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Mechanical Properties of Chemically Treated Coir and Betel Nut Fiber Reinforced Hybrid Polypropylene Composites

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Abstract. Natural fiber reinforcement in polymer is one of the best ways to enhance mechanical properties of polymer. Hybrid composites provide the potential of achieving a balanced a pursuit of stiffness, strength, ductility and other mechanical properties. For this purpose coir and betel nut fiber were used as reinforcement in polypropylene matrix in present research. Raw coir and betel nut husk fiber were chemically treated with sodium hydroxide to increase adhesion of those fibers with polypropylene. Both raw and alkali treated fibers were utilized during composite preparation with the help of hot press technique. Fiber loading were varied at 5, 10 and 15 wt%, while coir and betel nut husk fiber ratios were varied at 1:1, 3:1 and 1:3. Tensile, flexural, impact, hardness and water absorption tests of prepared composites were subsequently conducted. All mechanical properties except tensile strength increased with increase in fiber loading. Properties of prepared composites were found better as compared to polypropylene matrix. Composites containing coir and betel nut at same ratio had better mechanical properties than composites containing those fibers at 1:3 and 3:1 ratio. On the other hand, sodium hydroxide treatment of raw coir and betel nut fiber increased mechanical properties of treated fiber composites as compared to raw fiber reinforced composite. Thus alkali treated 15 wt% coir and betel but fiber (at 1:1) reinforced polypropylene composite had the optimum set of mechanical properties among all prepared composites.

Keywords: Hybrid Composite; Coir and Betel Nut Fiber; Chemical Treatment; Mechanical Properties

1. Introduction

Hybrid composites using natural fibers have unique features that can be used to meet various design requirements in a more economical way than conventional composites. Balanced strength and stiffness, balanced thermal distortion, balanced bending, reduced weight and cost, reduced energy consumption, renewability, recyclability etc. are the advantages of natural fibers which gives the outstanding output of the composite properties. Eco-friendly nature of natural fiber composites have enhanced the use of natural fiber reinforced composites because of their minimized environmental pollution. By using a hybrid composite that contains two or more types of fiber, the advantages of one type of fiber could complement with what are lacking in the other. As a consequence, a balance in cost and performance can be achieved through proper material design. Natural fiber reinforced composites have some special features like low emission of toxic fumes when subjected to heat and during incineration at end of life, less abrasion damage to processing equipment, fibers have low density and high specific strength and stiffness etc [1].

Among various natural fibers, both coir and betel nut fibers are abundant in nature. Coir fiber is the natural fiber of the coir husk where it is thick and coarse but durable fiber. Coir fiber has a minimal effect on the environment due to their bio-degradable properties [2]. It possesses high failure strain, which provides a better strain compatibility between the fiber and the matrix in short fiber reinforced composites. It also has high weather resistance due to higher amount of lignin and absorbs water to a lesser extent compared to other natural fibers due to its less cellulose content. A special feature or coir fiber is that it can be stretched beyond its elastic limit without rupture due to helical arrangement of micro-fibrils [3]. On the other hand betel nut fibers are obtained from the husk of the betel nut fruit. Betel nut fibers are predominantly composed of hemicellulose. It is famous for its strength and lightness. Its main advantage is that it is renewable fiber. They have low density, high toughness, acceptable strength property and good thermal property [4]. The goal of present research is to determine mechanical properties of a proposed combined polymer composite which consist of a polypropylene matrix and a mixture of coir and betel-nut fibers.

2. Materials and Methods

2.1 Materials

Commercial grade polypropylene (PP), coir and betel nut fibers were used in present research. All of them were collected from the local market. PP was white in colour and granular in form having a melting point of 160^0C. Coir fiber was collected from coconut husk. Coconut husks were wetted for one week for retting. After retting the husks were crushed by hammer and fiber was collected manually from the husk. Fresh fiber was washed and dried under sun for 24 hours. Betel nut fibers were collected from ripe betel nut husk. The husks were wetted for two days for retting. Then fiber was collected manually from the husk. Finally they were cleaned and dried under sun.

2.2 Alkali treatment of natural fiber

Alkali treatment (5%NaOH) is used to remove a certain amount of lignin, wax and oils covering of external surface of the natural fiber, depolymerizes cellulose and expose the short length crystallites and disruption of hydrogen bonding in the network structure, thereby increasing surface roughness [5].

$$\text{Fiber}-\text{OH}+\text{NaOH}\rightarrow\text{Fiber}-\text{O}-\text{Na}+H_2O$$

For this purpose, both fibers were soaked into 5% NaOH solution for 2 and half hours at room temperature. After that fiber was cleaned with distilled water. Finally 1% acetic acid solution treatment was done to remove excess NaOH. Then neutralized fiber was dried into the oven at 100^0C for 2 and half hours to remove excess moisture.

2.3 Composite preparation

Composites were prepared using hot press technique in a 150mm×150mm×3mm aluminum die. A hydraulic type hot press machine having maximum load of 35 kN and maximum temperature of 300^0C was utilized. The fiber loading was varied at 0, 5, 10 and 15 wt% with ratio of betel nut to coir of 1:1. later composites were prepared with betel nut to coir ratio of 3:1 and 1:3 for 15 wt% fiber loading. Alkali treated fiber composite was also prepared using 15 wt% fiber loading and 1:1coir and betel nut fiber ratio. Firstly fibers were chopped to 3-5 mm length. Then required amount of fiber and PP were weighed in a balance. In order to allow the removal of moisture, fibers and polypropylene were dried in an oven at 80^0C for 20 minutes before preparing each composite. Pre-mixed mixture was then placed inside the die. The fiber-matrix mixture was allowed to press at 30 kN pressure. The temperature was initially raised to 160^0C and hold there for around 15-20 minutes, after that the temperature was raised to $(185\text{-}190)^0$C. The die was cooled to room temperature, pressure was released and composites were withdrawn from the die.

2.4 Mechanical testing
Tensile, flexural, Charpy impact, hardness and water absorption tests were conducted. For each test, three specimens were tested and the average values are reported. Tensile test were conducted according to ASTM-D 638-01 [6] using an universal tensile machine at a crosshead speed of 5 mm/min. The dimension of the specimen used was 100 mm x 19 mm x 3 mm. Static flexural test was carried out according to ASTM D 790-00 [7] using the same testing machine at same cross head speed as mentioned before. The dimension of the specimens used was 78 mm x 12.5 mm x 3 mm. Dynamic Charpy impact tests were conducted according to ASTM D 6110-97 [8] using an impact tester MT 3016. The dimension of the specimens used was 72 mm x 18 mm x 3mm. Hardness of the composite were measured using a shore hardness testing machine in shore D scale.

2.5 Water absorption test. In order to measure the water uptake characteristics of natural fiber reinforced the composites water absorption were carried out. For the water absorption test, the specimens were dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed and immersed in distilled water according to ASTMD 570-99 [9] for 24 hours. The final weight of the specimens was then taken. The increase in the weight of the specimens was calculated using the following equation:

$$\text{Percent Water Absorption} = \frac{(\text{Wet weight} - \text{Dry weight})}{\text{Dry weight}} \times 100\% \quad \text{...} (4)$$

3. Results and Discussion

3.1 Tensile and flexural properties
Tensile test and three point flexural test were performed to evaluate tensile properties and flexibility of prepared composites. Tensile and flexural properties against raw fiber loading are shown in Figure 1. Tensile strength decreased with increase in fiber loading [10-14]. As fiber loading increased, the interfacial area between the fiber and matrix increased that is weak because of weak interfacial bonding between cellulose based hydrophilic fiber and hydrophobic matrix. With increasing fiber loading, the bond become continuously weak. As a result tensile strength decreased (Figure 1 (a)). The same trend was also observed by other researchers [15-17]. According to Figure 1 (b), Young's modulus increased with an increase in fiber loading [10-13]. This is because with an increase in fiber content, brittleness of the composite increased and stress/strain curves becomes steeper. Poor interfacial bonding creates partially separated micro spaces which obstruct stress propagation between the fiber and the matrix [17]. As the fiber loading increases, the degree of obstruction increases, which in turn increased stiffness.

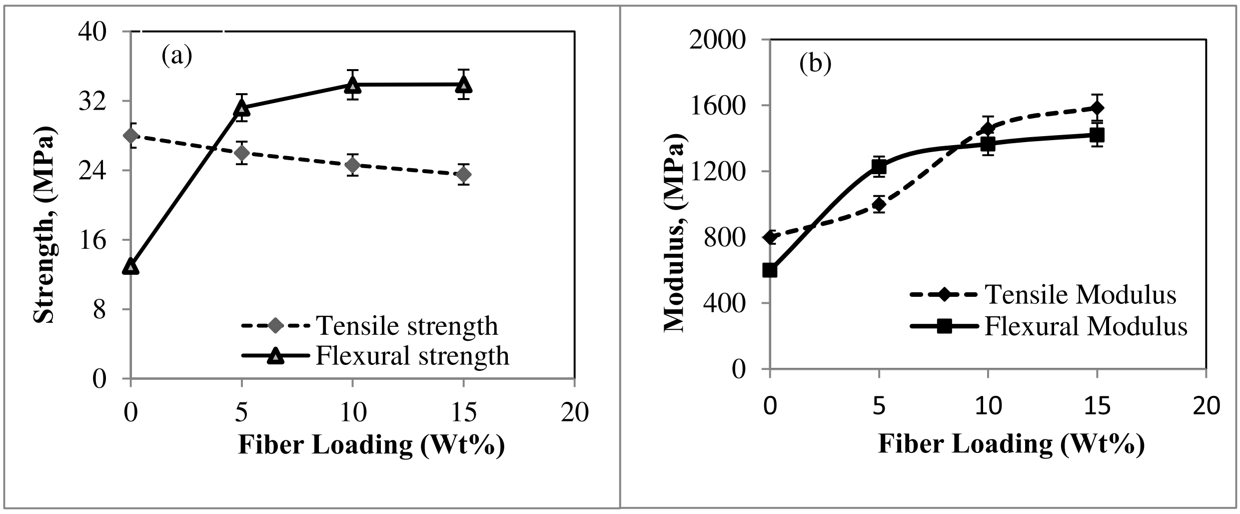

Figure 1. Variation of (a) tensile and flexural strength and (b) Young's modulus and flexural modulus against fiber loading.

On other hand, flexural properties (flexural strength and modulus) increased with increase in fiber content (Figure 1). This may be due to the favorable entanglement of polymer chain with filler which has overcome the weak filler matrix adhesion [16]. After 10% fiber loading, flexural properties did not change significantly. The reason may be weak filler matrix adhesion. With increase in fiber loading, they act as flaws and are not perfectly aligned with the matrix. Among different fiber ratio, better tensile sand flexural properties were found for coir and betel nut fiber ratio of 1:1 because of better compatibility of fibers with PP matrix and better fiber dispersion in the matrix (Figure 2). After alkali treatment tensile strength decreased and Young's modulus increased which conform better mechanical interlock of fiber and matrix [5]. Alkali treatment also ensures higher interfacial interaction between fiber and matrix, which increases effective surface area available of contact with the matrix and possibility of load transfer between the matrix and the reinforcing fibers. This resulted in increase of flexural strength and modulus (Figure 2).

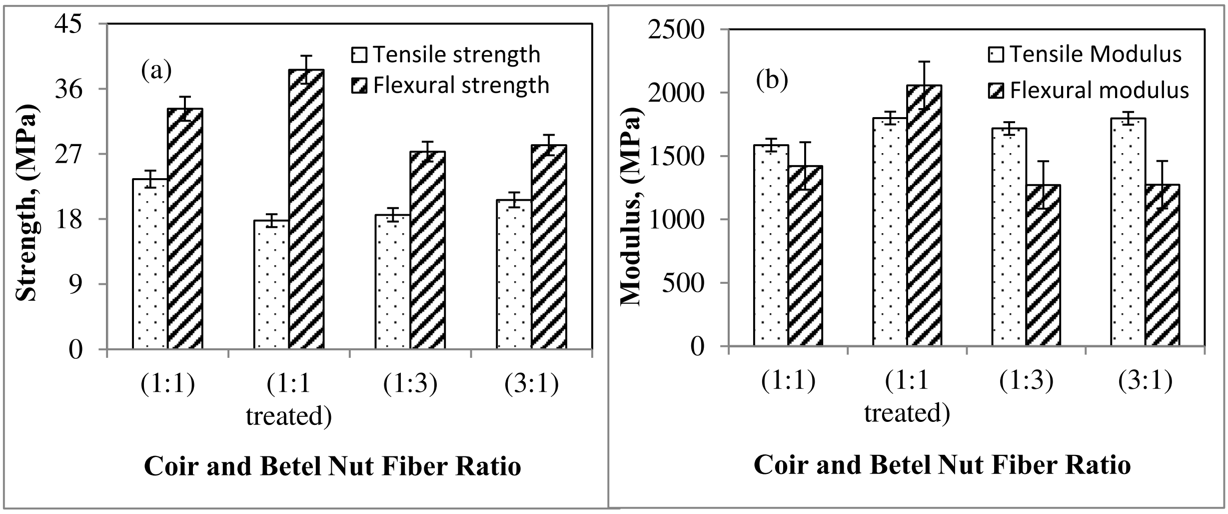

Figure 2. Variation of (a) tensile and flexural strength and (b) Young's modulus and flexural modulus against fiber ratio and alkali treatment.

3.2 Hardness Test Results

Incorporation of fiber into the PP matrix reduce the flexibility of the matrix which result in more rigid composite [15]. Hence with increase in fiber content, hardness values increased (Figure 3 (a)). Hardness of 25% coir-75% betel nut fiber reinforced composite was higher as compared to 75% coir-25% betel nut fiber reinforced composite (Figure 3 (b)). Due to combined effect of coir and betel fiber, highest hardness value was found in 50% coir-50% betel nut fiber reinforced composite. Alkali treatment of fiber resulted in collapse of the amorphous cellular structure into crystalline structure, which leads to better packing of cellulose chains and reduction of void, as well as better adhesion between the matrix and the filler [5]. Thus hardness increased after alkali treatment.

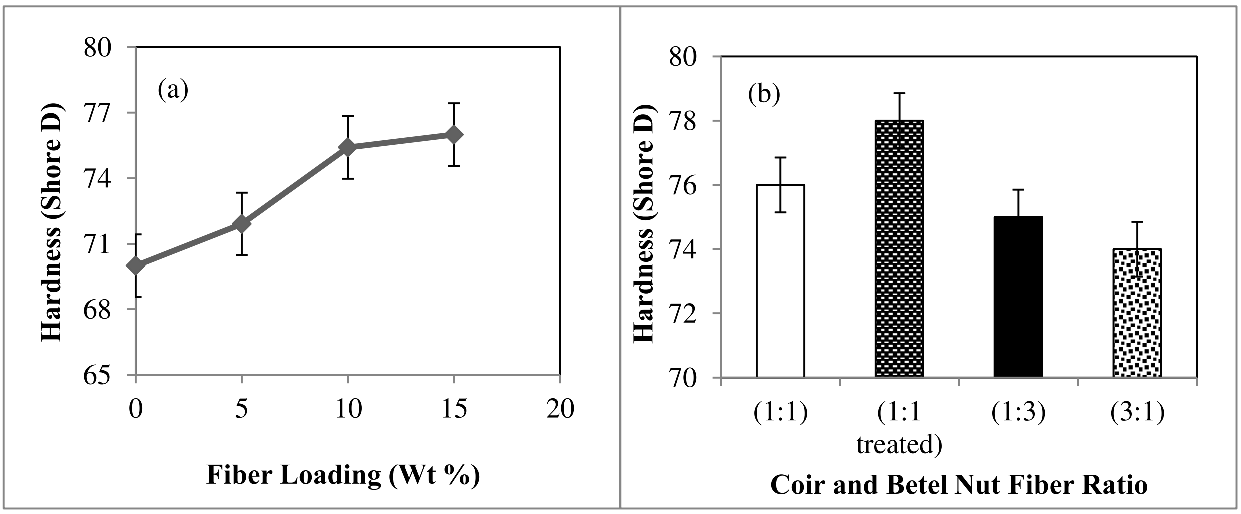

Figure 3. Variation of hardness against (a) fiber loading and (b) fiber ratio and alkali treatment.

3.3 Charpy Impact Test Results

Impact strength of fiber reinforced polymeric composites depends on the nature of the fiber, polymer and fiber-matrix interfacial bonding [5]. Impact strength of prepared composites increased with an increase in fiber loading (Figure 4 (a)), which is in agreement with other researcher [18, 19]. One of the factors of impact failure of a composite is fiber pull out. With the increase in fiber loading, stronger force is required to pull out the fibers. This in turn increases the impact strength. Alkaline treatment make the fiber surface rough, which help better fiber-matrix interfacial bonding. As a consequence impact strength of alkali treated fiber reinforced composites was higher than raw fiber reinforced composites (Figure 4 (b)).

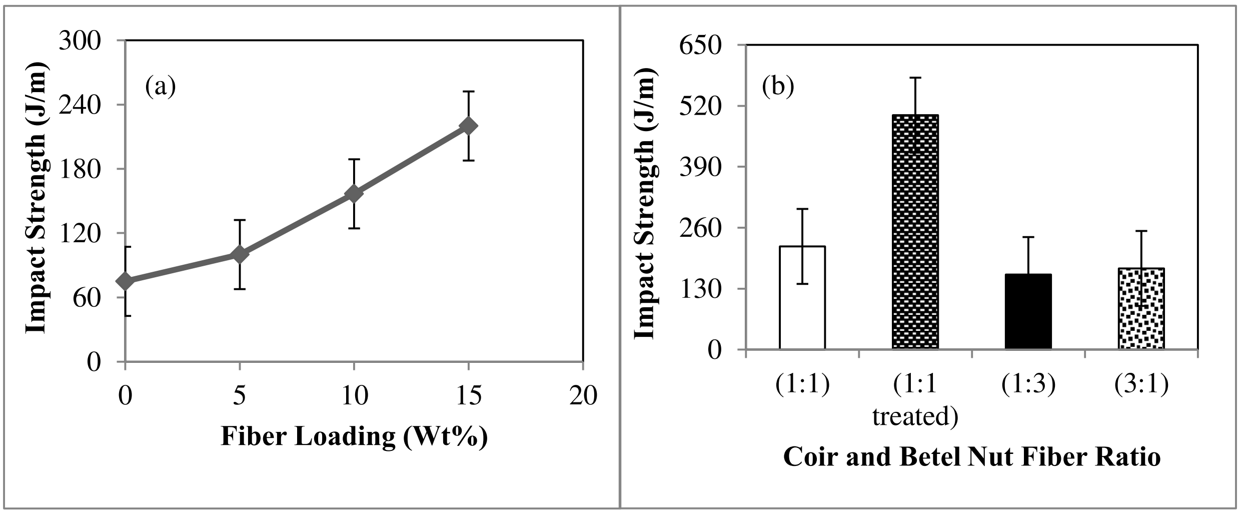

Figure 4. Variation of impact strength against (a) fiber loading and (b) fiber ratio and alkali treatment.

3.4 Water Absorption Characteristics

Polymer is hydrophilic in nature, however natural fiber is hydrophobic because of cellulose content. Water absorption property of composite depends on hydroxyl group in fiber. With increase in composite fiber content, number of hydroxyl groups in composite increases. As a result water absorption also increase [5] (Figure 5 (a)). Betel nut fiber contains high percentage of cellulose (53.3%) as compared to coir fiber (32-43%) [18]. Thus water absorption increased with increase in betel nut fiber ratio in composites (Figure 5 (b)). After alkali treatment, water absorption decreased due to decrease in number of hydroxyl groups in treated fiber reinforced composite [17].

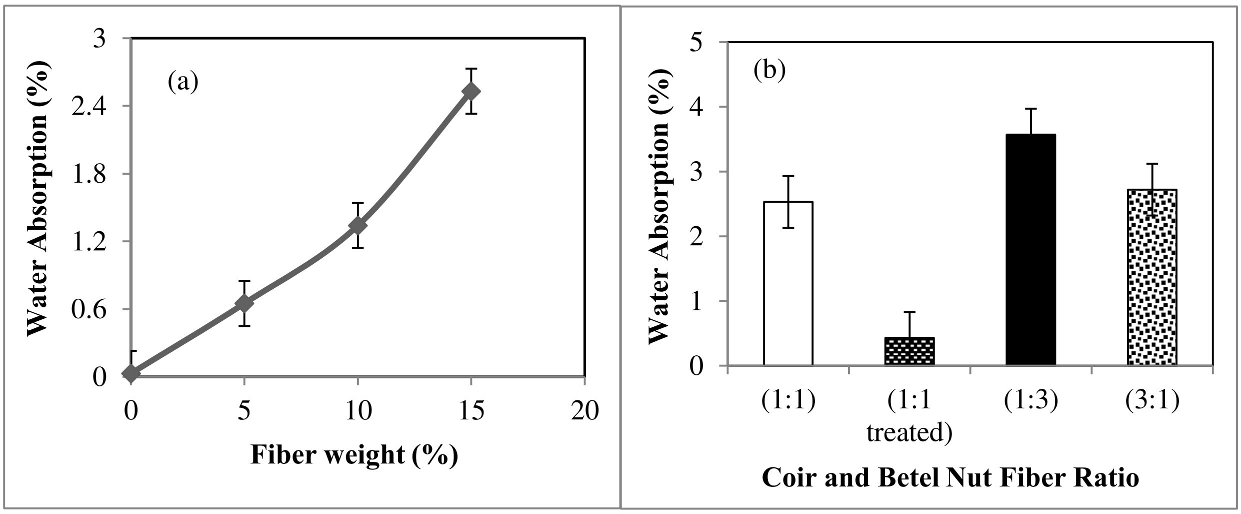

Figure 5. Variation of water absorption against (a) fiber loading and (b) fiber ratio and alkali treatment.

4. Conclusion

Mechanical properties of coir and betel nut fiber reinforced hybrid PP composites except tensile strength increased with fiber loading. On the other hand all properties of prepared composites were found better as compared to polypropylene matrix. Composites containing coir and betel nut at 1:1 ratio had better mechanical properties than composites containing those fibers at 1:3 and 3:1 ratio. Alkali treatment of raw coir and betel nut fiber increased mechanical properties of treated fiber composites as compared to raw fiber reinforced composite. Thus alkali treated 15 wt% coir and betel but fiber (at 1:1) reinforced polypropylene composite had the optimum set of mechanical properties among all prepared composites.

5. References

[1] Joshi S V, Drzal L T, Mohanty A K and Arora S 2004 *Are natural fiber composites environmentally superior to glass fiber reinforced composites?* Composites A, Vol. 35(3), pp. 371–376.
[2] Konduru S, Evans M R and Stamps R H 1999 *Coconut husk and processing effects on chemical and physical properties of coconut coir dust,* Hort Science, Vol. 34(1), pp. 88–90.
[3] Verma D and Gope P C 2015 *The use of coir/coconut fibers as reinforcements in composites,* Biofiber Reinforcements in Composite Materials, pp. 285-319.
[4] Yusriah L, Sapuan S M, Zainudin E S and Mariatti M 2012 *Exploring the potential of betel nut husk fiber as reinforcement in polymer composites: effect of fiber maturity*, Procedia Chemistry, Vol. 4, pp. 87-94.
[5] Li X, Tabil L G and Panigrahi S 2007 *Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review,* Journal of Polymers and the Environment, Vol. 15(1), pp. 25-33.
[6] ASTM Standard D 638-01, 2002 *Standard test methods for tensile properties of plastics*, Annual Book of ASTM Standard, Vol. 08.
[7] ASTM Standard D 790-00, 2002 *Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials,* Annual book of ASTM standard, Vol. 08.

[8] ASTM Standard D 6110-97, 2002 *Standard test methods for determining the Charpy impact resistance of notched specimens of plastics,* Annual Book of ASTM Standard, Vol. 08.
[9] ASTM Standard D 570-99, 2002 *Standard test methods for water absorption of plastics,* Annual book of ASTM standard, Vol. 08.
[10] Yang H S, Kim H J, Son J, Park H J, Lee B J and Hwang T S 2004 *Rice-husk flour filled polypropylene composites; mechanical and morphological study,* Composite Structures, Vol. 63, pp. 305-312.
[11] Lou C W, Lin C W, Lei C H, Su K H, Hsu C H, Liu Z H and Lin J H 2007 *PET/PP blends with bamboo charcoal to produce functional composites*, Journal of Materials Processing Technology, Vol. 192-193, pp. 428-433.
[12] Rana A K, Mandal A and Bandyopadhyay S 2003 *Short jute fiber reinforced polypropylene composites: effect of compatibilizer, impact modifier and fiber loading*, Composites Science and Technology, Vol. 63, pp. 801-806.
[13] Joseph S, Sreekala M, Oommen Z, Koshy P and Thomas S 2006 *A comparison of mechanical .properties of phenol formaldehyde composites reinforced with banana fibers and glass fibers,* Composites Science and Technology, Vol. 62, pp. 1857-1868.
[14] Ajay K, Chauhan S S, Modak J M and Chanda M 2007 *Mechanical properties of wood fiber reinforced polypropylene composites: effect of a novel compatibilizer with isocyanate functional group,* Composites A, Vol. 38, pp. 227-233.
[15] Jamil Md S, Ahmed I and Abdullah I 2006 *Effect of rice husk filler on the mechanical and thermal properties of liquid natural rubber compatibilized high-density polyethylene natural rubber blends,* Journal of Polymer Research, Vol. 13, pp. 315-321.
[16] Rahman M R, Haque M M, Islam M N and Hasan M 2008 *Improvement of physico-mechanical properties of jute fiber reinforced polypropylene composites by post treatment,* Composites A, Vol. 39, pp.1739-1747.
[17] Yang H S, Kim H J, Son J, Park H J, Lee B J and Hwang T S 2006 *Water absorption behavior and mechanical properties of lignocellulosic filler polyolefin biocomposites,* Composite Structures, Vol. 72, pp. 429-437.
[18] Sanadi A R, Caulfield D F, Jacobson R E and Rowell R M 1995 *Renewable agriculture fibers as reinforcing fillers in plastics: mechanical properties of kenaf fiber polypropylene composites*, Industrial Engineering and Chemistry Research, Vol. 34, pp. 1889-1896.
[19] Yang H, Yan R, Chen H, Lee D H and Zheng C 2007 *Chararteristics of hemicellulose, cellulose and lignin pyrolysis,* Fuel, Vol. 86(12-13), pp. 1781-1788.

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