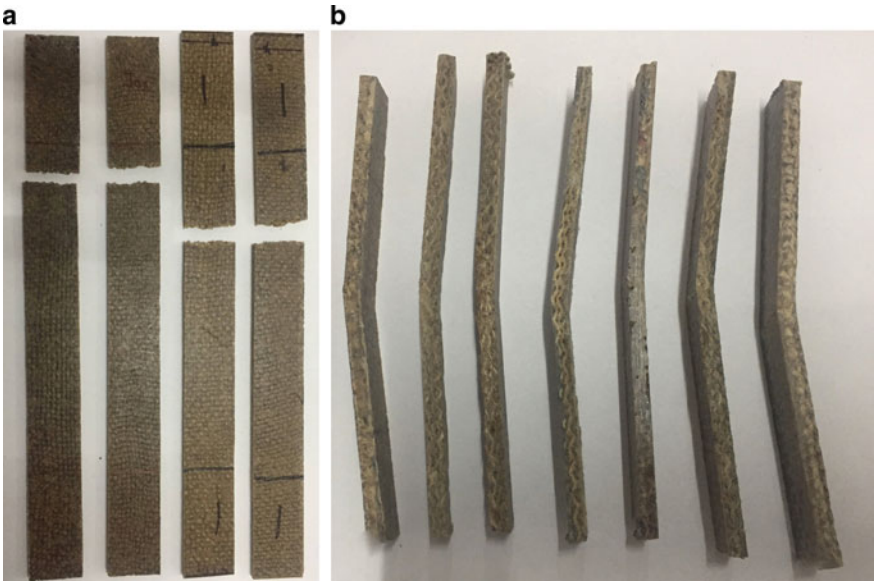

Fig. 2 **a** Fractured tensile specimens. **b** Fractured flexural specimens

3 Results and Discussion

3.1 FTIR Spectroscopy

FTIR spectra are shown in Fig. 3a, b for untreated and alkali-treated jute fiber. One finds different bands of absorption in the spectra from 4500 to 400 cm^{-1} in this figure. Due to the stretching vibration of hydroxyl (OH), the absorption band around 3300–3280 cm^{-1} is indicated. This could be a facility for desorption of water as well as decomposition of hemicellulose and lignin. An indication of C–H spreading vibration in cellulose and hemicellulose for methyl and methylene groups is a high peak observed in both spectra around 2900 cm^{-1}. Table 1 shows the transmittance peaks for untreated and treated jute fibers.

C=O stretching carboxylic acid vibration and hemicellulose ester components cause the sharp peak observed at 1750 cm^{-1} in untreated jute fiber (Fig. 3a). In the case of alkali-treated jute fiber, due to structural changes that are incompatible with Goripathi et al. [16], the height of 1740 cm^{-1} corresponding to C=O spreading hemicellulose vibration vanished. It clearly shows that the hemicellulose layer was removed in alkali treatment as compared to other surface treatments.

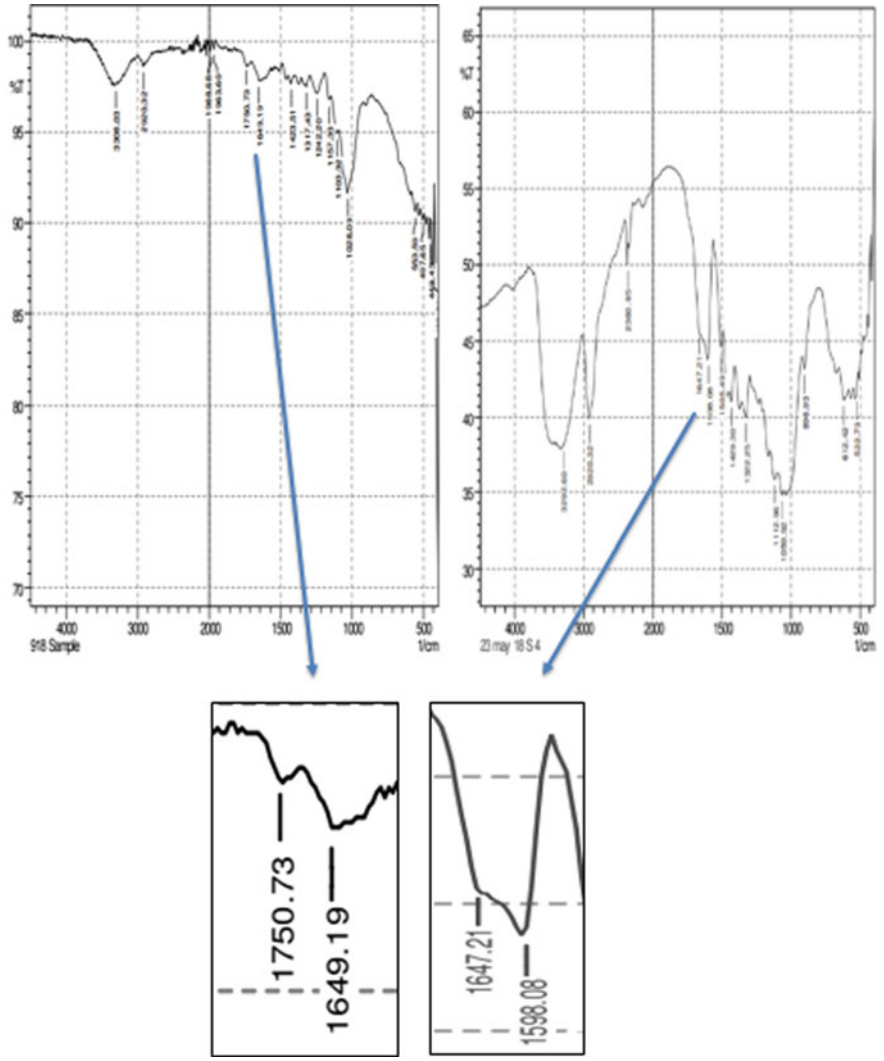

Fig. 3 **a**, **b** Untreated or alkali-treated FTIR spectra of jute material

3.2 Composites and Its Mechanical Properties

Figure 4 shows the effects of surface treatments on jute/PLA composites' tensile and flexural properties. The untreated jute/PLA's tensile strength and flexural strength were 24.42 MPa and 48 MPa, respectively. After different treatments, the tensile

Table 1 FTIR spectra for untreated and treated jute fibers

Possible assignments	Untreated	Alkali	Potassium dichromate	Potassium permanganate
−OH stretching vibration (cellulose)	3308	3292	3330	3520
C–H stretching vibration	2920	2920	2920	2920
C=O stretching vibration (hemicellulose)	1750	–	1740	1740
CH_2 symmetric bending	1423	1429	1430	1439
C–O stretching vibration (lignin)	1242	1235	1244	1245

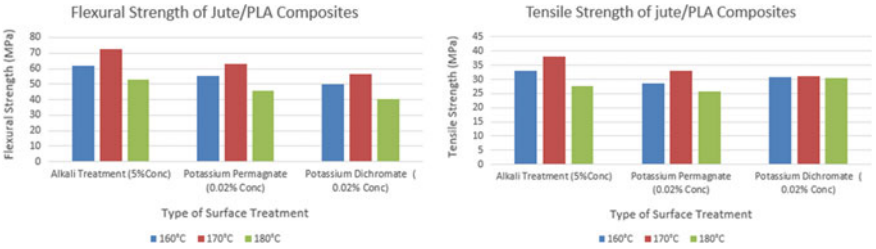

Fig. 4 Flexural and tensile properties of surface-treated jute/PLA composites

strength varies on the basis of different temperatures and surface treatments. Maximum tensile strength of 38.12 MPa was recorded for alkali-treated jute/PLA composite. Increment of tensile properties follows an order of alkalization > potassium dichromate > potassium permanganate > untreated.

Composites' mechanical properties depend on the interaction of the fiber matrix. It was also observed that the tensile strength decreases at higher temperatures. This may be due to higher temperature burning of the fibers. At higher curing temperature, the interfacial strength between matrix and natural fibers reduces due to thermal degradation of natural fibers at higher temperature [10]. Maximum flexural strength of 72.5 MPa was observed at 170 °C molding temperature with alkali-treated jute/PLA composites.

4 Conclusion

In this study, composites based on polylactic acid based on surface-treated jute fiber have been developed. Three different chemicals have been selected for the surface

treatment of jute fibers, such as sodium hydroxide, potassium permanganate, and potassium dichromate. Mechanical properties such as tensile strength and flexural strength have been evaluated.

The following conclusions will be drawn from this study.

1. The surface improvement in each treatment is shown by the FTIR spectra of all treated jute fibers.
2. Alkali-treated reinforced jute fiber shows the highest tensile strength and flexural strength relative to other fiber surface treatment.
3. The peak tensile strength is reported as 38.12 MPa for alkali-treated jute fiber composites.
4. Maximum flexural strength is reported as 72.5 MPa of alkali-treated jute fiber composite.

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