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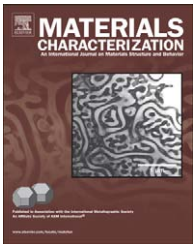

Mechanical property evaluation of natural fiber coir composite

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ABSTRACT

The fiber which serves as a reinforcement in reinforced plastics may be synthetic or natural. Past studies show that only artificial fibers such as glass, carbon etc., have been used in fiber-reinforced plastics. Although glass and other synthetic fiber-reinforced plastics possess high specific strength, their fields of application are very limited because of their inherent higher cost of production. In this connection, an investigation has been carried out to make use of coir, a natural fiber abundantly available in India. Natural fibers are not only strong and lightweight but also relatively very cheap. In the present work, coir composites are developed and their mechanical properties are evaluated. Scanning electron micrographs obtained from fractured surfaces were used for a qualitative evaluation of the interfacial properties of coir/epoxy and compared with glass fiber/epoxy. These results indicate that coir can be used as a potential reinforcing material for making low load bearing thermoplastic composites.

1. Introduction

Despite the fact that glass fiber-reinforced plastics have excellent thermal and mechanical properties, it is difficult to devise suitable disposal methods for them. Due to many environmental problems, the disposal methods for glass fiber-reinforced plastics (GFRP) and their recycling have been seriously acknowledged [1]. Natural fibers may play an important role in developing biodegradable composites to resolve the current ecological and environmental problems. Composites made of natural fibers offer the opportunity for extensive applications in fields such as consumer goods, low cost housing and civil structures, and for many other common applications where the prohibitive cost of reinforcements at present restricts the use of conventional lightweight reinforced plastics. In the past decade, natural fiber composites have been developed, in which several natural fibers such as ramie, hemp, jute, sisal, bamboo, banana, oil palm fibers, etc. are used as reinforcements in place of glass fibers. Shinichi et al. [2] have investigated the effects of the volume fraction and lengths of natural fibers on flexural properties of biodegradable composites. Kenaf and bagasse were mixed with corn-starch biodegradable resin, and composite flexural specimens were fabricated by press forming. The flexural modulus of the natural fiber composite made from Kenaf and bagasse increased, with an increase in fiber volume fraction up to 60% for Kenaf, and up to 66% for bagasse.

Maries et al. [3] investigated the thermal conductivity, diffusivity and specific heat of polyester/natural fiber (banana/sisal) composites as a function of filler concentration and for several fiber surface treatments. Guohua et al. [4] studied the nanomechanical properties of human hair including hardness, elastic modulus and creep, using the nanoindentation technique. Geethamma et al. [5] have studied the dynamic mechanical behavior of natural rubber and its composites reinforced with short coir fibers. Maxima in loss tangent (tan δ), loss modulus (E') and the middle point of the E'' vs. temperature curve of the gum natural rubber compound at 1 and 10 Hz almost coincided with one another. The maxima in tan δ and E'' did not coincide in the case of composites. It was

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observed that as frequency increases the values of tan δ and E'' decreased whereas the values of E' increased in the case of both gum and composites. The values of E', E'' and tan δ of the gum increase with fiber incorporation, indicating lower heat dissipation in gum.

Sapuan and Leenie [6] carried out experiments using tensile and flexural (three-point bending) tests of natural fibers reinforced with composite materials (Musaceae/epoxy). Harriette et al. [7] studied the mechanical properties of flax/polypropylene compounds, manufactured both with a batch kneading and an extrusion process and compared the properties with those of Natural fiber Mat Thermoplastic (NMT) composites. The fiber length and width distributions of the fibers from the compounds were determined and used to model the expected properties of the materials, which led to reasonable predictions of the interfacial shear stress.

The major problem identified with natural fibers during incorporation in hydrophobic polymers is their poor compatibility. To alleviate this problem, various fiber–polymer interface modifications have been proposed which results in improvement of performance of the resulting composite [5]. The present study focuses on the mechanical properties of a versatile natural fiber coir. Coir is the fibrous husk of the coconut shell. Total world coir fiber production is 250,000 tonnes. The coir fiber industry is particularly important in some areas of the developing world. India, mainly the coastal region of Kerala State, produces 60% of the total world supply of white coir fiber. Sri Lanka produces 36% of the total world brown fiber output. Over 50% of the coir fiber produced annually throughout the world is consumed in the countries of origin, mainly India. Being tough and naturally resistant to seawater, the coir protects the fruit enough to survive months floating on ocean currents upon which it may be washed up on a sandy shore where it may sprout and grow into a tree; this requires only the presence of fresh water, because all the other nutrients it needs have been carried along with the seed. In the present work the tensile, flexural and impact properties of coir composites were carried out and the results are compared with that of GFRP.

2. Experiment

2.1. Material

Coir is a lignocellulosic natural fiber. It is a seed-hair fiber obtained from the outer shell, or husk, of the coconut, the fruit of *Cocos nucifera*, a tropical plant of the Arecaceae (Palmae) family. The coarse, stiff, reddish brown fiber is made up of smaller threads, each about 0.01 to 0.04 in. (0.03 to 0.1 cm) long and 12 to 24 μm (a micrometer is about 0.00004 in.) in diameter, composed of lignin, a woody plant substance, and cellulose.

The individual fiber cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature but later become hardened and yellowed as a layer of lignin is deposited on their walls. Mature brown coir fibers contain more lignin and less cellulose than fibers such as flax and cotton and are thus stronger but less flexible. They are made up of small threads, each less than 0.05 in. (1.3 mm) long and 10 to 20 μm in diameter. White fiber is smoother and finer, but also weaker. The coir fiber is relatively waterproof and is the only natural fiber resistant to damage by salt water.

Green coconuts, harvested after about 6 to 12 months on the plant, contain pliable white fibers. Brown fiber is obtained by harvesting fully mature coconuts when the nutritious layer surrounding the seed is ready to be processed into copra and desiccated coconut. The fibrous layer of the fruit is then separated from the hard shell (manually) by driving the fruit down onto a spike to split it (de-husking). Machines are now available which crush the whole fruit to give the loose fibers.

2.2. Mould Preparation

The fabrication of the various composite materials is carried out through the hand lay-up technique. The mould used for preparing composites is made from two rectangular chromium-plated mild steel sheets having dimensions of 300 mm × 300 mm. Four beadings were used to maintain a 3 mm thickness all around the mould plates. The functions of these plates are to cover, compress the fiber after the epoxy is applied, and also to avoid the debris from entering into the composite parts during the curing time.

2.3. Preparation of Epoxy and Hardener

The matrix used to fabricate the fiber specimen was epoxy CY205 of density 1.15 to 1.20 g/cm^3, mixed with hardener HY951 of density 0.97 to 0.99 g/cm^3. The weight ratio of mixing epoxy and hardener was 10:1.

2.4. Sample Preparation

The samples were prepared using the fibers and epoxy, which are handled differently in the processing. The moulds are cleaned and dried before applying epoxy. Wax was used as the releasing agent. In the case of glass fiber/epoxy fabrication, the epoxy mixture is laid uniformly over the mould using a brush. Then a layer of the chopped strand mat is applied over the layer of epoxy. The same process was repeated until three such layers of epoxy and chopped strand mat are applied. Now the mould is closed and compressed for a curing time of 24 h.

For coir/epoxy fabrication, the coir fibers were laid uniformly over the mould before applying any releasing agent or epoxy. After arranging the fibers uniformly, they were compressed for a few minutes in the mould. Then the compressed form of coir is removed from the mould. This was followed by applying the releasing agent on the mould, after which a coat of epoxy was applied. The compressed fiber was laid over the coat of epoxy, ensuring uniform distribution of fibers. The epoxy mixture is then poured over the fiber uniformly and compressed for a curing time of 24 h. After the curing process, test samples were cut to the required sizes prescribed in the ASTM standards.

2.5. Mechanical Tests

After fabrication the test specimens were subjected to various mechanical tests as per ASTM standards. The standards followed were ASTM ASTM-D 3039/D 3039M, ASTM-D 790-03

and ASTM-D 256-05 for tensile tests, flexural tests and impact tests, respectively. To obtain a statistically significant result for each condition, five specimens were tested to evaluate the mechanical properties. The tensile tests were conducted at a speed of 2 mm/min at room temperature (303 K). Three-point bending (flexural) tests were carried out on the specimen at room temperature. The specimen is placed onto two supports having a 50-mm span length between the supports. The speed of the jaws was set to 2 mm/min. Izod impact tests were conducted for all specimens at room temperature to evaluate the resistance of the material to fracture.

3. Results and Discussion

3.1. *Mechanical Properties*

The tensile strength, flexural strength and impact strength values of the coir and GFRP composites are tabulated in Table 1. All measures of the strength reported here show that the GFRP specimens are significantly stronger than the coir/epoxy specimens.

3.2. *Fractography*

The fractographs of the three different samples which were obtained using scanning electron microscopy (SEM) after testing for tensile, flexural, and impact properties are discussed below.

Fig. 1(a) and (b) shows typical tensile failures of the glass fiber/epoxy resin in a local resin-rich region. The presence of a distinctive river pattern and crack growth surrounded by resin debris is seen. An overlapping platelet topography in the resin, which has been termed as hackles, is discernible; also seen in the fractograph are groove-like features caused by pull-out of the fibers under tension. The fibers are broken at many different levels: the fiber breaks are perpendicular to the fiber direction. There is substantial epoxy adhering to the fiber surfaces, indicating that the interfacial bond strength is fairly high.

Fig. 2(a–c) shows the tensile fracture of coir/epoxy specimens. From Fig. 2(a) it can be seen that the fibers are detached from the resin surface due to poor interfacial bonding, with some voids formed on the resin surface due to fiber pull-out.

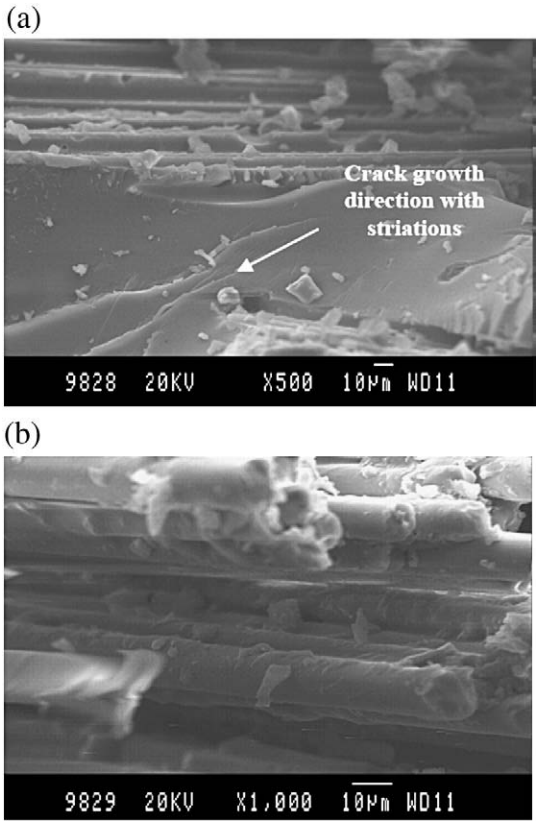

Fig. 1 – (a) and (b) — Scanning electron micrographs of glass fiber/epoxy specimens after tensile fracture.

Fig. 2(b) exhibits the crack growth direction and the formation of striations. The cracks have easily propagated through the resin matrix showing that little resistance has been offered. This fact can be evident from the poor interfacial bonding observed from the fracture. Fig. 2(c) exhibits the presence of river patterns near the fiber surface with hackle formation at the bottom of the fractograph. This is due to the fact that the fiber is fairly strong so some resistance offered by the fiber has caused these features, but poor bonding has resulted in easy crack propagation. From Table 1 it is clear that the strength of

Table 1 – Tensile, flexural and impact properties comparison

Composite type	Sample identification	Tensile strength (MPa)	Average tensile strength (MPa)	Flexural strength (MPa)	Average flexural strength (MPa)	Impact strength (kJ/m^2)	Average impact strength (kJ/m^2)
Coir	C1	18.110	17.86±2.32	40.230	31.08±6.01	10.551	11.49±0.99
	C2	14.101		28.550		12.636	
	C3	20.481		24.261		12.332	
	C4	18.550		29.226		11.504	
	C5	18.073		33.131		10.448	
GFRP	GFRP 1	83.453	85.35±4.32	121.276	132.39±11.85	53.695	52.66±3.13
	GFRP 2	86.548		132.578		54.334	
	GFRP 3	85.887		120.800		55.607	
	GFRP 4	91.329		138.661		47.520	
	GFRP 5	79.547		148.643		52.151	

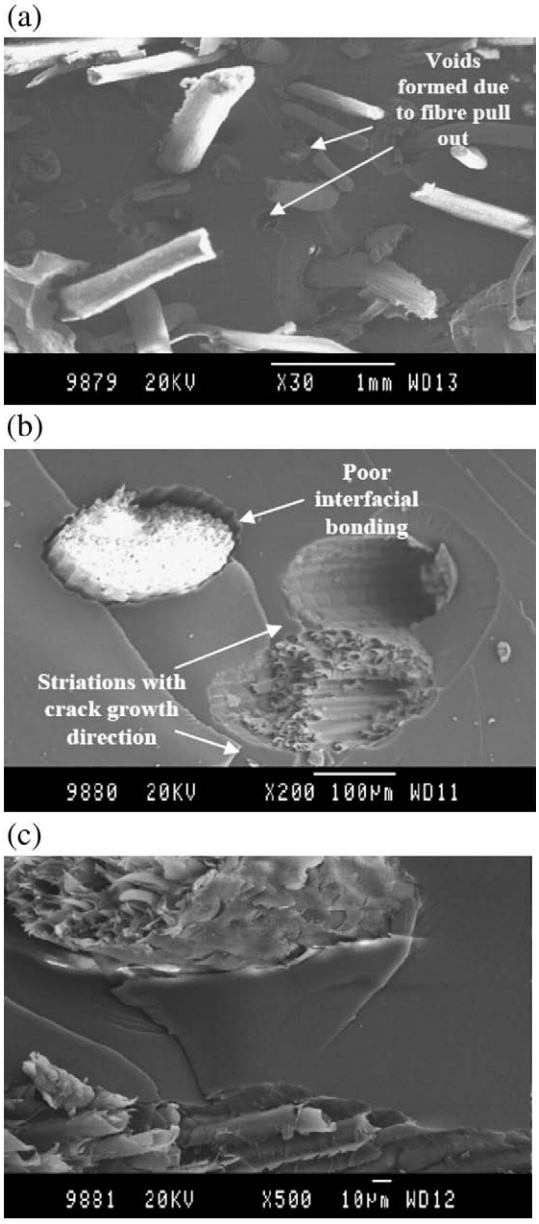

Fig. 2 – (a), (b) and (c) — Scanning electron micrographs of coir/epoxy specimens after tensile fracture.

the GFRP laminates was much greater than that of the coir/epoxy laminates; the SEM results indicate that this decrease is likely due to the poor interfacial bonding and fiber cracking in the coir fibers. In the glass/epoxy laminates the higher strength indicates there was better matrix–fiber bonding, combined with the fact that the glass fiber was stronger than the coir fiber.

The glass fiber/epoxy specimen failed in flexure shows the presence of hackles near the fiber bundle. The holes present in the resin, Fig. 3(a), are due to fiber pull-out due to the tensile load. River patterns are seen adjacent to the crack growth near the fiber pull-out region. In Fig. 3(b) the presence of river patterns is seen on the larger part of the resin-rich region; it is possible to discern some indication of the crack growth direction. The fibers are not bonded with the resin, leading to the conclusion that the fiber–matrix interface was weak. In Fig. 4(a), which shows the coir/epoxy specimen after flexural fracture, it is clear that there is virtually no contact between the fiber and the resin. Wetting was low in coir when compared to GFRP. Fiber pull-out has occurred, Fig. 4(b), indicating that the fiber has some strength but very poor interfacial bonding. The presence of uneven fibers in a brittle resin in the coir/epoxy is probably the cause of the poor flexural strength, Table 1; the poor interfacial bonding between the fiber and matrix would have exacerbated this condition.

The impact testing of the GFRP specimen, Fig. 5(a), resulted in hackle formation with significant matrix debris, indicative of the impact loading damage. The fibers at the top have broken due to the impact damage. In Fig. 5(b), in the overload region of the fracture surface, the fracture surface consists of glass fibers; an overlapping platelet topography in the resin has formed.

On the fracture surface of the coir/epoxy specimen, Fig. 6(a), the presence of river patterns with crack branching, and termination near a fiber pull-out at the right side of the fractograph, can be observed. The fiber has cracked at different levels, which indicates that a certain amount of energy has been absorbed during pull-out of the fibers. In Fig. 6(b) it can be seen that the fiber has offered resistance and has absorbed energy in its own fracture. The presence of matrix debris was found in all of the fracture fractographs due to impact damage.

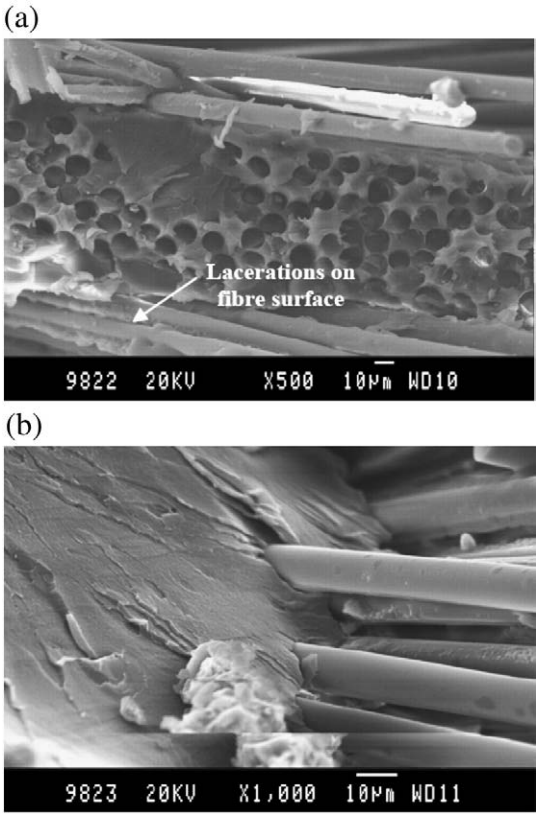

Fig. 3 – (a) and (b) — Scanning electron micrographs of glass fiber/epoxy specimens after flexural fracture testing.

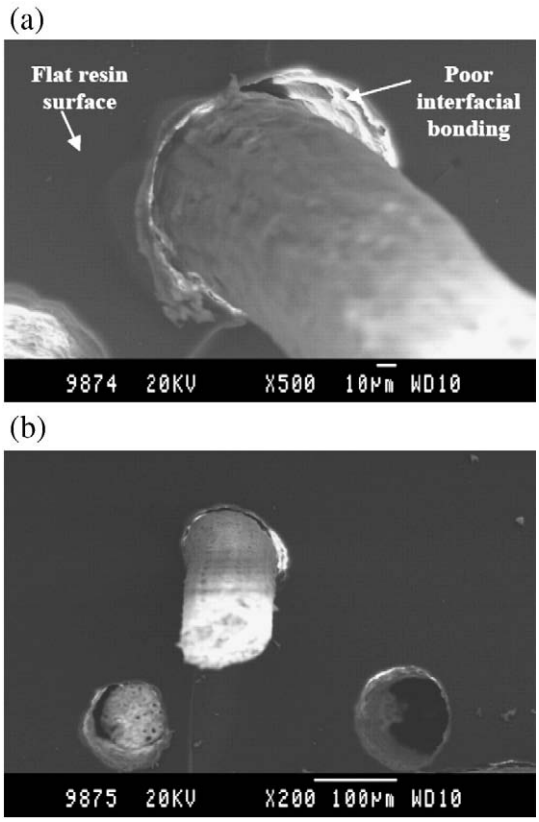

Fig. 4 – (a) and (b) — Scanning electron micrographs of coir/epoxy specimens after flexural fracture testing.

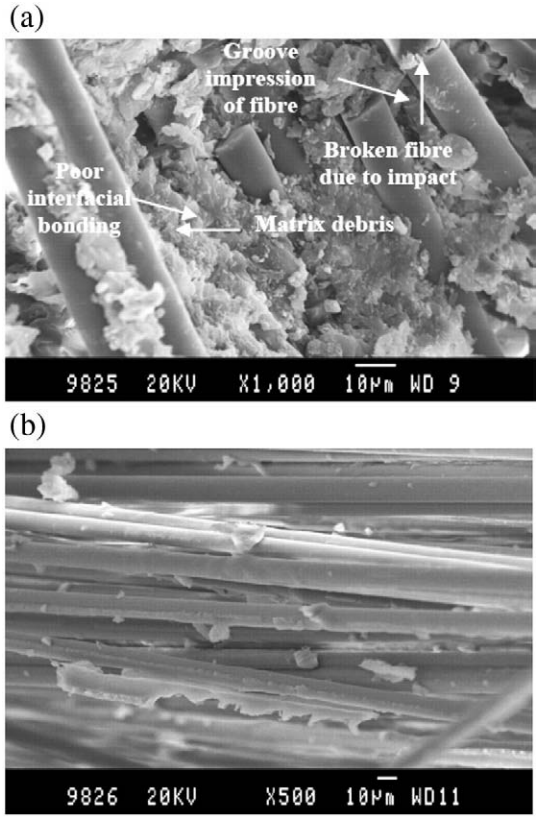

Fig. 5 – (a) and (b) — Scanning electron micrographs of glass fiber/epoxy specimens after impact testing.

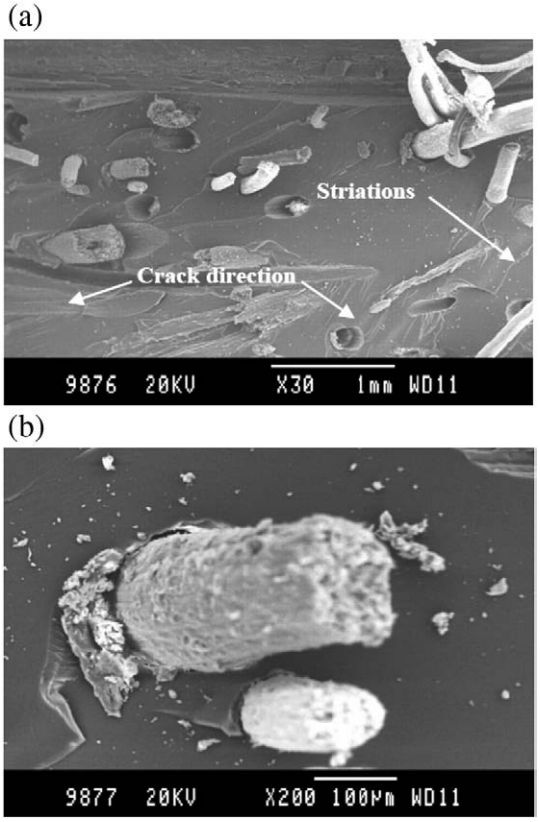

Fig. 6 – (a) and (b) — Scanning electron micrographs of coir/epoxy specimens after impact testing.

The lower impact strength of the coir/epoxy specimens was due to the poor interface bonding.

4. Conclusions

Coir/epoxy composites exhibit average values for the tensile strength, flexural strength and impact strength of 17.86 MPa, 31.08 MPa and 11.49 kJ/m^2, respectively. These values are significantly lower than those measured for GFRP laminate specimens.

Further research work needs to be carried out in the development of natural fiber composites. This is important if new improved materials are to be developed for safe usage against crack growth and environmental pollution.

Hybrid fiber composites with coir and other fibers rather than glass may open up new applications. However, as inferred from the results presented here, significant improvements in strength and fracture characteristics must be realized for this class of materials.

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