Studies on Water Sorption Behaviour of Laminated Bamboo Polymer Composite

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Abstract. The aim of this article is to evaluate water absorption in bamboo fiber composites. Bamboo is hydrophilic, means that it easily absorbs water. In this study the bamboo fiber-based composites were developed using hand lay up method, with epoxy resin as the matrix constituent. Water absorption characteristics of specimens of bamboo composite and epoxy were determined from water immersion tests at several temperatures. Gravimetric analysis was performed to determine the moisure absorbed as a function of time at two different temperatures: 25 ºC and 50 °C. The diffusivity of water in an epoxy bamboo composite was determined after reaching saturation point. During room temperature soaking, epoxy specimen showed the characteristic of Fickian behavior. Similar immersion tests on bamboo-epoxy composites followed non-fickian behavior. Changes in the mechanical properties of material due to water absorption were evaluated from tensile testing on materials with varied water content. It was found that the water absorption in all samples reduced the tensile properties. The degradation of tensile properties was greater with an increasing temperature of immersion. The results of this study emphasize the importance of considering deterioration of mechanical properties in the bamboo epoxy composites during their application in water and possibly in humid environment.

Key words: Bamboo composite, degradation, mechanical properties, water diffusion.

1 Introduction

Interest in natural fiber composite materials is growing for outdoor application such as wind turbine blades and some components of aircraft. Natural fiber composites are also suitable for tools that must be strong and light. Not only are natural fiber composites environmentally friendly, and light weight, but they are also economical to fabricate, they have a relatively high specific strength and stiffness, good fatigue strength and a low density [1–4].

Bamboo polymer composites are the latest development in natural fiber composites, utilizing the advantanges of bamboo in many form, such as fibers, strips, or webbing and combined it with thermoplastic polymers (such as: PVC, polypropylene, polyethylene) or

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thermosetting polymers (such as: polyester,vinylester,epoxy). Bamboo is herbaceous plant with hollowed and flavored stems. It grows easily in Southeast Asia, South America and some countries in Africa. Bamboo require 3 yr to 4 yr grow to reach the maturity point. Tensile strengh of bamboo fibers at maturity point can be comparable to mild steel [5–7], but with a much lower density and a high specific modulus of elasticity. Furthermore, it is more readily available and abundant than most other natural fibers [8].

Bamboo fiber consists of cellulose, hemi-celluloses, lignin, pectin, and waxy subtances that make it more sensitive to humidity. Chemical elements in bamboo called cellulose had hydrophilic characteristic that makes bamboo easily absorp water. Humid environments in long term will cause bamboo polymeric composite swelling. The consequence of swelling could be an increase in outdoor application of bamboo polymer composites. Swelling in the composite occurs because the hydrophilic OH groups react with water in humid environment causing the composite readily absorb moisure which will generally degrade of mechanical properties of the composites [9–11].

The characteristic of water absorption in bio-composite has been examined by some researchers. Composite with laminate fiber orientation gives lower water absorption, but also higher result in tensile and flexural strengh compared with composite with strip fiber. Abdul Some' studies reported that water absorption in composites increacese with long term immersion time and higher temperatures of immersion [12]. Immersion over particular period showed that water absorption of composite increases and the mechanism follows the Fickian diffusion process. However, another researcher concluded that the mechanism of water absoption of fiber composite deviated from Fickian diffusion process [13].

Mechanical properties of bamboo polymer composite might be affected by water absorption from a humid environment. One study reported that increasing the amount of water content within the composite material can cause the deterioration of the mechanical properties of natural fiber composite [14, 15]. Dhakal et al. [16] also reported that the increasing of water absorption in bamboo composites causes the mechanical properties to drop dramatically.

This study presents the characteristic of water absorption in bamboo polymer composites and epoxy resins. Gravimetric analysis was performed to determine changes of moisure content during immersion at two different temperatures: room temperature (25 ºC), and 50 ºC. The diffusivity for water in epoxy and the diffusion coefficient value for a bamboo composite was determined after reaching saturation point. During room temperature water immersion, epoxy specimen showed the characteristic of Fickian behavior. Meanwhile, the immersion of bamboo fiber composites was found to have non-Fickian behavior. Changes in the mechanical properties of specimens (epoxy and bamboo composites) due to water absorption were evaluated from tensile testing on materials with varied water content. It was found that the water absorption in all sample affected the tensile properties. Degradation of tensile properties was observed with increasing the temperature of immersion and associated quantities of water absorbed.

2 Materials and methods

2.1 Materials

The matrix material used in this study was a epoxy resin diglycidyl ether of bisphenol A (DEGBA) and with hardener cycloaliphatic amine EPH 555. This resin could be applied in various type of composite fabrication. Epoxy resin needs some sort of liquid diluent to reduce the viscosity [17].

The material for the reinforcement was bamboo wulung that a local indigenous grow in Indonesia. The from of bamboo is woven that obtained from local traditional craftmenThe woven bamboo mats were cut according standard test of ASTM3039 [(256 × 25.6 × 4) mm)] [18]. In every strip of bamboo has a thickness of 0.5 mm with a width of 5 mm to 8 mm.

Fig. 1. Woven-bamboo/epoxy composite [19].

Aquades was used to the immersion experiment of bamboo composite. The aquades provided by BRATACHEM which constitue distillation of water. In varying levels of fluid concentration, different immersion temperature were used to accelerate the level of water absorption.

2.2 Composite fabrication

Hand lay up was chosen to make bamboo polymer composite, this method was performed by manually applying the epoxy resin and woven bamboo in the mold, respectively. The laminates of bamboo composite consited of three epoxy layers and two bamboo mat layers. Tha uniform ratio between epoxy resin and reinforced must be maintance in 25 % reinforced material and 75 % matrix materials.

Table 1. Designation of composite specimens.

Designation	Treatment of Composite specimens
BC-WI	Bamboo Composite Without Treatment
FE-WI	Epoxy Specimens Without Treatment
BC-RT	Bamboo Composite with Room Temperature Immersion
FE-RT	Epoxy Specimen with Room Temperature Immersion
BC-50	Bamboo Composite with 50ºC Immersion
FE-50	Epoxy Specimen with 50ºC Immersion

2.3 Immersion method

The immersion method was performed by varying the temperature immersion into two different conditions: (i) room temperature (± 25 ºC), and (ii) 50 ºC. Gravimetric measurement was performed to determine changes of moisure content during immersion process. The bamboo composite spesimens were removed periodically for weight measurement until saturation occurs.

The weight gain of specimens was measured using the following relationship:

$$Mt\,(\%) = \frac{\mathrm{m_t} - m_0}{m_0} \times 100 \tag{1}$$

Where m_0 and m_t is the weight of dry specimens and wet specimen before and after immersion.

2.4 Testing on mechanical properties

Mechanical test are performed to evaluating degradation with different amount of water absorption in varying temperature of immersion. Tensile testing was performed under an international standard, ASTM D3039. This standard is for tensile properties of polymer composites. The samples tested were rectangular samples made using hand lay up method and glass mould. Specimens were cuts according to ASTM D3039 with 256 mm length, 25.6 mm to 25.9 mm width and 4 mm thickness. The samples were tested to failure under tension by using Hounsfield Universal Testing Machine.

The following equation is applied to calculated tensile strength generated on each samples in varying temperature of immersion.

$$\sigma = \frac{F}{A_0} \tag{2}$$

where F is load of samples and A_0 is cross-sectional area of specimens. The tensile extension (ε) of samples can be calculated with the following equation:

$$\varepsilon = \frac{\Delta l}{l} \tag{3}$$

Where Δl represent the length of samples, and l is the initial length of samples. Then, modulus elastisity of samples can be formulated by dividing the load of samples with the tensile extention of the samples :

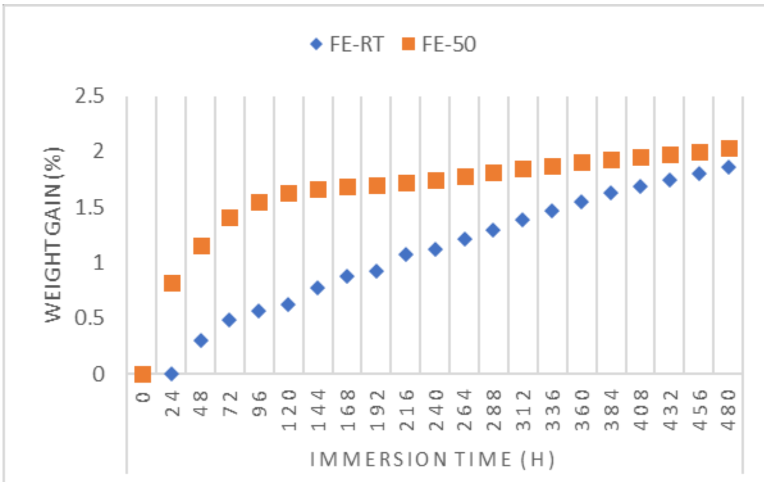
$$E = \frac{\sigma}{\varepsilon} \tag{4}$$

3 Results and discussion

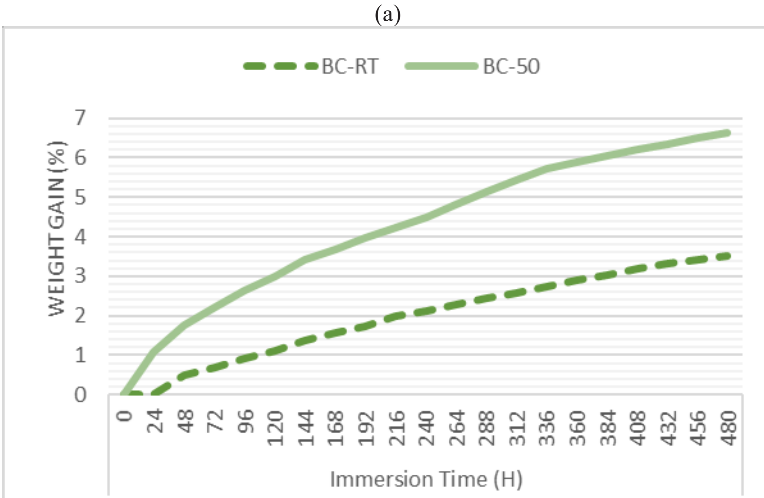
3.1 Result on diffusions experimental

Immersion was applied in two type of samples, epoxy samples and bamboo polymer composite samples, with varying temperature in room temperature and 50 ºC. The immersion of epoxy samples was observed to prove that this kind of polymer also absorp water event though in very small quantities.

Figure 2 shows the water absorption for all samples in room temperature immersion and 50 ºC immersion as a function of immersion in hours. Each data point represents the average of five specimens. This shows that water content in every samples increase periodically.



(a)



(b)

Fig. 2. Water uptake in (a) epoxy specimens and (b) bamboo composite specimens.

Epoxy specimen with room temperature and 50 ºC immersion showed there was a small difference in level of water absorption (Figure 2a). After 24 h of room temperature immersion, the water content in specimen increases slowly and periodically, then reach 1.8 % water content at 456 h. Meanwhile, fot the same specimen in 50 ºC , significant increase of water content was observed 48 hours. The water content of epoxy specimen in 50 ºC immersion temperature increased linearly and reach 1.8 % of saturated weight gain with the room temperature immersion at 168 h following the Fickian Law of diffusion. It could be conclude that there was an impact of temperature immersion in the water content of specimen. The water content of epoxy specimen increases with increase the temperature of immersion [12, 20–22].

In contrast with that, Figure 2b shows the significant increase of water content inside the bamboo composite. Epoxy specimens absorb water less water than the composite [23]. At 480 h immersion, bamboo composite with room temperature immersion was reached 3.5 % of water content. In the other hand, at 480 h, bamboo composite with bamboo polymer composite 50 ºC immersion was reached 6.7 % of water content. The changes of water absorption affected by bamboo filler in the composite. Cellulose of bamboo fibers had hydrophilic makes bamboo composite easily absorb water. It can be said that the bamboo fiber impact the water absorption of bamboo composites. In addition, increasing the temperature of immersion could be increase the water absorption of bamboo polymer composite larger [24, 25].

3.2 Tensile properties

Figure 3 represent the tensile strength and modulus elastisity of all specimen with immersion and without immersion. The tensile properties evaluated were tensile strength, modulus, and strain. It can be seen that the tensile strength and modolus elastisity of epoxy specimen without immersion is smaller than bamboo composite without immersion. Specimen of epoxy had tensile strength at 3.2 MPa, and modulus elastisity at 4. Meanwhile, bamboo composite without immersion had a bigger tensile strength with 45.5 MPa at tensile strength and 1752 at modulus elastisity. It is found that the bamboo fiber impact the tensile strength and modulus elastisity of composites. Bamboo fiber in composite give the better tensile stength and modulus elastisity of composite.

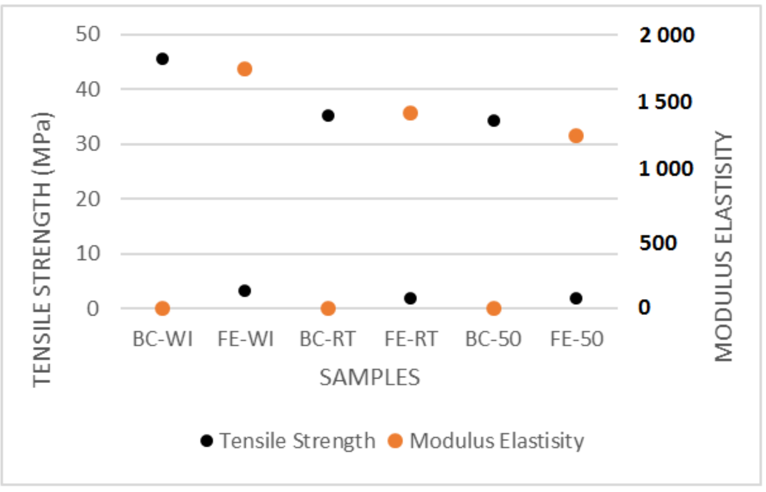


Fig. 3. Tensile properties of epoxy and bamboo composite specimens.

Immersion treatment affects the tensile strength and modulus elastisity of epoxy and bamboo composite specimen. It can be seen that the tensile strength and modulus elastisity of bamboo composite decrease progressively as a function of increasing the temperature of immersion. The specimen without treatment has tensile strength of 45.5 MPa for bamboo composite, and 3.2 for epoxy specimen. In addition, modulus elastisity for that is 1 752 for bamboo composite and 4 for epoxy specimen. Tensile strength modulus was observed after water immersion with varied temperature, there are decreases with increasing the water absorption, from 35.2 MPa to 34.4 MPa for tensile strength of bamboo composite in specimen with 6.6 %. Meanwhile, there was no difference in tensile strength and modulus elastisity of epoxy sample in room immersion treatment and 50 ºC immersion, the value of that condition is equal 2 MPa for tensile strength and 2 for modulus elastisity.

Tensile properties of bamboo composite can be decrease because of the increases of the temperature of immersion. The tensile properties of bamboo compostite decreases with increasing the temperature of immersion. In addition, tensile properties of bamboo composite and epoxy specimen can be different because in the bamboo composite, there was a filler (woven of bamboo). Bamboo had a hydrophilic group, and causing permanent damage in the form of microcracks in the matrix around the swollen fibers. The cracks aggravate water absorption in the composites by promoting capillarity and transport via the microcracks. The absorbed water may damage the fiber matrix interface by forming hydrogen bonding with natural fiber hence reduces the interfacial adhesion. Meanwhile, epoxy specimen not significantly absorb water [14, 23, 26, 27].

4 Conclusion

The water absorption of epoxy and bamboo composite affected by temperature of immersion. The water absorpsion of bamboo composite increases with increasing the temperature of immersion. Meanwhile temperature of immersion not affected the epoxy specimen. Tensile stength and modulus elastisity of epoxy and bamboo composite specimen decreases when the sample had immersion treatment. Bamboo composites samples also affected by temperature of immersion. The tensile strength and modulus elastisity decreases with increasing the temperature of immersion.

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