Mechanical and Thermal Properties of Polypropylene/Sugarcane Bagasse Composites

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ABSTRACT: To determine the possibility of using sugarcane bagasse (SCB) waste as reinforcing filler in the thermoplastic polymer matrix, SCB-reinforced polypropylene (PP) composites were prepared. The PP and SCB composites were prepared by the extrusion of PP resin with 5, 10, 15, and 20 wt % of SCB filler in a corotating twin screw extruder. The extruded strands were cut into pellets and injection molded to make test specimens. These specimens were tested for physicomechanical properties such as tensile, flexural, Izod, and Charpy impact strengths, density, water absorption, and thermal characteristics, namely, heat deflection temperature (HDT), melt flow index, and thermogravimetric analysis. It was found that the flexural strength increased from 23.66 to 26.84 MPa, Izod impact strength increased from 10.499 to 13.23 Kg cm/cm, Charpy impact strength increased from 10.096 to 13.98 Kg cm/cm, and HDT increased from 45.5 to 66.5°C, with increase in filler loading from 5 to 20% in the PP matrix. However, the tensile strength and elongation decreased from 32.22 to 27.21 MPa and 164.4 to 11.20% respectively. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 103: 3827–3832, 2007

Key words: composite; polypropylene; bagasse; mechanical properties; thermal properties

INTRODUCTION

Thermoplastic composites based on synthetic polymers with various amounts of organic fillers from renewable resources are considered as low environmental impact materials. The need for economically feasible degradable products, which do not adversely affect the environment upon disposal, has intensified the attention as an alternative source of raw materials. In recent years, natural fibers and powders have been widely used as reinforcing fillers in place of inorganic fillers and synthetic fibers in thermoplastic polymer matrix.[1–11] Reinforced polymeric composites were made using cellulose and lingocellulosic materials. These natural fillers have several advantages, such as their low cost, renewability, and biodegradability. The biodegradability allows these composites to play an important role in resolving future environmental problems. Agricultural residues such as bagasse, rice husks, and wood chips are particularly important natural resources. These natural fillers are lighter, cheaper, and provide much higher strength[12–14] per unit mass than do most of the inorganic fillers such as calcium carbonate, talc, zinc oxide, and carbon black. There is keen interest in utilizing these natural resources[13,15–24] in polymeric composites because of their positive environmental attributes. Further, these natural fillers are less abrasive, and do not cause the wear of barrels and screws during processing. The sugarcane bagasse waste, from sugarcane juice makers and from sugarcane industry, is one of the natural resources not utilized for any useful purpose. As these waste fibers are found in large quantity, there is a great interest in finding new applications. Sugarcane bagasse is mainly composed of cellulose, which is a polymer of significant importance. Compared with studies on natural fibers such as jute, sisal, coir, pineapple, and bamboo, less effort has been made on bagasse fiber reinforced plastics.

With the ongoing research efforts aimed at the preparation and evaluation of hydrophilic/biodegradable polymers,[25–29] the present study reports the preparation of polypropylene (PP)/sugarcane bagasse (SCB) powder composites to examine the possibility of using SCB as a filler in PP matrix. In today's environmentally focused society, the demand for cost-effective, environmental friendly materials continues to increase. The driving force behind the use of the sugarcane waste is its low cost, annually renewable resource utilization, and environmental benefits.

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EXPERIMENTAL

Materials

The thermoplastic polymer polypropylene (PP) was supplied by Reliance India (H 110MA) in the form of homopolymer pellets with density of 0.90 g/cc and a melt flow index (MFI) of 11 g/10min (230°C/2.16 kg). The sugarcane bagasse (SCB) was waste obtained from local sugar factory.

Filler preparation

The soft inner pulp of the bagasse was dried in sunlight carefully, then cut into small pieces and ground to fine powder in flour mill to pass through a 1.5-mm-size screen. This powder was soaked in 1% aqueous sodium hydroxide solution for 24 h at room temperature to remove impurities and waxy substances. Then it was washed with 1% acetic acid solution and distilled water to neutralize excess sodium hydroxide and the SCB powder was dried again in an oven with air circulation for 16 h at 50°C and utilized in this work. The chemical constituents[30] of the SCB are crude fibers 40–43%, cellulose 28–30%, lignin 9–11%, crude protein 8–9%, fat 2–2.5%, and ash 5–6%.

Compounding and specimen preparation

The ground SCB powder was mixed with PP granules in a high-speed mixer (Model FM 10 LB; Henschel, Germany). The mixed material was extruded in a twin screw extruder (Berstorff, Germany) with an L/D ratio of 33 with a temperature profile of 190, 190, 180, 180, and 190°C. The extruded strand was palletized and stored in sealed packs containing desiccant. Four levels of filler loading(5, 10, 15, and 20 wt %) were designed in sample preparation. Tensile, flexural, Izod, Charpy, heat distortion temperature (HDT), and water absorption specimens were prepared using an R.H. WINSOR INDIA, SP-130 automatic injection molding machine with 100 ton clamping pressure at 200°C and an injection pressure of 1200 psi. After molding, the test specimens were conditioned at (23 ± 2)°C and (50 ± 5)% RH for 40 h according to ASTM D 618 before testing.

Testing methods

Tensile and flexural strength tests were carried as per ASTM D 638 and ASTM D 790 respectively, on Universal Testing machine (Lloyds, LR 100 K). Izod and Charpy impact strength tests were carried out as per ASTM D 256 A and B respectively, on Izod–Charpy digital impact tester (ATS FAAR, Italy). Heat deflection temperature test was carried as per ASTM D 648 test method on HDT-VICAT Tester (model MP/3; ATS FAAR). MFI analysis was carried out on extrudate pellets on Melt flow Indexer (LLoyds MFI tester, Type 7273) at 190°C and at 2.16 kg load as per ASTM D 1238. Density measurements were made per ATM D 792. Water absorption measurements were made in 50-mm-diameter disc specimens per ASTM D 570. Thermogravimetric analysis (TGA) was carried out in Dupont 910 series thermal analyzer system at the rate of 20°C/min from ambient to 600°C under nitrogen atmosphere.

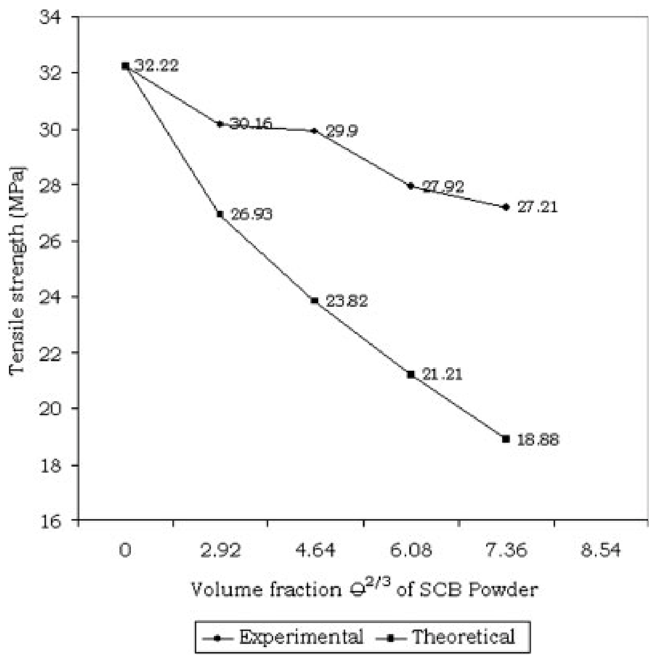

Figure 1 Tensile strength of PP composites at different filler loadings.

RESULTS AND DISCUSSION

Tensile properties of PP/SCB composites

The tensile strength and elongation test results of PP composites at different filler loadings are given in Figures 1 and 2 respectively, which show that the tensile strength and tensile elongation results decreased from 32.22 to 27.21 MPa and 164.40 to 11.20 % respectively. The reduction in tensile strength and tensile elongation may be due to the poor interaction between the hydrophilic filler and the polymer matrix. This is a generally observed phenomena as observed in PP/Rice husk flour composites.[31–33] This is because, as the filler loading increased, the interfacial area increased, worsening the interfacial bonding between filler(hydrophilic) and the matrix polymer (hydrophobic), which decreased the tensile strength.[34] For irregularly shaped fillers, the strength of the composite decreases because of the inability of the filler to support the stress transferred from the polymer matrix. Poor interfacial bonding causes partially separated microspaces between filler and matrix polymer, which obstructs stress propagation, when tensile stress is loaded, and induces brittleness.

The addition of SCB filler in PP matrix follows the general trend of filler effects on polymer properties,

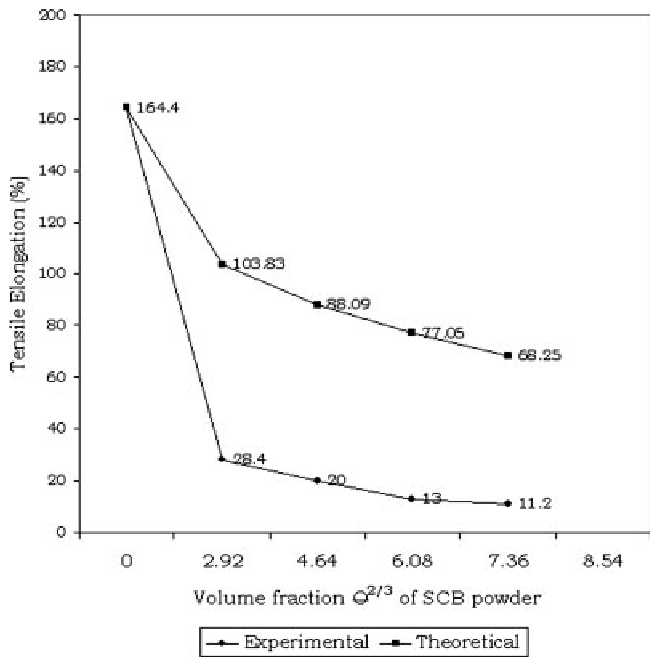

Figure 2 Tensile elongation of PP composites at different filler loadings.

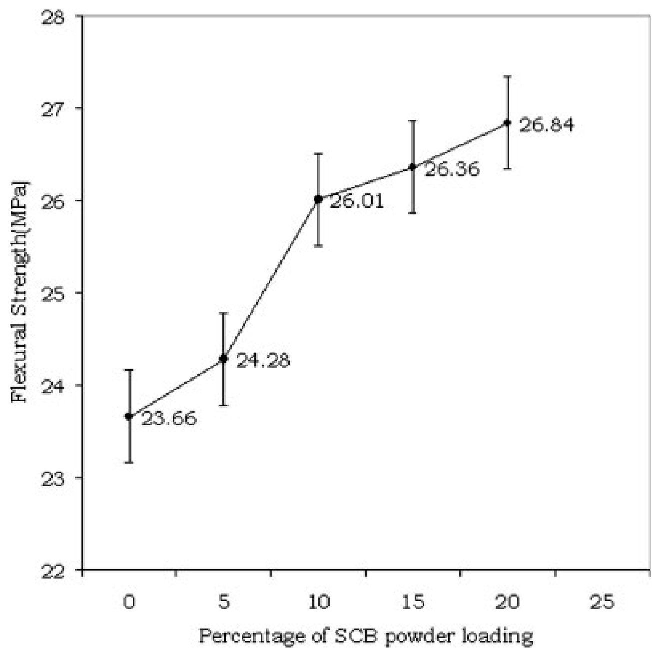

Figure 3 Flexural strength of PP composites at different filler loadings.

where the tensile strength and elongation decrease as the SCB addition increases. Several theories of the dependence of composite properties on filler volume fraction Φ and geometry have been investigated.[23,35–37] In a simple model Nicolais and Narkis[35] developed a geometric model for the tensile strength σ of a composite with uniformly distributed spherical filler particles of equal radius

$$\sigma_c = \sigma_o(1 - 1.21\Phi^{2/3}) \qquad (1)$$

The subscripts c and o represent the composite and the matrix polymer respectively. The experimental and the theoretical [the tensile values calculated based on eq. (1)] tensile strength results are plotted and shown in Figure 1. It is seen from the graph that the reduction in experimental values are much less than that of the value of −1.21 theoretically predicted by eq. (1). The drastic reduction of tensile strength, seen in the Figure 1, indicates the poor interaction and insufficient fiber length to receive proper tensile loads transferred from the matrix.[22,36]

Nielsen[37,38] derived the following relationship between elongation and volume fraction of the filler Φ

$$\varepsilon_c = \varepsilon_o(1 - \Phi^{1/3}) \qquad (2)$$

where ε_c is the elongation to break or yield of the composite and ε_0 is the corresponding elongation of the unfilled polymer. The tensile elongation calculated using eq. (2) and the experimental results are plotted in Figure 2. From the graph, it can be seen that the reduction in experimental values is much more than the theoretically predicted value of −1. The slope seen in Figure 2 may be attributed to a poorer interaction of the filler and matrix than that assumed in the eq. (2).

Tensile strength and tensile elongation decreased, while the flexural strength increased with filler loading, as seen in Figure 3. It has been observed that the flexural strength increased from 23.66 to

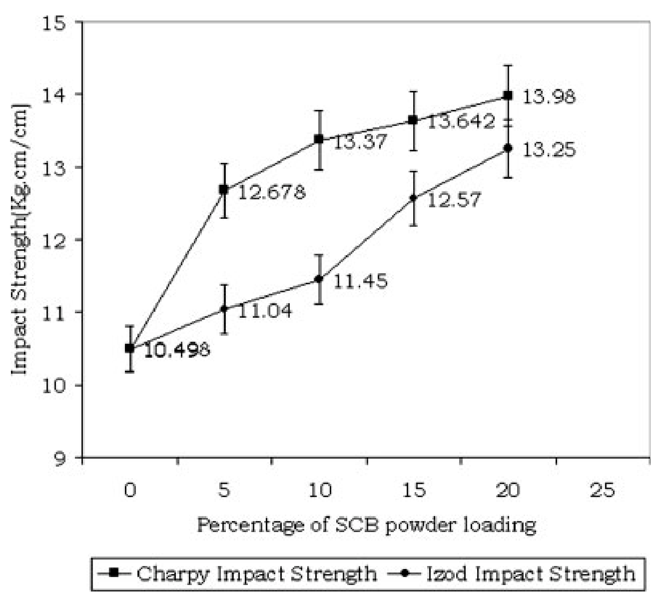

Figure 4 Izod and Charpy impact strengths of PP composites at different filler loadings.

TABLE I
Heat Deflection Temperature and Melt Flow Index of PP Composites at Different Filler Loadings

Composition (wt %)		Heat deflection temperature (°C)	Melt flow index (g/10 min)
PP Resin	SCB Powder		
100	00	45.5	8.984
95	05	61.0	9.372
90	10	65.0	9.042
85	15	66.0	6.466
80	20	66.5	6.227

26.84 MPa with addition of SCB powder from 0 to 20%. This contrasting behavior may be due to the orientation of this short fiber. In case of tensile test the force applied is parallel to the direction of fiber orientation, while in the case of flexural strength, the force applied is perpendicular to the fiber orientation.

Impact strength of PP/SCB composites

The impact strength of composites is even more complex than that of the unfilled polymers because of the part played by the fibers and the interface in addition to the polymer. The Izod and Charpy impact strengths of composites at different filler loadings are shown in Figure 4. The Izod and Charpy impact strengths of composites increased with filler loading, which may be due to poor adhesion, short fiber dissipates the maximum energy by mechanical friction, whereas in the case of rice husk flour filled PP composites the impact strength decreased with increase in filler loading.[7] This may be due to variation in interaction between filler and PP matrix due to change in nature and chemical composition of filler. The rice husk flour contains more ash content (40% at 600°C) in the form of silica,[33] whereas the ash content in the SCB is less (10% at 600°C).[39] As the composition of SCB powder varies from 0 to 20%, the Izod impact strength values vary from 10.499 to 13.230 Kg cm/cm. In general, mechanical properties deteriorated when organic fillers or wood fillers are used in polyolefine materials as a result of poor interfacial adhesion.[40] It has been observed that the Charpy impact strength of the material also increased from 10.096 to 13.980 Kg cm/cm with increase in SCB powder from 0 to 20%.

Thermal properties of PP/SCB composites

One of the striking effects of the fibers in the composites is the great increase in HDT. The HDT generally increased more for crystalline polymers than for amorphous ones.[41] In this case, the HDT of the PP matrix increased from 45.5 to 66.5°C when SCB loading was varied from 0 to 20 wt % (Table I). The increase in HDT in crystalline polymer on addition of fibers is due primarily to the increase in modulus. The HDT of the oriented fiber composite is more when the applied stress is parallel to the fibers and less when it is perpendicular.[42] In case of MFI, the addition of SCB reduces MFI from 8.984 to 6.223 g/10 min, even though initially there is a slight increase. The reduction in melt flow is as expected because SCB does not melt and also it is in fibrous nature.

Density and water absorption of PP/SCB composites

In case of density(Table II), there is only a marginal increase in density from 0.905 to 0.9536 g/cc with addition of SCB. The marginal increase in the density may be due to the bulky nature of SCB, which does not affect the material applications. The percentage of water absorption (Table II) of PP matrix increased with increase in the SCB powder content. However, increase is only marginal even though SCB powder is a hydrophilic material, because the SCB powder is encapsulated by hydrophobic material.

TGA of PP/SCB composites

Figure 5 shows the TGA thermograms of neat PP matrix and 20% SCB filled PP matrix. The thermal decomposition temperature of 20% SCB filled PP composite is lower than that of neat PP, which

TABLE II
Density and Water Absorption of PP Composites at Different Filler Loadings

Composition (wt %)		Percentage of water absorption after		Density (g/cc)
PP Resin	SCB Powder	24 h	48 h	
100	00	0.0004	0.0017	0.905
95	05	0.0350	0.0170	0.921
90	10	0.1360	0.1530	0.930
85	15	0.1580	0.1630	0.943
80	20	0.1700	0.2210	0.952

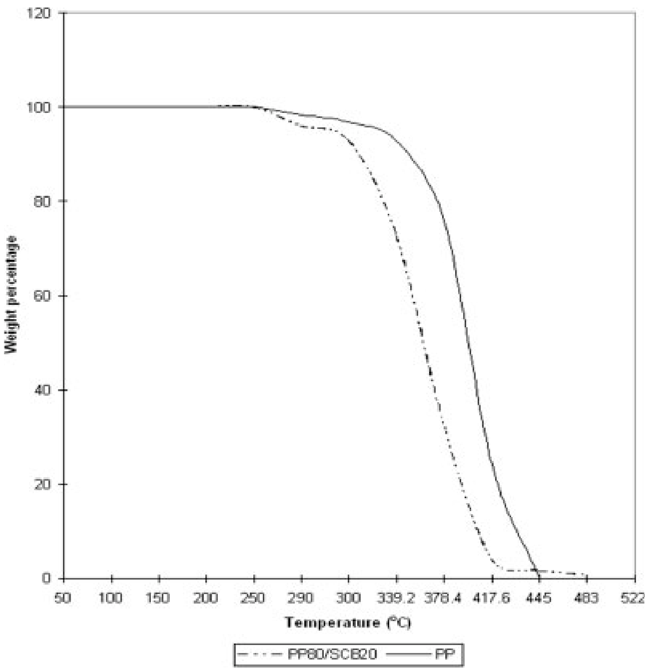

Figure 5 Thermogravimetric analysis thermogram of PP composites.

shows that the incorporation of SCB reduces the thermal decomposition temperature of PP. This is a logical consequence due to the lower thermal decomposition temperature of the SCB. The weight loss due to thermal decomposition at 340°C for PP is 7.25% only, whereas for 20% SCB filled PP composites, it is 27.40%. And further at 440°C weight loss for PP is 75.8% whereas 96.0% for 20% SCB filled PP composites. From the literature,[43,44] it is found that natural fibers show two (TGA curves) decomposition peaks. The first peak appearing at 300°C corresponds to the thermal decomposition of hemicellulose and the glycosidic links of cellulose; the second one appearing at around 360°C is due to the thermal decomposition of α-cellulose.

CONCLUSIONS

Polypropylene composites were prepared with SCB filler at different compositions. These specimens were tested for mechanical and thermal properties. It was found that the flexural strength increased from 23.66 to 26.84 MPa, Izod impact strength increased from 10.499 to 13.23 Kg cm/cm, Charpy impact strength increased from 10.096 to 13.98 Kg cm/cm, and HDT increased from 45.5 to 66.5°C, with increase in filler loading from 5 to 20% in the PP matrix. However, the tensile strength and elongation decreased from 32.22 to 27.21 MPa and 164.4 to 11.20% respectively. The decrease in tensile strength and elongation with addition of SCB filler to PP matrix follows the general trend of filler effects on polymer matrix. However, the main purpose of this work was to study the effect of SCB waste on the mechanical and thermal properties of the PP matrix. The SCB waste can be used as filler in the PP matrix, which will reduce cost and give environmental benefits.

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