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Property Enhancement of Polypropylene Composites through Plant and Animal Fiber Hybridization

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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; such as low density, low cost, continuous supply, easy and safe handling. Hybrid fiber reinforced composites are generally prepared to enhance different properties as compared to single fiber reinforced composites. In present research, sheep wool (animal) and jute (plant) fiber reinforced hybrid polypropylene composites were prepared by varying fiber ratio and fiber loading in a hot press machine. For mechanical characterization, tensile and flexural tests were conducted. From these tests, it was observed that the composite with 15 w.% fiber content had the best set of properties. For further enhancement, two separate samples with 1:3 and 3:1 fiber ratio's 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. After that, thermo-gravimetric analysis and scanning electron microscopic analysis of the prepared composites were carried out. 15 wt.% sheep wool and jute fiber (wool:jute = 1:3) reinforced composite had the best adhesion between fiber and matrix and had the best thermal stability.

Keywords: *Hybrid Composites; Jute and Sheep Wool Fiber; Mechanical Properties; TGA; SEM*

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 [1, 2]. It has also become attractive as an alternative reinforcement for fiber reinforced polymer (FRP) composites because of 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 [3, 4].

Polypropylene is a thermoplastic polymer and can be made by polymerizing molecules. Scientists prefer thermoplastic matrices than thermosets due to low production cycle, lower cost of processing and high reparability of thermoplastics. 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. They are strong and lightweight. The fibers provide strength and stiffness to the material and matrix holds the fibers in place and transfers internal load between them. PP does not create stress-cracking problems and it also has excellent electrical and chemical resistance at higher temperature [5, 6].

As natural fibers, jute and sheep wool fiber both are easily available in Bangladesh and they are cheap. Wool isthe most commonly used animal fiber,which is obtained from the soft hairy covering of sheep. Wool is flame-resistant and its natural moisture content makes it non- combustible. This fiber has good

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elasticity and resilience. Jute is annually regenerative, lignocellulosic self-composite biopolymer bast fiber. Jute fiber is 100% bio-degradable and recyclable, and thus environmentally friendly. It is nonabrasive, has low density and high strength. Jute Fiber can be blended with Natural and Synthetic fibers. It is one of the most versatile natural fibers that have been used in raw materials for packaging, textile, non-textile, and agricultural sectors. Because of these reasons, jute fiber and wool fiber were used as reinforcing fibers in the thermoplastic composite [5, 7].

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 [8]. The behavior of hybrid composites is a weighed sum of the individual components in which there is a more favorable 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 [9, 10].

A number of researches have been carried out so far on hybrid fiber reinforced polymer composites [5, 9, 10]. However, according to author’s best knowledge, plant and animal based fiber hybridization has never been used to reinforce polypropylene. The present research describes preparation of hybrid polypropylene composites using jute plant and sheep wool animal fiber as reinforcement. It further discusses mechanical, thermal and morphological property enhancement of prepared composites through fiber hybridization.

Materials and Methods:

Collection of Fibers and Polypropylene: Both jute and sheep wool were collected from the local market. Ignition temperature of jute fiber is around 195^0C, while melting point of sheep wool fiber is around 400^0C. Jute single fibers were separated from the bundle. Then they 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.

Preparation of Composites: 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.

Fig. 1. Picture of hybrid composite specimens.

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 ratio's of fibers. Picture of hybrid composite specimens prepared in present research is shown in Figure 1.

Characterization Techniques: 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. 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. Thermogravimetric analysis or thermal gravimetric analysis (TGA) is a method of thermal analysis in which the mass of a sample is measured over time as the temperature changes in a controlled atmosphere. In present research, TGA was carried out in a universal instrument (TGA Q50 V6.4) at a temperature range of 25-500 °C with a constant heating rate of 10°C/sec. The morphology and interfacial bonding between the jute-sheep wool fiber and polypropylene matrix in prepared composites was examined under a scanning electron microscope (Model: Philips XL 30).

Results and Discussion:

Tensile Properties: Effect of Fiber Loading: Variation of tensile properties of raw sheep wool and jute fiber (wool: jute=1:1) reinforced hybrid polypropylene composites against fiber loading are shown in Figure 2. Tensile strength of prepared composites increased with fiber loading upto 15 wt.% (Figure 2 (a)). The probable reason is that both fibers are stronger than polypropylene. Hence, strength increased with increase in fiber loading. With the rise of fiber quantity in the composite, the adhesion also gradually increased upto 15 wt.%. This led to continuous increase in strength. But for 20 wt.% fiber loading, adhesion between the fiber and matrix might not be proper, leading to decrease in strength.

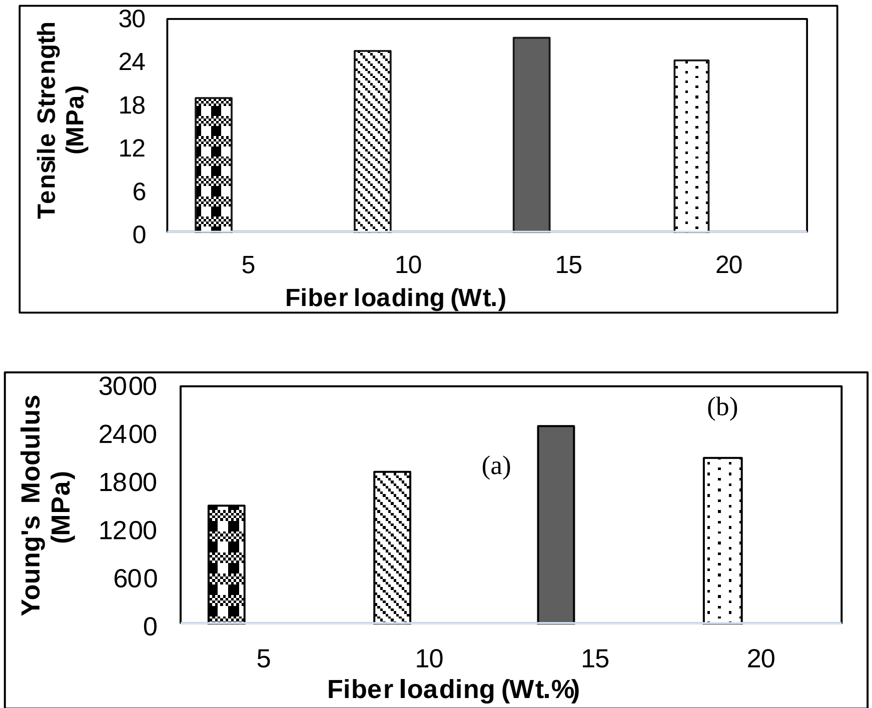
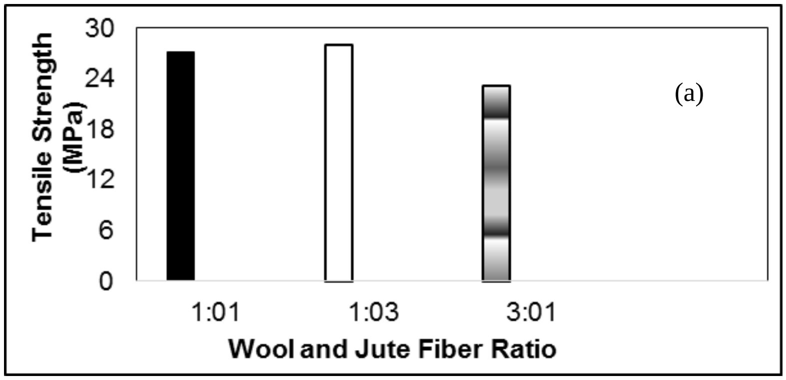


Fig. 2. Variation of (a) tensile strength and (b) Young's modulus against fiber loading.

Variation of Young's modulus values of wool and jute fiber reinforced polypropylene composites against fiber loadings are shown in Figure 2 (b). It is observed that Young's modulus increased with an increase in fiber loading. 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. The tensile properties of the wool-jute fiber composites increased till 15 wt.% of the fiber loading, further increment of the fiber content (20 wt.% loading) showed a decline in the properties because of formation of agglomerates, which block stress transfer. Another factor that may have contributed to this decline in strength and modulus is the increase of porosity in the composite during processing, due to insufficient wetting of fibers.

Effect of Fiber Ratio: Variation of tensile strength and Young's modulus of composites with different ratio of wool and jute fiber are shown in Figure 3. Both tensile strength and Young's modulus increased with increase in jute content of the composite. Composite containing wool and jute fiber ratio of 1:3 gave the best values. This is because of the tensile strength of wool is 1-1.7MPa, whereas tensile strength for jute fiber is 20-25MPa. Jute fiber also contains high cellulose content that contribute in increasing strength of the 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. Jute fiber has higher modulus (13-26 GPa) as compared to wool fiber (1.4 GPa). So higher concentration of jute fiber incorporation demands higher stress for the same deformation that enhanced the Young's modulus of the 75% jute fiber containing composite.



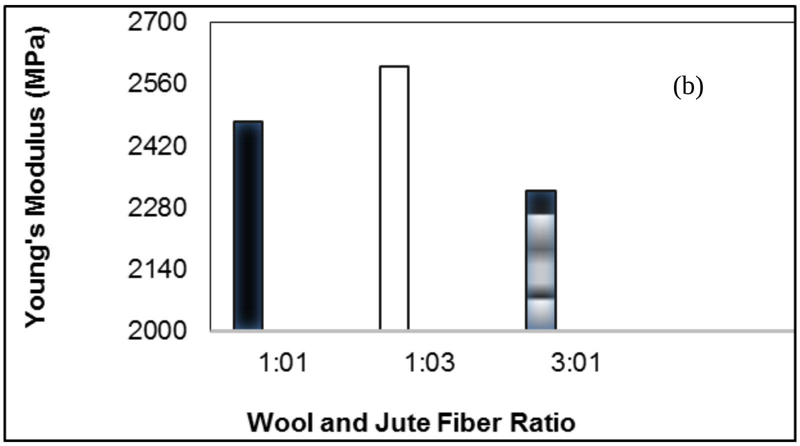


Fig. 3. Variation of (a) tensile strength and (b) Young's modulus against fiber ratio.

Flexural Properties

Effect of Fiber Loading: Variation of flexural strength and flexural modulus of sheep wool and jute fiber reinforced hybrid polypropylene composites at different fiber loadings are shown in Figure 4. Both of these properties increased with an increase in fiber loading [11, 12] upto 15 wt.%. The reason behind the increase in flexural strength is due to the favourable entanglement of the polymer chain with the filler which has overcome the weak filler matrix adhesion with increasing fiber content [13]. The flexural modulus values also 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 [14]. So the coalition of the filler (rigid jute and wool fiber) with the soft polypropylene matrix results into the rise in the modulus. The flexural properties (strength and modulus) of the jute-wool fiber composites increased till 15 wt.%fiber loading. Further increment in fiber content (20 wt.%) showed a decline in the properties because of formation of agglomerates that blocked stress transfer. The other probable reason behind the decrease in strength and modulus values is the presence of porosity. The porosity arises due to inclusion of air during processing, limited wettability of fibers, lumens and other hollow features within fiber bundles that might become close during processing at high pressure [15].

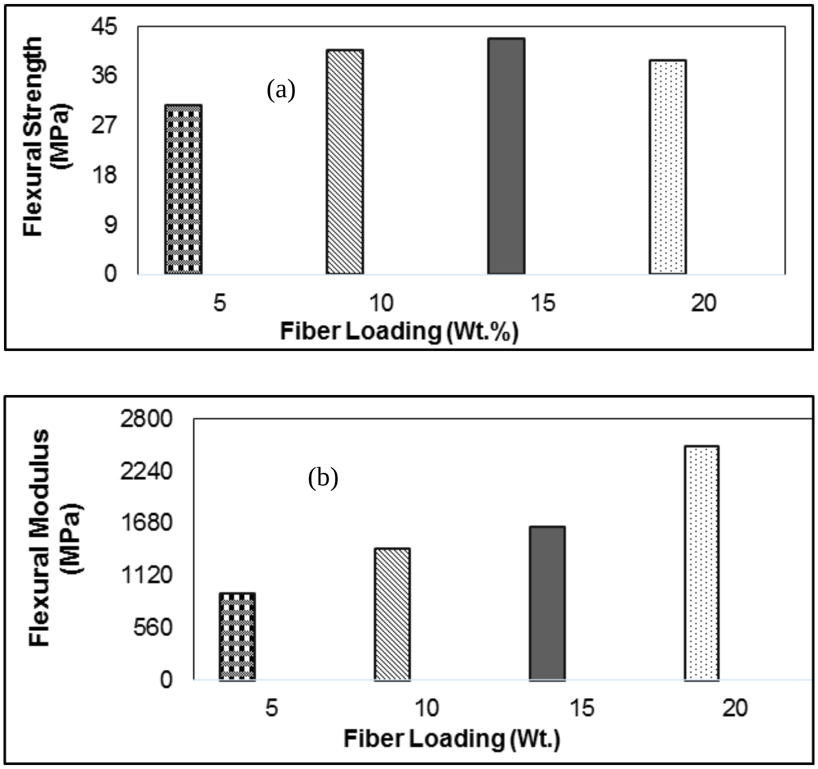
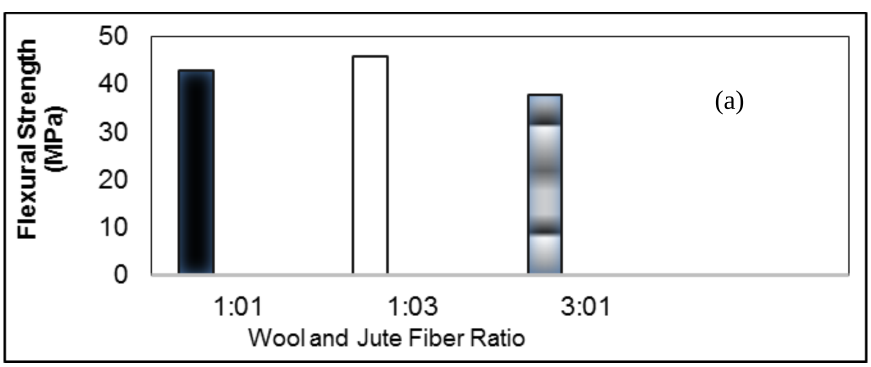


Fig. 4. Variation of (a) flexural strength and (b) flexural modulus against fiber loading.

Effect of Fiber Ratio: Variation of flexural strength and flexural modulus of sheep wool and jute fiber reinforced hybrid polypropylene composites against fiber ratio are shown in Figure 5. From the figure, it is clear that 1:3 wool and jute fiber containing composite had higher flexural strength and flexural modulus. As jute is a plant fiber it has high cellulose content and it also contains hemicellulose and lignin. On the other hand, wool fiber does not contain any cellulose as it is an animal fiber. The higher cellulose content and the smaller percentage of hemicellulose and lignin is the reason behind higher bending properties. This is the reason of higher flexural properties of high jute containing composite in comparison with higher wool carrying one [15-17].



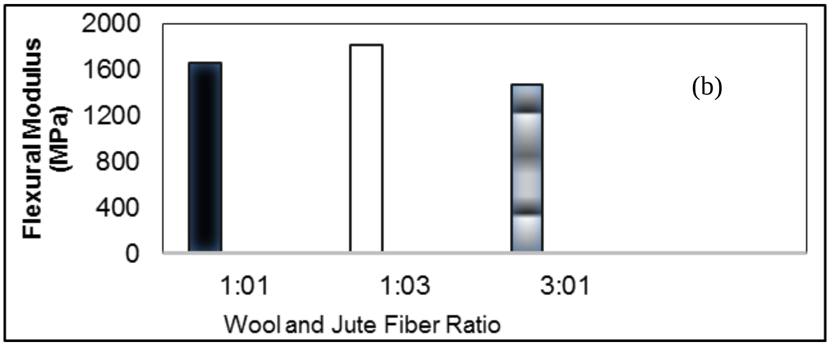


Fig. 5. Variation of (a) flexural strength and (b) flexural modulus against fiber ratio.

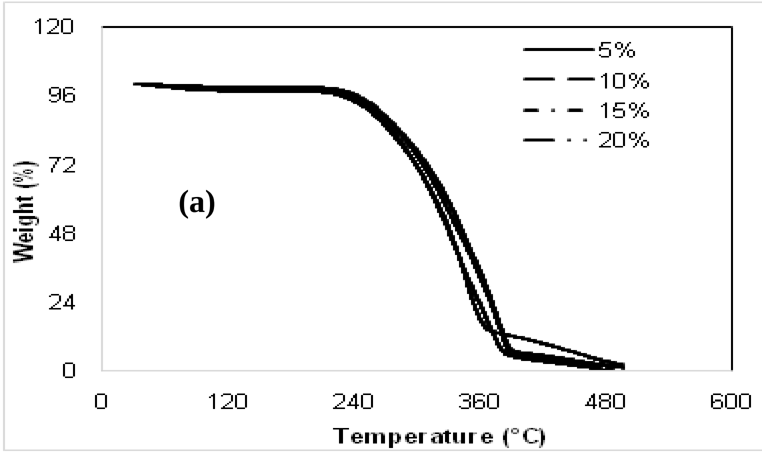
Thermo-Gravimetric Analysis Results

Effect of Fiber Loading: TGA is mainly used to characterize the decomposition and thermal stability of material. For manufacturing fiber reinforced composites, thermal stability of fiber is very important. From TGA curves shown in Figure 6, it can be observed that all the composites displayed a two-step decomposition process. From the weight loss of these composites, it is seen that an initial weight loss of 15 wt.% wool-jute fiber reinforced composite is comparatively low (2.0%) as compared to other composites. It had highest initial decomposition temperature at around 231.2^{o}C. This was usually associated with evaporation of water from the fiber surface. In practice, even if a natural fiber undergoes oven-drying before incorporation into a polymer composite, the total elimination of water is not possible because of the hydrophilic characteristic of the fiber.

The thermal stability of a composite depends on the range of temperature along, which it can withstand the temperature effect. For 5, 10 and 20 wt.% fiber loaded composites, the initial weight loss were 3.1%, 3.4% and 3.8% at temperatures of 223.5^{o}C, 236.0^{o}C and 224.4^{o}C respectively. After initial degradation, there was a steep decrease in wt% for in TGA curves. That means a major amount of degradation occurred at these temperature ranges. For 15 wt.% wool-jute fiber reinforced composite, the final degradation temperature was found to be 389.1^{o}C. It was higher than final degradation temperature of 5, 10 and 20 wt.% fiber loaded composites with values of 381.1^{o}C, 389.5^{o}C and 362.8^{o}C respectively. The residual weight loss of various prepared composites is mentioned in Table 1.

Effect of Fiber Ratio: TGA curves of hybrid composites at different fiber ratio are shown in Figure 5 (b). An initial weight loss of 2.6 wt.% was observed in 1:1 wool-jute fiber reinforced composite at around 231.2^{o}C. For 1:3 and 3:1 ratio of wool-jute fiber reinforced composites, the initial weight loss was found to be 1.8 wt.% and 1.6 wt.% at temperatures of 219.0^{o}C and 221.6^{o}C respectively that are lower than the initial degradation temperature of 1:1 ratio . But the degradation temperature range for 1:3 ratio of wool-jute fiber was higher than that of 1:1 and 3:1,

where their final decomposition temperatures were found to be 377.6^{o}C, 389.1^{o}C and 379.8^{o}C respectively. So, among the three ratios, the 1:3 ratio of wool-jute fiber reinforced composite had the highest thermal stability.



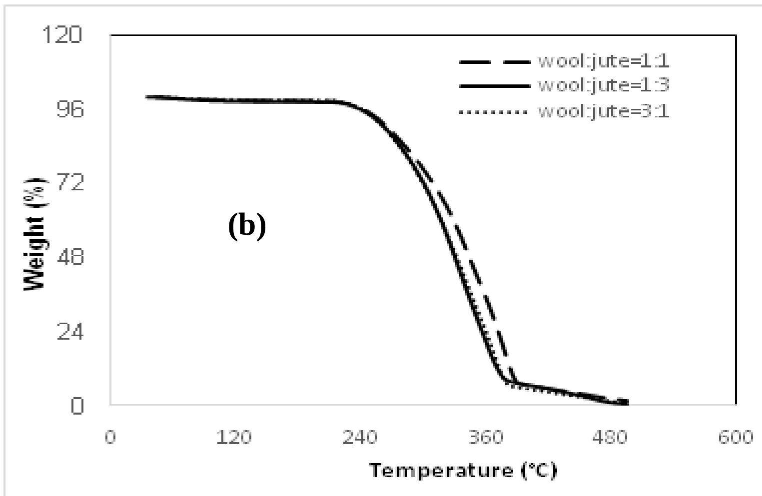


Fig. 6. TGA curves of wool and jute fiber reinforced hybrid composites against (a) fiber loading and (b) fiber ratio.

Table 1. Residual weight loss of prepared composites

Composite Type	Residual Weight Loss (%)
5 wt% fiber (1:1) sheep wool and jute reinforced PP composites	2.1
10 wt% fiber (1:1) sheep wool and jute reinforced PP composites	2.4
15 wt% fiber (1:1) sheep wool and jute reinforced PP composites	2.6
20 wt% fiber (1:1) sheep wool and jute reinforced PP composites	2.9
15 wt% fiber (3:1) sheep wool and jute reinforced PP composites	2.5
15 wt% fiber (1:3) sheep wool and jute reinforced PP composites	3.2

Surface Morphology: Tensile fracture surface of prepared wool-jute fiber reinforced hybrid polypropylene composites are shown in Figure 7. The important feature of these micrographs is that fracture, fiber pull out and debonding are shown. SEM micrograph of 15 wt % (1:1) fiber reinforced composite indicates slightly stronger adhesion and favorable entanglement between the fiber and the matrix (Figure 7 (c)) as compared to other composites prepared at 1:1 wool and jute fiber ratio.However, best adhesion of fiber and matrix is observed in case of 1:3 wool-jute fiber composite (Figure 7 (f)). As a result, this composite yielded be set of mechanical properties among all prepared composites [5, 18].

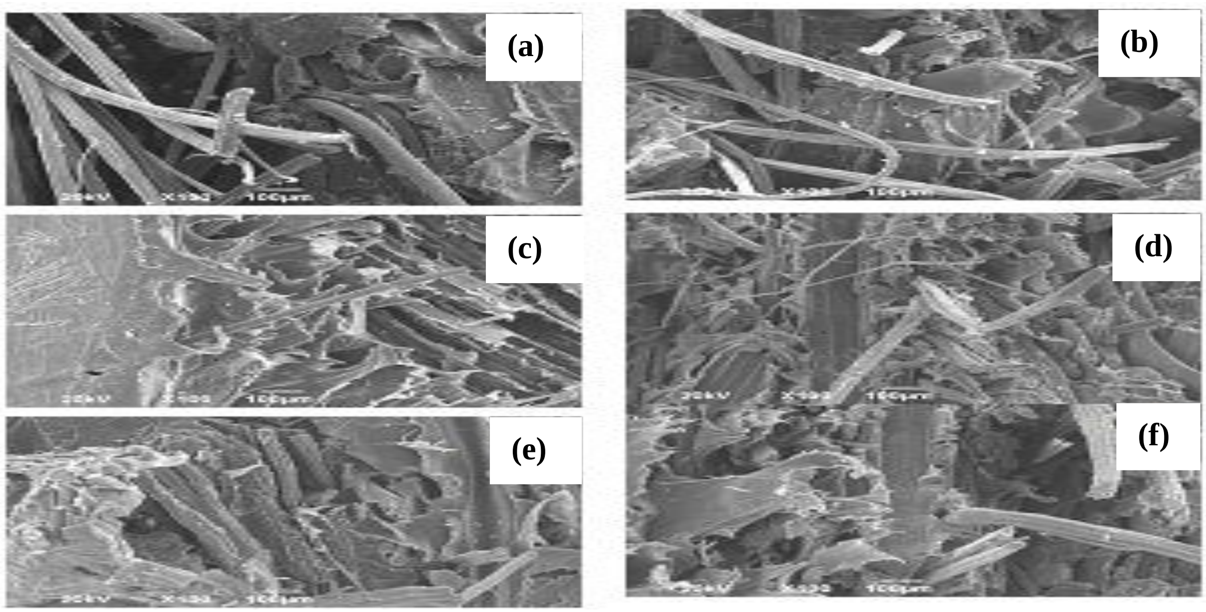


Fig. 7. SEM micrographs (a) 5 wt.% (1:1) (b) 10 wt.% (1:1), (c) 15 wt.% (1:1), (d) 20 wt.% (1:1), (e) 15 wt.% (3:1) and (f) 15 wt.% (1:3) sheep wool and jutefiber reinforced hybrid composites

Conclusion: In present research, sheep wool and jute fiber reinforced hybrid polypropylene composites were prepared using hot press technique. Fiber loading and fiber ratio were varied during composite preparation. Mechanical tests, thermogravimetric analysis and scanning electron microscopic analysis of the prepared composites were subsequently conducted. 15 wt.% sheep wool and jute fiber (wool:jute = 1:1) reinforced composite had the best adhesion between fiber and matrix and had the best thermal stability. Thus, in turn it also had the best set of mechanical properties.

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