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Research Article

Production of Jute Fiber Reinforced Polyethylene Matrix Coloured Composites

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Abstract

Jute fiber reinforced polyethylene (PE) matrix-coloured composites were fabricated by compression molding technique and then thermo-mechanical properties were evaluated. The fiber content in the composites was 30% by weight. The tensile strength (TS), elongation at break (Eb%), flexural strength (FS), and hardness of the control jute composites were found to be 14.78 MPa, 34.16%, 43.40 MPa, and 95 Shore A, respectively. On the other hand, coloured (green) jute composites showed 12.94 MPa, 24.39%, 25.64 MPa, and 94 Shore A, respectively. Results indicated a slight decrease in the mechanical properties of the coloured composites compared to the control sample. Interfacial properties of the composites were investigated by scanning electron microscopy and the thermal properties of the composites were evaluated by the thermos-mechanical analyzer. Finally, based on the investigated properties the results revealed that the coloured composites have good mechanical strength for application in the interior panel sectors with decorative purposes.

Keywords: Jute; Polyethylene, Coloured composites; Mechanical properties; Interior panel

Introduction

Natural fiber composites have been used in various fields from packaging materials to the body of automobiles. Typical applications of composites include civil construction, furniture, packing, and mainly the automotive industry [1]. Many household applications and lateral parts of vehicles have already been produced using natural fibers in association with phenol, polyester, or polypropylene. Natural fibers are undergoing a high-tech revolution that could see them replace synthetic materials in applications. Natural fibers have low abrasion multi-functionality, low density, low cost, high availability, high toughness, acceptable specific strength properties, good thermal properties, enhanced energy recovery, and biodegradability. This excellent price-performance ratio at low weight in combination with the environment-friendly character is very important for the acceptance of natural fibers in large-volume engineering markets such as automotive, aeronautic, and building industries [2-6].

It is also reported that natural fibers could turn up in everything from cars to golf clubs. Therefore, natural fibers have gained much interest among technologists and scientists for applications in civil, military, industrial, spacecraft, and biomedical sectors. Recently, with the growth of environmental awareness, sustainable development and green materials have become popular in protecting the environment and producing new economic possibilities [7-13].

Jute fiber is a natural fiber that is next to cotton fiber on the basis of industrial application. Jute fiber is mainly composed of cellulose (61-71%), hemicellulose (13.6-20.4%), lignin (12-13%), ash (0.5-2%), pectin (0.2%), wax (0.5%) and moisture (12.6%) [14-

17]. A digital image of the jute plant and jute is depicted in Figure 1. This fiber has two advantages: one is high cellulose content, and the other is the low micro-fibril angle. Cellulose is the crystalline portion of the fiber which is responsible for reinforcement in composites and cellulose is relatively resistant to alkali (17% alkali) but oxidized in strong oxidizing conditions. The other important factor is the low micro-fibril which is the controlling factor of rigidity, inflexibility and strong mechanical properties. The value of the micro-fibril angle varies, and thus the properties vary from fiber to fiber. Jute fiber has some drawbacks that prevent jute to be used as reinforced fiber in composite fabrication. One of the major problems of jute fiber is the presence of a hydroxyl group in the cellulose structure. These hydroxyl groups make the jute fiber strong and hydrophilic in nature whereas the polymer matrix is hydrophobic in nature. This opposite behaviour restricts the jute fiber to be used widely in composite fabrication. For this incompatibility in behaviour, optimum mechanical properties cannot be obtained from the jute fiber-reinforced composite. Thus, the hydrophilic character of jute fiber can be reduced by different mechanical methods such as compression molding, and hand-lay-up technique by combining with other hydrophobic materials to improve its mechanical properties [18-20].

Jute Plant (A)

Jute Fiber (B)

Figure 1: Digital Images of Jute plant (A) and Jute Fiber (B).

The basic monomer of polymer polyethylene (PE) is ethylene. It is not biodegradable but can be recycled. Polyethylene (PE) is a widely used thermoplastic with adaptable properties based on molecular conformation [21-22], with applications ranging from film packaging and electrical insulation to containers and piping. It is a non-polar synthetic polymer that has excellent chemical inertness. The key characteristics of PE are impact toughness, low-temperature impact resistance, good resistance to chemicals, and good creep resistance [23-24].

The introduction of natural particles to a polymer matrix does not affect the results of tensile strength; however, the use of natural fiber increases the stiffness several times. But the introduction of natural particles causes an increase in water absorption that affects the surface quality of the tested materials [25].

Bazan et al. [26] presented research on composites with natural fibers as reinforcement with bio-polyethylene and showed that at a content of 12% by weight, resulting in an increase of strength and rigidity of materials. Ovalı et al. [27] investigated the effect of jute fabric surface treatments and additives added to Polyethylene on the tensile strength, flexural strength, and impact resistance properties of the PE/jute composites The results indicated that the alkali/silane treatment of jute fibers led to more than 30% improvement in the mechanical properties of the composite structures when reinforced to untreated PE, and the mechanical properties of the composites had more than 45% improvement by maleic anhydride addition to the polymer in ideal ratios with untreated jute reinforcement. Prasad et al. [28] investigated the effect of coir fiber addition and banana fiber in PE to develop cost-effective and high-performance composite materials. Sayem et al. [29] showed in their research the effect of manufacturing multi-layered jute fabric-reinforced PE composite and its mechanical performance. The mechanical performance of the composite laminates having four and six layers of jute fabric was found to have improved significantly when compared to the pure high-density polyethylene laminates. Shahinur et al. [30] discussed research advancements in enhancing the physical, mechanical, thermal, and tribological properties of polymeric materials reinforced with jute fibers in a variety of forms. In this article, the key challenges for jute and its derivative products in gaining commercial success were highlighted and potential future directions were also discussed.

The aim of the present study was to fabricate jute fiber-reinforced PE-based coloured composites and characterize mechanical, thermo-mechanical, and morphological properties for interior panel applications. For future research, we will try to modify the reinforcement material and matrix structure for better performance of interior panel application and give a comparison with the present research data.

Materials and Methods

Materials

Bleached jute fabrics (Hessian cloth) were collected from the local market, Savar Bazar, Dhaka, Bangladesh. Polyethylene (PE) granules were purchased from the Cosmoplene Polyolefin Company Ltd, Singapore. The colouring agent used in this investigation was BD Lacquer Spray (green color), China. A digital image of jute (hessian cloth) and coloured jute (coloured hessian cloth) is shown in Figure 2.

Figure 2: Digital Images of Jute (A) and Coloured Jute (B).

Methods

Composite fabrication: For making one PE sheet, granules of PE (10 g) were placed in two steel plates and then into the heat press (Carver, INC, USA, Model 3856). The press was operated at 120°C temperature and 4 tons consolidation pressure for 5 min. The plates were then cooled for 10 min in a separate press under 4 tons of pressure. The resulting PE sheet was cut into the desired size and so the jute fabrics for composite fabrication. Composites were prepared by sandwiching one layer of jute fabrics between two sheets of PE. The sandwich was then placed between two steel plates and heated at 120 °C for 5 min at a pressure of 4 tons and cooled like PE sheet. The fiber weight fraction of the composites was calculated to be about 30% by weight. For making colored composites, jute samples were spray coated and dried overnight then made the composite using the same technique mentioned above.

Mechanical properties of the composites: Tensile and flexural properties of the composites were evaluated by using the Hounsfield series S testing machine (UK) with a cross-head speed of 1 mm/s. The dimension of the test specimen was (ISO 14125): 60 mm ×15 mm×2 mm. Composite samples were cut to the required dimension using a band saw. The hardness of the composites was determined by HPE Shore-A Hardness Tester (model 60578, Germany).

Thermal properties: Thermal properties of the composites were determined by the Netzsch Thermo-mechanical Analyzer (TMA), Model 402 F3 Hyperion, USA. The thermal expansion coefficients of the bio-composites were measured by manufacturing samples in the form of bars with dimensions of 8mm×8mm and then tested by TMA (using a thermomechanical analyzer), with expansion mode.

Scanning electron microscopic analysis: Composite samples were examined by Philips scanning electron microscope (SEM) at an accelerating voltage of 10 kV. After the bending test, the fracture sides of the composites were observed using SEM. In an aluminum disk plate, gold-coated composite samples were kept, and a computer is connected to the machine with relevant software. After that, scanning electron micrographs of the sample are obtained from a computer.

Results and Discussion

Mechanical properties of the fibers and matrix

In this investigation, jute fiber (hessian cloth) reinforced PE-based composites (both control and coloured) were prepared by compression molding technique then mechanical, thermal and interfacial properties were evaluated. Table 1 shows the mechanical properties of jute (hessian cloth), coloured jute (coloured hessian cloth), and PE. The tensile strength (TS), elongation at break (Eb%), and tensile modulus (TM) of jute samples were found to be 600 MPa, 1.3% and 30 GPa respectively. On the other hand, the TS, Eb and TM of the coloured jute were 593 MPa, 1.5%, and 26.5 GPa respectively. The TS, Eb, and TM of the matrix, PE were found to be 14 MPa, 440%, and 0.55 GPa, respectively.

Table 1: Mechanical properties of Jute, Coloured Jute, and Polyethylene.

Sample Type	Tensile Strength (MPa)	Elongation Break (%)	Tensile Modulus (GPa)
Jute	600	1.3	30
Coloured Jute	593	1.5	26.5
Polyethylene	14	440	0.55

Mechanical properties of the composites

Jute fiber reinforced PE-based coloured composites were fabricated by a compression molding technique. The ratio of the laminates was 1:2 (1 layer jute fiber and 2 layers PE). Figure 3 Showed the digital images of the jute (hessian cloth)/PE-based composites (A) and coloured jute (hessian cloth)/PE-based composites (B). The appearance of both composites was good.

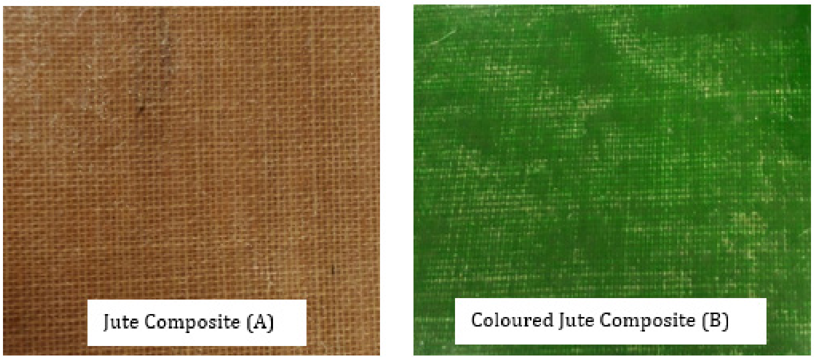

Figure 3: Digital Images of the Fabricated Jute/PE Composites.

Table 2 shows the mechanical properties of the control composite (Jute/PE) and Coloured Composite (Coloured Jute/PE). The tensile strength (TS), elongation at break (Eb%), flexural strength (FS), and hardness (Shore A) of the control composite sample were found to be 14.78 MPa, 34.16%, 43.40 MPa and 95 respectively. On the other hand, the TS, Eb, FS, and hardness (Shore A) of the coloured composite sample were 12.94 MPa, 24.39%, 25.64 MPa, and 94 respectively.

Table 2: Mechanical properties of the composites.

Composite	Tensile Strength (MPa)	Elongation Break (%)	Flexural Strength (MPa)	Hardness (Shore A)
Control Composite (Jute/PE)	14.78	34.16	43.4	95
Coloured Composite (Coloured Jute/PE)	12.94	24.39	25.64	94

From this table, this is clear that coloured jute composite lost a fraction of TS, FS, and hardness but gained Eb. The reason behind the decrease of strength may be due to poor fiber-matrix adhesion. Here, synthetic colour is used for jute which is a natural fiber. Usually, jute fiber contains a lot of hydroxyl group at the surface and as a result a poor fiber matrix bond might occur.

Thermal properties of the composites

TMA applications are the simplest, most reliable and sensitive among the other existing TA techniques. Thermo-mechanical Analyzer (TMA) is a very sensitive micrometer, closely related to dilatometry (vertical dilatometer) and its basis involves the accurate investigation of material dimensional (length) change as a function of temperature under a defined mechanical force or negligible load [31]. The typical TMA curve for the thermal expansion of the jute fiber-PE composite (both control & colour) is shown in Figure 4. Here, TMA represents the dimensional change (μm) of composites against temperature (°C).

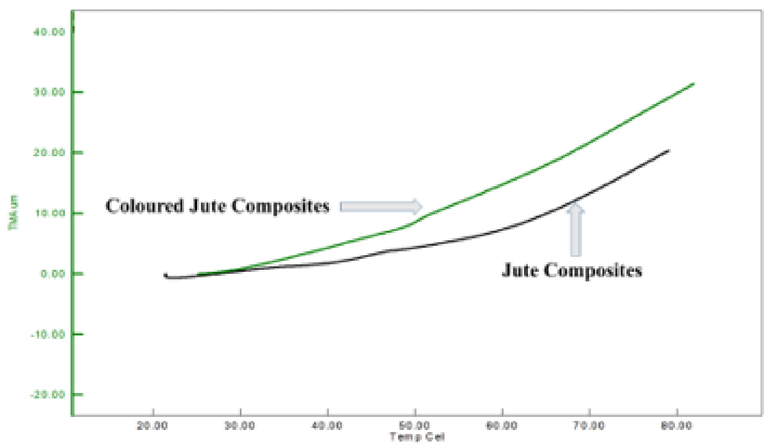

Figure 4: Thermo-mechanical Analysis of the Composites.

From the graphical representation, it was found that coloured composite expanded more with increasing temperature than the controlled one. At 79°C temperature, coloured composite expanded 29.81µm whereas the control sample expanded 20.32µm. Moreover, coloured composite expanded 31µm at 81°C temperatures while there was no expansion for the control one. The reason is that there was a weak intermolecular bond in coloured sample as colouring agent might reduce the number of cross-linking of the polymer & change the chemical structure.

Interfacial properties of the composites

Scanning Electron Microscopy (SEM) technique was carried out to study the interfacial properties of the composites. SEM studies were more important to find out the adhesion of the fiber matrix inside the composites. Figure 5 indicates SEM images of the jute composite (A) and coloured jute composite (B). From the SEM images of both composites, it is clearly visible that the bonding between jute and PE is not so good and small gaps are evident in the matrix near the jute fiber. The poor fiber matrix adhesion is because of the hydrophilic nature of the jute fiber and hydrophobic nature of the polymer matrix. For better fiber matrix adhesion, we should work to reduce the hydrophilic nature of the jute fiber in future.

Jute Composite (A)

Coloured Jute Composite (B)

Figure 5: SEM image of the Jute/PE Composites.

Conclusion

Jute fiber and PE-based coloured composites were prepared successfully. In this investigation, natural fiber jute was used for composite fabrication. The mechanical properties of the coloured composites were in a promising level for the application in interior panel applications in homes and offices. The coloured composites looked very decorative and had the potential to replace the existing non-degradable materials. Moreover, the fabricated coloured composites were lightweight and partially degradable. In conclusion, this research will open a new dimension of further investigation for the application of natural fiber-reinforced composites in many civil constructions.

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Conflict of Interest

All authors state that there is no conflict of interest.

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