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Effect of Weave Structure and Yarn Density on Mechanical Attributes of Jute Fabric Reinforced Polypropylene Composites

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Abstract

This paper represents a comparative study of the different weave structures of jute woven fabric reinforced polypropylene (PP) composites. The weave structures were selected as plain (1/1), twill (2/1), twill (3/1) and basket (2/2). Composites (40% fiber by wt.) were prepared by using compression molding technique. The mechanical properties such as tensile strength (TS), bending strength (BS) and impact strength (IS) of the composites were evaluated and compared. It was found that basket weave/PP based composite showed the highest mechanical properties. The optimum value of TS, BS, TM, BM and IS of the composite were found to be 49.7 MPa, 92.5 MPa, 867 MPa, 5.6 GPa and 29.8 KJ/m^2.To find out the effect of yarn density on mechanical properties of the composites, 2/1 twill structure was selected and found significant improvement in the mechanical properties with the increase of Ends/Inch (EPI) and Picks/Inch (PPI) in the fabric. Water uptake and degradation behavior in aqueous medium of the composites was also observed.

Keywords: Jute fiber; Polypropylene; Plain; Twill; Basket weave; Mechanical Properties

Introduction

Natural fibers as reinforcement have attracted the attention of researchers because of their advantages over established materials as they are environmentally friendly, fully biodegradable, abundantly available and cheap. Plant fibers are lighter weight compared to glass and carbon fibers. Currently, many types of natural fibers have been investigated for use in plastics including flax, hemp, jute straw, alginate, rice husk, wheat, kenaf etc. Natural fibers are undergoing a high-tech revolution that could see them replace synthetic materials in many applications. Among all the natural fibers, jute fibers appear to be one of the most useful, inexpensive and commercially available lignocellulose fibers. Jute is one of the strongest natural fibers. Jute fabric reinforced plastic composites combine the advantages of both jute fibers and plastics. Thus, they can be widely used in the packaging, electronic and aircraft industries. In the case of automotive industries, these composites have been used in bumpers, roofs, doors, panels, seats of cars, buses, and so on [1-4].

Natural fiber reinforced composites based on fabric reinforcement are becoming popular because of their superior strength, stiffness to weight ratio, higher impact strength and balanced physico-mechanical properties compared to the unidirectional fiber composites. These composites are primarily used in the aerospace, marine, defence, land transportation, construction, and power generation sectors as load bearing materials. Furthermore, fabric reinforcements have good extensibility, easy manufacture ability, better energy absorption ability that exceeds those of conventional short fibers thus proving its suitability for the manufacture of structural parts [5].

Nassif stated that the different weft densities in plain, twill and satin weave patterns will be affected the physical and mechanical properties in woven fabric. Among the various parameters influencing the mechanical properties of fabric, weave structure is identified as one of the main factors influencing the mechanical performance for high strength application [6-8]. In particular, the woven fabric composites provide more balance in strength, toughness and stiffness compare to nonwoven fabrics.

Polypropylene is chosen in this study because it possesses several outstanding properties like low density, high softening point, good flux life, good surface hardness, scratch resistance, transparency, dimensional stability, flame resistance, high heat-distortion temperature, very good abrasion resistance, low moisture pickup, high impact strength and excellent electrical properties [9].

The aim of the present study was to fabricate partially biodegradable composites using jute fabric as reinforcing agent and PP as the matrix material by compression molding. Four types of weave structures were used to prepare composite. So, comparative mechanical studies were carried out between four types of composites.

Materials and Methods

Materials

Jute fabrics were collected from Bangladesh Jute Research Institute (BJRI), Dhaka, Bangladesh and Polypropylene was purchased from Polyolefin Company, Private Ltd., Singapore.

Methods

Polypropylene sheets of 0.50-0.55 mm thickness were prepared from granules of PP by pressing at 190°C for 5 min between two steel molds under 5 Metric Ton consolidation pressure in the heat press (Carver, INC, USA, Model 3856).The molds were then cooled for 5 min in a separate press under 5 Metric Ton pressure at room temperature.

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The resulting PP sheet was cut into the desired size (12 cm × 12 cm) for composite fabrication. Jute fabrics were cut into size of (10 cm × 10 cm). Composites were prepared by sandwiching 4 layers of fabrics between 5 sheets of pre-weighted PP. The sandwich was then placed between two steel molds and heated at 190°C for 5 min under a pressure of 5 Metric Ton.

Mechanical Testing of the Composites: Tensile tests (TS) were evaluated according to DIN 53455 standard method using a Universal Testing Machine (Hounsfield series S, model: H 50 KS-0404, UK). The load capacity was 50 KN and a cross-head speed of 10 mm/min using gauze length of 20 mm. The dimensions of the test specimen were 60 mm × 15 mm × 3 mm. Bending tests (BS) were carried out according to DIN 53452 using the same testing machine mentioned above at a cross-head speed of 10 mm/min and span distance was 40 mm. The impact strength (IS) was measured using impact tester (MT-3016, Pendulum type, Germany) according to DIN EN ISO 179 standard in the flat wise, un-notched mode [10].

Before testing, samples were conditioned at 25°C and 50% relative humidity for several days and all the tests were performed under the same conditions. The results were taken as the average values of five samples.

Water uptake: Measurement of water uptake of the composite samples (20 × 10 × 3 mm^3) was performed in deionized water at room temperature (25°C) up to 30 h. Composite samples were placed into static glass beakers containing 250 mL of deionized water. At set time points, samples were taken out and dried for 1 h at 105°C and then reweighed [11].

Degradation behaviour of the composites in aqueous medium: Degradation tests of the composites were performed in deionized water at room temperature (25°C) up to 4 weeks. Composite samples were placed into static glass beakers containing 250 mL of deionized water. At set time points, samples were taken out and dried for 1 h at 105°C and then reweighed [11].

Results and Discussions

Effect of weave structure on the mechanical properties of the composites

The tensile strength of a composite material is more sensitive to the fiber matrix interfacial properties, whereas the modulus is dependent on the fiber properties. To find out the effect of weave structure on mechanical properties of the composites, four structures were chosen. The formulations of the composites are presented in Table 1.

The mechanical properties such as tensile, bending and impact strength of PP sheet and composites (40% fiber by wt.) were evaluated and compared. The results are presented in the Figures 1-4. It was found that TS, BS, TM, BM and IS of the PP sheet were found to be 22.7 MPa, 34.8 MPa, 470 MPa, 1.73 GPa and 4.83 KJ/m^2 respectively (Figure 1).

All the fabric reinforced PP composites gained a significant improvement of the mechanical properties. The TS, BS, TM, BM and IS of the F1 composite were found to be 35.6 MPa, 68.6 MPa, 678 MPa, 3.4 GPa and 22.8 KJ/m^2 respectively. The average value of TS, BS, TM, BM and IS of the F2 composite were found to be 47.8 MPa, 87.9 MPa, 778 MPa, 4.7 GPa and 27.6 KJ/m^2 respectively. Similarly, the value of TS, BS, TM, BM and IS of the F3 composite were found to be 43.5 MPa, 75.8 MPa, 710 MPa, 3.9 GPa and 24.3 KJ/m^2 respectively and the average value of TS, BS, TM, BM and IS of F4 composites were found to be 49.7 MPa, 92.5 MPa, 867 MPa, 5.6 GPa and 29.8 KJ/m^2 respectively (Figure 3).

Composites	Weave Structure	EPI	PPI	Matrix Material
F1	Plain (1/1)	20	18	Polypropylene
F2	Twill (2/1)			
F3	Twill (2/2)			
F4	Basket (2/2)			

Table 1: Composite formulations.

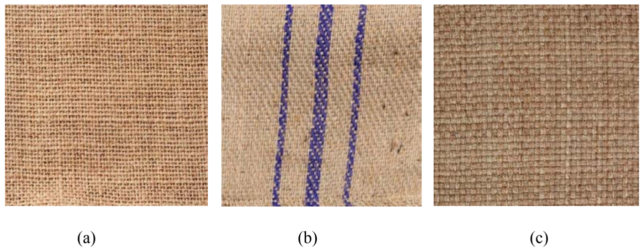

Figure 1: Image of Plain (1/1) weave (a), Twill (2/1) weave (b), and Basket (2/2) weave (c).

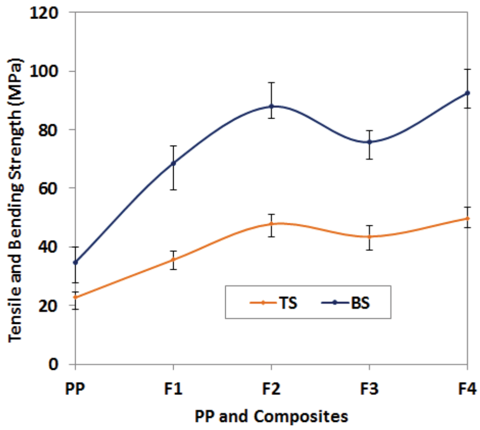

Figure 2: Tensile and Bending Strength of PP and Composites.

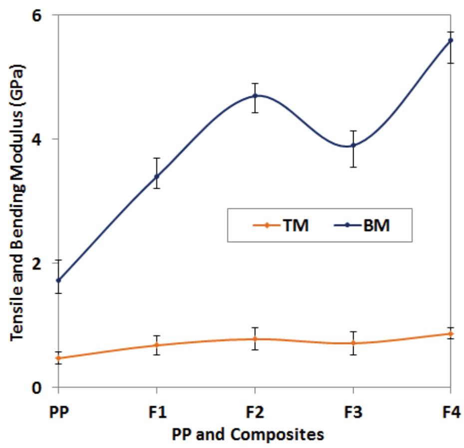

Figure 3: Tensile and Bending Modulus of PP and Composites.

It is observed that among all the composites basket weave/PP based composite showed highest mechanical properties than other

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composites. It is because in basket weave the yarns work as group wise which causes the enhanced mechanical properties. During tensile loading, all yarns in the direction of loading share the load. Twill weave/PP composite showed improved mechanical properties than plain weave/PP due to the presence of more no. of yarns in the same volume fraction which participates in load bearing. In the plain weave due to higher interlacement, crimp% is also higher, as a result, lowest extensibility is found in the fabric which reduces the ultimate mechanical property of the composite [2]. The TS, BS, TM, BM and IS of basket weave/PP based composite were increased to 118, 165.8, 84.4, 223 and 51.7% respectively than that of the matrix PP. From this investigation, this is clear that the woven fabric based jute composites gained huge mechanical properties over the matrix material PP (Figure 4).

Effect of yarn density on the mechanical properties of the composites

To observe the effect of yarn density, 2/1 twill structure was selected. EPI was changed according to available reed count and PPI was changed according to available change wheel. The formulations of the composites are given in Table 2.

From Figures 5-7, it is clear that the composites showed substantial improvement in mechanical properties due to increase of yarn density in the fabric. The value of TS, BS, TM, BM and IS of the C2 composite was 58.9 MPa, 96.8 MPa, 826 MPa, 5.8 GPa and 28.5 KJ/m^2 respectively. TS, BS, TM, BM and IS was increased to 23.2, 10, 6, 23.4 and 3.7% compared to C1 composite.

Similarly, the value of TS, BS, TM, BM and IS were found to be 68.7 MPa, 110.6 MPa, 895 MPa, 6.5 GPa and 31.7 KJ/m^2. TS, BS, TM, BM and IS was increased to 43.7, 25.8, 15, 38.2 and 14.8% compared to C1 composite. As the EPI and PPI increased, the fabric becomes more compact and more no. of yarns present per unit area, as a result, more no. of yarns participate in the load bearing which causes improved mechanical properties of the composite (Figures 6 and 7).

Water uptake behaviour of the composites

Water uptake was measured by immersing the composite samples in a static glass beaker containing deionized water at room temperature (25°C) for 30 h. The results are depicted in Figure 8. It was found that the composites absorbed water rapidly with time. After 30 h of immersion in water, the F1, F2, F3, F4, C2, C3 composite absorbed 14.7, 15.6, 16.5, 15.3, 17.4 and 19.7% respectively which were well expected. Among the composites, C3 composite absorbed the highest amount of water due to the presence of higher number of yarns per unit area. Jute is a natural biodegradable fiber and mainly built up with cellulose

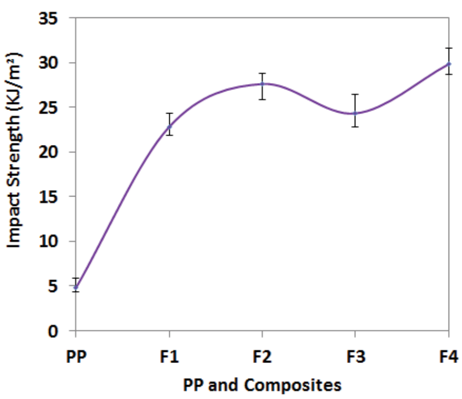

Figure 4: Impact Strength of PP and Composites.

Composites	EPI	PPI	Weave Structure
C1	20	18	Twill (2/1)
C2	30	25	
C3	40	30	

Table 2: Composite formulations.

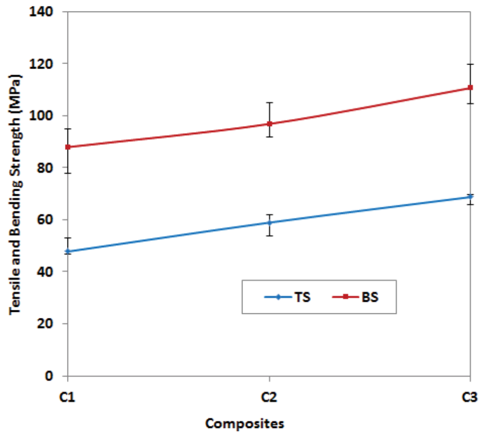

Figure 5: Effect of Yarn density on tensile and bending strength of the composites.

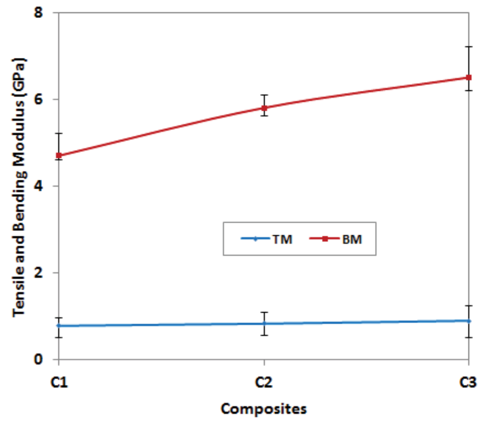

Figure 6: Effect of yarn density on tensile and bending modulus of composites.

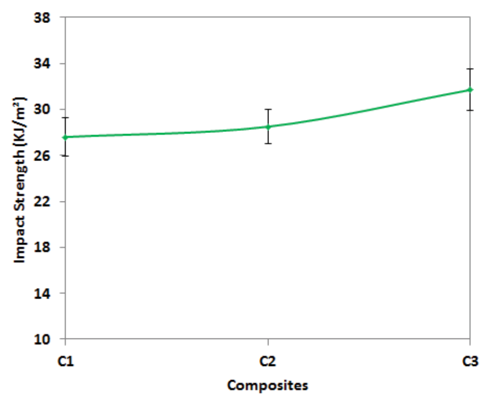

Figure 7: Effect of yarn density on impact strength of the composites.

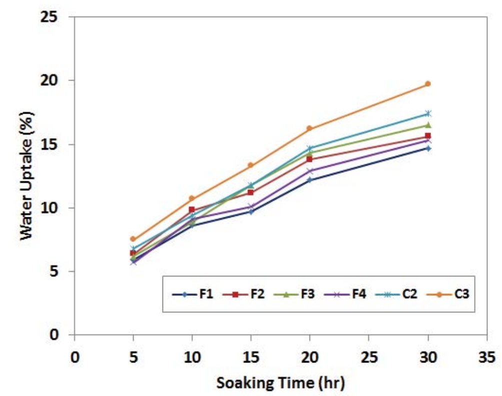

Figure 8: Water uptake behaviour of composites.

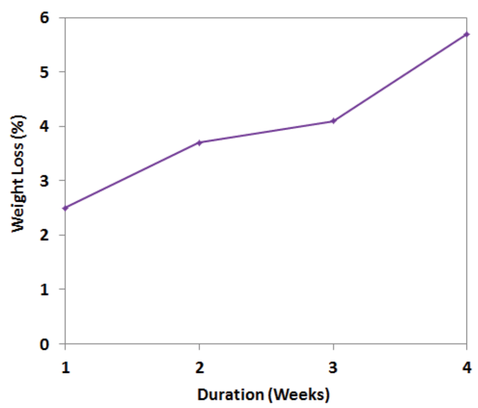

Figure 9: Mass loss of C2 composite in aqueous medium.

which is a hydrophilic glucan polymer. The elementary unit of jute is Anhydro-d-glucose which contains three hydroxyls (–OH) group [12]. These hydroxyl groups in the cellulose structure are responsible for the strong hydrophilic nature of jute and as a result, within a short time (30 h) jute absorbed such a large percentage of water (Figure 8).

Weight loss of the composites in aqueous medium

Weight loss of the jute composites was performed in deionized water for 4 weeks and the results are depicted in Figure 9. The only C2 composite was chosen to find out the weight loss characteristics of the composites. It is quite clear that the composite lost weight gradually with immersion time. After 4 weeks of immersion, the composite lost 5.7% of weight. Jute is biodegradable but PP is a petroleum-based non-degradable polymer. During degradation tests in aqueous medium, jute and PP, both were degraded and as a result, the weight loss was found [13] (Figure 9).

Conclusions

The mechanical properties of jute woven fabric-reinforced PP composites having four different structures have been evaluated and compared. It was found that basket weave/PP composite exhibited the highest mechanical properties. It was also found that the mechanical properties of the composites were greatly influenced by the structure of the fabrics. Composites having twill fabrics showed the improved mechanical properties than plain weave. It was also observed that increment of EPI and PPI in the fabric is a powerful way to increase the mechanical properties of the composites. Water uptake behaviour and degradation test in aqueous medium revealed that the composites retained their excellent biodegradability.

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