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Physical, Mechanical and Water Absorption Behavior of Bi-Directional Jute/Glass Fiber Reinforced Epoxy Composites

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Abstract: In the present work, effect of fiber loadings and orientations on the physical, mechanical and water absorption behaviour of jute/glass fiber reinforced epoxy composites have been studied. From the studies of different properties it has been observed that the maximum values of hardness, flexural and inter-laminar shear strengths are obtained for composites reinforced with 40 wt% fiber loading and at 30° fiber orientation whereas, the maximum tensile strength is observed for composites with 30 wt% of fiber loading and at 0° fiber orientation. The water absorption rate increases with increase in fiber loading irrespective of fiber orientation.
Keywords: Natural fiber, jute/glass fiber, epoxy, inter-laminar strength, scanning electron microscopy

I. Introduction

Now-a-days global warming is a major environmental crisis and main focus area for the international community. Because of this, the material designers are constantly searching for new materials which are environmental friendly, sustainable, biodegradable, light weight with high specific properties and above all low cost. Composites, reinforced with natural fibers are proved to be the best alternatives compared to their synthetic counterpart that meet the above requirements. However, composite made of the same reinforcing material system may not give better results as it undergoes different loading conditions during the service life. For this purpose, hybrid composite is the best solution for such applications.

A fiber reinforced hybrid composite is a combination of two or more different types of fiber in which one type of fiber balance the deficiency of other. The purpose of hybridization is to design a new composite material that will retain the advantages of its constituents providing specific application where single fiber composite fails. Further, it gives flexibility to the design engineers to tailor the material properties according to the requirements. Natural fiber sometimes combines with stronger and more corrosion-resistant synthetic fiber to produce hybrid composite which can improve the strength, stiffness and also moisture resistant property of the composite. Till date, few studies[1-7] on hybrid composites reinforced with either natural fiber with synthetic fiber combination or natural with natural fiber have been done to analyze various properties to be fit for different applications.

Ashmed et al. (Ashmed et al., 2007) have investigated the elastic properties and notch sensitivity of untreated woven jute and jute/glass fabric reinforced polyester hybrid composites, analytically and experimentally. They have observed that the jute composites exhibited higher notch sensitivity than jute/glass hybrid composites. Dixit et al. (Dixit et al., 2012) have reported a remarkable improvement in the tensile and flexural properties of hybrid composites compared to the un-hybrid composites. Experimental investigation carried out by Mishra et al. (Mishra et al., 2003) depicts that addition of quite small amount of glass fiber to the pineapple leaf fiber and sisal fiber-reinforced in polyester matrix improves the mechanical properties of the resulting composites.

Jawaid et al. (Jawaid et al., 2013) have studied the mechanical behaviour of hybrid composites based on jute and oil palm fiber. It has been found that the use of hybrid system is effective in increasing the tensile and dynamic mechanical properties of the oil palm-epoxy composite because of enhanced fiber/matrix interface bonding. Verma et al. (Verma et al., 1989) have examined the mechanical properties of jute/glass fiber hybrid composites. The jute fabrics have been modified by treatment with different chemicals. It has been observed that titanate treatment of jute fabric results in enhanced performance characteristics and mechanical properties of hybrid composites. Ahmed et al. (Ahmed et al., 2008) have experimentally investigated the effect of stacking sequence on mechanical properties of woven jute and glass fabric reinforced polyester hybrid composites. They have observed that the layering sequence has larger effect on the flexural and inter-laminar shear properties than tensile properties. On comparing the overall properties of the laminates it has been concluded that the hybrid laminates with two extreme glass plies on both sides has the optimum combination with a good balance between the properties and the cost. Sreekala et al. (Sreekala et al., 2002) have found that incorporation of small volume fraction of glass fiber in composites results in enhanced tensile and flexural properties. The works done so far on various hybrid composites lack the effect of various properties on fiber orientations as well as fiber loadings. The aim of the present work is to study the effects of fiber loadings and orientations on physical, mechanical and water absorption behaviour of jute/glass fiber reinforced epoxy hybrid composite. Further, the fracture behavior of the composite has been analyzed with the help of scanning electron microscope (SEM).

II. Experimentation

Materials

The woven jute fabric and the plain weave E-glass fabric (bi-directional) have been purchased from Shakti glass and Traders, Chennai, India. The matrix system consists of epoxy LY556 having density 1.12-1.18 g/cm^3 and hardener HY951 having density 0.96-0.98 g/cm^3 both have been procured from Naphtha resins and chemicals Pvt. Ltd., Bangalore, India.

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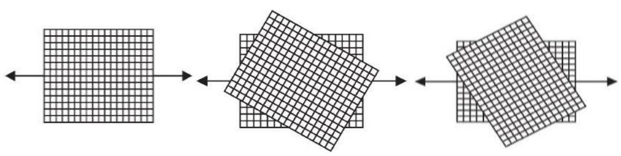
Specimen Fabrication

Hybrid laminates of woven jute and E-glass mat have been prepared by simple hand lay-up technique. PVA release agent was applied to the surfaces of the mold. The low temperature curing epoxy resin and corresponding hardener have been mixed in a ratio of 10:1 by weight and used as matrix material. Jute and glass fabrics have been pre-impregnated with the matrix and the impregnated layers have been placed one over the other in the mold (20 cm×20 cm) and pressed for 1h before removal. Provision has been made in the mold to allow the hot gases to escape. Uniform thickness of 3 mm has been achieved by using spacers of desired thickness between the mold plates. The laminate has been cured by applying a load of 50 kg at room temperature for 24h. The composite laminates with three different fiber loadings (30, 40 and 50 wt%) have been made with three different fiber orientations (0°, 30° and 60°). In each fiber orientation, total weight percentage have been varied maintaining constant weight percentage (20 wt%) of glass fiber. The designation of all the composite laminates along with the fiber loadings and orientations have been presented in Table-1. The detailed arrangement of fiber mats in the composites with three fiber orientations have been shown in Fig. 1. Fig. 2 (a) shows the samples of jute and glass fiber mats whereas; Fig. 2 (b) shows a composite laminate sample with 40% fiber loading and 60^o orientation.



(a) 0^o (b) 30^o (c) 60^o

Fig. 1: Schematic diagram of fiber orientations in the composite

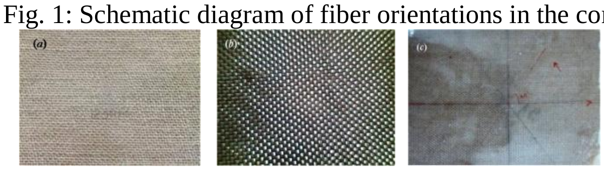


Fig. 2: Specimen samples (a) jute fiber (b) glass fiber (c) jute/glass hybrid composite (60^o) fiber with 40% fiber loading

Table 1: Designation of composites

Samples	Orientation (degree)	Compositions (Wt%)
C_1^1	0	Epoxy (70) + Glass (20) + Jute (10)
C_2^1	0	Epoxy (60) + Glass (20) + Jute (20)
C_3^1	0	Epoxy (50) + Glass (20) + Jute (30)
C_1^2	30	Epoxy (70) + Glass (20) + Jute (10)
C_2^2	30	Epoxy (60) + Glass (20) + Jute (20)
C_3^2	30	Epoxy (50) + Glass (20) + Jute (30)
C_1^3	60	Epoxy (70) + Glass (20) + Jute (10)
C_2^3	60	Epoxy (60) + Glass (20) + Jute (20)
C_3^3	60	Epoxy (50) + Glass (20) + Jute (30)

Density measurement

Density of composite samples has been measured in accordance with ASTM D792 standards (ASTM D792, 1987). Square specimens having size 20 mm × 20 mm × 3 mm have been immersed in distilled water (immersion fluid) at room temperature and the weights have been measured using digital balance with a 10^{-3}g resolution. The mean density has been calculated by taking average of five specimens of each group. The theoretical density of the composites has been determined by adopting the principles of rule of mixture (Fukuda et al., 1974). The void percentage in the composite samples has been determined as per ASTM D2734 standards (ASTM D2734, 1987).

Tensile test

The specimens for the tensile test have been cut from the composite samples to a size of 150 mm × 15 mm × 3 mm. The test has been conducted by using *INSTRON* 1195 Universal Testing Machine having load capacity of 50 kN at a cross-head speed of 2 mm/min in laboratory environment as per ASTM 3039 standards. The strain has been measured by extensometer with a gauge length of 25 mm. For each composite sample, five identical specimens have been tested and the average result has been noted.

Flexural Test

The flexural test has been performed according to ASTM D790 with specimen size of 125 mm length and 10 mm wide under three point bending method. The test has been conducted in the same machine using a load cell of 10 kN at a cross-head speed of 2 mm/min. The flexural stress has been calculated as per the following equation.

$$\sigma_{\max} = \left(\frac{3P_{\max}L}{bh^2} \right) \quad (1)$$

Where, $P_{\max}$ is the maximum load at failure (*N*); L is the span (mm); *b* & *h* are the width and thickness of the specimen (mm) respectively. For each composite sample, five identical specimens have been tested and the average value has been taken.

Inter-laminar tests

Inter-laminar shear strength (ILSS) test has been conducted on the same *INSTRON* 1195 machine as per ASTM D2344. The specimen is loaded under 3-point bending at the rate of 1.3 mm/min and the transverse shear stress has been calculated as per equation (2).

$$\tau = \frac{3P_B}{4bh} \quad (2)$$

Where, τ is the Inter-laminar shear strength (N/mm^2); P_B is the breaking load (*N*). Foe each composite system, five identical specimens have been tested and the average result has been obtained.

Micro-hardness test

Micro-hardness test of composite specimens has been done using Leitz Micro-Hardness Tester as per ASTM D2240. A diamond indenter in the form of a right pyramid of square base having an angle of 136° between opposite faces under a load *P* is forced into the specimen. After the removal of load, the two diagonals of the indentation (*X* and *Y*) left on the surface of the specimen have been measured and their arithmetic mean *L* has been calculated. Vickers hardness number is calculated as per the following equation.

$$H_v = 0.1889\frac{F}{L^2} \text{ and } L = \frac{X+Y}{2} \qquad (3)$$

Where, *F* is the applied load (N), *L* is the mean diagonal of the square impression (mm).

Water absorption test

The study of water absorption on composite samples has been carried out in river water having pH value of 7.40 in accordance with ASTM D570 standard. Humidity chamber (desiccator) has been set up at 100% humidity using the above water. The composite samples have been dried in hot air oven at 60°C for 24 h, weighed in a balance accurate to 4 decimal places (± 0.1 mg) and then placed in the humidity chamber maintained at room temperature. After 24 h, each sample has been taken out from the humidity chamber and excess water has been carefully soaked with filter paper. Finally, the weight of the samples has been measured and the water absorption has been calculated by weight difference as per the following equation.

$$\text{Water absorption } \% = \frac{(W_t - W_0)}{W_0} \times 100 \qquad (4)$$

Where, W_t is the weight of sample after exposing to water and W_0 is the weight of dry sample.

Surface Morphology

Microscopic examinations have been performed using a HITACHI SU3500 scanning electron microscope (SEM). All specimens are sputtered with a 10 nm layer of gold and mounted on aluminum holders using double-sided electrically conducted carbon adhesive tabs prior to SEM observations.

III. Results and Discussion

Effect of fiber loading and orientation on density of composite

It is obvious that the difference in theoretical and measured densities indicates the presence of micro-voids and pores which affects various properties of the composites. Hence, it is essential to measure the volume percentage of void contents in the composites. Table 2 shows the theoretical and measured density along with their corresponding void contents. It has been observed that the density as well as the void content increases with the fiber loading in the composites. However, the fiber orientation has less effect on density and void content. The increase in density and void content with fiber loading is mainly because of the presence of jute fiber as it contains more number of hydroxyl groups.

Table 2: Void fraction of hybrid composites

Composites	Theoretical Density (gm/cc)	Measured Density (gm/cc)	Void Content (%)
C_1^1	1.31	1.299	0.839
C_2^1	1.328	1.3	2.108
C_3^1	1.345	1.298	3.494
C_1^2	1.31	1.307	0.229
C_2^2	1.328	1.311	1.28
C_3^2	1.345	1.289	4.163
C_1^3	1.31	1.297	0.992
C_2^3	1.328	1.3077	1.528
C_3^3	1.345	1.303	3.122

Fiber loading and orientation on hardness of composites

Hardness is one of the most important factors that control wear resistance of materials. The variations of jute/glass hybrid composites with different fiber loading and fiber orientations have been shown in Figure 3. From the figure it is observed that, with increase in fiber loading the micro-hardness values significantly goes on increasing up to 40% fiber content. However with further increase in fiber loading, the micro-hardness values decrease irrespective of fiber orientation. Similar trend is also observed in case of fiber orientation. Composites with 40wt% of fiber loading and 30° fiber orientation show maximum hardness value. It may be due to good adhesion between fiber and matrix at 40% fiber content.

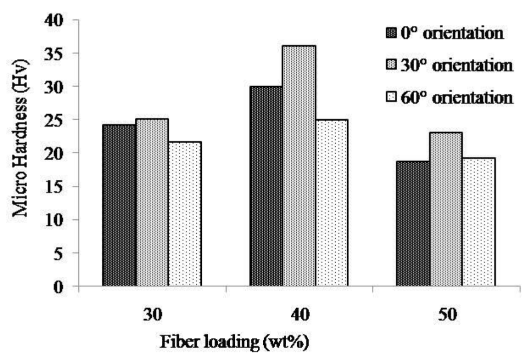


Fig. 3: Effect of fiber loading and orientation on micro-hardness of composites

Effect of fiber loading and orientation on tensile properties of composites

The influence of fiber loading and orientation on the tensile strength and tensile modulus of the composites are shown in Figs. 4 and 5 respectively. The tensile strength of the composites decreases with increase in fiber loading and orientation. The maximum tensile strength is observed (Fig. 4) for composite with 30 wt% fiber loading and 0° fiber orientation. Tensile strength of the composite is dependent on the tensile strength and modulus of fibers. As glass fiber has superior tensile strength than jute fiber therefore, sample having 30% fiber loading containing major amount of jute/glass fiber ratio gives maximum tensile strength. Further, it is observed that tensile strength of the composite is significantly affected by fiber orientations. In case of 0 degree oriented composite specimen, the tensile strength is higher as compared to 30 and 60 degree orientation. The reason is that at 0 degree fiber orientation the external tensile load is equally distributed on all the fibers and transmitted along the fibers axis whereas, in other fiber orientations fiber axis is not parallel to loading axis resulting in pulling-off of fibers which causes early failure.

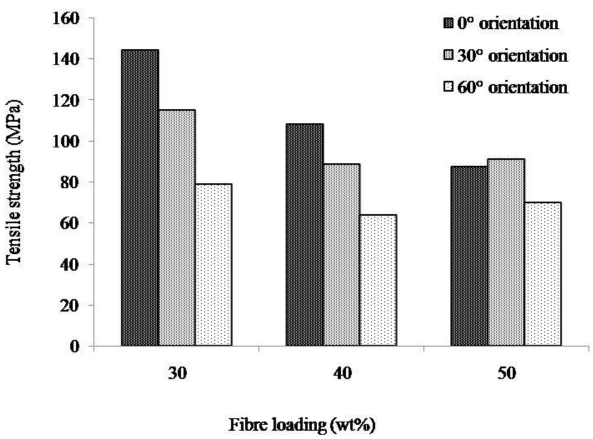


Fig.4: Effect of fiber loading and orientation on tensile strength of composites

The tensile modulus of composite is found to be increasing with increase in fiber orientations irrespective of fiber loadings as observed in Fig. 5. However, with increase in fiber loading, the tensile modulus gradually goes on decreasing in each fiber orientation. The decrease in tensile modulus with fiber loading may possibly be attributed to the higher resin-normalized void content.

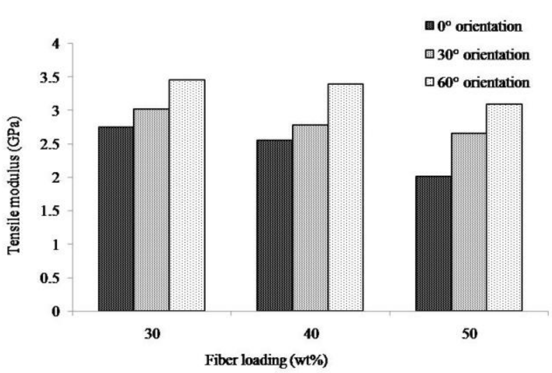


Fig. 5: Effect of fiber loading and fiber orientation on tensile modulus of composites

Effect of fiber loading and orientation on flexural properties of composite

The effect of fiber loading and orientation on the flexural strength and flexural modulus of jute-glass reinforced epoxy based hybrid composites are shown in Figs. 6 and 7 respectively. As observed in Fig. 6, the flexural strength of composites is increased up to 40 wt% fiber loading and then decreased with the increase in fibre loading irrespective of fibre orientation. It has been observed that in case of fiber reinforced polymer composites, the improvement of interfacial adhesion between the fiber and matrix improves the mechanical properties of composites through an efficient load transfer between the fibers and the matrix. Hence, at 40% fiber content there is a good adhesion between the fiber and the matrix which is responsible for higher flexural strength. This may be treated as optimum fiber loading for this particular case as far as flexural strength is concerned. As fiber content increases above this value there may be difficulty in compatibility which decreases the flexural strength. As far as effect of fibre orientation in flexural strength is concerned, almost similar trend is obtained and 30 degree oriented composites show better flexural strength than other oriented composites. In case of flexural modulus (Fig. 7), it is observed that maximum flexural modulus is obtained at 30% fiber loading irrespective of fiber orientation.

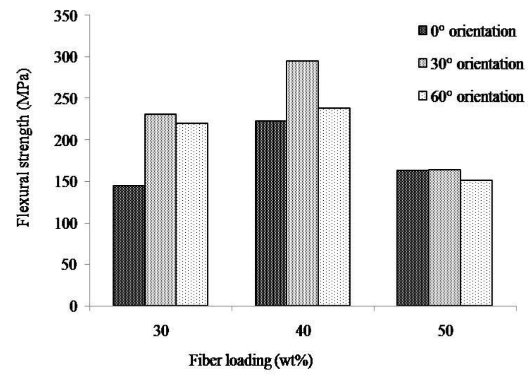


Fig. 6: Effect of fiber loading and orientation on flexural strength of composites

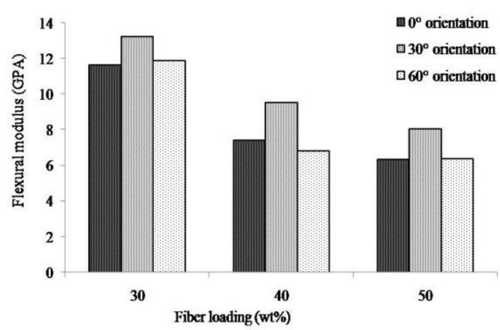


Fig. 7: Effect of fiber loading and fiber orientation on flexural modulus of composites

Effect of fiber loading and orientation on inter-laminar shear strength of composites

The effect of fiber loading and orientation on inter-laminar shear strength of composite is shown in Fig. 8. The inter-laminar shear strength of the composite is found to increase up to 40% of fiber loading with the increase in fiber loading and then decreases. Similarly, with increase in fiber orientation the inter-laminar shear strength increases up to 30° fiber orientation then it decreases. This may be because of the failure of the composite specimen by delamination, which occurs due to poor adhesion between fiber and epoxy interface.

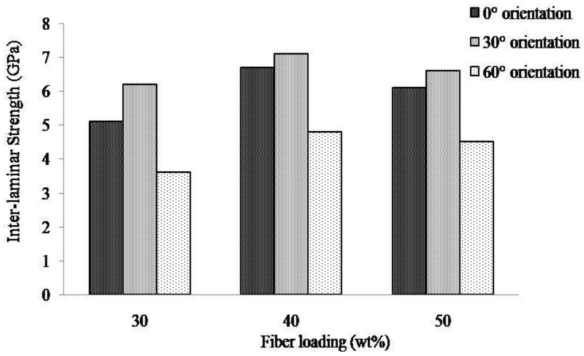
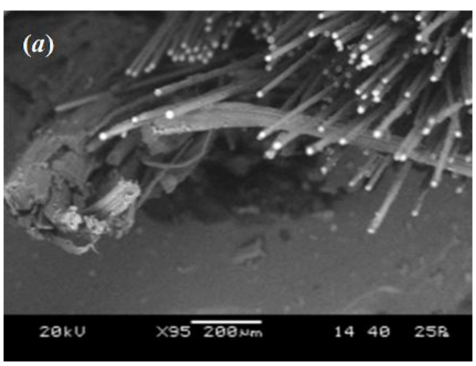
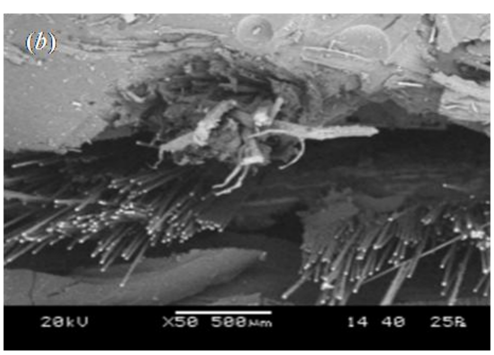


Fig. 8: Effect of fiber loading and orientation on inter-laminar shear strength

Surface Morphology

Fig. 9 shows the fracture surfaces of jute/glass fiber reinforced epoxy composite after the flexural test under different fiber loadings and orientations. Figure 9a shows the fracture of composite specimen at 40 wt% fiber loading and 0° fiber orientation. Figure 9b shows the SEM image of fracture surface of composite specimen reinforced with 50 wt% fiber loading at 60° fiber orientation. It can be seen from the figures that the fibers are detached from the resin surface due to poor interfacial bonding. Fracture surface of composites reinforced with 40wt% fiber loading at 30° fiber orientation shown in Figure 9c. It is evident from the figure that surface without much fiber pull out is clearly visible which leads to the better compatibility of fiber and matrix.





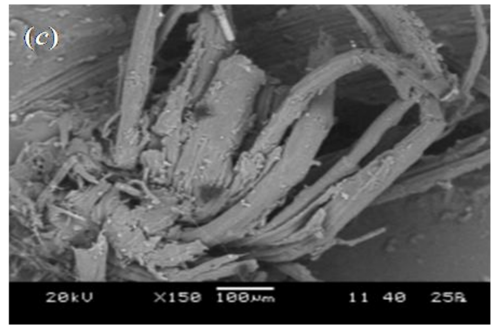


Fig. 9: Scanning electron micrographs of fracture surface of jute/glass fiber reinforced epoxy composite. (a) 30 wt% fiber loading and 0° fiber orientation (b) 50 wt% fiber loading at 60° fiber orientation (c) 40wt% fiber loading at 30° fiber orientation.

Water Absorption Behaviour of Composites

The water absorption of these composites is mainly due to the presence of jute fibers. The percentage of weight gain in various composites with time duration is shown in Figure 10.

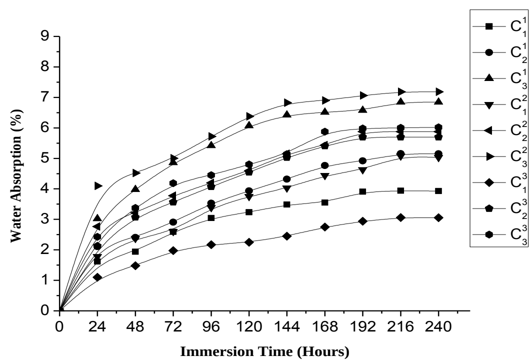


Fig.10: Effect of immersion time on water absorption properties of composites

It is observed from the figure that with increase in fiber loading the water absorption gradually increases irrespective of fiber orientation. The maximum water absorption obtains at 50% fiber loading irrespective of fiber orientation.

IV. Conclusion

The effect of fiber loading and orientation on physical, mechanical and water absorption behaviour of jute/glass fiber reinforced epoxy composites has been experimentally investigated. From the experimental findings the following conclusions are drawn:

1. Incorporation of jute fiber in glass fiber increases the properties of resulting hybrid composites.
2. The maximum values of hardness, flexural strength and inter-laminar shear strength are obtained for composites reinforced with 40 wt% fiber loading and at 30° fiber orientation. However, the maximum tensile strength is observed for composites with 30wt% of fiber loading and at 0° fiber orientation.
3. The water absorption rate gradually increases with increase in fiber loading irrespective of fiber orientation. The maximum water absorption is obtained for composites with

50% fiber loading irrespective of fiber orientation. As far as effect of fiber orientation on the water absorption of composites is concerned, it has less effect on water absorption behavior.

4. Comparing the overall properties of all the laminates it can be concluded that the composites with fiber loading between 30 wt% to 40 wt% and fiber orientation between 0° to 30° could be a good balance for practical use. However, this requires further investigation.

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