Properties of Jute and Sheep Wool Fiber Reinforced Hybrid Polypropylene Composites

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Abstract. Use of plant and animal-based biodegradable resources as reinforcement in polymeric composites has incontestable advantages compared to synthetic fiber composites-including low density, low cost, continuous supply, easy and safe handling and supports their potential across a wide range of applications. Hybrid fiber reinforced composites are generally prepared to enhance different properties as compared to single-fiber reinforced composites. In present research, sheep wool fiber and jute fiber reinforced hybrid polypropylene composites were prepared. Their mechanical properties were examined first by varying the fiber and polypropylene ratio and then by varying wool and jute fiber ratio keeping the polypropylene quantity unchanged. Here, 5%, 10% and 15% of the fibers in a ratio of 1:1 were copulated with polypropylene in a hot press machine. For mechanical characterization, tensile, flexural, impact and hardness tests were conducted. From these tests, it was observed that the composite with 15% fiber content had the best properties. For further enhancement, two separate samples with 1:3 and 3:1 fiber ratios and 85% polypropylene were prepared. Running the aforementioned tests, it was revealed that the sample with wool and jute fiber at 1:3 ratio had the best set of properties.

Keywords. Hybrid composite; Sheep wool fiber; Jute fiber; Polypropylene; Mechanical properties

1. Introduction

Recently, people have realized that the whole world will be threatened by the over consumption of natural resources if the environment is not conserved. For that reason there has been a rapid growth in research and innovation in the natural fiber composite (NFC) area. It has also become attractive as an alternative reinforcement for fiber reinforced polymer (FRP) composites due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradability characteristics. They are exploited as a replacement for the conventional fiber, such as glass, aramid and carbon [1]. Among all the thermoplastics, polypropylene (PP) has great properties like good fatigue resistance, very good abrasion resistance, good surface hardness, lower density, higher softening point and higher rigidity. PP does not create stress-cracking problems and it has also excellent electrical and chemical resistance at higher temperatures [2]. As natural fiber, jute and sheep wool fiber both are easily available and also cheap in Bangladesh. Wool is the most commonly used animal fiber which is obtained from the soft, hairy covering of sheep. They have good elasticity and resilience. Jute is annually regenerative, ligno-cellulosic self-composite biopolymer bast fiber. It is nonabrasive, has low density and high strength. Because of these reasons, it was decided to use jute fiber as a reinforcing fiber in the thermoplastic composite [2, 3].

Polymer matrix composites (PMCs) are used widely because they are strong and lightweight materials. The fibers provide strength and stiffness to the material, while the matrix holds the fibers in place and transfers internal load between them. Only simple equipments are required to produce PMCs. PMCs do not require high pressures or high temperatures. Therefore the possibilities of fiber damage and degradation are minimum [4]. The behaviour of hybrid composites is a weighed sum of the individual components in which there is a more favourable balance between the inherent advantages and disadvantages. Also, using a hybrid composite that contains two or more types of fiber, the advantages of one type of fiber could compliment with what are lacking in the other. As a consequence, a balance in cost and performance can be achieved through proper material design [5]. Thus, combination of these two fibers in making composite is a new work. The main goal of present research is to prepare hybrid composites from jute and sheep wool fiber and determine their mechanical properties. The effects of fiber loading and fiber ratio on mechanical properties of prepared composites are also evaluated.

2. Methodology

2.1 Collection of Fibers and Polypropylene Resin
At first, jute and sheep wool both were collected from the local market. Jute single fibers were separated from the bundle. Then the fibers were dried in normal atmosphere to remove moisture. Commercial grade polypropylene (PP) was collected from the local market. It was white in color and granular in form, having a melting point of 160^0C.

2.2 Composite Preparation
Hybrid composite was prepared in five different steps. At first fibers were weighted according to the required weight fraction needed. Then both fibers were cut into 3mm size in length. The required amount of polypropylene was weighted. To prevent voids, water bubbles, poor fiber matrix adhesion of the polypropylene, the fibers were dried in an oven at about 80-110^0C for around 40 minutes. Then the mould surface was cleaned very carefully and a mould releasing agent (silicon spray) was sprayed all over the mould surface properly for the easy removal and a good surface finishing of the product. After preparing the mould, a layer of polypropylene was poured onto one part of it. Chopped fibers were evenly spread out on this layer. Then finally a second layer of polypropylene was given on the chopped fiber. Care was taken so as to ensure uniform distribution of the fibers and the matrix throughout the entire sample. Then the mould with randomly oriented fiber and polypropylene were covered with another part of the mould according to the indication provided in both the mould sections. Finally the die was placed in a hot press machine. A hydraulic type machine having capacity of maximum load of 50KN and maximum temperature of 300°C was used. The fiber matrix mixture was allowed to press at 30KN pressure. The temperature was initially raised to 160°C and held for 20 minutes. After that the temperature was raised to 195°C. As soon as this temperature was reached, the dial was brought down to 0^0C and water cooling system was turned on. The die was then cooled to room temperature, pressure was released and the specimen was carefully withdrawn from the die. This same procedure was applied for other percentage and ratios of fibers.

2.3 Mechanical Tests
*2.3.1 Tensile Test.*Tensile tests were carried out according to ASTM D 638-01 using an Instron machine, having a maximum capacity 50 kN. Each test was continued until tensile failure. The tensile properties as obtained from this test method indicates the stress of the composite specimen, their fracture characteristics under tensile load, load strain behaviour bearing properties of fiber and the matrix materials. To perform the tensile test, at first the dimensions of the specimen were taken. Then the test machine was calibrated following the standard chart. After that the ultimate tensile strength (UTS) was calculated from the following formula:

$$\text{UTS} = \frac{maximum\ load}{initial\ area}\text{(MPa)} \quad \text{or} \quad \sigma = {Pmax}/{A}\ \text{(MPa)} \tag{1}$$

The modulus was calculated by taking the slope of the stress-strain curve.

2.3.2 Flexural Test. Flexural test of the composite specimens was conducted according to ASTM D 790-00 using the same Instron machine. The loading nose and supports were aligned in such a way that the axis of the cylindrical surfaces was parallel and the loading nose was midway between the supports. The load was applied to the specimen at the specified cross head motion and simultaneously load deflection data was taken. The test was terminated when rupture occurred at the outer surface of the test specimen. The flexural stress was calculated by means of the following equation:

$$\sigma_f = (3PL)/(2bd^2) \tag{2}$$

Where, σ_f is the stress in the outer fibers at midpoint, P is the load, L is the length of support span, b is the width of beam, and d is the depth of beam. Again, flexural modulus was calculated by means of the following equation:

$$E_B = (L^3m)/(4bd^3) \tag{3}$$

Where, m is the gradient (i.e. slope) of the initial straight-line portion of the load deflection curve.

2.3.3 Impact Test. Impact strength is generally defined as the resistance of a material to fracture by a blow or impact loading, expressed in terms of the amount of energy absorbed before fracture. It is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture which is a measure of a given material's toughness. The dynamic Charpy impact test of the composite was conducted using an impact tester MT 3016 and specimen were prepared according to ASTM D 6110-97.

2.3.4 Hardness Test. Hardness is defined as the ability of a material to resist plastic deformation. The hardness of the composite was measured using a shore hardness tester. Shore Durometer is typically used as a measure of hardness in polymer, elastomers and rubbers. There are several scales of durometer, used for materials with different properties. The A scale is for softer plastics, while the D scale is for relatively harder ones. In present research D scale was used.

3. Results and discussion

3.1 Effect of Fibre Loading

3.1.1 Tensile Properties. Tensile properties of the composite samples were measured for each fiber content (5, 10 and 15 wt%) with the help of stress/strain curves. The variation of these properties for different percentage weights of raw sheep wool and jute fiber (wool: jute=1:1) reinforced hybrid polypropylene composites are shown in figure 1. Tensile strength of prepared composites increased with fiber loading, as shown in figure 1 (a). Young's modulus values of jute and wool fiber reinforced polypropylene composites for different fiber loadings are shown in figure 1 (b). It is observed that Young's modulus increased with an increase in fiber loading [6, 7]. This is because with an increase in fiber content, the brittleness of the composite increased and stress/strain curves became steeper. Poor interfacial bonding creates partially separated micro spaces which obstruct stress propagation between the fiber and the matrix. As the fiber loading increases, the degree of obstruction increases, which in turn increased the stiffness [8].

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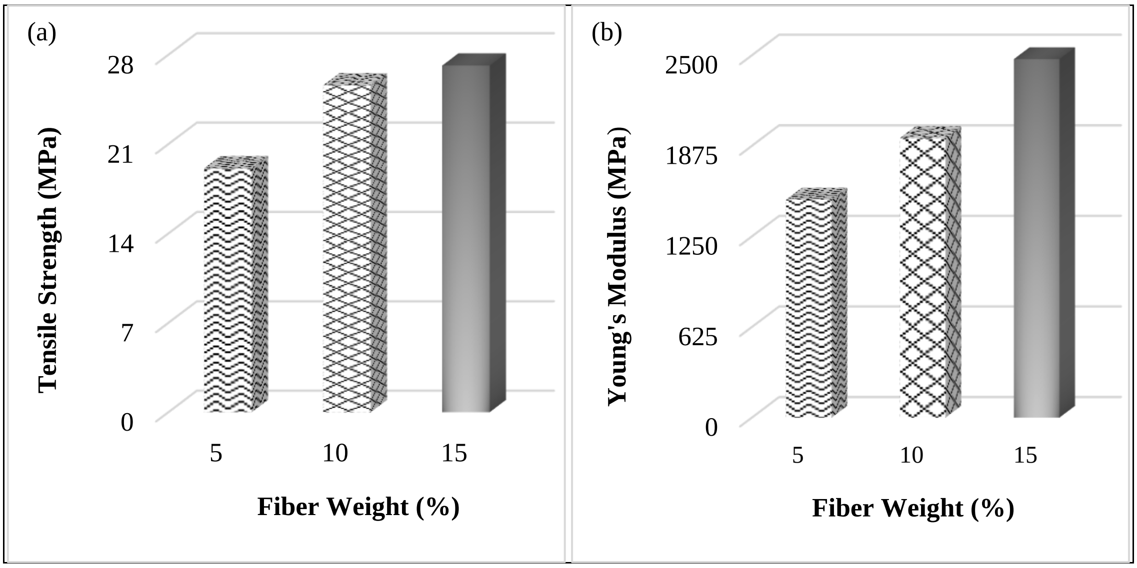

Figure 1. Variation of (a) tensile strength and (b) Young's modulus against fiber loading.

3.1.2 Flexural Properties. Flexural properties were measured for samples of each fiber content with the help of flexural stress/strain curves and respective equations. Flexural strength and flexural modulus of raw sheep wool and jute fiber reinforced hybrid polypropylene composites at different fiber loadings (wool: jute=1:1) are shown in figure 2. Both of these properties increased with an increase in fiber loading [6, 7]. The reason behind the increase in flexural strength may be due to the favourable entanglement of the polymer chain with the filler which has overcome the weak filler matrix adhesion with increasing fiber content [8]. The flexural modulus values increased with an increase in fiber loading. Since both jute and wool are high modulus material, higher fiber concentration demands higher stress for the same deformation [9]. So the coalition of the filler (rigid jute and wool fiber) with the soft polypropylene matrix results into the rise in the modulus.

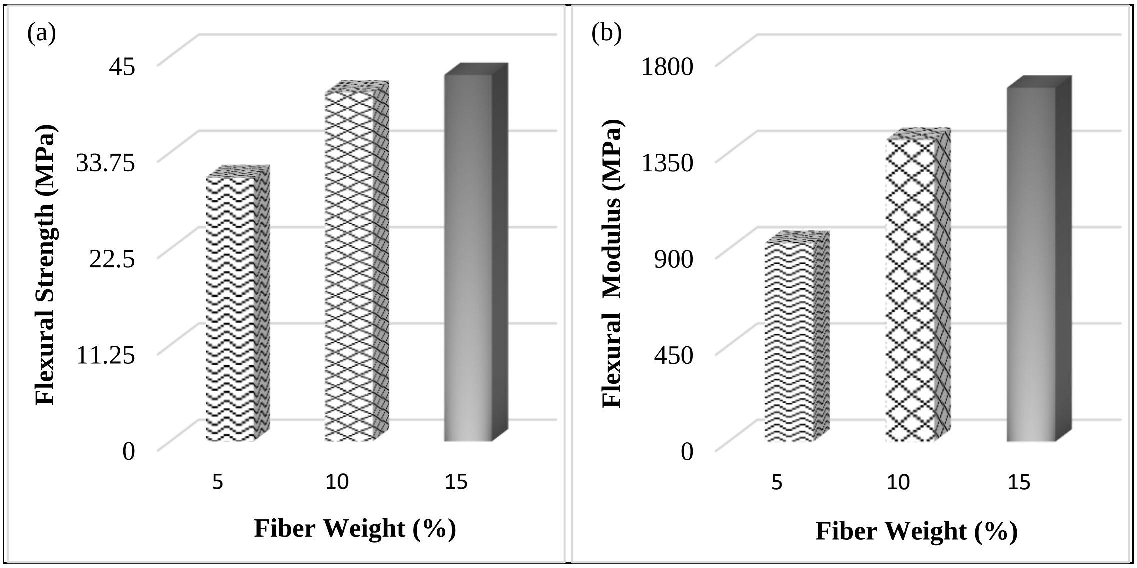

Figure 2. Variation of (a) flexural strength and (b) flexural modulus against fiber loading.

*3.1.3 Impact Properties.*Variation of Charpy impact strength with different fiber loading for raw jute and sheep wool fiber (jute: wool= 1:1) reinforced hybrid composite is shown in figure 3 (a). Impact strength increased with fiber loading [8, 10]. Impact strength of a material provides information regarding the energy required to break a specimen of given dimension, the magnitude of which reflects the material's ability to resist sudden impact. The impact strength of the fiber reinforced polymeric composites depends on the nature of the fiber, polymer and fiber-matrix interfacial bonding [11]. As presented in the figure, impact strength of all composites increased with fiber loading. This result suggests that the fiber was capable of absorbing energy because of favourable entanglement of fiber matrix. Fiber pull out is found to be an important energy dissipation mechanism in fiber reinforced composites. One of the factors of impact failure of a composite is fiber pulled out. With the increase in fiber loading, stronger force is required to pull out the fibers. This in turn increased the impact strength.

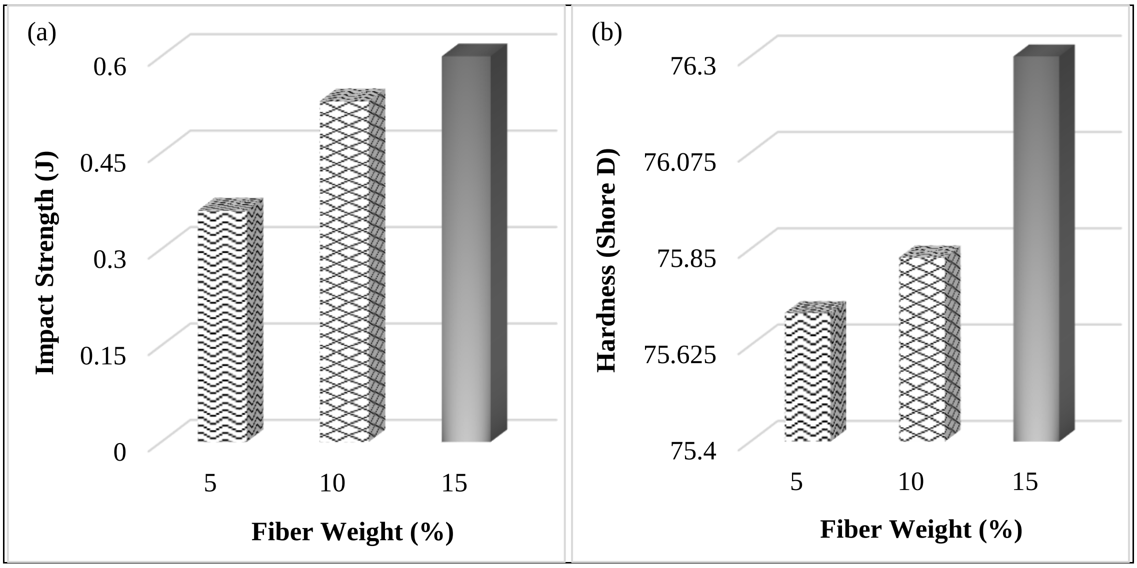

Figure 3. Variation of (a) impact strength and (b) hardness against fiber loading.

3.1.4 Hardness Test Results. The polypropylene matrix is a soft matrix. Incorporation of fiber into it makes the composite hard. So the hardness of composite is higher than polypropylene matrix which is observed in figure 3 (b). Hardness of a composite depends on the distribution of filler into the matrix and incorporation of fiber into polypropylene matrix. This reduces the flexibility of the matrix which results in more rigid composite [10].

3.2 Effects of Fibre Ratio

3.2.1 Tensile Properties. Variations of tensile strength and Young's modulus of composites with different ratio of wool and jute fiber are shown in figure 4. The value of tensile strength is different at different fiber ratio. The best value is shown by composite containing wool and jute fiber ratio of 1:3. An increase in jute fiber ratio resulted in the enhancement of tensile strength by 3.32%, whereas increase in wool fiber ratio resulted in the decrease of tensile strength by 14.44%. The enhancement of jute fiber ratio also resulted in enhancement of Young's modulus by 5.16% and that of wool fiber resulted in a decrease by 6.31%. Tensile strength of any composite are related to the chemical composition of the fiber and their respective internal structure [12]. The tensile strength of wool is 1-1.7 MPa, whereas tensile strength of jute fiber is 20-25 MPa. Jute fiber has also high cellulose content which plays important role in contributing to the strength of natural fiber .So the high value of tensile strength of composites containing more jute fiber is related to its single fiber properties according to which the tensile strength of single jute fiber is higher compared to sheep wool fiber. As jute fiber has higher modulus (13-26 GPa) compared to wool fiber (1.4 GPa) so higher concentration of jute fiber incorporation demands higher stress for the same deformation and results into the enhancement of Young's modulus [13].

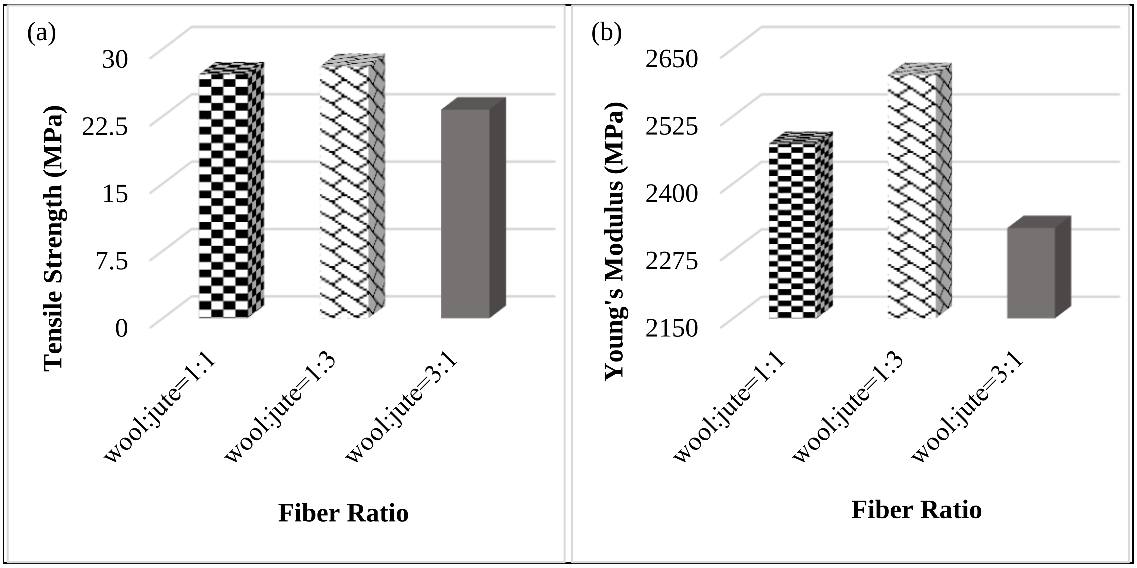

Figure 4. Variation of (a) tensile strength and (b) Young's modulus against fiber ratio.

3.2.2 Flexural Properties. The flexural strength was changed with different fiber ratio. Enhancement of wool and jute ratio from 1:1 to 1:3 resulted in enhancement of flexural strength by 7.17%, whereas enhancement of wool content resulted in a decrease in flexural strength by 11.66%. The higher cellulose content and the smaller percentage of hemicellulose and lignin may be the reason behind the higher bending properties of high jute containing composite in comparison with higher wool carrying one. The incorporation of 75% higher modulus fiber jute resulted in an enhancement of flexural modulus of 9.29% as compared to 50% jute incorporated composite. On the other hand, 75% wool fiber in the composite resulted in a decrease in flexural modulus by 11.33% as compared to 50% jute incorporated composite. Jute is a plant fiber. So high cellulose content may be the reason of the higher bending properties of high jute containing composite in comparison with higher wool carrying one [2].

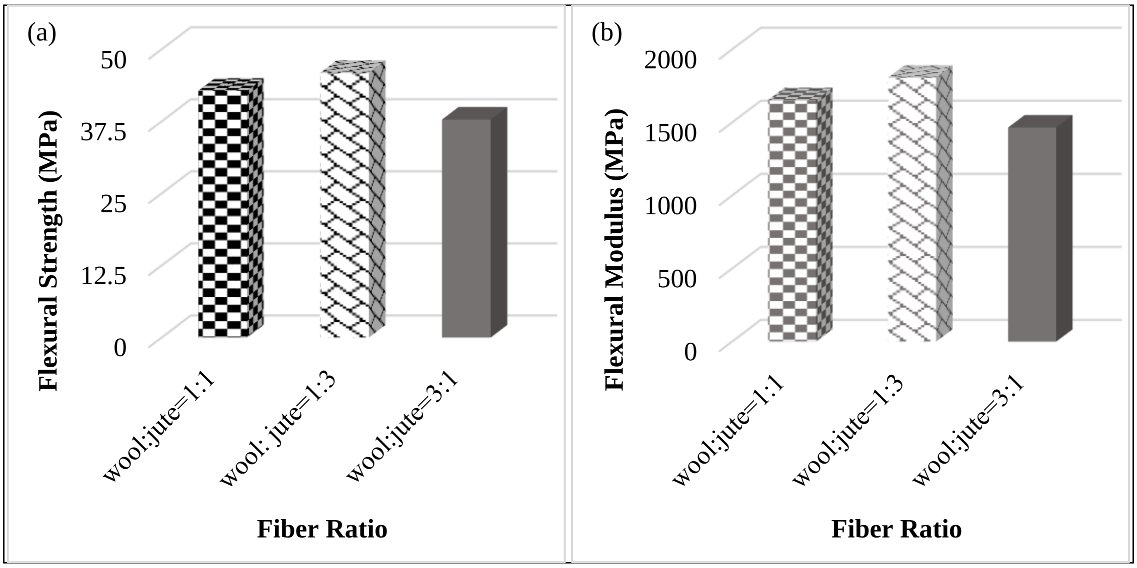

Figure 5. Variation of (a) flexural strength and (b) flexural modulus against fiber ratio.

3.2.3 Impact and Hardness Properties. The composites with high volume fraction of jute fiber showed higher impact strength as compared to the composite with high volume fraction of wool fiber. Jute increases the bonding capability and the area under stress-strain curve and so produces greater impact strength [14]. The change in fiber ratio did not affect the hardness data much as expected. Jute percentage enhancement to 50% and 75% from 25% resulted in enhancement of hardness value by 7.16% and 5.48% respectively.

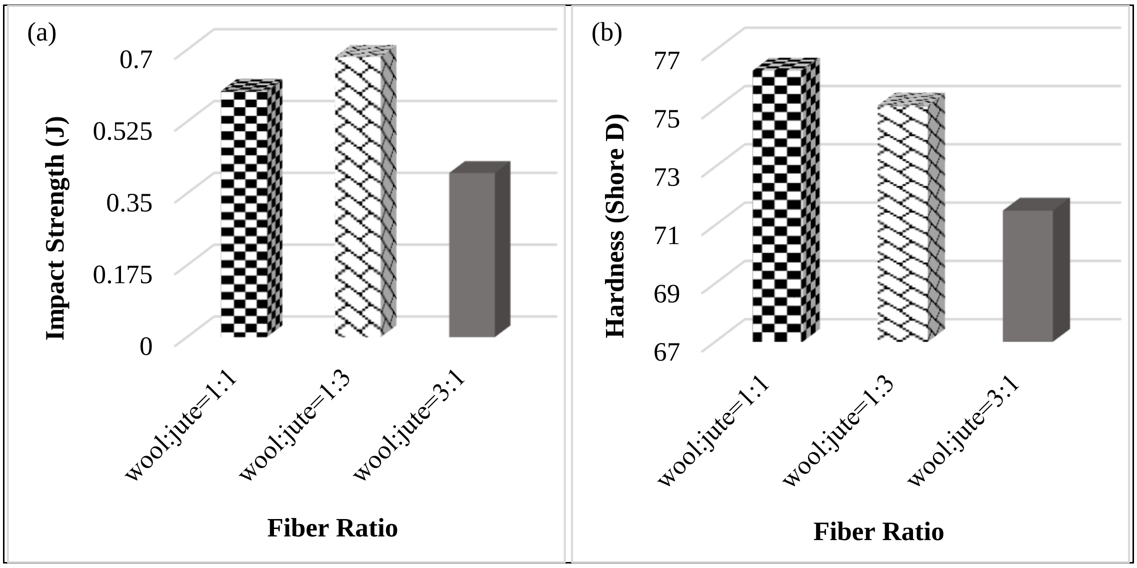

Figure 6. Variation of (a) impact strength and (b) hardness against fiber ratio.

4. Conclusion

Development of new composite products from the easily renewable natural materials has a strong potential to deliver novel biodegradable and recyclable materials suitable for the automotive, packaging industry and all other applications. Polypropylene is soft as compared to jute and wool fiber. In present research, jute fiber and sheep wool fiber reinforced hybrid polypropylene composites were prepared by varying fiber loading and fiber ratio. Prepared composites were subsequently characterized. Mechanical properties increased with an increase in fiber loading. Best set of properties were obtained from 15% fiber loading with jute and wool fiber ratio of 3:1. These tests could help further to unveil other properties besides mechanical ones and help in comparison of raw fibers with chemically treated fibers in future.

5. References

[1] Ku H, Wang H, Pattarachaiyakoop N and Trada M 2011*A review on the tensile properties of natural fiber reinforced polymer composites,* Composites B, Vol. 42(2), pp. 856-873.

[2] Siddika S, Mansura F and Hasan M 2014*Effect of reinforcement and chemical treatment of fiber on the properties of jute-coir fiber reinforced hybrid polypropylene composites*,Fibers and Polymer, 15(5), pp. 1023-1028.

[3] Rana A K, Mandal A, Mitra B C, Jocobson R, Rowell R and Banerjee A N 1998 *Short jute fiber reinforced polypropylene composite: Effect of compatibilizer,* Journal of Applied Polymer Science, Vol.69, pp.329-338.

[4] Srinivasan K 2009 *Composite Materials* (UK: Alpha Science International Ltd).

[5] Sathishkumar T P, Naveen J and Satheeshkumar S 2014 *Hybrid fiber reinforced polymer composites – a review*, Journal of Reinforced Plastics and Composites, Vol. 33(5), pp. 454-471.

[6] Rana A K, Mandal A and Bandyopadhyay S 2003 *Short jute fiber reinforced polypropylene composite: Effect of compatibilizer, impact modifier and fiber loading*, Composites Science and Technology, Vol. 63, pp.801-806.

[7] 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.

[8] 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 Structure, Vol. 72, pp. 429-437.

[9] Mansour R, Osmani H, Abdellatif I and Noureddine B 2011 *Effect of chemical treatment on flexure properties of Natural Fiber-Reinforced Polyester Composite*, Procedia Engineering, Vol. 10, pp. 2092-2097.

[10] 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.

[11] Jayaraman K 2003 *Manufacturing sisal-polypropylene composites with minimum fiber degradation,* Composites Science and Technology, Vol.63, pp. 367-374.

[12] Maschinenwesen D F 2006 *Investigation on Jute Fibers and their Composites based on Polypropylene and Epoxy Matrices* (Vietnam: Technischen Universitat Dresden)

[13] Feughelman M and Robinson M S 1971 *Some mechanical properties of wool fibers in the 'Hookean' region from zero to 100% relative humidity,* Textile Research Journal, Vol. 41(6), pp. 469-474.

[14] Kumar M and Singh S 2013 *Analysis of mechanical properties and cost of glass/jute fiber-reinforced hybrid polyester composites*, Journal of Materials: Design and Applications, Vol. 229(3), pp. 202-208.

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