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Bamboo Fiber Reinforced Composite Using Non-Chemical Modified Bamboo Fibers

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A B S T R A C T

In the present work epoxy resin have been reinforced with water treated bamboo strip matting to develop bamboo fiber reinforced plastic (BFRP) composites. Bamboo was treated with water for different time interval. The mechanical properties (tensile and flexural strengths, impact strength) and water absorption properties of the treated bamboo composites were determined. Improved mechanical properties were obtained for bamboo composite treated for one month. The morphology analysis by scanning electron microscopy (SEM) reveals that the modified bamboo exhibited better compatibility with the epoxy resins than the untreated bamboo.

1. Introduction

In order to overcome the highly hydrophilic character of natural fibers, several chemical treatments like alkalization, graft copolymerization and coupling agents have been used successfully. But chemical treatments pollute the environment and sometimes lead to significant increase in product cost. Moreover, attempt to replace glass fibers with natural fibers is a step toward bio-based composites, which is undermined by the use of chemicals to improve interfacial adhesion. Gulati et al [1] investigated the changes induced by a fungal treatment (O. ulmi) on plant fibers and improved adhesion of plant fibers with the thermosetting resins was obtained.

So, an attempt has been made to modify the bamboo fiber surface through the use of water. This is a very clean process as no chemical is involved. Hemicellulose is mainly responsible for moisture absorption in fibers, which in turn leads to poor interfacial adhesion with matrix and delamination. Hemicellulose is very hydrophilic and can be hydrolyzed in water after long term immersion. Water leaching and drying remove the starch partially.

2. Experimental

Orthogonal bamboo strip mats were acquired from the local market. The cross-section of the strip used in the mats is 4.25mm × 0.5mm. Bamboo mats cut to size 300×200 mm^2 were cleaned with washing powder and washed in running water thoroughly to remove dust and other deposits from the surface. They were left in the open to dry out for 4 h. Epoxy resin (CY-230) and hardener (HY-951) were purchased from CIBA-GEIGY.

Epoxy resin was heated in oven for 10 min to remove the moisture and air bubbles. After cooling the resin to room temperature, hardener, 10% by weight, was added, stirred to mix thoroughly and subsequently applied on the bamboo mats. Piled one over another to seven layers. Placed in between two Perspex sheets, 300×200 mm^2, and pressed in the hydraulic press under a pressure of 170 KN for 24 h. Then the composites were cured at 80 ^{o}C for 4 h in oven.

Three sets of bamboo mats were immersed in distilled water for different time interval. First set for 1 month, second set for 3 months and third set for 6 months. In addition to this one set is prepared by boiling mats in distilled water at 90-100 ^{o}C for 6 hours. At the end of the time mats were thoroughly cleaned with water and dried in hot air circulating oven at 110 ^oC for 24 h. Composites were fabricated with epoxy matrix. A number of composites were fabricated as tabulated in Table 1.

Table 1: Nomenclature of water modified composites.

Material	Specification
BE	Untreated bamboo epoxy composite.
B1ME	Bamboo epoxy composite with fibers immersed in water for 1 month
B3ME	Bamboo epoxy composite with fibers immersed in water for 3 month
B6ME	Bamboo epoxy composite with fibers immersed in water for 6 month
B6HE	Bamboo epoxy composite with fibers boiled for 6 hours.

The tensile test was performed according to the ASTM D638. Dog bone shaped specimens of the composites were cut. At least five replicate specimens were tested for each formulation. Each specimen was tested to failure under tension at a cross-head speed of 2 mm/min on INSTRON 3369. Three-point bending test was performed according to ASTM D790. Specimens of dimension 96×13 mm^2 were prepared. Support separation was 70 mm and test speed was 5mm/min on ZWICK Z010. Notched Izod impact test samples with dimensions of 63.5×12.5 mm^2 by the thickness were cut from the laminate composites. The testing was conducted according to ASTM D256 on a Zwick model 5101 with a pendulum weight of 25 J. Five samples were tested and the average value was taken as the Izod impact strength. The Izod impact strength was calculated using the formula given below:

$$\text{Impact strength } (kJ/m^2) = [\text{Impact energy } (J)/\text{Cross sectional area}] \times 10^3$$

Tensile fracture surface of the composite samples were coated with silver and then analyzed using CARL ZEISS EVO 50 scanning electron microscope.

Water absorption studies were performed following the ASTM D570-98 method at room temperature (25 ^oC). The samples were taken out periodically and weighed immediately, after wiping out the water on the surface of the sample, to find out the content of water absorbed. The amount of water absorbed in the composites was calculated by the weight difference between the samples exposed to water and the dried samples.

3. Results and Discussion

3.1 Mechanical Properties

The tensile and flexural properties of water modified bamboo reinforced epoxy matrix composites are plotted in Figures 1 and 2. The tensile strength of a composite material is mainly dependent on the strength and modulus of the fibers, the strength and chemical stability of the matrix, and the effectiveness of the bonding strength between matrix and fibers in transferring stress across the interface [2]. One month water modified bamboo improved the tensile strength of the bamboo-epoxy composite by 36% compared to raw bamboo composite. This may be due to intrinsically increased strength of fiber after mercerization and stress transfer efficiency which results from improved interfacial adhesion between fiber and matrix. During water treatment, when hemicelluloses are removed, the interfibrillar region is likely to be less dense and less rigid and thereby makes the fibrils more capable of rearranging themselves along the direction of tensile deformation. Hemicellulose removal can lead to an increase in the crystallinity index because it allows a better packing of the cellulose chains. And it leads to increase in fiber strength and hence the composites. The increase in the tensile strength of the composites reinforced with bamboo modified for 3 months and 6 months is 24% and 7% respectively. This may be due to degradation of cellulose caused by the long term immersion of the fibers. With increase in time of immersion of fibers in water the improvement in tensile strength decreases. The boiling of fibers has reduced the tensile strength by 8% compared to unmodified bamboo composite. It can be observed from the SEM micrographs, Figure 3, that interfacial adhesion has improved after fiber modification. So it can be concluded that reduction in tensile strength is due to cellulose degradation. The boiling of fiber allowed the extraction of lignin in a greater proportion, and probably in a way that worsened the mechanical properties of the fibers. The reduction in the lignin content of the fiber can yield a fiber with a chemical structure less strongly bound, given that lignin connects the three-dimensional cellulose network as well as fibrils [3].

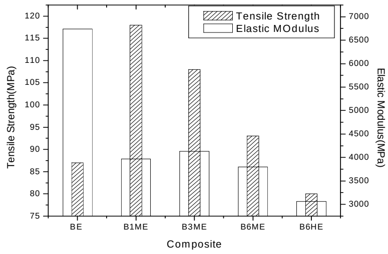

Figure 1: Tensile properties of water treated bamboo composites.

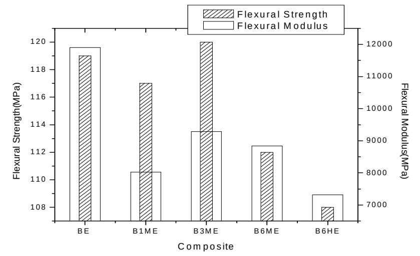

Figure 2: Flexural properties of water treated bamboo composites

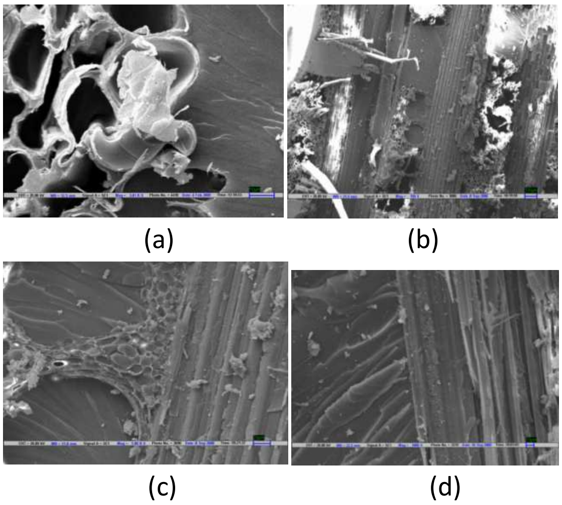

Figure 3: SEM micrograph of tensile fracture surfaces of (a) B1ME, (b) B3ME, (c) B6ME, (d) B6HE

Flexural strength is a combination of the tensile and compressive strengths, which directly varies with the interlaminar shear strength. In flexural testing various mechanism such as tension, compression, shearing etc. take place simultaneously. In three point flexural test, failure occurs due to bending and shear failure.

The flexural strength of composite B3ME remained same but that of other composites have decreased significantly. Maximum decrease is found out for the composite reinforced with bamboo modified with boiling water. The compressive strength and interfacial shear strength of fiber depends significantly on the fiber matrix (lignin). Water might have leached out the lignin.

The elastic and flexural modulus of all composites has decreased. The elastic modulus of B1ME has decreased by 41%. When hemicellulose is removed, the interfibrillar region becomes less tense, reducing stiffness and lending the fibrils a larger capacity of rearranging in the direction of deformation tension. The increased elongation characteristic is probably attributable to the increase in the degree of molecular orientation in the fibril as a result of the treatment. And this results in decrease in the modulus.

The impact strength of composite B6ME has improved by 40%, Figure 4. The enhancement of impact strength of water modified fiber composites as compared to raw fiber composite might be attributed to the flexibility of the interface molecular chain resulting in comparatively greater energy absorption. Impact strength of B1ME is lower than BE. The lower impact strength of composites having high tensile strength can be explained by assuming that a higher fiber–matrix adhesion results in shorter average pull-out lengths and therefore causes lower impact strengths [4]. Composite B6HE has lower tensile strength and also the impact strength. This may be attributed to fiber weakening due to degradation of cellulose by boiling.

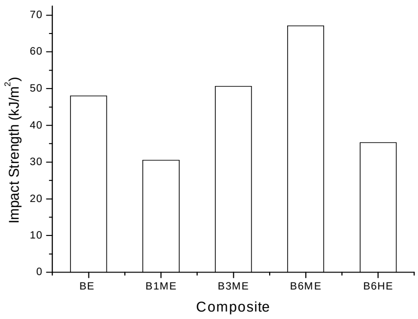

Figure 4: Impact strength of water treated bamboo composites.

3.2 Water Absorption

The water uptake by composites depends on the nature of the fiber and interaction between fiber and matrix. The hydrophilicity is responsible for the higher percentage of water uptake in untreated bamboo composites due to the present of lignin and hemicellulose component. Hemicelluloses are mainly responsible for the water uptake, although noncrystalline cellulose and lignin and interfacial adhesion also play an important role in the process.

Water resistance of all the composites reinforced with modified fibers has improved, Figure 5. Water absorption by composites B1ME, B3ME, B6ME and B6HE is reduced to 34.38%, 31.69%, 37.38% and 33.24% compared to 41% of BE. This is mainly due to leaching out of the hydrophilic hemicelluloses and improved interfacial adhesion. The interaction between the fiber surface and polymer matrix is enhanced as a result of strong bonding at the interface, so that water molecules which may be absorbed by the cellulosic fibers cannot be accommodated in the composite. After 2h boiling, Figure

6, water absorption of modified composites has increased. It is 24% for B1ME and 13.68% for B6HE against 14.06% of BE.

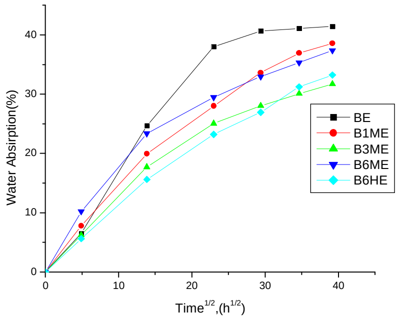

Figure 5: Water absorption curve for water treated bamboo composites.

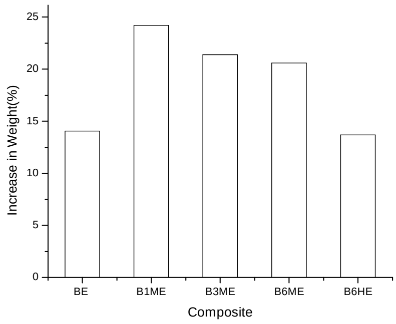

Figure 6: Water absorption by water treated bamboo composites after 2 hour boiling.

As shown in Figure 5, where percentage moisture absorption increases steadily with $t^{1/2}$ in the initial stage and then tend to level off following the saturation point, indicating a Fickian mode of diffusion.

4. Conclusion

Water leaching and drying remove the starch partially. The 1 month water modified bamboo has improved the tensile strength of the composite by 36% compared to untreated fiber-epoxy composite. 3 months water modified bamboo epoxy composite provides a balanced combination of mechanical and water resistance properties. Increase in tensile strength is 24% and water absorption is 31.69%. Boiling of bamboo affects the mechanical properties of the composites adversely.

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