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Mechanical Properties of Natural Fiber Containing Polymer Composites

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We have studied the mechanical properties of ethylene vinyl acetate (EVA) and cellulose acetate (CA) composite containing cellulosic natural fibers (*Sterculia villosa*) and tried to explain with the help of mixing of fiber in the composite. It is observed that the tensile strength (TS) of EVA composite decreases with the addition of fiber. Whereas in a CA composite, TS increases or reinforcement happens with the fiber content. This anomalous trend could be explained with the adhesion of fiber with the polymer matrix in the composite. The composite shows the same increasing trend for flexural strength (FS) up to a certain composition of fiber. With the further addition of fiber, we have found decreasing FS for the EVA composite, but a gradual increase in the CA composite with the fiber content. It is thought that fiber is well distributed in the CA composite and that the fiber-matrix could bear the load resulting in an increase of FS. This consideration can be well explained from the SEM picture that shows fiber forms a domain in the EVA composite or coagulation of fiber, as a result the FS decrease, but there is no such type of coagulation in the CA composite, resulting in increasing TS and FS with the fiber content. Toughness of the composites are also compared. It is believed that the cellulose-containing EVA and CA composites will be environment-friendly. We also suggest that this composite could be used in a low weight application such as gasket materials, toothbrushes, spoon handles, mirror frames, partition panels, etc.

Keywords Cellulose acetate; Ethyl vinyl acetate; Extruder; SEM; Tensile strength; Udal fiber

INTRODUCTION

Recently, attention is increasingly being given to the use of natural fibers as reinforcement-filler in low melting thermoplastics[1]. Natural fiber can be obtained from different sources, e.g., vegetables (flax, hemp, sisal, etc.), proteins (wool, silk, etc.), minerals (asbestos)[2]. Among these, vegetable fibers are getting more attention, because they are renewable and show excellent reinforcing properties for polymer composites. Because of low density, easy processing, biodegradability, and availability in nature, combined with a better cost-performance ratio, cellulosic materials show bright potentiality as a filler for thermoplastics[3,4]. The properties exhibited by a composite material are strongly influenced by the properties of the individual constituents, such as their respective amounts (%), shape, orientation, and distribution, plus any synergistic interaction between these constituents when they are combined in composite formation[5]. Theoretically, the maximum reinforcement strength of the composite material is gained by incorporating a high volume fraction of filler if there is an efficient stress-transfer mechanism at the fiber-matrix interface[4]. The increased uniformity of the fibers would increase the strengths, as a point of unconformity, natural fiber-reinforced composites are determined both by the tensile strength of the fiber and by the presence of weak lateral fiber bonds[6]. Several reports are found in the literature about the composite with natural fiber such as wood, flax, hemp, jute, etc., due to the ecology and interesting physical properties[7–9].

Sterculia Villosa roxb (also known as udal fiber) is one of the fastest-growing plant species abundantly available in the hilly areas of India, Bangladesh, Pakistan, and China, etc. It belongs to the *Malvaceae* family. The flakes of the bark have a characteristic net-like appearance. The main interest of this fiber is its use for making rope, string, or other similar purposes, due to its long fiber length and high strength. It is also a good source for pulp and paper[10]. Due to its good strength properties, it is thought

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that it could be a good candidate for the polymer composite. The bark of the tree contains dirt that should be removed before use. The stripped bark of the tree was soaked in water to loosen the fibers from the cork. The fiber separates upon pounding with a wooden mallet. These were washed with detergent to remove dirt gum, and other extraneous materials. The fibers were dried in the sun before blending with a polymer. Although the formation of a polymer matrix with natural fiber is common in the literature, *Sterculia Villosa* could open a new horizon in the composite field. Ethylene vinyl acetate (EVA) is a copolymer of ethylene and vinyl acetate that varies from 10–40%. It has good clarity and gloss, barrier properties, low-temperature toughness, stress-crack resistance and also UV radiation protection. It is used as a shock absorber in tennis shoes in the form of a foam called crocslite. EVA is also important for encapsulation material for silicon cells in photovoltaic modules. It is familiar as an expanded rubber or foam rubber. Cellulose acetates (CA) are primarily triacetate derived from wood pulp and are a nontoxic, odorless, soluble in acetone, water, dichloromethane. They are used in personal hygiene products, absorbent cloths, wipes, special paper, filter media, etc.

In this paper, we have evaluated the mechanical properties of composites containing EVA and CA polymer with udal fiber, and have tried to explain the findings with the help of a scanning electron microscopic analysis. We hope this study will introduce udal fiber in the composite field as a cheap filler reinforcement agent and expand the composite arena.

EXPERIMENTAL

Materials

EVA was procured from a local market, with a purity of 95%. It's density was 0.926 gm/m^3. CA was also purchased from market as an acetate containing 30–39 wt%. *Udal fiber* was collected from Sylhet, a renowned hilly area of Bangladesh. Density of the Udal fiber was determined to be 1.31 gm/m^3[11]. The holocellulose percentage of the fibers was experimentally determined to be 57.66%, of which 88.18% was α-cellulose.

Methods

A locally built single screw extruder (L/D ratio of 9:1, open die diameter 1.5 inch) was used for the primary mixing of the fiber and matrix, and to avoid the bubbles from the composite. A Weber-Pressen hydraulic press was used for the compression molding of specimens, which is a very low cost process than the other processes for fabrication of the composite. Hounsfield UTM 10KN (H10KS) was used for tensile (TS) and flexural (FS) testing of the specimen. Scanning electron microscopy (SEM) was carried out with the help of an HITACHI S-2600N.

Composite Preparation

Dried udal fiber was chopped down to an average length of 5 mm. Resin pellets and fibers were mixed at different compositions of fiber (0, 15, 20, 25, 30, 35 wt% of fiber) and shaken in a closed vessel for uniform distribution. The solid mixture was fed to the hopper of the extruder at 120°C at 120 rpm. The output was cooled in the open air. The extruded product was cut down to small pieces with the help of scissors. The solid particles were formed into sheets by compression molding at 90°C under a pressure of 1.66 MPa for 25 m. The cooled sheets were cut into specific shapes for measuring tensile and flexural strength. The strain rate applied in the tests was 5 mm/sec.

RESULTS AND DISCUSSIONS

We prepared our sample as described in the previous section and the results are shown in Table 1. A different trend was observable TS and FS strength in CA composites increase with the addition of fiber. Whereas, TS decreases in EVA composite. FS increases similar to CA composites up to a certain composition of fiber. The reinforcing ability of the fibers depends on the mechanical strength of fibers, polarity of the fiber, surface characterization, presence of

TABLE 1
Mechanical properties of EVA and CA polymer composite containing natural fiber (udal fiber)

Udal fiber composition (wt%)	EVA-composite			CA-composite		
	TS (MPa)	FS (MPa)	FT (KJ/m^3)	TS (MPa)	FS (MPa)	FT (KJ/m^3)
0	4.81	1.87	–	1.54	1.92	–
15	3.09	2.43	–	4.53	6.4	66.86
20	2.89	2.64	35.42	5.94	7.72	79.97
25	2.72	2.71	60.31	7.23	10.58	125.67
30	2.25	3.12	30.56	9.07	12.16	147.49
35	1.71	2.61	15.34	9.83	12.55	154.45

TS = Tensile strength (MPa), FS = Flexural strength (MPa), FT = Fracture toughness (KJ/m^3).

reactive center, and adhesion of matrix (polymer) in the composite.

It is believed that the uniformity of the fibers in the composite would increase the strength, due to the presence of a weak, lateral fiber bond[6]. Theoretically, the maximum reinforcement strength of the composite material is gained by incorporating a high volume fraction of filler if there is an efficient stress-transfer mechanism at the fiber-matrix interface[4]. It is thought that up to a certain composition of fiber, reinforcement would increase and after that decrease. In this case, both the fiber and matrix bear the load and fiber resists to slip, as in the case of age hardening of metal[12]. It is inferred from Table 1 that there is a lack of effective adhesion between fiber and EVA, hence, TS decreases with fiber, but an increasing TS for CA composites indicates a good adhesion with fiber and matrix in the composite. This behavior was also explained in Karnani et al.[13] in a case of modified fiber with polypropylene composites. We also presented an electron microscopic photo (Fig. 1) to explain the adhesion between fiber and matrix in the composites. It is noticeable that the FS of EVA composites reaches maximum and after that inclines to the opposite with the further addition of fiber. This can be explained by the fact that fibers are finely distributed in the composite, and fiber-matrix bears the load. On the other hand, just after adding a small composition of fiber, fibers start to coagulate as a bundle of fibers; consequently a decreasing tendency of FS could happen. But in the CA composite, fiber can distributed well-enough with the matrix and increase FS with fiber as observed in Table 1. We also determined the water absorption (data not shown), and observed that increasing fiber content also increases the water intake capacity up to a saturation point.

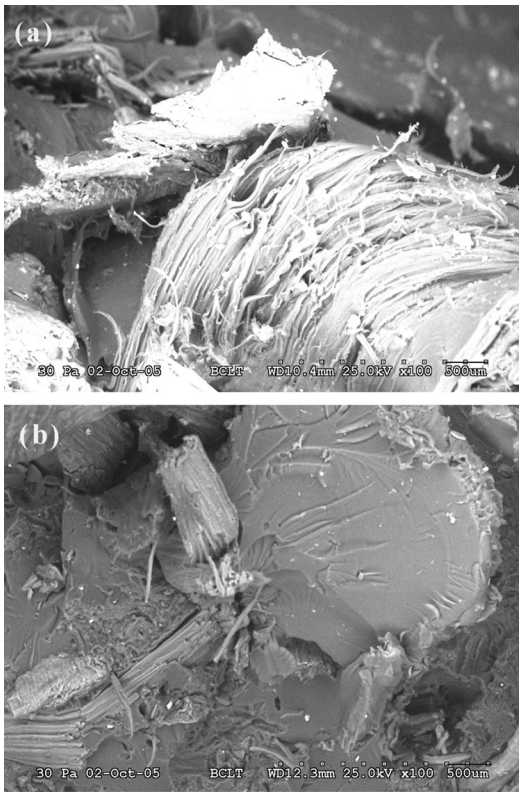

FIG. 1. Electron microscopic photo of the composite containing 30 wt% of fiber. (a) EVA-udal (b) CA-udal. Black bar indicates 500 μm.

It is well known that a tough material absorbs a large amount of energy before it fractures. Thus, the amount of energy absorbed by a unit volume of material under strain up to fracture is an indication of its toughness. One can see from Table 1 that fracture toughness (FT) increases both the composites first, but after a certain composition it decreases for EVA composite, whereas an increasing trend is consistent with the rest of fiber composition in the CA composite. The increasing trend is similar to the property of some alloys where heat treatment produces microstructures, which impart both the strength and toughness of the alloys. We need further study to solve this anomalous trend. The cross section of the composite containing 30 wt% of fiber (a) EVA composite (b) CA composite is presented in Fig. 1.

It is clearly implied that fibers are not well distributed with an EVA polymer (Fig. 1a), because a separate domain is formed in the composite, which could affect the composite strength. But such type of domain is not found in the CA composite (Fig. 1b), suggesting well distribution in the composite, resulting in good reinforcement. In both cases some void places are also observed. It is not well known if there is any role for this void place on the strength of the composite.

CONCLUSION

In this paper we have reported on some mechanical properties of EVA and CA composites with udal fiber. We have shown that fiber adhesion with the polymer matrix in the composite is an important factor for reinforcement. TS decreases in EVA composites but an increasing trend is observed in CA composites with the fiber addition. FS first increases in both composites up to a certain fiber composition and then a different trend is viewed with further increasing fiber content. It seems that the fiber distribution might play role for FS although the proper mechanism is not evaluated yet. CA composites have a higher value of FT than EVA composites, suggesting that tough material suggesting tough material that could help to improve composite properties. It is clearly seen from the SEM picture that the goal distribution of fiber and matrix in the composite. It is also assumed that adding cellulosic material in the composite will make it environmental-friendly. These composites can be used in low weight applications, such as gasket materials, toothbrushes, spoon handles, mirror frames, partition panels,

etc. Hence the udal fiber can be an inexpensive filler for polymer composites.

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