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Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment

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ABSTRACT

In preparing polymer–matrix composites, natural fibers are widely used as "reinforcing agents" because of their biodegradable characteristic. In present research, coir fiber reinforced polypropylene biocomposites were manufactured using hot press method. In order to increase the compatibility between the coir fiber and polypropylene matrix, raw coir fiber was chemically treated with basic chromium sulfate and sodium bicarbonate salt in acidic media. Both raw and treated coir at different fiber loading (10, 15 and 20 wt%) were utilized during composite manufacturing. During chemical treatment, hydrophilic –OH groups in the raw coir cellulose were converted to hydrophobic –OH–Cr groups. Microstructural analysis and mechanical tests were conducted. Scanning electron microscopic analysis indicates improvement in interfacial adhesion between the coir and polypropylene matrix upon treatment. Chemically treated specimens yielded the best set of mechanical properties. On the basis of fiber loading, 20% fiber reinforced composites had the optimum set of mechanical properties among all composites manufactured.
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1. Introduction

Over the past several years, there has been an increasing interest in the use of biodegradable polymers, due to the serious environmental pollution arising from consumed plastics with time. Polypropylene is one of the most extensively used plastics both in developed and developing countries. It provides advantages in regard to economy (price), ecological (recycling behavior), and technical requirements (higher thermal stability). Synthetic polymers are currently combined with various biodegradable reinforcing fibers in order to improve mechanical properties and obtain the characteristics demanded in actual applications. Premlal et al. and Yang et al. manufactured rice husk reinforced polypropylene composites and found better mechanical properties in their composites [1,2]. Yang et al. indicated lower water absorption in their composites prepared with wood flour and polyolefin [3]. Better mechanical properties were also attained in rick husk reinforced polystyrene and PVC composites [4,5]. Research is moving forward in order to find ways to use lingo-cellulosic fibers in place of synthetic fibers as reinforcement in polymers. Thwe and Liao manufactured bamboo fiber reinforced PP composites using compression molding [6], Park et al. showed the potential of rice husk in reinforcing thermoplastic polymer [7], while Yang et al. prepared rick husk filled PP using extrusion technique [8]. Few researchers utilized injection molding in manufacturing jute fiber based polymer composites [9,10]. Recycled polymer was also reinforced with lingo-cellulosic fiber like flax [11]. The physical and mechanical properties of lingo-cellulosic biocomposites largely depend on the type of matrix, the content and properties of the reinforcing fiber and fiber–matrix interaction. Better dispersion of the fiber can be achieved by effective mixing of the components and a proper compounding process. The compatibility between the two components can be achieved by chemical treatment of the fiber using a suitable chemical agent [3]. In the present research, coir fiber was used as the reinforcing material since it is abundant in nature and has a minimal effect on the environment due to their biodegradable properties [12]. Coir fiber possesses high failure strain, which provides a better strain compatibility between the fiber and the matrix in short fiber reinforced composites [13]. 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. Coir fiber can be stretched beyond its elastic limit without rupture due to helical arrangement of micro-fibrils at 45° [14]. One of the major drawbacks of using coir as fiber material is its hydrophilic nature, responsible for moisture absorption and consequent deformation of the product. In order to overcome this problem coir is chemically treated, which in turn improves the mechanical properties of the biocomposites. Adhesion between the fiber and polymer is one of factors affecting the strength of manufactured composites.

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In order to increase the adhesion, the coir fiber was chemically treated separately for 3 h with $Cr_2(SO_4)_3{\cdot}12(H_2O)$ and 5 h with $CrSO_4$ and $NaHCO_3$. To speed up the reaction a continuous shaking was maintained by using a sieve shaker. The chemically treated coir biocomposites might be useful in making lightweight furniture, doors, window, and so on. Thus, the aim of this research is to prepare composite materials using raw and chemically treated coir fiber and polypropylene. The effect of fiber loading on the mechanical and morphological properties of coir fiber reinforced polypropylene is also reported.

2. Materials and methods

2.1. Materials

The thermoplastic polypropylene (PP), used as matrix material, was supplied by the Polyolefin Company, Private Limited Singapore in the form of homo-polymer pellets. The coir, used as reinforcing fiber, was collected from a rural area of Bangladesh. It comprises 43.44% cellulose, 45.84% lignin, 0.25% hemi-cellulose, 3% pectin, 5.6% ash, and 7.47% other constituents [15]. Chemicals used in this study to treat coir were HCl, basic chromium sulfate ($Cr_2(SO_4)_3{\cdot}12(H_2O)$) and sodium bicarbonate ($NaHCO_3$).

2.2. Treatment of coir

A solution of 0.5% chromium sulfate with 2/3 drops of HCl was made. An initial pH of 2.5–3 was maintained (during reaction this pH became 8–9) by a pH meter. Coir fiber was taken in that solution. It was shaken for 3 h in a sieve shaker. The vibration of shaking was 100 rpm. After 3 h shaking in the acidic solution of basic chromium sulfate salt, coir fiber was taken out and washed properly in distilled water. The 3 h chemical treatment of coir fiber was thus completed. For 5 h $CrSO_4$ and $NaHCO_3$ treatment, the same procedure was followed with an addition of 0.02% $NaHCO_3$ solution. The solution along with coir fiber was shaken for another 2 h. Later the fiber was washed properly with distilled water. Thus the 5 h chemical treatment was completed [16].

2.3. Fabrication of composites

At first raw fiber was weighted according to the required weight fraction needed. The required amount of coir fiber was cut into 3 mm size. Then they were dried in an oven at 100 °C for about 1 h to evaporate moisture. Sufficient amount of commercial polypropylene was taken on a beaker and weighted. To prevent voids, water bubbles, poor fiber–matrix adhesion, the polypropylene was dried in an oven at about 100 °C for 3 h [17]. Both dried fiber and polypropylene were taken into a beaker for uniform mixing of the fiber and polypropylene. Mold surface was cleaned very carefully and mold releasing agent was sprayed over the mold surface properly for the easy removal of the product. Then the uniformly mixed fiber and polypropylene was taken into the die. The die was placed in hot pressing machine at around 170 °C temperature and 30 KN pressure for about 20 min. Then it was cooled slowly using water cooling system. At last the specimen was carefully discharged from the mold after complete cooling.

2.4. Microstructural analysis

The infrared spectra of the raw and treated coir were recorded on a Nicolet 380 spectrophotometer using attenuated total reflectance (ATR) technique. The transmittance range of the scan used was 370–4000 cm^{-1}. The diameter of the coir fiber was measured and the interfacial bonding between the coir fiber and PP matrix in manufactured biocomposites was examined using a scanning electron microscope (Philips XL 30). Since the coir and composites are not conductive, those were needed to be made conductive. It was done by applying a gold coating sputtering technique. The thin gold coating caused the electron to interact with the inner atomic shells of the sample.

2.5. Mechanical testing

Tensile tests were conducted according to *ASTM: D 638-10* using a Universal Testing Machine (Model MSC-5/500, Agawn Seiki Co., Ltd., Tokyo, Japan). The test was performed at a crosshead speed of 10 mm/min. The dimension of the specimen used was 165 mm × 19 mm × 4.1 mm. Static flexural tests were carried out according to *ASTM: D 790-10* using the same testing machine mentioned above at the same crosshead speed. The dimension of the specimen used was 79 mm × 10 mm × 4.1 mm. Dynamic Charpy impact test was conducted according to *ASTM: D 6110-10* using a universal impact testing machine. Notched composite specimen was used during the experiment. The dimension of the specimen used was 127 mm × 12.8 mm × 4.1 mm. The hardness tests of the composites were carried out using a Shore hardness testing machine. The water absorption tests of the composites were carried out following *ASTM: D 570-98*. To measure the water uptake capacity of the composites, rectangular specimen of dimension 76 mm × 25 mm × 3.4 mm was prepared. From the difference of the final and initial weights before and after immersion in a water bath for 24 h, percentage of water uptake was calculated. In each test and type of composite, 10 specimens were tested and the average values are reported.

3. Results and discussion

3.1. Tensile properties

The tensile strength of raw and treated coir fiber reinforced PP biocomposites at different fiber loading is shown in Fig. 1. It is observed from the figure that the tensile strength of the raw coir reinforced PP composites decreased with fiber loading. Similar results were also reported by other researchers [2,3,6,8,18–20]. Coir fiber is hydrophilic in nature, whereas the nature of PP is hydrophobic. Thus, the hydrophilic coir does not interact well with the hydrophobic PP. When the fiber loading was increased, the weak interfacial area between the coir fiber and PP matrix increased. As a result the tensile strength decreased. It is also observed from the figure that the tensile strength of PP biocomposites reinforced with chemically treated coir also changed with fiber loading. In treated

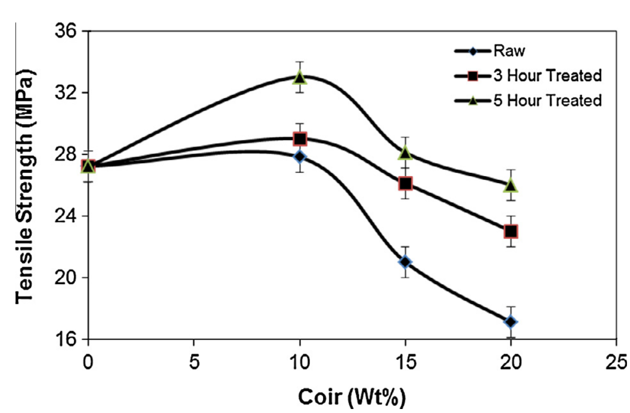

Fig. 1. Variation of tensile strength of PP biocomposites reinforced with raw, 3 h treated and 5 h treated coir.

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