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Effect of Soil Burial on Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites

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Abstract. Nowadays, natural fiber reinforced composites in structural strengthening and rehabilitation was preferable due to its environmentally friendly, low cost and biodegradable characteristics compared to the synthetic strengthening material, fiber reinforced polymer (FRP). However, limited information is available on natural fiber composite durability when exposed to environmental elements. This paper presents the effect of environmental exposure to the durability of bamboo fiber reinforced epoxy composite. Bamboo fiber reinforced epoxy composite samples were prepared and buried in soil for 20, 40, 60 and 80 days. The composite samples were prepared using 40% fiber volume fractions. The mechanical properties (tensile and flexural) and surface morphology of the samples before and after degradation were investigated. The experimental results show that the mechanical properties deteriorate as the exposure time increases. The tensile and flexural properties of the composites decreased by about 6-19% compared to the fresh sample. The result from this work may be useful to determine the durability of natural fiber composite when exposed to environmental elements.

1. Introduction

Natural fiber composites are often used in many engineering applications due to their desirable properties such as light weight, renewability, low cost and environmentally friendly. The natural fiber composites have been used in many industries such as automotive, sporting goods, marine, electrical, household appliances and construction [1]. Natural fibers such as kenaf, sisal, coir, banana, jute, flax, pulp, wood flour, oil palm, pineapple leaf, mengkuang leaves, bamboo can be used for structural reinforcement [2][3][4]. Bamboo fibers has a high tensile and flexural properties, making it suitable to be used as reinforcement in polymer composites [2][5].

Bamboo fiber reinforced composite is widely investigated as an alternative to the synthetic commercially available fiber reinforced polymer (FRP) owing to its strength and sustainability credential. FRP is non-environmentally friendly and expensive to manufacture, which leads to more study on natural fiber composite. Most of the past investigations studied kenaf [6], jute [7][8] and sisal fiber [9] composites for structural strengthening. However, the studies using bamboo fiber reinforced composites are still very limited, especially related to its durability when exposed to the environment, and hence this is the aim of the current work. Bamboo fiber reinforced composite is suitable for the purpose of structural strengthening application due to its strength, low-cost, eco-friendliness, abundant availability and its biodegradable nature [10].

This study examines the effect of soil burial on the degradation of the alkali treated bamboo fiber reinforced epoxy composite (BFREC). The effects of degradation on the morphological structure and the mechanical properties of the composites with and without chemical treatment are also studied. This study aims to provide a background information on the durability of alkali treated BFREC when exposed to environmental elements.

2. Materials and Methods

2.1 Preparation of bamboo fibers

A matured Malaysian bamboo species of *Gigantochloa Scortechinni Gamble* was used in this study. The bamboo culms were cleaved and treated with NaOH solution of 10% for 48 hours at ambient temperature. Subsequently, the alkali-treated bamboo strips were washed using a running distilled water to remove the alkali residue until a pH around 6 to 7 was obtained. The bamboo strips were then placed into the mill roller machine to obtain the fibers. The bamboo fibers were rinsed with distilled water to remove the alkaline content. The fiber was then dried in an electric oven at 60 °C for 24 hours.

2.2. Fabrication of bamboo fiber reinforced epoxy composites (BFREC)

A hand lay-up method was adopted for the fabrication of BFREC. The first layer of the bamboo fiber was arranged methodically on the epoxy adhesive and pressed gently using a spatula to ensure the fibers were soaked entirely in the resin. The second layer of resin was poured on the first layer of bamboo fibers for interfacial bonding. Another layer of bamboo fibers was manually aligned on top of the resin followed by addition of polymer resin layers. The amount of fiber to be used with respect to the resin was set at 40% fiber volume fractions following by the study by Chin et al. [11]. Chin et al. [11] studied the effect of bamboo fiber loading to the BFREC tensile and flexural strength. They found the BFREC with 40% fiber volume fractions is the strongest among all the specimen tested. These steps were repeated until the required fiber amount was all filled in the mould. A sheet of fiber cloth placed on top of the last resin layer before pressure was applied on the top of the mould. The BFREC was cured at room temperature for 24 hours to enable a cross-linking between the bamboo fiber and the thermosetting resin. Subsequently, the sample was post cured in oven at 110 °C for 4 hours.

2.3. Soil burial test

The deterioration of the mechanical properties of natural fiber reinforced polymer composites upon exposure to environmental elements, such as moisture is important in order to understand their stability and durability performance [12]. Thus, the soil burial test was performed on the BFREC specimen to examine their durability according to the method by Sapuan et al. [13]. The BFREC which possessed excellent physico-mechanical properties were subjected to this test. Both tensile and flexural samples were buried under the same gardening soil for 20, 40, 60, and 80 days, respectively. The buried samples were watered for every 2 days. After the predetermined buried interval, the buried samples were taken out of the pot, the mechanical properties and surface morphology of the soil buried BFREC specimens were examined and compared with unburied specimen.

2.4. Mechanical testing

Tensile test of the BFREC samples before and after soil burial were performed according to the ASTM D3039-17 using a Universal Testing Machine (Shimadzu 50 kN) at a cross-head speed of 2 mm/min. For each test, five replicates of the sample were tested the result is reported as an average ± standard deviation. Meanwhile, the flexural properties of the composite samples were performed according to ASTM D790-17.

2.5. Morphology study
The surface morphology of the BFREC samples was examined using scanning electron microscope (TM3030, Hitachi, Japan). The specimen is attached to an aluminium stub using a carbon tape. The SEM test was performed at accelerating voltages of 5 to 15 kV.

3. Results and discussion

3.1 Soil burial test
Figure 1 shows the tensile and flexural properties of the BFREC before and after soil burial at 20, 40, 60 and 80 days, respectively. Chin et al. [11] reported earlier that BFREC at 40% fiber volume fraction exhibited the highest mechanical performance, thus this optimal mix ratio was used for the soil burial test.

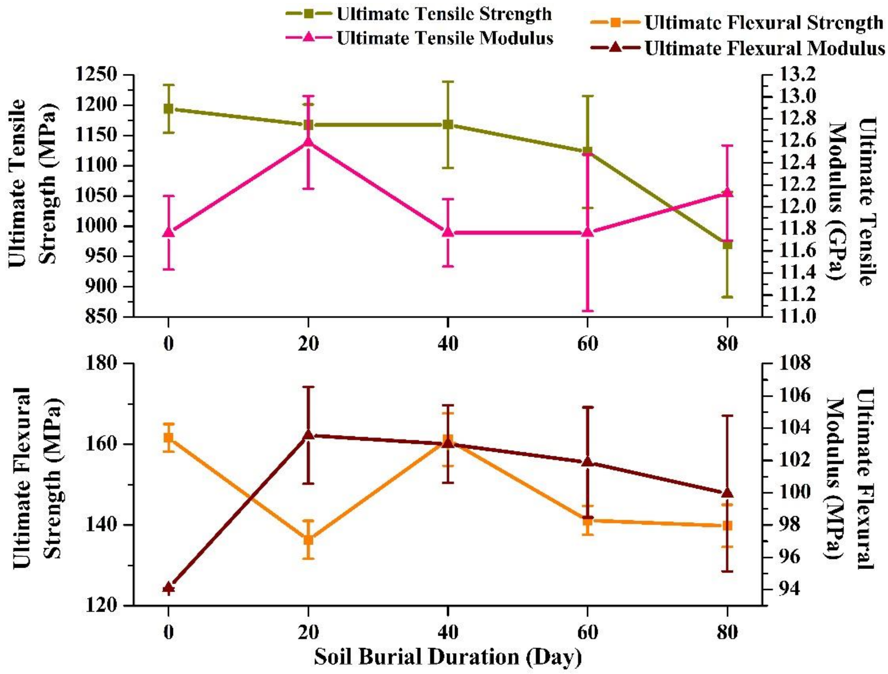

Figure 1. The effect of soil buried days on the tensile and flexural properties of the BFREC sample

The combined effects due to the moisture absorbance, soil, and weather gave the profound impact on the mechanical properties of BFREC. It was found that the ultimate tensile strength of the BFREC declined as the duration of soil buried increased. The tensile strength of BFREC after 20, 40, and 60 days reduced slightly up to 6% from 1193.9 to 1167.6, 1167.7, and 1123 MPa, respectively. The BFREC exhibited the lowest tensile strength of 969.95 MPa after 80 days of soil burial, which represents about 19% decrease in strength. The reduction in the tensile strength most probably due to the degradation of material impaired by the water uptake. Changes may occur on the bamboo fiber and polymer matrix as well as the interface between the fiber and matrix. The hydrogen bond could be formed between the hydroxyl group of fibers and absorbed water molecules which caused the loss of compatibilization between the fibers and polymer matrix [12], [14], [15]. The absorbed moisture may also cause swelling in the fiber, which initiates the microcracks that led to the fiber debonding [15] and weakening the adhesion of fiber-matrix interface [16]. Hence, causing more water penetration into the interface through the microcracks. The impairment of the interfacial bonding may also lead to the interfacial failure and degradation of stress transfer capability from the matrix to fiber, which causes in the premature failure of the composite [12], [17]. The deterioration of the interfacial adhesion between the fiber and polymer matrix due to water uptake was reported earlier by Kumar et al. [18]. No clear trend was observed in the tensile modulus, flexural strength and flexural modulus of the soil buried specimens. The tensile modulus of soil buried specimen is not affected by the soil burial up to 80 days.

It was observed that the tensile modulus reduced slightly from 12.59 GPa to 12.12 GPa after 80 days, however the difference is not statistically significant. The flexural strength of BFREC did not show any significant changes after the soil burial, indicating that the flexural reinforcement is still intact after 80 days of exposure to environmental elements.

The flexural modulus of BFREC increases slightly in the first 20 days to 103.55 MPa, and then consistently decrease beyond 20 days to 99.96 MPa. The initial increase in the flexural modulus implied that the microcracks and weakening of fiber-polymer matrix adhesion may not be significant in the first 20 days. In fact, the initial moisture absorption, may fill the pore that exists in the bamboo fiber matrix causing it to swell to its initial size without causing a microcracks. At this stage, the swelled bamboo fiber is tightly packed to the polymer matrix causing an increase in its flexural modulus. Thus, in that way the moisture content probably had imparted the small stiffness and toughness to the BFREC. This type of improvement may be due to the plasticization effect of moisture sorption that increased the fiber bridging, which in turn enhanced the tensile modulus and flexural properties [14].

3.2 Surface morphology

The SEM micrograph of the soil buried tensile fractured specimen is shown in Figure 2. The BFREC exhibited an excellent interface of the matrix and bonding before placing in the soil. A rougher fracture surface with a significant number of holes caused by the fiber pull-out and a considerable fiber breakage were observed. The soil buried samples showed an apparent separation between the interface of fiber and matrix, which could be due to the microcracks induced by swelling of bamboo fibers after the water uptake. The swollen fibers induced the microvoids and developed stress at the fiber-matrix interface. It is known that the microcracks may be initiated in the matrix around the swollen fibers [12], [16]. The microcracks allowed the water molecules to move along the fiber-matrix interface and causing structural deterioration after subjected to prolonged contact with moisture. The absorbed moisture subsequently resides in the intermolecular bonding with the fibers and decreased the interfacial adhesion of fiber-matrix. This eventually leached out the water-soluble substances from the fibers and led to the fiber debonding.

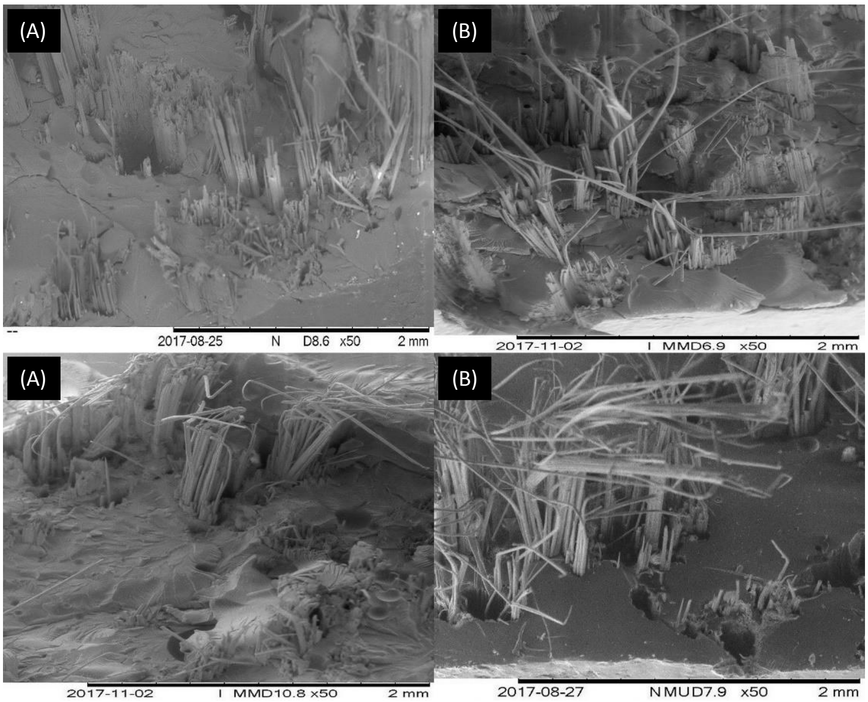

Figure 2. SEM images of tensile fracture of BFREC at 40% fiber loading after soil burial test at (a) 20 days, (b) 40 days, (c) 60 days, and (d) 80 days

The interfacial gaps significantly increased and impaired interfacial adhesion as the soil burial duration extended. This will cause an insufficient load transfer from the matrix to fibers, which contributed to a lower mechanical strength. The phenomenon of dimensional changes was not observed within the experiments time span, which confirmed the encapsulation of fiber into the epoxy matrix [19]. This was confirmed that the majority moisture uptake took part in the micro spaces of the fiber-matrix interface. The finding from this work further validated that the bamboo fibers provided a pathway for the water to pass through and leave the BFREC.

4. Conclusions

It can be concluded that the ultimate tensile strength of the BFREC declined as the duration of soil burial increased. The reduction in the tensile strength most probably due to the degradation of material impaired by the water uptake. The BFREC exhibited the lowest tensile strength at 969.95 MPa after the 80 days, with approximately 19% reduction compared to the fresh sample. Initially the flexural modulus increases slightly in the first 20 days as the water absorption has not cause a significant formation of microcracks or fiber-polymer debonding. However, the flexural modulus eventually decreased consistently from 20 days onward to 80 days. SEM results showed an apparent separation between the interface of fiber and matrix, which could be due to the swelling of bamboo fibers after the water uptake. The swollen fibers induced the microvoids and developed stress at the fiber-matrix interface, hence compromising the BFREC mechanical properties.

5. Acknowledgement

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