Preliminary Study on Tensile and Impact Properties of Kenaf/Bamboo Fiber Reinforced Epoxy Composites

Ahmad Safwan[1], Mohammad Jawaid[1]*, Mohamed T. H. Sultan[1,2] and Azman Hassan[3]

[1]*Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[2]*Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[3]*Department of Polymer Engineering, Faculty of Chemical and Petroleum, Universiti Teknologi Malaysia, Skudai, Johor Bharu, Malaysia*

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ABSTRACT: The application of natural fibers as reinforcement in composite material has increased due to environmental concerns, low cost, degradability and health concerns. The purpose of this study is to identify the best type of bamboo fibers to be used as reinforcement for kenaf (K)/bamboo hybrid composite. There were three types of bamboo fibers evaluated in this study which include bamboo mat (B), bamboo fabric (BF) and bamboo powder (BP). Chemical composition of B, BF, BP and K fibers were analyzed in this study. The effect of different types of bamboo fibers on tensile, impact, and morphological properties were investigated. The B/epoxy composites displayed the highest tensile strength (53.03 MPa) while K/epoxy composite had the highest tensile modulus (4.71 GPa). Scanning electron micrographs of B/epoxy composites displayed better fiber/matrix interfacial bonding in comparison to other studied composites. Results showed that impact strength of BF-based composite was highest (45.70 J/m). In conclusion, the tensile strength of B/epoxy composite is superior to the other bamboo reinforced composites and will be further evaluated in the next study.

KEYWORDS: Composite, kenaf, bamboo, natural fiber polymer composite, tensile properties, impact properties, morphological properties

1 INTRODUCTION

Nowadays, composite material is used in many applications because of its good properties such as light weight and high strength. Composite material is made up of two or more materials with different properties. This combination produces a material with unique properties, which is different from the individual materials [1]. Polymer reinforced composites are a type of composite material which is widely used nowadays, especially in automotive, aerospace, construction and marine industries [2]. Conventional reinforcement uses synthetic fibers such as carbon, glass and aramid. Despite their good properties, synthetic fibers are difficult to dispose of because of their non-degradable nature and cannot be disposed of using an incinerator. Non-biodegradable polymers, such as epoxy, can be disposed of using an incinerator for energy recovery. Polymer reinforced synthetic fiber, such as glass fiber, is not suitable for disposal using an incinerator since it will reduce the net heat, damage the furnace and will have problems disposing the remaining fiber in the incinerator [3].

Natural fiber polymer composites (NFPCs) have attracted the attention of researchers and their potential is being explored as alternative reinforcements in order to reduce the usage of synthetic fibers due to environmental concerns and government regulations. The advantages of using natural fibers as reinforcement include low density, renewability, cost-effectiveness, biodegradability and eco-friendliness [1, 4]. Natural fibers can be harvested from animals, minerals and plants which are abundant in nature [5, 6]. Silk and wool are examples of fibers from animals while asbestos is an example of a mineral fiber. Plant fibers are classified based on the purpose of their cultivation. Plants grown primarily for harvesting their fibers, such as hemp, jute and kenaf, are known as primary sources while fibers harvested from agricultural waste, such as oil palm and pineapple, are secondary sources [5, 7].

**Corresponding author*: jawaid_md@yahoo.co.in

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Kenaf can be harvested in 4–6 months if conditions are favorable for its growth, and the price is cheap [8, 9]. In addition, kenaf has many interesting properties such as low density and high specific mechanical strength [10]. Nowadays, the use of kenaf has expanded to more advanced applications such as automotive, food packing and furniture. Many studies have been conducted to explore the potential of kenaf as reinforcement. In 2014, Mahjoub *et al*. studied the physical and mechanical properties of continuous unidirectional kenaf fiber epoxy composites [11]. The tensile properties increase as fiber loading increases. Recently, Asim *et al*. studied the effect of pineapple leaf fiber and kenaf fiber treatment on the mechanical performance of phenolic hybrid composites [12]. In this study, it was found that saline treatment improved the overall performance of the hybrid composites. Alavudeen *et al*. studied the effect of woven fabric and random orientation on mechanical properties of banana/kenaf fiber-reinforced polyester hybrid composites [13].

Bamboo is one of the fastest growing grasses and it can achieve maturity in 3 years. Matured bamboo has good tensile strength which is almost similar to mild steel [14]. Bamboo has been used in many applications, such as fishing rods and bridges in rural areas, for many years. Nowadays, the usability of bamboo has expanded and it is being used in polymer composite. Bamboo reinforced polymer composite is being used in various applications such as automotive, aircraft and bicyclist helmets [14, 15]. In a review article covering the extraction method of bamboo fiber, Zakikhani *et al*. outlined that the properties of bamboo fiber will vary depending on the extraction method of the fiber [16]. Many studies have been done to evaluate the performance of bamboo as reinforcement. Biswas studied the mechanical properties of bamboo reinforced epoxy composites [17]. It was found that as fiber loading increases the mechanical properties increased. Further study on addition of silicon carbide (SiC) has been carried out. The addition of SiC improves the performance of bamboo reinforced epoxy composites. Samal *et al*. conducted a study on mechanical, morphological, thermal and dynamic mechanical properties of polypropylene reinforced bamboo and glass [18].

In this work, we carried out a preliminary study to investigate the tensile, impact and morphological properties of kenaf mat (K), bamboo mat (B), bamboo fabric (BF) and bamboo powder (BP) reinforced epoxy matrix. Pure epoxy was prepared as reference. In this study, chemical composition analysis was carried out to identify the composition of cellulose, hemicellulose and lignin of material used. Findings from this study will be used to design further work on investigating the properties of hybrid kenaf/bamboo reinforced composite.

2 EXPERIMENTAL

2.1 Materials

Woven kenaf fiber mat and bamboo fiber were supplied by Zul Sdn Bhd, Malaysia. Bamboo mat was procured from Shijiazhuang Bi Yang Technology Co. Ltd, China. Bamboo fabric was supplied by Bamboo Malaysia Sdn Bhd, Malaysia. Figure 1 shows the fiber mat and fabric used in this experiment. Unit area weight of bamboo mat, bamboo fabric and kenaf mat are 800 g/m^2, 150 g/m^2 and 600g/m^2. Bamboo mat is punched mat while kenaf mat is woven mat with plain weave. Bamboo fabric is a woven type using 40s yarn range and density of 52 warp and 38 weft per cm. D.E.R.^{TM} 331 epoxy resin (reaction product of epichlorohydrin and bisphenol A) and epoxy hardener Jointmine 905-3S (modified cycloaliphatic amine) were used in this study. Reaction between epoxy resin and hardener is illustrated in Figure 2. Both the epoxy resin and commercial curing agent were obtained from Tazdiq Engineering Sdn Bhd, Malaysia. Table 1 shows the information for the kenaf, bamboo mat and bamboo fabric.

2.2 Preparation of Bamboo Powder

Bamboo fiber was ground into powder using a grinder. Bamboo powder was sieved to get powder size between 250–500 µm.

Figure 1 (**a**) Bamboo mat, (**b**) bamboo fabric and (**c**) kenaf mat.

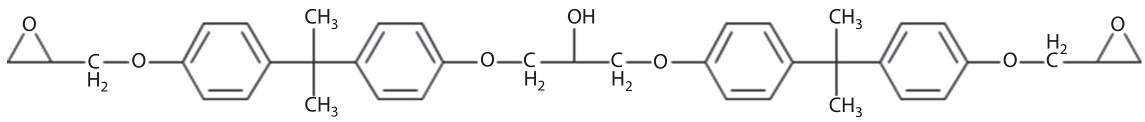

Figure 2 Epoxy resin and hardener reaction.

Table 1 Chemical composition of bamboo and kenaf.

Fiber sources	Cellulose	Hemicellulose	Lignin	Ash and extractives
Bamboo Mat	72.59	11.08	9.51	6.82
Bamboo Fabric	80.46	8.34	3.77	7.43
Bamboo Powder	54.61	6.85	20.85	17.69
Kenaf	65.71	17.82	5.99	10.48

2.3 Composite Fabrication

Bamboo powder was put into an oven at 60 °C for 24 hours to remove moisture. Epoxy and hardener were mixed with ratio 2:1 and stirred using a wooden stick for about 2–4 minutes at room temperature. The epoxy was mixed with 30 g of dried bamboo powder and stirred until all powder was evenly distributed in the epoxy before being poured into a stainless steel mold with dimensions 150 mm × 150 mm × 4 mm and put into a hot press at temperature 110 °C for 10 minutes. After 10 minutes, the composite was transferred into a cold press for 5 minutes before composite could be demolded. Fiber loading for bamboo powder was maintained 30% by weight. Hand lay-up method was used to fabricate bamboo mat, bamboo fabric and kenaf composites. Bamboo mat/fabric/woven kenaf was cut according to mold size, which was 150 mm × 150 mm, and put into the oven at 60 °C for 24 hours to remove moisture. Epoxy and hardener were mixed with ratio 2:1 and stirred using a wooden stick for about 2–4 minutes at room temperature. One thin layer of epoxy was poured into the stainless steel mold followed by bamboo mat/fabric/woven kenaf. Epoxy was applied on every layer of bamboo mat/fabric/woven kenaf. The total fiber loading was maintained 30% by weight. The mold was transferred into a hot press at temperature 110 °C for 10 minutes then into a cold press for 5 minutes before it could be demolded.

2.4 Chemical Composition

The chemical composition of bamboo mat, bamboo fabric, bamboo powder and kenaf fiber is determined by using neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL). The percentage of cellulose and hemicelluloses can be determined by using Equations 1 and 2, respectively. The sample was sent to Malaysian Agricultural Research and Development Institute, Serdang, Selangor, for chemical composition analysis.

$$\text{Cellulose} = \text{ADF} - \text{lignin} \quad (1)$$

$$\text{Hemicelluloses} = \text{NDF} - \text{ADF} \quad (2)$$

2.5 Tensile Testing

The specimen for tensile test with dimensions 120 mm × 20 mm × 4 mm was prepared and tested according to ASTM D3039 using an Instron 4201 universal testing machine with 100 kN capacity load cell. The gauge length used was 60 mm and testing speed was set at 5 mm/min. In every sample, five replications were made and tested. Average value was tabulated.

2.6 Impact Testing

Notched Izod impact test specimens with dimensions 70 mm × 15 mm × 4 mm were prepared and tested according to ASTM D256 using a Gotech GT-7045-MD machine. Notch angle was 45° and depth was 2.5 mm. In every sample, five replications were made and tested. Average value was tabulated

2.7 Scanning Electron Microscopy (SEM)

The surface morphology of fracture surface of the tensile sample of composites was examined using JSM-6400 scanning electron microscopy (SEM) with an acceleration voltage of 15 kV. The samples were coated with a thin layer of gold prior to structure analysis.

3 RESULTS AND DISCUSSION

3.1 Chemical Composition

Chemical composition consists of extractive, cellulose, hemicellulose, lignin, and ash. This will influence the physical, mechanical and thermal properties of natural fibers reinforced polymer composites. The main component in plant cell wall and fiber is cellulose, which provides most of the strength and stability to the plan cell walls and the fiber [19, 20]. Composites that used fibers with high cellulose content as reinforcement usually have good tensile strength. Hemicellulose contributes slightly to the stiffness and strength of the fibers [19]. The application of natural fiber depends on its composition. Fiber with high cellulose content is usually used for textile, paper and other fibrous applications while a high hemicellulose content is suitable for production of ethanol and other fermentation products [19]. Lignin acts as binder between individual cells and between the fibrils forming the cell wall. It is a highly crosslinked molecular complex with amorphous structure [19, 21]. The presence of lignin in the fibers influences the structure, properties and morphology [22].

The chemical composition of bamboo mat and bamboo fabric is different than bamboo, which is due to the extraction process and treatment. Chemical composition of natural fiber was influenced by factors such as fiber sources, locality in which it grows, extraction process and maturity [22–24].

3.2 Tensile Properties

Tensile strength will determine the ability of composites to resist breaking under tensile stress. Figure 3 shows the tensile strength of bamboo and kenaf reinforced epoxy composites. The reinforcement has improved the tensile strength of the composites. From Figure 3 it can be seen that B has the highest tensile strength (53.03 MPa) compared to other composites, which is 2 times higher than neat epoxy. There are a lot of factors that will affect the properties of a composite such as fiber size, fiber loading and chemical composition of fiber.

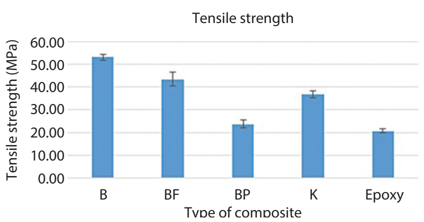

Figure 3 Tensile strength of bamboo reinforced epoxy composites and kenaf reinforced epoxy composites.

There will be a significant difference in mechanical properties of composite when long fiber and short fiber are used. In this case, there are three different forms of bamboo used as reinforcement; B (nonwoven) and BF (woven) are long fiber while BP (filler) is short fiber. Composite which uses long fiber will have high tensile strength compared to short fiber. This is because short fiber will never reach breaking stress since it only deflects matrix crack propagation during stress transfer [25]. Study on the effect of fiber length on the performance of the composites shows that long fiber has higher tensile strength compared to short fiber [26–28]. Even though B, BF and K are long fiber, there are differences in the tensile properties of the composite. The lower strength is due to fiber failure; as a result, the fiber cannot effectively deflect micro crack propagation [25].

Besides that, cellulose content also influences the strength of composite since it is responsible for providing strength to the fiber [9, 29, 30]. From Figure 3 it can be seen that tensile strength of K composite is slightly lower than B and BF. This can be explained by looking at the cellulose content of the fibers. Among these three fibers, the cellulose content of kenaf is lowest. This is one of the reasons why tensile strength of K is lower than B and BF. Although BF has the highest cellulose content, which is 80.46%, its tensile strength is lower than B. Fiber orientation also plays a role in determining the mechanical properties of composite. It can be seen that nonwoven (B) has high tensile strength compared to woven (BF). This is because most of the stress carried by fiber is in the same direction of the stress applied.

Tensile modulus will determine the rigidity of composites. The tensile modulus of bamboo reinforced epoxy composites and kenaf reinforced epoxy composites can be seen in Figure 4. Tensile modulus has increased significantly when reinforcement is used. The trend of tensile modulus for B, BF and BP is the same as tensile strength. Among these three types of bamboo, B has the highest tensile modulus, which is 3.94 GPa. Long fiber shows high tensile modulus compared to short fiber. This is because long fibers carry more loads due to increase in transfer length [25]. When a comparison of bamboo and kenaf was made, K showed the highest tensile modulus (4.71 GPa).

3.3 Scanning Electron Microscopy (SEM)

Interfacial adhesion between fiber and the matrix will determine the mechanical properties of composites [13, 31, 32]. Figure 5a shows the tensile fracture of B. It can be seen that there is less void content in the composite. In addition, the bamboo fibers were broken, which indicates that the adhesion between bamboo fibers and matrix are good. As a result,

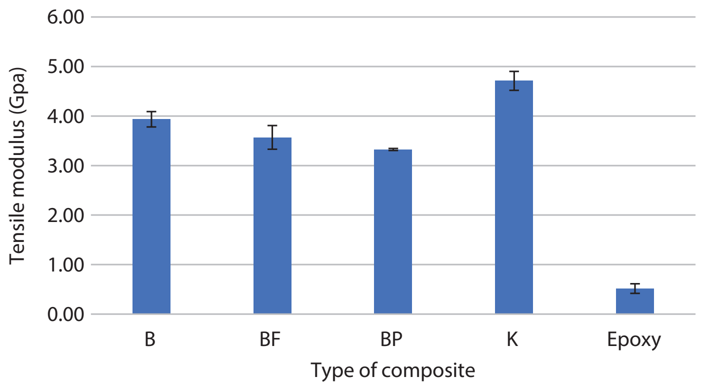

Figure 4 Tensile modulus of bamboo reinforced epoxy composites and kenaf reinforced epoxy composites.

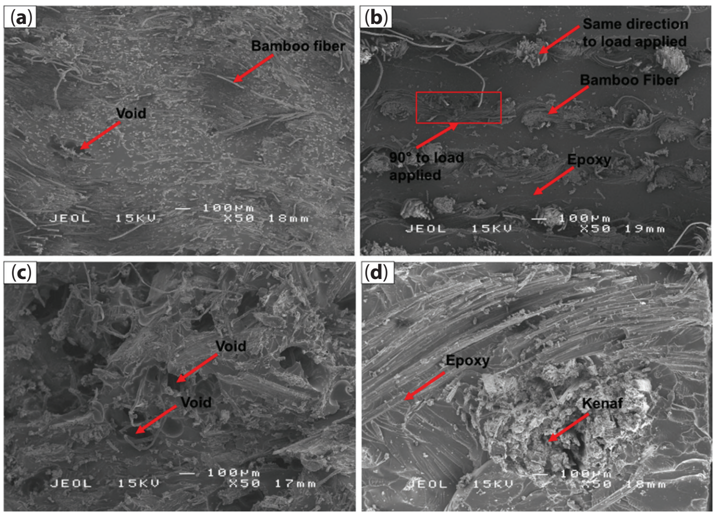

Figure 5 SEM micrographs of fractured composites: (**a**) B, (**b**) BF, (**c**) BP, (**d**) K.

tensile strength of B is the highest compared to other composites. From Figure 5b, there are fibers in the direction of stress applied and 90° of stress. Most of the loads were carried by the fibers, which is in the same direction of the stress. Fiber pull-out can be seen clearly when fibers are perpendicular to the stress. Fiber pull-out indicates that interfacial bonding between fibers and matrix is poor [33]. BP has the lowest improvement in tensile strength compared to other composites. There is a lot of void content and fiber pulled out in BP, as seen in Figure 5c, which is the result of weak interaction between fibers and matrix [34]. This is the reason BP has the lowest tensile properties compared to other composites. Figure 5d shows the tensile fracture of K. Kenaf fibers have good adhesion with epoxy. However, the arrangement of kenaf fibers in woven form is one of the reasons it has lower tensile strength compared to B, because most of the stress was carried by fibers, which is in the same direction with stress. A decrease in strength efficiency was shown when fiber orientation angle used is 90° to the load [35].

3.4 Impact Properties

Impact property is the ability of a material to absorb and dissipate energy under impact or shock loading [28]. The impact properties depend on the interlaminar and interfacial bonding, fiber and matrix properties, the construction and geometry of the composite and test conditions [13, 28, 36]. Figure 6 shows the impact properties of bamboo and kenaf composites. The highest improvement of impact strength is shown by BF (31.06 J/m). The improvement of impact strength is about 1.8 times compared to neat epoxy. The strength and structure of the individual fiber will affect the impact strength of composite. The impact strength of random orientation fiber basically depends on the interfacial bonding of fiber and matrix, but for woven mat, interlaminar delimitation will be an addition to

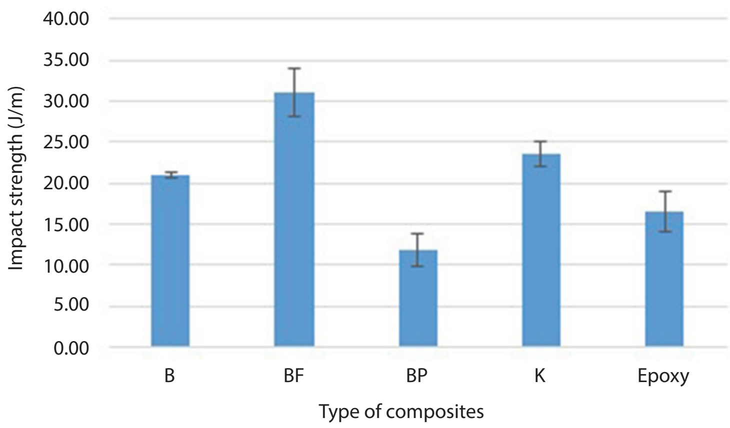

Figure 6 Impact strength of bamboo reinforced epoxy composites and kenaf reinforced epoxy composites.

interfacial strength, thus increasing the impact strength of composites [13]. It can be seen that woven (BF and K) material has higher impact strength compared to non-woven (B) and filler (BP). However, the impact strength is seen to decrease when short bamboo fibers are used. The decrease in impact strength was due to the agglomeration of the bamboo fibers. Besides that, the decrease in impact strength when bamboo powder is used may be due to the poor interfacial bonding between fibers and matrix, which promotes micro crack formation.

4 CONCLUSIONS

Addition of bamboo fibers and kenaf fibers as reinforcement has enhanced the mechanical performance of the composites compared to neat epoxy. Bamboo mat/epoxy shows the highest tensile strength while kenaf/epoxy show the highest tensile modulus. However, the highest impact strength was given by bamboo fabric/epoxy. A fracture surface study of the composites after tensile testing was carried out. The findings suggested that poor interfacial bonding and void content led to a decrease in efficiency of stress transfer. Based on SEM, the compatibility of bamboo mat with epoxy is better than bamboo fabric and bamboo powder with epoxy. Based on the chemical composition analysis, bamboo fabric has the highest cellulose content followed by bamboo mat. Even though bamboo fabric has the highest cellulose content, bamboo mat has shown the best overall mechanical performance. Thus, bamboo mat was chosen for further study on kenaf/bamboo hybrid composites.

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