Mechanical Properties and Water Absorption of Fiber-Reinforced Polypropylene Composites Prepared by Bagasse and Beech Fiber

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ABSTRACT: The present study investigates the tensile, flexural, notched Izod impact, and water absorption properties of bagasse and beech reinforced polypropylene (PP) composites as a function of fiber content. The surface of fibers was modified through the use of maleated polypropylene (MAPP) coupling agent. From this study, it was found that mechanical properties increase with an increase in fiber loading in both cases. However, the addition of wood fibers resulted in a decrease in impact strength of the composites. The water absorption property at varying fiber loading was evaluated and found maximum for the BA/PP composites. The weight gains for all specimens were less than 7%. In general, the results showed the usefulness of bagasse fiber as a good alternative and reinforcing agent for composite. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 114: 653–657, 2009

Key words: fiber-reinforced composites; mechanical properties; tensile modulus; strength

INTRODUCTION

It is well known that over the past few decades, polymers have replaced many conventional materials in various applications, which is obviously due to the advantages of polymers over conventional materials. The most important advantages of using polymers are ease of processing, high productivity and low cost, in combination with their versatility. In fact, polymers can be modified by the use of fillers and reinforcing fibers to suit the high strength/high modulus requirements.[1]

Fiber-reinforced polymers have received considerable attention from industry in recent years.[2–5] The growing commercial importance of these composites has expanded efforts to understand their structure–properties relations and for exploring new methodologies for their production. Wood fibers are interesting reinforcement for thermoplastic polymers due to their low cost, low density, high specific strength, and stiffness.[6] They are renewable, abundance, biodegradable, and nonabrasive during processing, improving the stiffness and the strength of thermoplastics. Because of their wide availability, natural fibers offer a real alternative to the reinforcing fibers presently available.[6–8]

However, forests, the major sources of wood fibers, are declining at the alarming rate of 13.0 million hectares per year in developing countries. Because of the sharp ecological damage, the global demand for fibrous material and worldwide shortage of trees in many areas, there has been growing interest in the use of recycled fibers as an alternative or supplementary fiber source for the 21st century.[9,10]

Shortage of fiber supply in Iran made researchers to look out for new sources of fibrous materials. If a decision is taken to substitute a new material for an established one, care must be taken to ensure that all the characteristics of the new material are well understood. This research explores the potential of using bagasse fiber as an alternative fiber to reinforce polypropylene (PP) composite. Therefore, attempt has been made to investigate the utility of bagasse/PP composites, compared with similar products made with virgin beech (*Fagus orientalis*) fibers, for packaging, furniture, and automotive applications. In the present work, a thorough study was carried out on the variation of mechanical properties such as tensile, flexural and impact strength of fiber-reinforced composites. In addition, the water absorption property of composites at different fiber loading and temperature were evaluated.

EXPERIMENTAL

Materials

Fibers

The fibrous raw materials for this work were the above-mentioned resources. Bagasse was supplied by a local sugar cane mill, after the extraction of

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TABLE I

Properties of PP

Appearance	White
Density (g/cm^3)	1.36
Elongation at yield (%)	4.75
Tensile strength (MPa)	28.5
Young's modulus (MPa)	1250
Flexural strength (MPa)	38.5
Flexural modulus (MPa)	1150

cane juice. Both fibers were produced by refiner mechanical pulp process. There were no significant differences in the beech and bagasse fiber length distributions. Fiber length and aspect (*L/D*) ratio were measured at 0.96 mm and 42 : 1 for bagasse and 1.02 mm and 47 : 1 for the beech. Before composite preparation, all fibers were oven dried at 95°C for 24 h. The moisture content of oven-dried fiber was lower than 3%.

Polymer matrix

PP (trade name Poliran P10800) was obtained from Bandar Imam Petrochemical Company, Iran. The melt flow rate of PP was 7–10 g/10 min at 230°C. The important characteristics of the polymer matrix used are given in Table I.

Coupling agent

Maleated polypropylene (MAPP) was supplied by Eastman Chemical Company, as Epolene PMG-3003 polymer with 6% acid anhydride. MAPP acts as a coupling agent in polymer blends and is particularly effective when one polymer is hydrophilic and the other polymer is hydrophobic.

Composite preparation

Formulation of the mixes and abbreviation used for the respective mixes prepared are given in Table II. After mixing PP and MAPP and, as soon as the registered torque indicated that the polymer melt had reached a steady state, fibers were added. The mixture was compounded at 190°C and 50 rpm for 10 min in a Hakke blender (SYS 9000 model). Tensile, flexural, and impact specimens were produced by compression molding using in a carver press at 190°C under a pressure of 4 MPa followed by cooling in another press equipped with refrigeration facilities.

Testing procedure

Several mechanical tests had been carried out on the samples. Strength measurements of samples were conducted using an INSTRON testing machine (Model 1186). Following testing procedures were used:

a. Tensile properties; ASTM D-638
b. Flexural properties; ASTM D-747
c. Izod impact strength; ASTM D-256

The size of tensile sample was 120 mm × 25 mm. The tensile load was measured at 2 mm/min strain rate and flexural strength at 1 mm/min strain rate. All flexural and impact samples were cut into rectangular specimens. Six specimens were tested in each experiment to obtain a reliable average value. All the mechanical properties were performed at room temperature. Mechanical properties were analyzed using factorial experimental design at completely random and DMRT test.

Water absorption

The sample dimensions for water absorption experiments were 1 cm × 1 cm × 0.5 mm. A minimum of three samples were tested for each composite. Samples were weighted and then soaked for 24 h in distilled water at room temperature and boiled in water for 2 h. The samples were removed at specific time intervals, blotted to remove the excess water on the surface, and immediately weighed. The difference between the mass after a given time of immersion and the initial mass compared to the initial mass led to the determination of the water absorption.

RESULTS AND DISCUSSION

Tensile properties

The tensile properties of composites as a function of fibers content are presented in Figures 1 and 2. From the curves of Figure 1, it is evident that moderate increase in tensile strength occurs on filling the polymer matrix with fibers, indicating a considerable reinforcing effect from these fibers. The phenomenon was stronger for the composites made by beech fibers. Similar behavior can be observed in Figure 2, where the significant increase in tensile modulus is plotted versus fiber content.

Similar results have been published, which studied the properties of wood plastic composites.[11–17] Their data showed that the tensile strength of wood fiber/PP composites increased with increasing fiber content. The possible reasons proposed for this kind

TABLE II

Materials Used in Making Bagasse/PP and Beech/PP Composites

Materials	Abbreviation	Content (wt %)
Fibers	–	10, 20, 30, 40
Plastic	PP	88, 78, 68, 58
Coupling agent	MAPP	2

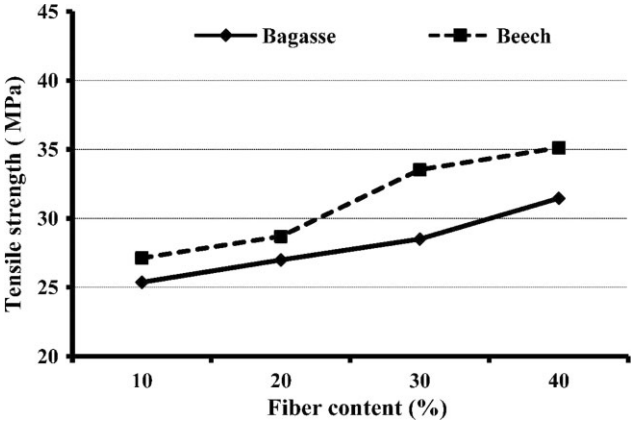

Figure 1 Comparison of tensile yield stress for bagasse/PP and beech/PP composites.

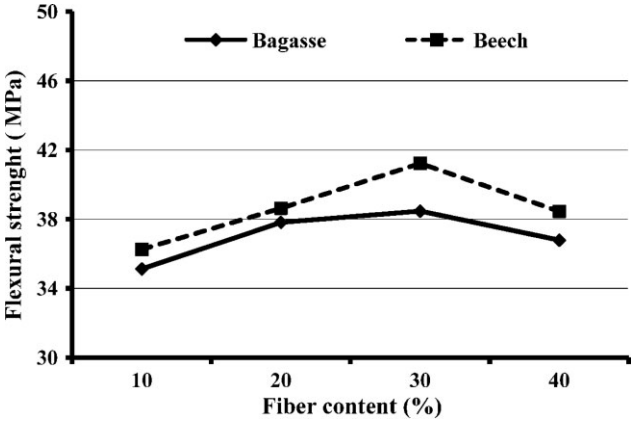

Figure 3 Comparison of flexural strength for bagasse/PP and beech/PP composites.

of behavior may be due to the improved interfacial adhesion between the matrix and fibers. In addition, various parameters influence the mechanical properties of fiber-reinforced composites including the fiber aspect ratio, fiber-matrix adhesion, stress transfer at the interface, and mixing temperatures. The bagasse fiber, which had a low aspect ratio, showed inferior strength to the beech fiber PP composites. In other words, the aspect ratio of the beech fibers is higher than that of the bagasse, which permits better stress transfer between the matrix and the fibers.

The result of tensile modulus measurement as a function of fiber contents is presented in Figure 2. The tensile modulus of beech and bagasse fiber composites shows that the modulus of PP filled with beech fiber was considerably higher than bagasse fibers in composites. The aspect ratio of beech fiber and fiber length are very important parameters in development of tensile modulus. Bagasse fibers are short. In short fiber-reinforced composites a critical fiber length is required under the full stressed condition in the polymer matrix. Fiber lengths shorter than this critical length lead to failure due to debonding at the interface at a lower load. On the other hand, for fiber lengths greater than the critical length, the fiber is stressed under applied load and thus results in a higher strength of the composites.

Flexural behaviors

The effect of fiber loading on the flexural strength and flexural modulus for bagasse/PP and BE/PP composites are given in Figures 3 and 4, respectively. It should be noted that as fiber content increases flexural strength and flexural modulus increase up to a fiber load of 30%. Further increase in the fiber loading results in a decrease in properties. Thus, addition of wood–fibers results in significant improvement in tensile and flexural properties of the composites. The improvement in mechanical properties achieved can be attributed to high strength and modulus of cellulosic fibers and to improved interfacial adhesion between the matrix and the fiber.[18]

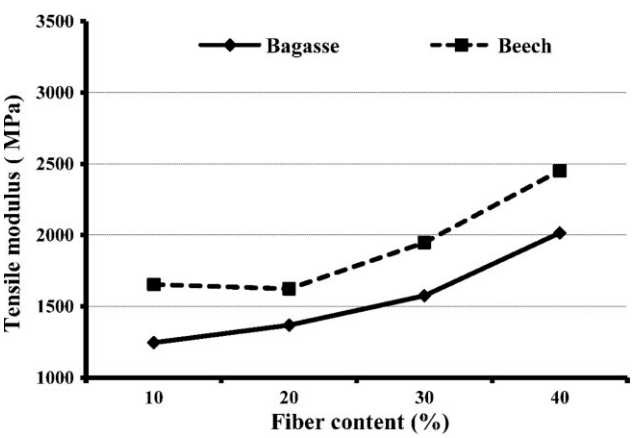

Figure 2 Comparison of tensile modulus for bagasse/PP and beech/PP composites.

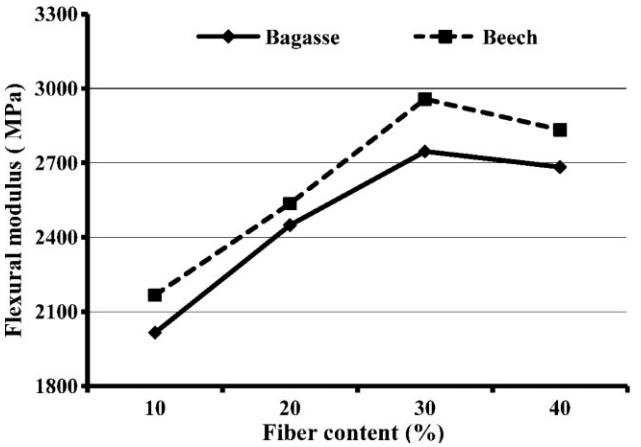

Figure 4 Comparison of flexural modulus for bagasse/PP and beech/PP composites.

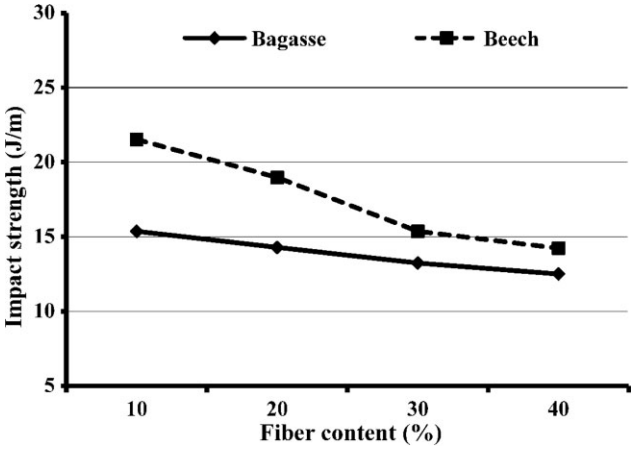

Figure 5 Comparison of impact strength for bagasse/PP and beech/PP composites.

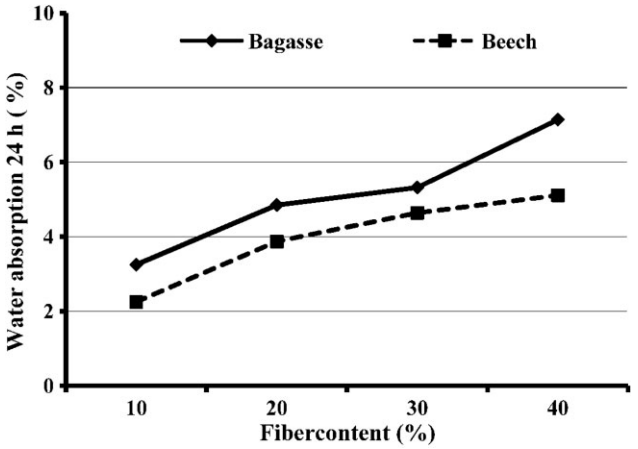

Figure 6 Comparison of water absorption after 24 h for bagasse/PP and beech/PP composites.

Flexural strength and flexural modulus reached the maximum value at 30% of bagasse and beech fiber content. However, the addition of 30% bagasse and beech fibers to PP significantly improved the flexural strength and modulus of composites as compared to 10, 20, and 40% of bagasse and beech fiber content.

Izod impact strength

Figure 5 reports the result of notched Izod impact strength measurement function of fiber contents. With increasing fiber contents, Izod impact strength decreased linearly. The beech fiber appeared to improve impact strength in comparison with the bagasse fiber. This was expected because beech fibers should be more resistant to crack propagation in the matrix. This is consistent with the results reported by most authors.[14–19] The presence of wood fibers in the PP matrix provides points of stress concentrations, thus providing sites for crack initiation. Another reason for decrease in impact strength may be the stiffening of polymer chains due to bonding between wood fibers and matrix. For high impact properties, in fact, a slightly weaker adhesion between fiber and polymer is desirable, as it would result in a higher degradation of impact energy, supporting the so-called fiber pull out.[12] Good adhesion on the contrary results in abrupt fiber fracture with a minor energy degradation. On the other hand, poor impact strength may also be partly attributed to some thermal degradation of fiber due to high shear forces in the kneading section of the twin screw extruder during compounding.[18,20,21]

Water absorption

Figures 6 and 7 show the values of the water absorption for the composites, which vary depending on the fiber loading. Weight gain on exposure to water after 24 h and 2 h boil increased as the percentage of bagasse and beech fibers increased for all composites tested, but the weight gains for all specimens were less than 7%. The PP did not absorb any moisture as a result of the different levels indicating that moisture is absorbed by the wood component in the composite. It is obvious that bagasse fibers cause higher water absorption as a result of the larger surface area. This is due to the fact bagasse fibers are shorter and finer and consequently have a much larger surface area per weight unit than beech fibers. Furthermore, increasing the amount of bagasse fibers at the same condition level reduces the polymer coverage and consequently water absorption increased significantly.

The above study proved that water sorption increases with increasing fiber content. Similar results have been published, which studied the influence of moisture content on fiber/matrix adhesion for HDPE/pine composites by scanning electron microscopic (SEM) observations.[19] Water

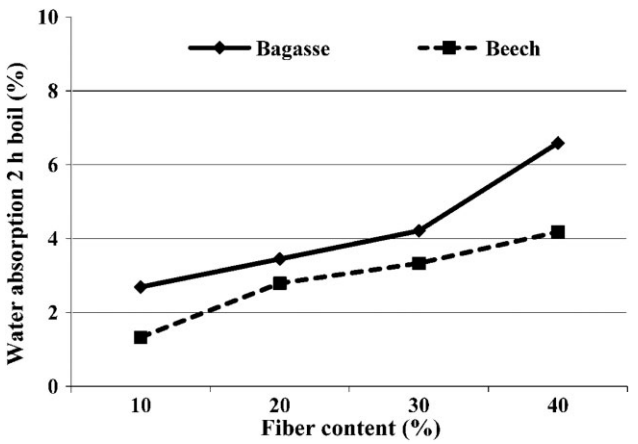

Figure 7 Comparison of water absorption after 2 h boil for bagasse/PP and beech/PP composites.

absorption in a fibrous composite is dependent on temperature, fiber loading, orientation of fibers, permeability of fibers, surface protection, area of the exposed surfaces, diffusivity, void content, hydrophilicity of the individual components, etc. As the fiber content increased, the water absorption also increased due to the increased hydrophilic nature of the fibers. Additionally, large number of porous tubular structures present in fiber accelerates the penetration of water by the so-called capillary action. Similar trend is observed in for the composites prepared by compression molding process.[20–23]

CONCLUSIONS

Bagasse fibers could be considered as a potential source of low cost, natural fibers for composites. It has been demonstrated that the fiber content had the greatest effect on mechanical strength and water absorption of PP/fibers composites. On the basis of the results of this investigation, the highest mechanical properties of bagasse and beech fiber reinforced composites can be reached with 30% and 40% fiber contents. The notched Izod impact strength composites improved with 10% fiber.

Bagasse and beech fibers plastics composites absorb less moisture and do so more slowly than solid wood, they have better dimensional stability when exposed to moisture. The results of our study indicate that incomplete encapsulation of bagasse and beech fibers by PP matrix occurs in both 30% and 40% wood fiber composites; less encapsulation occurs with the higher natural fiber content. Thus, more moisture is absorbed by the wood fiber at higher concentrations.

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