Surface Modification and Performance Analysis of Jute Based Nanophased Green Composite

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ABSTRACT

Jute-based green composites can be used in consumer goods, low-cost housing, and interior of cars, civil structures, and biomedical applications due to their ease of availability, echo-friendliness, low cost, and good specific properties that are comparable to synthetic fibers. Biodegradable and green nanophased jute composites are manufactured using chemically treated jute fibers and biodegradable polymer (Biopol) for this study. The surface modification of jute fibers was accomplished by performing subsequent chemical treatments such as detergent washing, dewaxing, alkali, and acetic acid treatment. The morphology of the modified surface was examined using the scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR). Thermal performance of the treated fibers was studied using the state-of-the-art thermogravimetric analysis (TGA). It was found that the finally treated jute fiber contained only 4% moisture and the higher amount of cellulose, which is a promising result for proper fiber-surface wetting and bonding with the matrix. Biodegradable jute Composites were fabricated using traditional routes such as compression molding technique. The mechanical properties of this green composite were studied by three point bending test. The result showed that surface modification improved the thermal and mechanical properties of the jute based biocomposites. Addition of nanoclay in this biocomposite is on progress and the resultant data would be presented in the conference.

Keywords: Biodegradable composite, Biopol, Jute fiber, Surface modification, FTIR.

1. INTRODUCTION

Synthetic fibers such as carbon, glass, aramid fibers etc. are generally used to make composite materials due to their better mechanical and thermal properties than natural fibers. However, they are expensive and non-degradable. On the other hand, natural fibers like banana, cotton, sisal, coir, jutes are inexpensive, biodegradable or recyclable at reasonable cost, easily available in nature, and have good mechanical, thermal, and electrical properties. Moreover, they are renewable [1]. Jute is one kind of natural bast fiber which is found from jute plant. Among the all natural fibers, jute fibers are easily available in fabric and fiber forms with good mechanical and thermal properties [2]. Jute fibers are echo-friendly, low cost, and low-density fibers with high specific properties. Therefore, jute-based composite materials can be used in consumer goods, low-cost housing, and interior of cars, civil structures, and biomedical applications. The main elements of jute fibers are- cellulose, hemicelluloses, lignin, and pectin. Cellulose is the main element of jute fiber, which is resistant to alkali but hydrolyzed by acid. Hemicellulose works as supporting matrix agents of cellulose. Hemicellulose is hydrophilic, soluble in alkali and easily hydrolyzed in acids. Lignins are amorphous and hydrophobic in nature. It contains aromatic and aliphatic constituents. Pectins are like waxes. It gives plant flexibility [3].

Despite the advantages of cellulosic fiber, its main disadvantage is the incompatibility of phase during the mixing of the hydrophilic cellulosic fiber with the hydrophobic polymer matrix. The prime objective of the surface treatment is to increase the bonding strength between hydrophilic fiber and hydrophobic polymeric matrix [4, 5]. There are many attempts underway to control the interfacial adhesion between fiber and matrix. These methods include physical or chemical modification of fibers or the use of coupling agents. Chemical modification of the fibers such as dewaxing, treatment with alkali, acetylation, and grafting alters the surface properties that results better wetting of the fibers with the matrix [6]. Co-polyester of 3-hydroxybutyrate (HB) and 3-hydroxyvalerate (HV) is commercially known as biopol was used as a matrix system in the jute based biocomposites. Among all the biodegradable polymeric materials biopol is considered as

the true bio-polymers, because it is synthesized by bacteria. Poly(3-hydroxybutyrate) is brittle while poly(3-hydroxybutyrate-co-3-hydroxyvalerate) is ductile in nature [7]. Nanoclay improves barrier, flammability resistance, thermal and mechanical properties for polymer composites at a very low filler loading. The nanoclay particle increases the modulus and decreases strain to failure of nanocomposite **[8]**. Dispersion of nanoclay into the composites is very important for nanophased composites.
The objective of this study is to modify the jute fabrics by chemical treatment for the better interfacial adhesion with matrix and produce biodegradable nanocomposites. The surface modification was evaluated by the morphological, mechanical, and thermal characterization of jute fibers and its composites.

2. EXPERIEMNTAL

2.1 Materials Selection

The bacterial copolyester, poly(3-hydroxybutyrate-co-3-hydroxyvalerate) or biopol granule (5 mm), with the average 3-hydroxyvalerate content of 12 mol%, supplied by the Goodfellow Company (UK) was used without additional purification. Natural jute fabric obtained from the onlinefabricstore.net (USA) was used after chemically surface modification. Alcojet detergent, ethanol (50% solution), NaOH (50% solution), and acetic acid (99%) received from the Sigma–Aldrich were used without further purification.

2.2 Surface Modification

Jute fibers are hydrophilic in nature. On the other hand, all polymers (resins) are hydrophobic in nature. Hydrophilic fiber and hydrophobic polymer result poor interaction bonding at fiber/matrix interface. Surface modifications of the fibers are necessary to improve bonding and adhesion affinity to polymer matrices and dimensional stability. Surface treatment not only decreases moisture absorption, but also increases wettability of the fibers in the matrix polymer and the interfacial bond strength.

- Detergent washed: Detergent wash is performed to remove dirt which comes with jute fabrics. Jute fabrics keep into 5% detergent solutions at 30 °C for 1 hour and it is then washed with water and dried at room temperature.
- Dewaxing: Dewaxing is performed to remove pectin and waxes come with jute fabrics during the processing. Detergent washed jute fabrics keep into 5% ethanol solution at 30 °C for 2 hours followed by washing with distilled water and drying at room temperature for 24 hours.
- Alkali treatment: It is the most important steps for surface modification. It increases the wettability of the fibers and improves adhesion affinity to polymer matrices. Dewaxed jute fabrics keep into 5% NaOH solution for 2 hours at 30 °C.
- Alkali treated jute fabrics are washed with distilled water-acetic acid (2%) solution followed by washing with distilled water and vacuum drying.

The morphology of the modified surface was examined using SEM and the performance of the treated fibers was studied by TGA and FTIR.

2.2 Composite Fabrication

Jute biopol composites were fabricated using untreated and chemically treated jute fabrics and bipol using a hot press unit. The solution of biopol granules were prepared dissolving it into the cholorofrom in a ratio of 1:10. The solution was then dried and a thin firm was prepared using the hot press machine at 180 °C and 2 ton pressure. The thickness of the film was maintained 0.5 mm. The biopol film and jute fabric were stacked like a sandwich and jute/biopol composites were manufactured using the compression molding technique. In step 1- the composite panel was heated upto 166 °C at 1 ton pressure and held for 5 minutes. In step 2- the temperature was maintained 140 °C at a pressure of 2 ton and held for 10 minutes. After that samples were kept on the heated plate for cooling at room temperature.

2.3 Test Procedure

2.3.1 Spectral and Thermal Analysis

The FTIR spectra of parent and surface-treated jute fabrics were recorded with a Nicolet 10 DX FTIR spectrophotometer. Thermo gravimetric analysis (TGA) was carried out under nitrogen gas atmosphere on a TA Instruments (Q 500), Inc. apparatus. TGA measurements were carried out to obtain information on the thermal stability of the jute fabrics, biopol, and jute/biopol composite. The samples were cut into small pieces to maintain the sample weight within a 10–15 mg range. Then the samples were kept in a platinum sample pan, weighed and heated to 450 °C from room temperature (30 °C) at a heating rate of 10 °C/min. The real time characteristic curves were generated by Universal Analysis 2000-TA Instruments, Inc. data acquisition system.

2.3.2 Morphological Characterization

Morphology of untreated and treated jute samples were examined under a Field Emission Scanning Electron Microscope (FE-SEM Hitachi S-900) JEOL JSM 5800). An accelerating voltage was applied to accomplish desired magnification.

2.3.3 Differential Scanning Calorimetry (DSC)

DSC scans were performed using TA Instruments Q 1000 with sealed pans in the temperature range 30 °C to 200 °C at 5 °C/min heating rate under nitrogen flow. The melting and crystallization temperatures (T_m and T_c, respectively) of the biopol were taken at the corresponding peak maximum.

2.3.4 Flexure Test

Flexural tests under three-point bend configuration were performed on the Zwick Roell testing unit according to ASTM D790-02 to determine the ultimate strength, strain and young modulus of the jute/biopol composites. The machines were run under displacement control mode at a crosshead speed of 2.0 mm/min and tests were performed at room temperature.

3. RESULTS AND DISCUSSIONS

3.1 FTIR Spectroscopy

Characterizations of modified fabrics constituents are an important part of our investigation. Figure 1 illustrates the FTIR spectra of different modified jute fabrics. A broad absorption band in the region 3400–3300 cm^{-1} characteristic of hydrogen bonded O-H stretching vibration, is common to all of the spectra. The O-H stretching vibration decreases due to surface modification. Near to wave number 2950 cm^{-1} shows the C-H vibration. It is also decreases due to the surface modification. Hemicelluloses are the main concern of the surface modification that appears near to 1100 cm^{-1} wave number. The amount of hemicelluloses decreases due to alkali treatment.

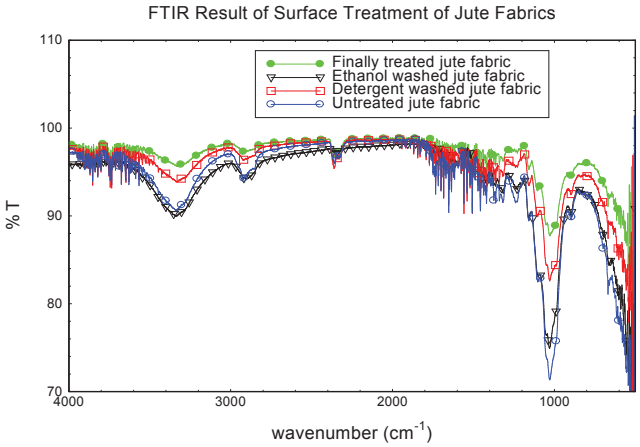

Figure 1: FTIR Spectra of Jute Fibers

3.2 Thermal Stability

From the TGA curves, it is found that the moisture content of the fabrics decreases due to the surface modification of fabrics. It is also observed that the decomposition temperature slightly increases with the surface treatment. Decomposition temperatures of the finally treated jute fiber and the neat biopol are about 310 and 270 °C, respectively (Figure 2). It is noticed that the decomposition temperature of jute/biopol composite is higher than the neat biopol but lower than finally treated jute fiber, as shown in Figure 3. From the TGA curve it is also evident that the amount of residue increases due to the surface modification. It indicates the higher percentage of cellulose content compared to the untreated fiber.

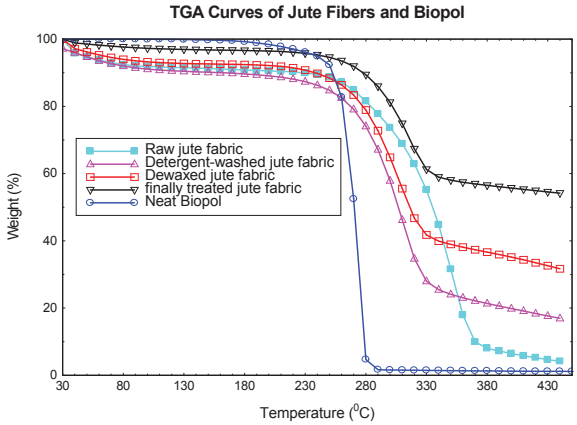

Figure 2: TGA curves of Jute and Biopol

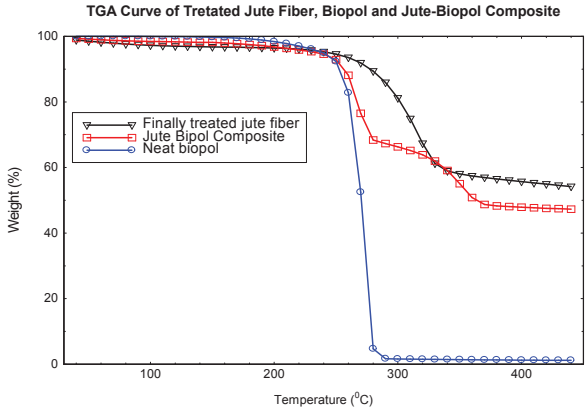

Figure 3: TGA curves of Jute, Biopol, and Composite

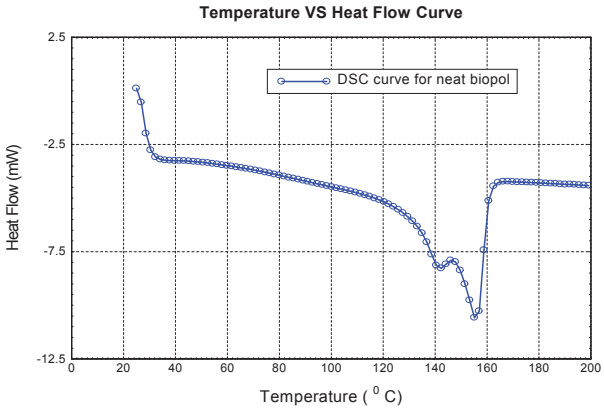

Figure 4: DSC curve of Biopol

3.3 Thermal Properties of Biopol

Thermal properties including melting and crystallization temperature of biopol were measured using differential scanning calorimetry (DSC) test. Melting temperature is important to process the thermoplastic polymer. Form the DSC result it is found that the melting temperature of neat biopol is 158 °C.

3.4 Flexural Properties

Figure 5 shows the flexural result of untreated and treated jute/biopol composites. Surface modified jute fabrics result better adhesion with the matrix. As a result, better flexural properties of the surface modified jute/biopol composite are found compared to the untreated jute/biopol composite. The results are shown in the table 1.

Jute/ Biopol Composite	Max Force (N)	Strain at F_{max} (%)	Max Stress (MPa)	Modulus (GPa)
Treated	60.03	6.13	30.30	1.33
Untreated	56.06	12.61	24.06	1.25

Table 1: Flexural test results

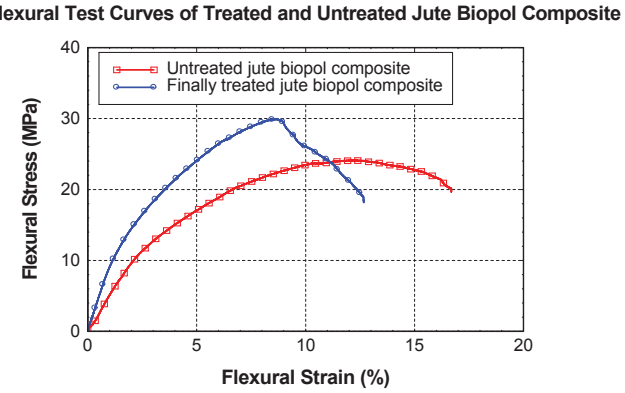

Figure 5: Flexural stress-strain curves

3.5 Morphological Characterization

The surface morphology of the jute fabrics was investigated using SEM micrograph (Figure 6). From the micrograph it is noticed that the untreated fiber surface is smooth. Untreated jute fibers contain cellulose, hemicelluloses, pectins, and lignins. Detergent and ethanol washed jute fabrics contain a lot of granules which are waxes and other impurities on the fiber surfaces. Those impurities are removed due to the subsequent detergent and ethanol treatment. Finally treated jute fibers do not have the white granules. It indicates that the hemicellulose is removed due to the alkali treatment and results higher percentage of cellulose. The finally treated surface also rougher compared to untreated jute fibers. The rough surface attributes to better interaction with matrix due to larger surface area.

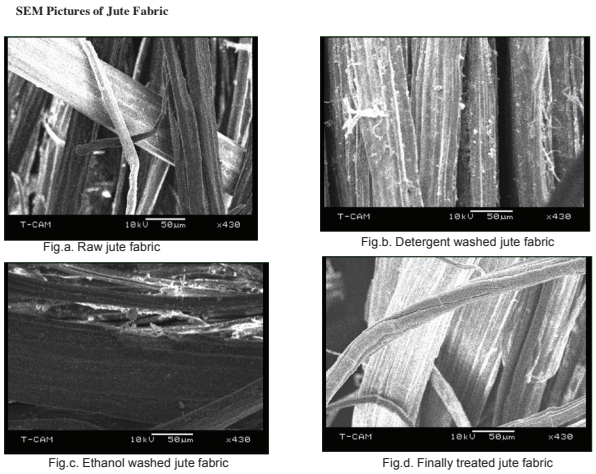

Figure 6: SEM micrographs of Jute Fibers

4. SUMMARY AND CONCLUSIONS

In this paper, it is demonstrated that four subsequent surface modification treatments improved cellulose content which is promising for composite fabrication. FTIR results showed lower amount of hemicelluloses due to surface modifications. TGA results showed that decomposition temperature increases due to the surface treatment. SEM results also showed the improvement of surface due to the chemical modification. From flexural results it was concluded that the treated jute fiber/biopol composite results better mechanical properties compared to the untreated jute fiber/biopol composite.

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