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Study on effect of peroxide modification on bamboo fiber reinforced thermosetting resin composites

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ABSTRACT

Peroxide modified bamboo reinforced epoxy and polyester composites were fabricated. The mechanical properties (tensile strength, elastic modulus, flexural strength, flexural modulus and impact strength) and water absorption properties were determined. Peroxide treatment decreases the hydrophilicity of fibers and also improves interfacial adhesion between the fiber and matrix leading to decrease in water absorption by the composites. It also leads to increased tensile strength of the composites. Peroxide treatment improves the flexural properties of epoxy composites significantly.

Introduction:

The use of bio-fibers, as opposed to synthetic fibers, has been well recognized due to the positive environmental benefits with respect to ultimate disposability and raw material utilization. In addition, it has properties like low cost, light-weight, high specific strength and free from health hazard. Owing to the poor wettability and absorbability towards polymers resulting from the hydrophilicity of plant fibers, however, the adhesion between the fibers and polymer matrices is generally insufficient.

One of the most important factors for obtaining good fiber reinforcement in the composite is the bonding strength between natural fiber and polymer matrix. Due to the presence of pendant hydroxyl and polar groups in various constituents of fiber, moisture absorption of fiber is very high which leads to poor interfacial bonding with the hydrophobic matrix polymers. The hydrophilic natural fibers absorb a large amount of water in the composite leading to failure by delamination. Adequate adhesion across the interface can be achieved at desirable levels by better wetting and chemical bonding between fiber and matrix. To make good use of bamboo fiber reinforcement in composites, fiber surface treatment must be carried out to obtain an enhanced interface between the hydrophilic bamboo fiber and the hydrophobic polymer matrices. Such treatments will decrease the moisture absorption and hydrophilic character of fibers. Surface modification is therefore necessary to obtain better performance of the resulting composites [1]

The peroxide treatment of different natural fibers, pineapple leaf fiber, oil palm fiber, sisal fiber, flax fiber etc., and were reinforced with polyethylene, rubber, formaldehyde have been studied [2-6]. Peroxide treated short sisal fiber reinforced polyethylene composite showed an enhancement in tensile properties due to peroxide induced grafting of polyethylene on fiber [2]. Tensile strength of peroxide treated pineapple leaf fiber- natural composite increases relative to untreated composite [3]. Peroxide induced adhesion in cellulose fiber-reinforce thermoplastic composites has attracted the attention of various workers due to the easy processability and improvement in mechanical properties.

There are various literatures on the bleaching of wood, jute, cotton etc. [7-9]. There is no literature on the bleached bamboo or on bleached natural fiber reinforced plastic composite.

In this paper, attempts have been made to study the effects of peroxide treatments of bamboo fiber reinforced with thermosetting resins.

Experimental:

Treatment:

5% alkali treated fibers were dried for 24 hours and then soaked in 6% solution of Benzoyl peroxide (BP) in acetone. The fibers were filtered out and dried in oven at $80^{O}C$ for 8h. Similar treatment procedure was carried out with dicumyl peroxide (DCP).

The bamboo mats were immersed in 5% NaOH aqueous solution for 5 minutes. Rinsed from the solution and kept in the open. After this, an even coat of the hydrogen peroxide (H_20_2) is applied on both the sides of the mats and is left for 1h for the bleaching process.

Fabrication of Composite:

Perspex sheets of size 300×200 mm^2 were used as mould to prepare the epoxy composites. Stainless steel plates of size 300×200 mm^2 were used as mould to prepare the polyester composites. Hand lay-up technique was used to fabricate the composite. Polymer matrix was spread over the mats, piled one over another to seven layers, placed in between the sheets and compressed in the hydraulic press to 170 kN for 24 h for epoxy based composite and for 6h for polyester based composite. The Epoxy and Polyester composites were cured at $80^{O}C$ for 4 h and 1.5 h respectively.

Table: 1 Materials analyzed

Material	Specification
BE/BP	Untreated bamboo fiber reinforced epoxy/polyester composite
BPOE/BPOP	Benzoyl peroxide treated bamboo epoxy/polyester composite
BDPE/BDPP	Dicumyl peroxide treated bamboo epoxy/polyester composite
BHPE/BHPP	Hydrogen peroxide treated bamboo epoxy/polyester composite

Result and Discussion:

The decomposition of the peroxide and the subsequent reaction at the interface is expected at the time of curing of composites. Higher temperature is favoured for decomposition of the peroxides. This can be shown as

$$RO - OR \rightarrow 2RO.$$

$$RO. + Cellulose\text{-}H \rightarrow R - OH + Cellulose.$$

Figure 1 shows the tensile properties of the composites. Peroxide treatment of alkali treated fibers has improved the tensile strength and modulus. Improvement in dicumyl peroxide (DCP) treated epoxy composite is more than the benzoyl peroxide(BP) treated composite. In the case of polyester composites also, the tensile strength and modulus show the same behavior as the epoxy composites. It is clear from the above results that DCP is more effective than BP at all levels of peroxide addition. This difference may be due to difference in the relative rates of peroxide decomposition [2]. Peroxide treatment improves the tensile properties significantly. For example, the tensile strength of DCP and BP treated fiber-epoxy composites are 104 and 100 MPa respectively. These are approximately 20 and 15% more than the tensile strength of the untreated composites. This may be attributed to the increases in hydrophobic character on these fiber surfaces, therefore making the surfaces more compatible with the matrix [3].

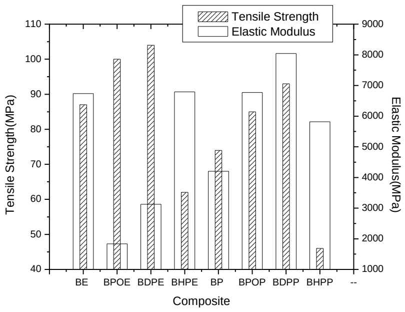

Figure: 1 Tensile properties of peroxide treated bamboo composites.

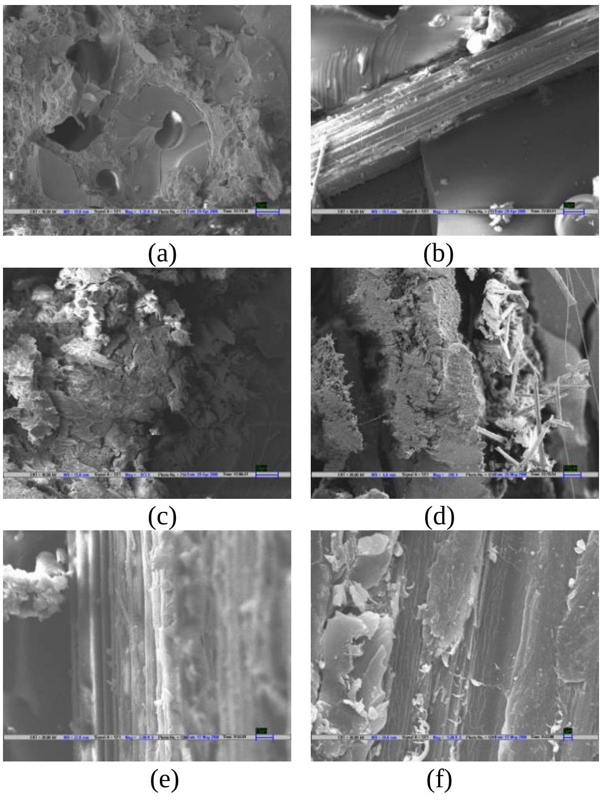

Figure: 2. SEM micrograph of tensile fracture surfaces of (a) BPOE, (b) BDPE, (c) BHPE, (d) BPOP, (e) BDPP and (f) BHPP

From the figure 2, it can be observed that treated fibers adhere well to the polymer matrix and undergo breaking and delamination during tensile failure, whereas untreated fibres are easily pulled out from the matrix during tensile failure. From the fracture surfaces of DCP treated and BP treated composites, it can be understood that the interfacial bonding is stronger in the DCP system. The tensile strength of DCP and BP treated fiber-polyester composites are approximately 26 and 15% more than the tensile strength of the untreated composites.

Figure 3 shows the flexural properties of the composites. It is interesting to note that peroxide treatment improves the flexural properties of epoxy composites significantly. The flexural strength of DCP and BP treated fiber-epoxy composites are approximately 65 and 42% more than the tensile strength of the untreated composites. Whereas, flexural strength of DCP treated fiber polyester show only 7.5% improvement and BP treated composite show a sharp decline of 45%.

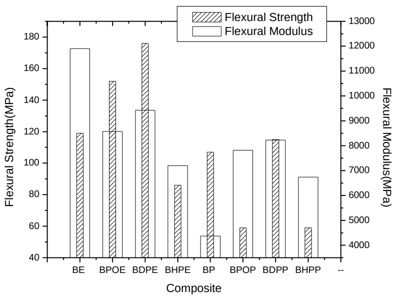

Figure: 3 Flexural properties of peroxide treated bamboo composites.

In industry, the most common process of bleaching the cellulose uses oxidizing agents such as sodium hypochlorite, calcium hypochlorite, or hydrogen peroxide. The reaction mechanism is as given below [10]:

$$H_2O_2 \longrightarrow HOO^- + H^+$$

In the presence of concentrated H_20_2 and alkali wood undergoes vigorous decomposition at ordinary temperatures. At comparatively low concentrations, however, H_20_2 has a bleaching action on wood which has found some application commercially. Initial application of alkali renders the hydrogen peroxide unstable, whereupon it decomposes and liberates a large amount of oxygen in a chemically active condition, which does the bleaching. Alkali reacts with fiber and isolates the lignin. That isolated alkali-lignin can be partially converted into soluble products by H_20_2 [7]. Decomposition of lignin by means of H_20_2

Bleaching of bamboo fibers with H_2O_2 results in loss of mechanical strength of the composites. The tensile and flexural strength of both epoxy and polyester composites were reduced. But, there was not much effect on the modulus of the composites. Bleaching generally results in loss of weight and tensile strength. These losses are mainly attributed to the action of the bleaching agent on the noncellulosic constituents of fibers such as hemicellulose and lignin [10].

The impact strength of the composites is plotted in figure 4. The impact strength of the treated bamboo reinforced epoxy composites has not changed except for the hydrogen peroxide treatment, in which case strength has decreased than the untreated bamboo composite. In case of polyester composites, only composite BDPP has shown a slight improvement, whereas the strength of other composites has decreased.

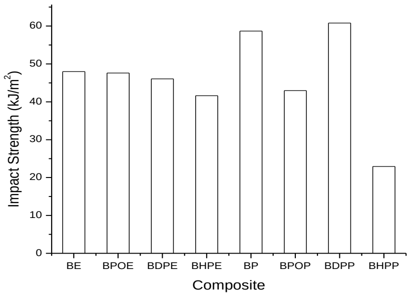

Figure: 4 Impact strength of peroxide treated bamboo composites.

Water absorption:

Figure 5 shows the water absorption by the peroxide treated composites. The water absorption of the DCP and BP treated bamboo fiber-epoxy composite show a decrease in value compared to the untreated fiber composite. As a result of peroxide treatment the hydrophilicity of the fibers decreased [6]. Also improved interfacial adhesion between the fiber and matrix leads to decrease in water absorption by the composites. Similar results have been obtained for the DCP and BP treated bamboo fiber-polyester composite.

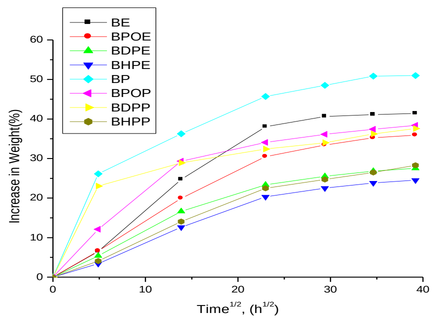

Figure: 5 Percent increase in water absorption by peroxide treated bamboo composites.

The main effect of bleaching is on the water absorption properties. The bleached bamboo- epoxy composite show a decrease in water absorption to 25% from 41% of non-treated bamboo epoxy composite. The bleached bamboo polyester composite also show the similar results. Here too, water absorption reduced to nearly 28% from 51% of untreated bamboo polyester composite. This is due to decomposition of hemicellulose and amorphous waxy cuticle layer of the fiber, which hold the water molecule.

Figure 6 shows the water absorption after 2h boiling. Hydrogen peroxide treated bamboo polyester composite is better in resisting water under boiling condition. It absorbs only 15.20% water compared to 60.51% by untreated composite.

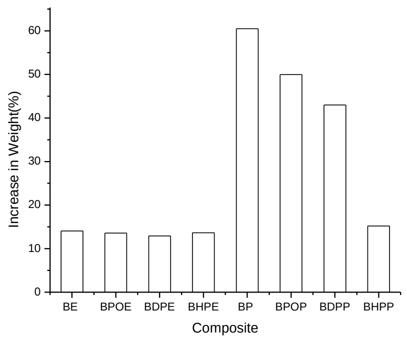

Figure: 6 Water absorption by peroxide bamboo composites after 2 hour boiling.

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.

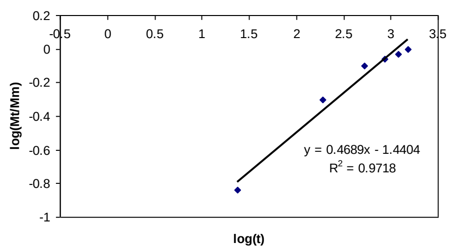

Figure: 7 Diffusion curve fitting plot for BHPP to determine constants n and k.

Figure 7 show example of the fitting of the experimental data. The values of the parameters n and k obtained from the fitting curves of the water absorption of the composites are summarized in Table 2. Since the value of the parameter n approach to 0.5 the composites show a tendency to approach Fickian behavior. Among the polyester composite only BHPP approaches fickinan mode of diffusion. Other polyester composites indicate a deviation from Fickian diffusion. The deviation observed may be due to the additional mechanism observed as a result of the fiber swelling, fiber matrix interface weakening, micro cracking, and leaching. Similarly the k value of BHPP is less than the BP, while other polyester composites show an increased value, indicating increase in the moisture interaction with the composite material.

Figure 8 shows the diffusion curve fitting plots for composites for diffusion coefficient. The values of D are also summarized in Table 2. D value BHPE is more than that of BE. This indicates faster diffusion rate and faster attainment of equilibrium water uptake. D value of BHPP is lesser, indicating slower diffusion of water.

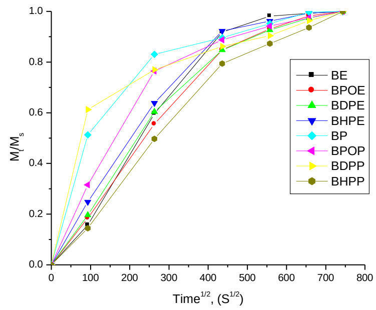

Figure: 8 Diffusion curve fitting plots for diffusion coefficient for peroxide treated bamboo composites.

Table: 2 Moisture absorption constants and diffusions coefficient of composites.

Sample	n	k	D × 10^{-12} m^2/s
BE	0.4538	0.0438	11.36
BPOE	0.4153	0.0547	9.749
BDPE	0.3955	0.0629	11.29
BHPE	0.3434	0.0923	33.23
BP	0.3002	0.1306	180.11
BPOP	0.2735	0.1484	31.45
BDPP	0.1155	0.4215	113.55
BHPP	0.4689	0.0363	15.98

Conclusion:

DCP and BP treatment of bamboo results in increased strength of the composites. The tensile strength of DCP and BP treated fiber-epoxy composites are increased by 20% and 15% compared to that of untreated composite. The flexural strength of DCP and BP treated fiber-epoxy composites are approximately 65% and 42% more than that of untreated composites. DCP is more effective than BP at all levels of peroxide addition. As a result of peroxide treatment the hydrophilicity of the fibers decreased. Hydrogen peroxide treated composites are better at resisting water uptake. After bleaching of bamboo, water absorption has reduced to nearly 25% and 28% for bamboo epoxy and bamboo polyester composites respectively.

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