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Effect of Fiber Length on Mechanical Behavior of Coir Fiber Reinforced Epoxy Composites

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Abstract: Fiber reinforced polymer composites have played a dominant role for a long time in a variety of applications for their high specific strength and modulus. The fiber which serves as a reinforcement in reinforced plastics may be synthetic or natural. To this end, 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. The present work describes the development and characterization of a new set of natural fiber based polymer composites consisting of coconut coir as reinforcement and epoxy resin as matrix material. The developed composites are characterized with respect to their mechanical characteristics. Experiments are carried out to study the effect of fiber length on mechanical behavior of these epoxy based polymer composites. Finally, the scanning electron microscope (SEM) of fractured surfaces has been done to study their surface morphology.

Keywords: Polymer composites, Coir fiber, Fiber length, Mechanical behavior, Scanning electron microscope

Introduction

In recent years, there has been growing environmental consciousness and understanding of the need for sustainable development, which has raised interest in using natural fibres as reinforcements in polymer composites to replace synthetic fibres such as glass. The advantages of natural fibres include low price, low density, unlimited, sustainable availability, and low abrasive wear of processing machinery [1]. Further, natural fibres are recyclable, biodegradable and carbon dioxide neutral and their energy can be recovered in an environmentally acceptable way. A number of investigations have been carried out to assess the potential of natural fibres as reinforcement in polymers [2,3]. Satyanarayana *et al.* [4] suggested that relatively low aggregated value can utilize only small quantity of coir fibers, there are many researches and developing efforts to find new uses with high aggregated value such as a composite reinforcement. However investigations carried out so far [5-8] have shown that coir fiber are not an effective reinforcement for polymer matrix composites. The water adsorbed into the lignocellulosic surface of the hydrophilic coir fiber apparently prevents an efficient adhesion to the hydrophobic polymer matrix, which also happens in other natural fiber composites [9,10]. As a consequence the incorporation of coir fiber tends to decrease the mechanical strength of polyester composites for any volume fraction of fiber [7]. In principle, there are ways to reverse this decreasing mechanical properties condition. Therefore, Monteiro and co-authors [11] proposed, a strong alkali treatment of coir fiber improves the adhesion to the polyester matrix and thus increases the composites strength by approximately 50 % for a volume fraction of 30 % of coir fiber. Another possibility of effective reinforcement to a polymer matrix could be obtained through the selection of thinner coir fiber. Again Monteiro and co-authors [12] group further fabricated with the thinnest fibers of sisal, ramie and curaua in their recent work and shows improved polymer matrix composites mechanical properties. It was found that the level of flexural strengths of these composites was more than 30 % of the corresponding values obtained for identical composites with non-selected, average diameters, fibers. The mechanism suggested for higher strength composites reinforced with thinner fibers was a relatively more uniform rupture of these fibers, which statistically has a greater probability of having less structure defects [12].

Many authors [13-16] have carried out their studies in this area. They had indicated that the incorporation of natural fibers into polymers could improve some desired properties. However, less attention has been paid to the incorporation of natural fibers to form elastomeric composites [17-20]. These composites exhibit combined behavior of the soft, elastic rubber matrix, and the sti strong fibrous reinforcement.

Growing attention is now-a-days being compensated to coconut fiber due to it was easily available. The coconut husk is available in large quantities as residue from coconut production in many areas, which is yielding the coarse coir fiber. Because of its hard-wearing quality, durability and other advantages, it is used for making a wide variety of floor furnishing materials, yarn, rope etc [4]. Coconut coir is the most interesting products as it has the lowest thermal conductivity and bulk density as compared to other natural fibers [21]. The addition of coconut coir reduced the thermal conductivity of the composite specimens and yielded a lightweight product. Development of composite materials for buildings using natural fiber as coconut coir with low thermal conductivity is an interesting alternative which

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would solve environment and energy concern [21,22]. Coir fiber-polyester composites were tested as helmets, as roofing and post-boxes [23]. These composites, with coir loading ranging from 9 to 15 wt%, have a flexural strength of about 38 MPa. Coir-polyester composites with untreated and treated coir fibers, and with fiber loading of 17 wt%, were tested in tension, flexure and notched Izod impact [24].

The results obtained with the untreated fibers show clear signs of the presence of a weak interface long pulled-out fibers without any resin adhered to the fibers and low mechanical properties were obtained. Few investigations have also been made on the effect of fiber treatments on the performance of coir-polyester composites [25,26]. Although a great deal of work has been done on coir fiber reinforced polymer composites, very limited work has been done on effect of fiber length on mechanical behaviour of coir fiber reinforced epoxy composites. Against this background, the present research work has been undertaken, with an objective to explore the potential use of coir fiber as a reinforcing material in polymer composites and to investigate its effect on the mechanical behaviour of the resulting composites.

Experimental

Specimen Preparation

Coconut coir fibers were first chopped to a length of approximately 10 to 30 mm by a guillotine machine. The fabrication of the various composite materials is carried out through the hand lay-up technique. Short coconut coir fibers (Figure 1) are reinforced with Epoxy LY 556 resin, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The low temperature curing epoxy resin (Araldite LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight percentage as recommended. The epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. The coir fiber is collected from rural areas of Orissa, India. Three different types of composites has been fabricated with three different fiber lengths such as 5, 20, and 30 mm. Each composite consisting of 30 % of fiber and 70 % of epoxy resin. The designations of these composites are given in Table 1. The mix is stirred manually to disperse the fibers in the matrix. The cast of each composite is cured at room temperature under a load of about 50 kg for 24 h before it removed from the mould.

Figure 1. Coconut coir fiber.

Table 1. Designation of composites

Composites	Compositions
C_1	Epoxy (70 wt%)+Coir fiber (fiber length 5 mm) (30 wt%)
C_2	Epoxy (70 wt%)+Coir fiber (fiber length 20 mm) (30 wt%)
C_3	Epoxy (70 wt%)+Coir fiber (fiber length 30 mm) (30 wt%)

Mechanical Testing

Micro-hardness

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136° between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered $F = 24.54$ N and Vickers hardness number is calculated using the following equation.

$$H_V = 0.1889\frac{F}{L^2} \tag{1}$$

and $L = \frac{X+Y}{2}$

where, F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

Tensile and Flexural Strength

The tensile test is generally performed on flat specimens. The commonly used specimens for tensile test are the dog-bone type and the straight side type with end tabs. During the test a uniaxial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The length of the test section should be 200 mm. The tensile test is performed in the universal testing machine (UTM) Instron 1195 and results are analyzed to calculate the tensile strength of composite samples. The flexural test is conducted as per ASTM standard (D2344-84) using the same UTM. Span length of 40 mm and the cross head speed of 10 mm/min are maintained. The flexural strength (F.S.) of any composite specimen is determined using the following equation.

$$F.S = \frac{3PL}{2bt^2} \quad (2)$$

Where, P is maximum load, L is the span length of the sample, b is the width of specimen, and t is the thickness of specimen.

Impact Strength

Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy, and relating it to the cross section of the specimen. The standard specimen for ASTM D 256 is same as the flexural and inter-laminar shear strength and the depth under the notch is 20 mm. Each test is repeated six times and the mean value of impact strength is reported. The machine is adjusted such that the blade on the free-hanging pendulum just barely contracts the specimen (zero position). Since there are practically no losses due to bearing friction, etc. (<0.3 %), the testing conditions may be regarded as ideal. The specimens are clamped in a square support and are struck at their central point by a hemispherical bolt of diameter 5 mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator.

Scanning Electron Microscopy

The surfaces of the specimens are examined directly by scanning electron microscope JEOL JSM-6480LV. The eroded samples are mounted on stubs with silver past. To enhance the conductivity of the eroded samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

Results and Discussion

Mechanical Characteristics of Composites

The characterization of the composites reveals that the fiber length is having significant effect on the mechanical properties of composites. The properties of the composites with different fiber lengths under this investigation are presented in Table 2.

Effect of Fiber Length on Micro-hardness

The measured hardness values of all the three composites are presented in Table 2. It can be seen that the hardness is decreasing with the increase in fiber length up to 20 mm. However further increase in fiber length increases the micro hardness value. This may be due to the fact that the void small gap formed was probably caused by incomplete wettability or bonding between matrix resin and fibre during the fabrication of composites. This was also reported by Arib *et al.* [27] and Lee *et al.* [28].

Effect of Fiber Length on Tensile Properties

Joseph *et al.* [29] studied the tensile properties of short sisal fiber/polyethylene composites in relation to processing methods and the effects of fiber content, length and orientation. For this experiment, it is shown that the chopped fibre distribution in epoxy is random, so, the fibre could not hold the load when matrix was transferred. Doan *et al.* [30] stated that fibre length plays an important role in the mechanical performance of fibre reinforced composites. Arib *et al*. [27] compared the experimental and theoretical tensile strengths for pineapple leaf fibre reinforced polypropylene composites and found that the equation for rule of mixture fails to provide a good fit, and the discrepancy increases with the increase in fibre volume fraction. The fibre is not perfectly aligned and the presence of voids in the composites may also be the factor contributing to the lower experimental value. According to Baiardo *et al.* [31] the mechanical properties of short fibre reinforced composites are expected to depend on (i) the intrinsic properties of matrix and fibres, (ii) aspect ratio, content, length distribution and orientation of the fibres in the composite, and (iii) fibre-matrix adhesion that is responsible for the efficiency of load transfer in the composites.

The test results for tensile strengths and moduli are shown in Table 2, respectively. As expected, the tensile properties show a gradual increases with increase in fiber length reaching a maximum at about 30 mm (13.05 MPa). There can be a reason for this increase in the strength properties of these composites is that the chemical reaction at the interface between the fiber and the matrix may be too strong to transfer the tensile. From Table 2, it is clear that with the increase in fiber length the tensile moduli of the coir fiber reinforced epoxy composites also increases gradually.

Effect of Fiber Length on Flexural Strength

Table 2 shows the comparison of flexural strengths of the composites with effect of coir fiber obtained experimentally

Table 2. Mechanical properties of the composites

Composites	Hardness (Hv)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Impact energy (kJ/m^2)
C_1	15	3.208	1.331	25.41	16.0
C_2	12.6	9.155	1.518	31.28	16.5
C_3	16.9	13.05	2.064	35.42	17.5

from the bend tests. It is interesting to note that flexural strength increases with increase in fiber length. Khalil *et al.* [32] reported that the weak fibre/matrix bonding contributed to poor flexural properties. The efficiency of stress transferred between resin and fibre decreased from the weak interfacial regions. Factors that determine the quality of interfacial bonding include the nature of the fiber and binder as well as their compositions, the fiber aspect ratio, the types of mixing procedures, processing conditions employed and on the treatment of the polymer or fiber with various chemicals, coupling agents and compatibilizers. The result of the current study is slightly different than the result obtained by Khalil *et al.* [32].

Effect of Fiber Length on Impact Strength

The impact property of a material is its capacity to absorb and dissipate energies under impact or shock loading. The impact performance of fiber-reinforced composites depends on many factors including the nature of the constituent, fiber/matrix interface, the construction and geometry of the composite and test conditions. The impact failure of a composite occurs by factors like matrix fracture, fiber/matrix debonding and fiber pull out. Even though, fiber pull out is found to be an important energy dissipation mechanism in fiber reinforced composites [33]. The applied load transferred by shear to fibers may exceed the fiber/matrix interfacial bond strength and debonding occurs. When the stress level exceeds the fiber strength, fiber fracture occurs. The fractured fibers may be pulled out of the matrix, which involves energy dissipation [34]. Finally, the impact strength of these materials is measured as well and the results are reported in Table 2. It shows that the resistance to impact loading of coconut coir fiber reinforced epoxy composites improves with increase in fiber length as shown in Table 2. High strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing properties.

Surface Morphology of the Composites

The fracture surfaces study of coir fiber reinforced epoxy composite after the tensile test, flexural test and impact test has been shown in Figures 2-4. SEM photograph of the cross section of the coconut coir fiber reinforced epoxy composite is shown in Figure 2(a). It shows the tensile fracture of coir/epoxy specimens. From Figure 2(a) it can be seen that the fibers are detached from the resin surface due to poor interfacial bonding. The surface of the fiber is not smooth indicating that the compatibility between fibers and epoxy matrices is poor. From Figure 2(a) it is observed that the slipping of the coir fiber from the matrix can clearly be seen (For 20 mm Fiber length). However, this compatibility can be improved when fiber length increases to 30 mm shows lesser surface fracture may be the increase of fiber length from 20 to 30 mm as shown in Figure 2(b).

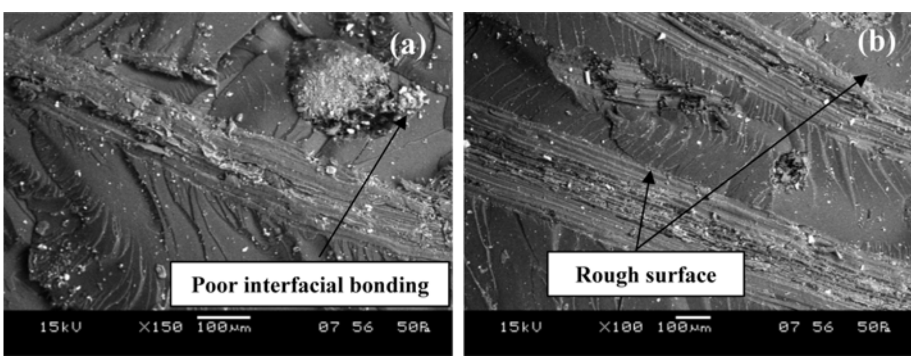

Figure 2. Scanning electron micrographs of coir/epoxy specimens after tensile testing.

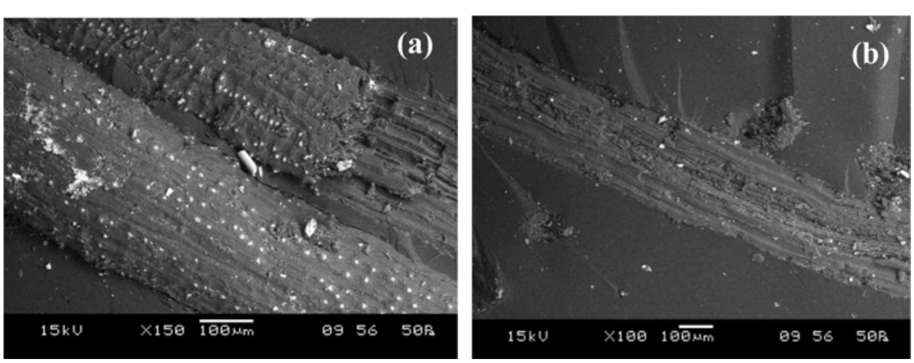

Figure 3. Scanning electron micrographs of coir/epoxy specimens after flexural testing.

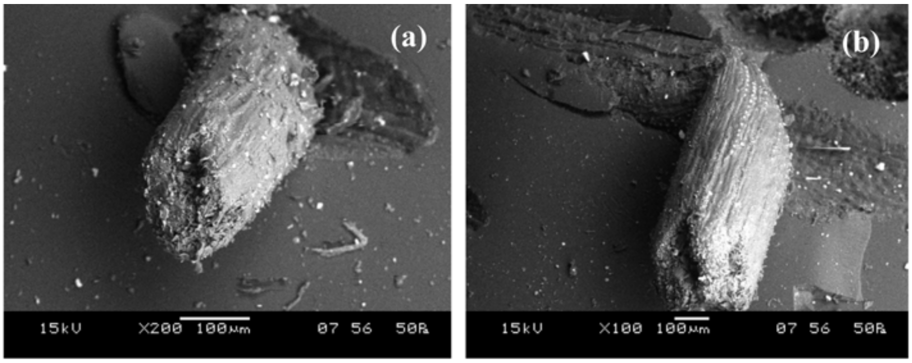

Figure 4. Scanning electron micrographs of coir/epoxy specimens after impact testing.

SEM photograph of the cross section of the coconut coir fiber reinforced epoxy composite is shown in Figure 3. It shows the coconut coir/epoxy specimen after flexural fracture. From Figure 3(a)-(b) it can be seen that the fibers are detached from the resin surface due to 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 [35].

SEM images of the impact fracture surface for coir fiber reinforced epoxy composite are shown in Figures 4. Pulled out fiber is clearly visible in the composite. In Figure 4(a), it can be seen that the fiber has offered resistance and has absorbed energy in its own fracture. Furthermore, it can be seen that the surfaces of the pulled out fibers are clean. The lower impact strength of the coir/epoxy specimens was due to the poor interface bonding. This indicates decohesion of the fibers due to a low interface resistance with the matrix [3], which causes longitudinal cracks to propagate between the coir fiber and the epoxy matrix. Additionally, Figure 4(b) shows the fiber pull-outs are much longer and the fiber surfaces are cleaner which indicates an even worse adhesion between coconut coir fiber and epoxy resin.

Conclusion

This experimental investigation of mechanical behaviour of coconut coir fiber reinforced epoxy composites leads to the following conclusions:

1. This work shows that successful fabrication of a coir fiber reinforced epoxy composites with different fiber lengths is possible by simple hand stirring technique.
2. It can be seen that the hardness is decreasing with the increase in fiber length up to 20 mm. However, on further increase in fiber length increases the micro hardness value up to 16.9 Hv.
3. In this study, untreated coconut coir fibers have been used in epoxy resin composites as reinforcement materials. This study has confirmed that coconut coir fiber reinforced epoxy composites have better tensile strength (13.05 MPa), tensile modulus (2.064 GPa), flexural strength (35.42 MPa) and higher impact strength (17.5 kJ/m^2) of the composites are also greatly influenced by the fibre lengths.
4. The fracture surfaces study of coir fiber reinforced epoxy composite after the tensile test, flexural test and impact test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.

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