Injection Molding of Polypropylene Reinforced with Short Jute Fibers

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SYNOPSIS

Composites with polypropylene (PP) and jute fiber were prepared by injection molding technique. Maleic anhydride-grafted polypropylene was added as coupling agent to improve the adhesion between jute fiber and PP. A high fiber attrition was noted during injection molding, which had negative effects on the mechanical properties of the composites. The coupling agent improved the tensile and bending strengths, however the elastic and bending moduli were found not to be influenced by the coupling agent. The role of the average fiber length in strengthening of the composites was interpreted with help of the critical fiber length. Fracture surfaces of the composites, and the fiber orientations, were investigated by scanning electron microscopy and light microscopy, respectively. © 1996 John Wiley & Sons, Inc.

INTRODUCTION

There is a growing interest in the use of agro-fibers as reinforcing components for thermoplastics, because they are biodegradable, renewable, and environmentally friendly. Jute is one of the most common agro-fibers which obtains high tensile modulus and low elongation at break. If the low density (1.4 g/cm^3) of this fiber is taken into consideration, then its specific stiffness and strength are comparable to those of glass fiber.[1-3] There are many reports about the use of jute as reinforcing fibers for thermosets.[4-6] Previous works[7-8] suggest that jute can also be used as reinforcing fiber for polypropylene (PP) and polyethylene. However, according to our knowledge, there are very few reports about the effect and feasibility of injection molding technique for jute/PP composite systems.

One of the important investigations of this study was the effect of fiber attrition, which occurred during the injection molding, on the mechanical performance of jute/PP composites. Contribution of a fiber to strengthening the composite performance is considerably high, when the fiber is sufficiently longer than the critical length. On the other hand, the higher the adhesion between fiber and matrix polymer, the shorter is the critical fiber length. The ideal situation occurs when the fibers in the composite are longer than the critical fiber length and when the adhesion between the fibers and the matrix polymer is high. Generally, hydrophilic jute fibers do not adhere well to PP, which is hydrophobic. Maleic anhydride grafted polypropylene (MAPP) had been widely used as coupling agent[9-12] to improve the bonding between different ligno-cellulosic fibers and PP. This paper reports on the effect that MAPP and fiber length have on the performance of a jute/PP composite system.

MATERIALS AND EXPERIMENTAL

Polypropylene (PP T101) and jute fiber were received from Hercules (Norcross, GA) and Dixie Manufacturing (Norfolk, VA), respectively. The coupling agent was MAPP, type G-3002, from Eastman Chemical Products (Kingston, TN), which had an average molecular weight of 40,000. MAPP contains 6 wt % of maleic anhydride.

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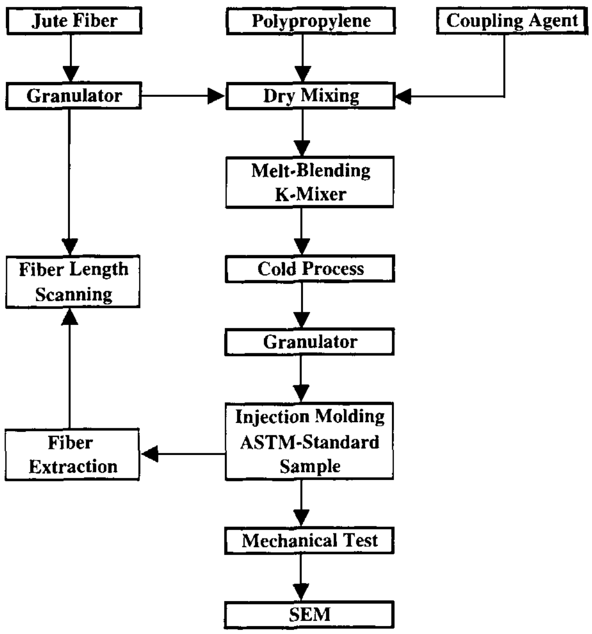

Figure 1 Flow chart of sample production and testing.

Virgin jute fibers were washed with water to remove contaminates and dried in an oven to 8% moisture content. The original fibers were about 3–3.5 m long. To insure an easy blending, they were chopped into short lengths. The chopped jute fibers and PP were then compounded with or without the coupling agent in a high-intensity kinetic mixer, known as a K-mixer. The ratio of jute fibers and PP was 50 : 50 by weight. In the case of coupling agent, 3 wt % MAPP was added on the basis of jute content. The mixed blends were molded into ASTM standard specimens by a 33-ton injection molder at a molding temperature of 188°C. A flow chart of sample preparation and characterization is given in Figure 1. The details of blending and molding techniques were reported earlier.[13]

In addition to the ASTM standard tests,[14–16] other tests were also conducted on the prepared specimens. Individual fibers from molded samples were obtained by dissolving the matrix PP in xylene in a Soxhlet vessel at 140°C for several hours. Fiber lengths were measured by a Jandel SigmaScan Digitizer. Samples 15 μm thick were cut at different angles (0°, 90°) from the middle part of tensile specimens with the help of Microtome equipment (Reichert, Austria) and were treated with a 0.3% dye mixture of methylene and toluidine blue in water. The dye mixture was strongly absorbed by the jute fibers, and the fibers were easily recognizable under the microscope.

RESULTS AND DISCUSSION

Mechanical Properties

Figure 2 shows the effect of jute fibers and coupling agent on the tensile and bending strengths of virgin and reinforced PP. The addition of 50 wt % jute fibers increased the bending strength of virgin PP from 31.33 MPa to 49.97 MPa. Further improvement (up to 87.66 MPa) was achieved by adding 3 wt % MAPP as a coupling agent. There was a small improvement in tensile strengths without coupling agent. But tensile strengths of composites were increased to about double (from 29.82 to 59.13 MPa) when coupling agent was added.

The improvement of mechanical properties by adding of MAPP was also reported for other lignocellulosic fibers/PP composites.[9–11,17–19] Strengthening of the composite occurred through a better bonding between cellulosic fiber surfaces and PP, and was caused by the esterification of the anhydride groups of MAPP with the hydroxyl groups of cellulosic fibers.[18] Because of the fact that jute fiber is lignocellulosic and contains more than 60% cellulose, we assume that a similar chemical bonding occurred between the hydroxyl groups of jute fibers and anhydride groups of MAPP. The elastic and bending moduli were remarkably higher than those of virgin PP, and they were almost independent of whether coupling agent was added or not (see Fig. 3). The moduli were determined from the initial slope of the stress–strain curve. At the initial slope, only a very

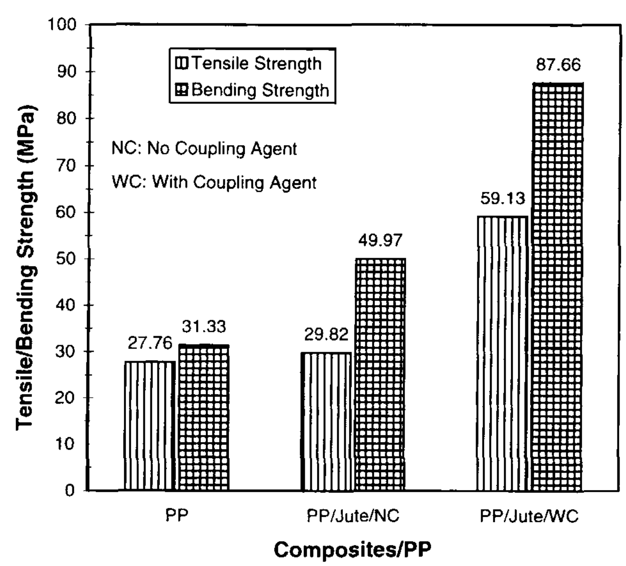

Figure 2 Tensile and bending strengths of virgin and reinforced polypropylene.

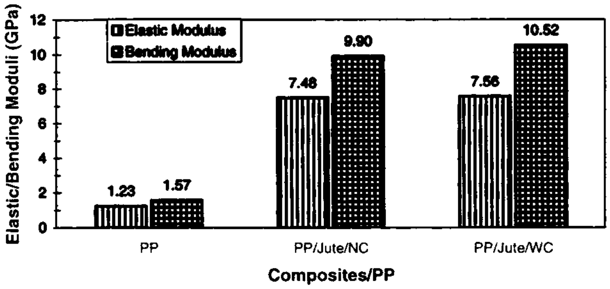

Figure 3 Elastic and bending moduli of virgin and reinforced polypropylene.

small strain region can be considered, which is practically not influenced by the interface between fiber and matrix.[13] Figure 4 shows that the fiber surface was covered by a thin layer of matrix polymer. This indicated a good adhesion between jute fiber and PP, and it was the case when MAPP was added as a coupling agent. When no coupling agent was added, the fiber surface was recognizable in its virgin state (see Fig. 5). In the latter case a gap between jute fiber and PP was found, caused supposedly by the thermal shrinkage of PP melt.

Distribution of Fiber Lengths

One of the important factors for the strengthening of a composite is the average fiber length remaining after processing. A processing technique such as injection molding can cause a high fiber attrition, depending on fiber content, viscosity of the polymer melt, melt-flow velocity, etc. The length distributions of jute fibers after injection molding are pre-

Figure 4 Scanning electron microscopy photograph of fracture surface of jute/polypropylene composite *with MAPP* showing the bridging between fiber and matrix.

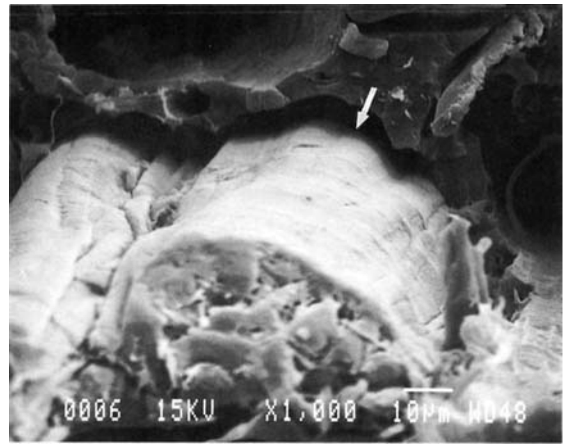

Figure 5 Scanning electron microscopy photograph of fracture surface of jute/polypropylene composite *without MAPP* showing the gap surrounding the fiber.

sented in Figure 6. The median fiber lengths in composite formulations with and without coupling agent were 390 and 350 μm, respectively. MAPP had been evaluated as a compatibilizer and also as a lubricating agent for ligno-cellulosic-filled PP composites.[11] Both factors might have caused a reduction of shearing between individual fibers as well as between fibers and PP melt. This was supposed to be the main reason for the reduction of fiber attrition in a system with coupling agent. Using glass fiber in PP, high fiber attrition during injection molding was reported by other authors.[20] According to those authors, glass fibers, which were originally 9 and 0.57 mm long, respectively, were reduced to lengths of 0.82 and 0.39 mm, respectively, when they were injection molded with PP. Considering those results, the attrition of jute fibers in PP was not a big sur-

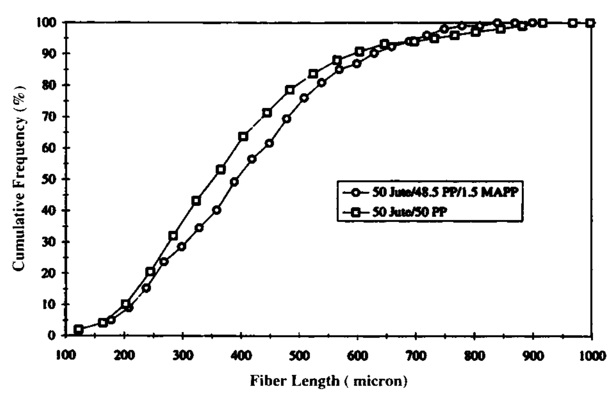

Figure 6 Distribution of fiber lengths of different composite formulations.

prise because jute fibers contained frequent weaker regions caused by naturally developed microvoids.

Reinforcing Effect of Fibers

In order to get the average fiber stress as close as possible to the maximum fiber stress, the fibers in a composite should be considerably longer than the critical length, because at the critical length the average fiber stress is only half of the value achieved in continuous fibers.[21] The critical length of jute fiber in PP without coupling agent was found to be 530 μm.[22] On the other hand, the median fiber length in the composite formulation without coupling agent was only 350 μm (see DISTRIBUTION OF FIBER LENGTHS). This seemed to be the main reason that the adding of jute fiber without coupling agent did not improve the tensile strength of virgin PP. The median fiber length in composite with coupling agent was 390 μm. While no experimental result on the critical fiber length in a system with coupling agent was available, the value (350 μm) of average fiber length in the injection-molded composite could not be compared with the critical fiber length. However, because of the better bonding between jute fiber and PP provided by the coupling agent, it was expected that the effective fiber length of the system with coupling agent was shorter than that of the system without coupling agent. Therefore, the remaining fiber length after injection molding had more reinforcing efficiency when coupling agent was added.

Fiber Orientation

Figures 7 and 8 show the light microscopy photographs of the cross sections, cut at different angles

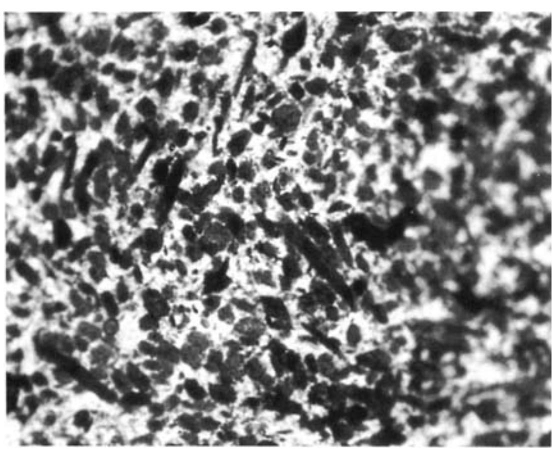

Figure 7 Light microscopy photographs of the cross section *perpendicular* to the length of a tensile specimen.

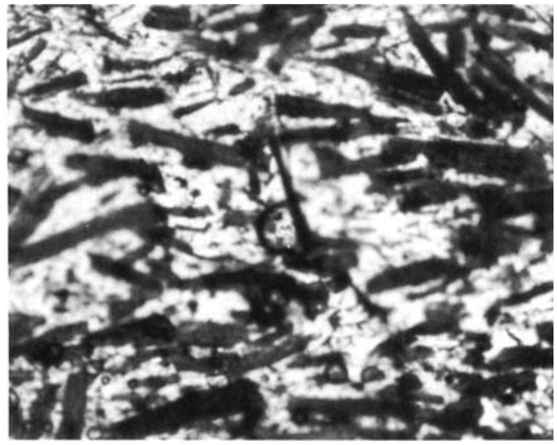

Figure 8 Light microscopy photographs of the cross section *parallel* to the length of a tensile specimen.

from a composite tensile specimen. In Figure 7, where the sample was cut at 90° angle to the specimen length, the cross-sections of individual fiber strands dispersed in PP are visible. Some longer fibers can also be seen, which were pulled out of the matrix during specimen preparation. In the sample cut parallel to the specimen length (Fig. 8), there was a 2-dimensional fiber orientation with the fibers mainly oriented in the specimen length direction.

CONCLUSIONS

Injection molding caused a high fiber attrition resulting in an average fiber length of 390 and 350 μm for formulations with and without coupling agent, respectively. The effect of jute fibers on the tensile and bending strengths was poor when there was no coupling agent. The addition of MAPP as coupling agent improved the composite performance by enhancing the adhesion between jute fibers and PP. The improved adhesion did partially offset the fiber attrition and the associated strength loss that resulted from injection molding. Fiber orientation occurred mainly in the melt-flow direction.

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