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Effect of Fiber Orientation on Mechanical Properties of Woven Bamboo/E-Glass Fiber Reinforced Epoxy Hybrid Composites

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ABSTRACT

Now days there has been a greater importance towards development of natural fiber reinforced polymer composites because these are environmentally friendly and cost effective to synthetic fiber reinforced composites. But, natural fiber reinforced composites are the poor resistance to absorption of moisture. Due to this problem, a natural fiber may be combined with a synthetic fiber with the same matrix material so as to achieve the best advantage in enhancement of their properties. In this connection, hybrid composite materials of natural and man-made fibers reinforced polymer composites are essential for current demands. This paper deals with investigating the effect of fiber orientation on mechanical properties of bi-directional Bamboo and E-Glass fiber reinforced epoxy hybrid composites. This hybrid samples was prepared at different fiber orientations such as 15^0, 30^0, and 60^0. The hand lay-up method is adopted to prepared the samples. The mechanical properties such as tensile strength, flexural strength, and inter-laminar shear strength is evaluated experimentally according to ASTM standards. The conclusions drawn on the basis of the experimental results are discussed and composite with 15^0 fiber orientation shows better tensile strength compared with other fiber orientations. Similar observations are also presented for other mechanical properties of the composites such as flexural strength, and inter-laminar shear strength. The morphology of testing tensile surfaces is examined using scanning electron microscopy (SEM), and propable fracture mechanisms are identified clearly.

Keywords - Bamoo fiber, hybrid composites, fiber orientation, mechanical properties, hand lay-up method, ASTM standards, SEM.

I. INTRODUCTION

Polymeric materials reinforced with synthetic fibers such as Glass, Carbon, Kevlar and Aramid provide advantages of high stiffness and strength to weight ratio as compared to conventional construction materials, i.e., concrete, wood and steel. Despite these advantages, the widespread use of synthetic fiber reinforced polymer composite has a tendency to decline because of their high initial costs, and most importantly their adverse effect on environmental issues [1]. Natural fibers exhibit many advantageous properties such as low density materials, yielding a relatively lightweight composite with high specific properties. Therefore, the increased interest in using natural fibers as reinforcement in plastics to substitute conventional synthetic fibers in some applications has become one of the most concerns to study the potential of using natural fibers as reinforcement for polymer matrix composites [2-3]. The main disadvantage of natural fiber composites is the poor resistance to moisture absorption. Hence, the use of natural fiber alone in polymer matrix is inadequate in satisfactorily tackling all needs of fiber-reinforced composites. Due to this, a natural fiber can be combined with a synthetic fiber with the same matrix material so as to take the best advantage of the properties of both natural and synthetic fibers. This idea results in a hybrid composite and having increased mechanical properties than natural fiber reinforced composite material [4-5]. Byoung-Ho Lee, et. al. [6] concluded that mechanical testing of the jute fiber reinforced composites having fiber fraction of 40% seems to be the optimum one in respect to tensile and flexural modulus. Jayabal S, et.al. [7] evaluated the mechanical properties of woven coir and compared results of woven coir/glass fiber reinforced polyester composites. The results predicted that the properties of woven coir composites were significantly improved by incorporation of glass fibers.

To obtain the favorable material properties for a particular application, it is important to know how the material performance changes with the fiber orientation [8] under given loading conditions. D. Dash, et.al. [9] studied the mechanical properties of jute fiber and bamboo fiber reinforced epoxy hybrid composites. Hand lay-up technique was used for fabrication of the composite specimens with fiber orientation ($0/90^0$, $15/-75^0$, $30/-60^0$, and $45/-45^0$). The results concluded that the fiber orientation of $0/90^0$ provides higher strength and stiffness than other fiber orientations. S. Biswas, et. al.[10] investigated the effect of fiber loading and fiber orientation on mechanical and erosion behavior of glass fiber reinforced epoxy composites. The results revealed the composite with 30^0 fiber orientation showed better micro hardness compared with other fiber orientations and 60^0 fiber orientation showed superior tensile modulus and impact energy, where as tensile strength, and flexural strength, showed better results in 15^0, 30^0, and 15^0 fiber orientation with the increase in fiber loading. Vijaya Ramnath B, et.al.[11] evaluated the mechanical behaviour of a jute-flax based glass fiber reinforced composite. The results revealed that the hybrid composite exhibited good mechanical properties. B Stanly J.R., et. al.[12] studied hybrid bamboo/glass woven fabrics in different orientations such as 0°/90° and ± 45°. The hybrid specimen with ±45° orientation yielded higher tensile strength and flexural strength when compared with 90^0 fiber orientation. Mohaiman J. Sharba, et. al.[13] investigated the effect of fiber orientation on mechanical properties such as tensile strength, compression strength, and flexural strength of Glass/Kenaf hybrid composites. Results predicted that non-woven random mat Kenaf hybrid composite exhibited poor mechanical properties with other composite mats. P. Sathish, et.al.[14] studied the effect of fiber orientation and stacking sequence on mechanical characteristics of banana/kenaf hybrid epoxy composites. The results showed that the hybrid composite with 45^0 fiber orientation had better properties than the other orientations. Mahmud Zuhudi, et.al.[15] evaluated the mechanical, thermal and impact performances of the bamboo fabric-reinforced polymer composites. The results significant at the 50 wt.% of bamboo contents, where the tensile strength and its modulus were increased 238% and 100% compared to neat PP, respectively. Similarly, the flexural strength and modulus contributed to about at least 170% increase over the neat polypropylene.

Against this background, the present investigation has been undertaken to study of the mechanical behavior of bi-directional Bamboo and E-Glass fiber reinforced hybrid epoxy composites and compare with different fiber orientations.

II. MATERIALS AND METHODS

A. Materials

In the present investigation, bi-directional E-Glass fiber was supplied by the Vijay trading corporation, J.C. Road, Bengaluru, India. Woven Bamboo fiber was procured from Jolly Enterprise, Kolkata, West Bengal (India).

Figure1 Bi-directional Bamboo and Glass fiber mat

The plain weave E-glass with an areal weight of 220 g/m^2 and Bamboo with an areal weight of 240 g/m^2 was used to develop the hybrid laminates. Figure 1 shows the bi-directional Bamboo and E-Glass fiber mat used during fabrication of samples. The epoxy resin used in the investigation was general purpose quick curing, medium viscosity epoxy resin HSC 7600 and the hardener used was HSC 8210. Both resin and hardener procured from the Hindusthan Urban Infrastructure Ltd. (HUIL), Kolkata, West Bengal (India).

B. Preparation of composite laminates

Fabrication of the composite laminates was done by usual conventional hand lay-up technique followed by light compression molding technique. The mould was prepared with mild steel of size 310*310 mm^2. It contains of two mild steel plates, lower die with rectangular slot and upper die with flat surface. Initially the mould was thoroughly cleaned by thinner solution and then coated with release agent used to facilitate easy removal of the composite from the mould. The mould was allowed to dry for 25 minutes. The composite laminate consists of seven layers of glass and six layers of bamboo fibers were placed alternately until the desired thickness might achieved. Woven bamboo fibers and glass fibers were arranged in three different orientations, namely 15^0, 30^0, and 60^0 with respective to the base fiber. The laminates were prepared from bamboo and glass fabrics of particular dimension 300*300*5 mm^3. The laminates were named C_1, C_2, and C_3 according to the various combinations of composites as mentioned in the Table 1. The epoxy resin was mixed with hardener in the proportion of 10:1 as recommended by manufacturer and then poured onto each layer of woven fabric and remove entrapped air bubbles if present. Both lower and upper dies were tightened with C-Clamps. Curing was done at room temperature for approximately 30 hours. As soon as the curing was completed, mould was opened and the laminate was taken out carefully [10]. The same procedure was repeatedly followed to make other composite laminates as per different fiber orientations.

Table 1 Designation of laminates

Composite Type	Fiber Orientation	Fiber Content		No. of Layers	
		Bamboo	Glass	**Glass**	**Bamboo**
C_1	15^0	50	50	7	6
C_2	30^0	50	50	7	6
C_3	60^0	50	50	7	6

C. Mechanical Properties of Composites

Tensile test: Rectangular shaped specimens were cut from the composite laminates with a length 250 mm, width 25 mm using the power hacksaw machine and the edges were smoothed and finished to the required dimensions. All specimens were equipped with 50 mm long and 3 mm thick aluminum end-tabs, leaving specimen gauge length of 150 mm. Tensile tests were conducted according to ASTM-D3039 standard testing procedure using a computerized Universal Testing Machine. Specimens were placed in the grips and pulled at a constant strain rate of 3 mm/min until failure occurred.

Flexural test: This test is performed using 3-point bending test on rectangular specimens according into ASTM-D790. Specimens were cut from the composite laminates with a length 127 mm and width 12.7 mm using the power hacksaw machine. The specimens were tested with a crosshead speed of 5 mm/min. The edges were smoothed and finished to the required dimensions of both tensile and flexural test specimens. Five specimens of each composite were tested for accuracy and then mean of the tensile strength and flexural strength was reported. The flexural strength (σ) was determined by using the following equation,

$$\sigma = \frac{3PL}{2wt^2} \qquad (1)$$

Inter-Laminar Shear Strength (ILSS): It is also evaluated to help of data recorded during 3-point bend test as per ASTM 2344 and ILSS is determined by using the following equation,

$$ILSS = \frac{3P}{4wt} \qquad (2)$$

Where, **P** is the maximum load in N, **L** is the span length of the sample in mm, **w** is the width of the specimen in mm, **t** is the thickness of the specimen in mm.

III. RESULTS AND DISCUSSION

In this study, the effect of fiber orientation on mechanical properties of woven Bamboo and E-Glass fiber reinforced epoxy hybrid composites are evaluated and compared. The results of the tensile, flexural, and ILSS testing of the composite laminates are presented in the Table 2.

Table 2 Mechanical properties of Bamboo-Glass hybrid epoxy composite laminates

Composite Type	Fiber Orientation	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	ILSS (MPa)
C_1	15^0	97.2	2.49	207.95	5.59
C_2	30^0	81.8	1.74	266.93	8.49
C_3	60^0	75.8	2.04	210.12	6.43

A. Effect of Fiber Orientation on Tensile test

Different composite specimens are tested in the universal testing machine to determine the tensile properties. Figure 2 describes load v/s elongation curve obtained during a tensile test. The load can increases with respect to increase in elongation for the composites. The composite with 15^0 fiber orientation withstand a maximum load of 11.6 kN and maximum elongation of 7.9 mm and 30^0 fiber orientation withstand a maximum load of 11.06 kN. Similarly, 60^0 composite laminate shows a maximum load of 10.99 kN and maximum elongation of 8.8 mm. Composite type C_1 can withstand more load than 60^0 specimen, but this composite type can exhibit more elongation than composite with 15^0 fiber orientation.

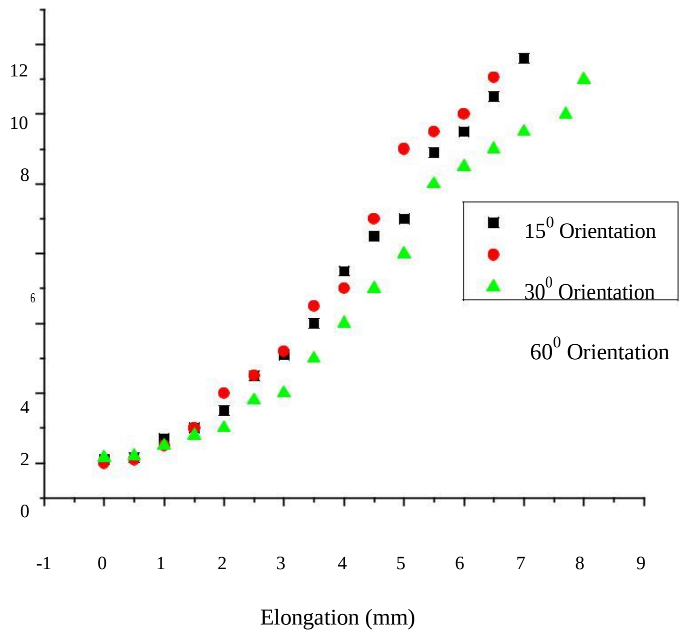

Figure 2 Load v/s elongation curve of bamboo-glass hybrid epoxy composites

The variation of tensile strength and tensile modulus of bamboo-glass hybrid fiber reinforced epoxy composites with different fiber orientations were presented in Figure 3 and 4. The tensile modulus is calculated by taking the corresponding values of stress and strain from the linear portion of the graph. The maximum tensile strength of composite was observed in 15^0 and minimum in 60^0 fiber orientation. Similarly, the maximum tensile modulus of composites was observed in 15^0 fiber orientation, which has a value 2.49 GPa and 30^0 fiber orientation exhibited 1.74 GPa lesser than other fiber orientations.

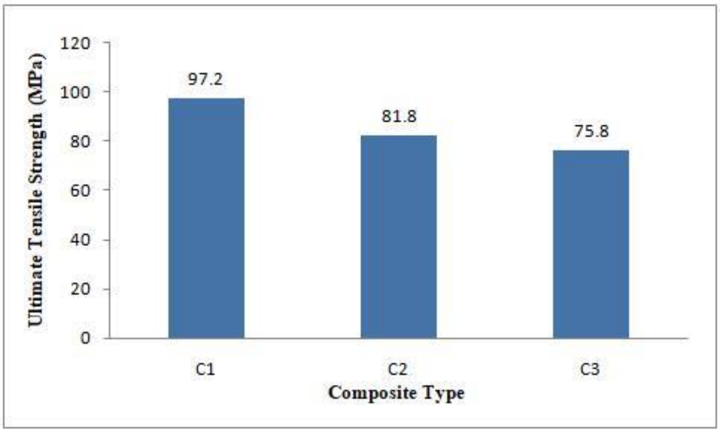

Figure 3 Tensile strength of bamboo-glass hybrid epoxy composites

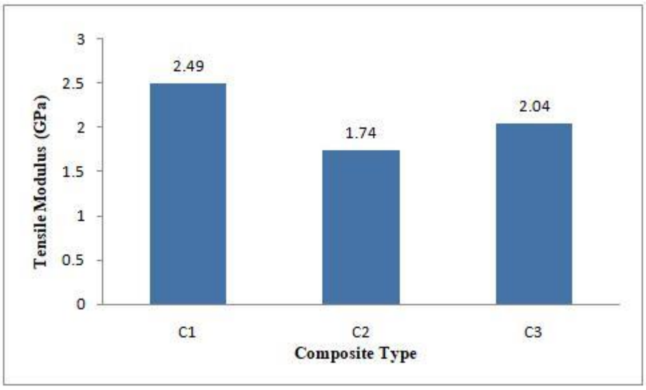

Figure 4 Tensile modulus of bamboo-glass hybrid epoxy composites

B. Effect of Fiber Orientation on Flexural test

The flexural properties of the composite laminates are tested in the UTM and the typical load-displacement curve generated for bamboo/glass hybrid epoxy composite laminate is presented in Figure 5. The result indicated that the displacement increases with the increase of applied load up to around 740 N for 30^0 composite type, after that, it tends to decrease and maximum displacement observed is 7.2 mm. Composite with 60^0 laminate shows a maximum load of 520 N and maximum displacement of 8.3 mm. Similarly, composite with 15^0 specimens shows a maximum load of 480 N and maximum displacement of 6.5 mm. The flexural strength of composite specimens with different fiber orientations of bamboo-glass hybrid epoxy composite is outlined in Figure 6.

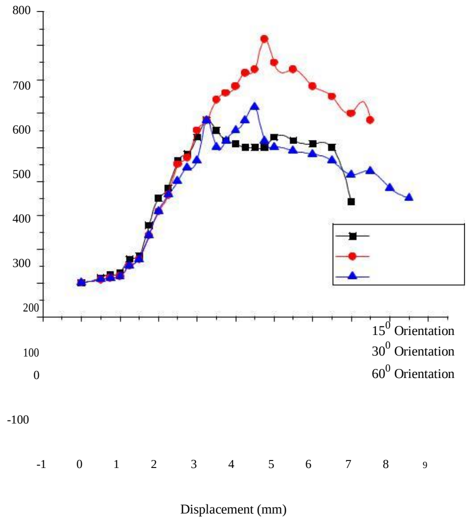

Figure 5 Load v/s displacement curve of bamboo-glass hybrid epoxy composites

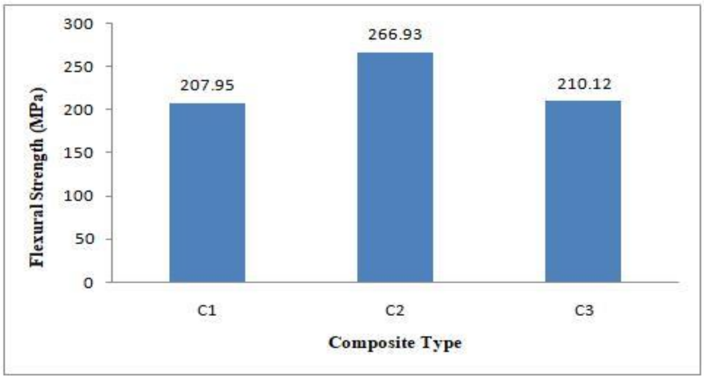

Figure 6 Flexural strength of bamboo-glass hybrid epoxy composites

The maximum flexural strength of 266.93 MPa has been observed in 30^0 fiber orientation, 15^0 fiber orientation showed a flexural strength of 207.95 MPa, and 60^0 composite specimen show a value of flexural strength of 210.12 MPa. The results indicated that the composite with 30^0 fiber orientation shows better flexural strength than the 15^0 fiber orientation composite laminates tested.

C. Effect of Fiber Orientation on ILSS

Inter-Laminar Shear Strength for composite laminates with different fiber orientations of bamboo-glass hybrid epoxy composite are presented in Figure 7. The maximum inter-laminar shear strength of 8.49 MPa was observed in 30^0 composite, 60^0 composite type shows a value of 6.43 MPa and minimum inter-laminar shear strength of 5.59 MPa was observed in 15^0 composite laminates.

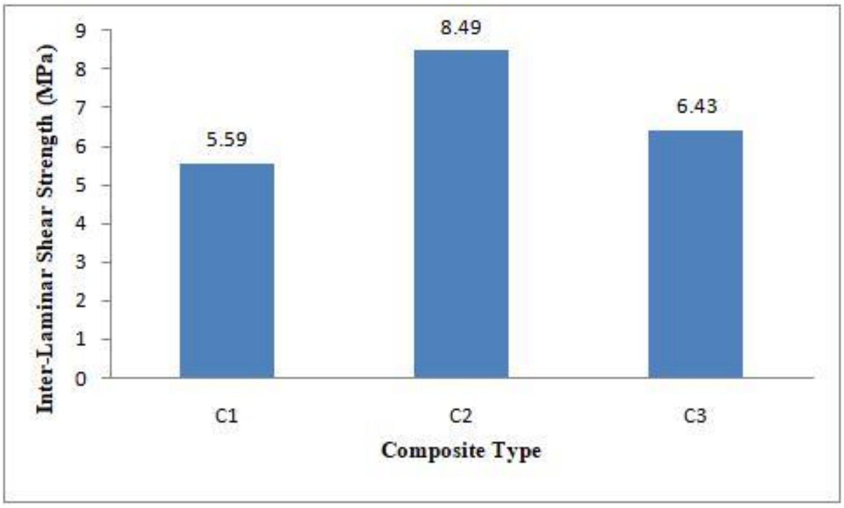

Figure 7 ILSS of bamboo-glass hybrid epoxy composites

3.5 Surface Morphology

The failure morphological analysis of the tensile tested specimen is carried out using a scanning electron microscope (SEM). A sample specimen from each tensile test is taken for carrying out surface morphological analysis. The SEM image of each tensile specimen shows the nature of adhesion between the resin and the fibers and also the nature of failure of specimens after each test. The adhesion between epoxy resin and the fiber is good in the beginning. But after the tensile load has been applied to the composite laminate, the fibers pull out which leads to fiber breakage as observed in Figure 8 (a-c).

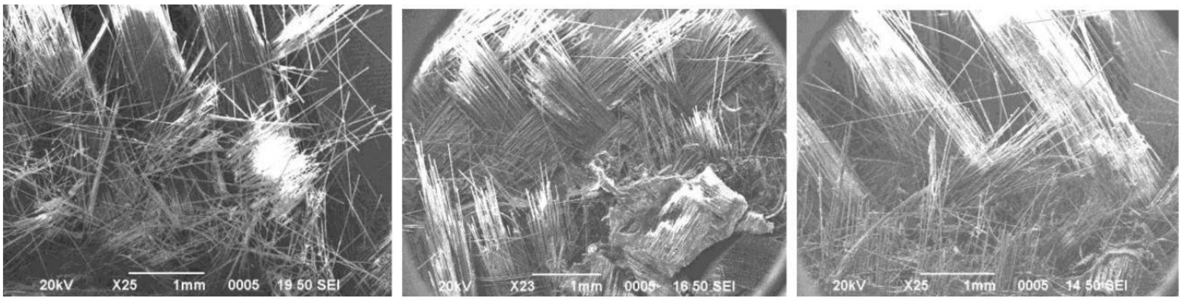

Figure 8 (a) SEM image of 15^0 laminate;(b) SEM image of 30^0 laminate;(c) SEM image of 60^0 laminate

The fiber has cracked at different locations, which indicates that a certain amount of energy has been absorbed during pull-out of the fibers from the matrix. From the micrographs of SEM analysis, the morphological properties like fiber breakage, fiber pull-out, fractured edge of fiber, dislocation of fiber and the orientation of the fiber of each tensile tested specimen and matrix due to various mechanical loadings were studied.

IV. CONCLUSIONS

Based on the study of the mechanical properties of different layered fiber orientation of bamboo and glass hybrid fiber reinforced epoxy composites, the following conclusions can be drawn:

1. The successful fabrication of bamboo-glass hybrid fiber reinforced epoxy hybrid composites with different fiber orientations are possible by simple hand lay-up technique.
2. The tensile strength of the composites is governed by the type of fiber orientations. Composite laminate with 15^0 fiber orientation shows a better tensile strength and tensile modulus when compared with other fiber orientations. Similar observations are also noticed for other mechanical properties of the composites such as flexural strength, and inter-laminar shear strength.

3. This experimental investigation revealed that composite with 30^0 fiber orientation shows a superior flexural strength than remaining fiber orientations
4. Composite laminate with 30^0 fiber orientation obtained maximum inter-laminar shear strength than when compared with remaining fiber orientations.
5. The effects of fiber orientation are analyzed and surface morphologies of composite laminates are studied using SEM and it is concluded that fiber orientation influences the mechanical behavior of the composite. SEM images of tensile tests identify fiber pull out from the composite laminate and fiber breakage during continuous loading conditions which is used to predict crack propagation in the composite.

This work can be further extended by introducing any filler materials in the epoxy matrix and also using various bio-degradable resins. Instead of the hand lay-up technique, other manufacturing techniques may be adopted to improve the mechanical properties of the composites.

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