Mechanical Properties of Woven Carbon Fiber/Kenaf Fabric Reinforced Epoxy Matrix Hybrid Composites

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Abstract

The demand for composite materials in manufacturing industries is increasing especially in structural applications due to its outstanding properties, especially in mechanical aspects. Nowadays, the fabrication of hybrid composite has widely developed where the combination of natural and synthetic fibers with a matrix resin gained major interest in many pieces of research. Unfortunately, from previous studies, the research that utilizes the adoption of fine kenaf fiber as a reinforcement using the vacuum infusion as a fabrication technique was limited. Indeed, the mechanical properties of fabricated hybrid composites rely upon the condition of kenaf fiber and also fabrication method. Therefore, to occupy the gap, in the present work, a hybrid composite was fabricated where the combination of two different reinforcements; fine kenaf fiber and carbon fiber were used together with the epoxy matrix via vacuum infusion technique. The fiber contents were varied at 40 and 50 vol.%. The sample of carbon fiber reinforced epoxy matrix and kenaf fiber reinforced epoxy matrix were also fabricated as a reference. The effect of different fibers/matrix ratio of the hybrid composite was evaluated by conducting tensile and flexural tests according to ASTM D3039 and ASTM D790. The fractures and mode failures of hybrid composites were characterized using scanning electron microscope (SEM) and the optical microscope, respectively. The result highlights that hybrid composite with fiber/matrix ratio of 40/60 vol.% exhibits good tensile and flexural strength in which both values gained at 325.70 MPa and 345.23 MPa, respectively.

Keywords: hybrid composite, vacuum infusion (vi), carbon/kenaf fiber, natural fiber

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Introduction

In the past few years, the consciousness toward sustainability of the environment has gained great interest from many material scientists and researchers in producing an environmentally friendly product. In recent years, researchers start to explore the benefits of natural fiber as the reinforcing element in composite materials for the structural application. The natural fibers such as hemp, jute, sisal, banana, and kenaf are common types of materials introduced as a reinforcement in a composite system [1]. The selection of natural fibers due to its advantages such as renewable resources, cost-effective, reasonable mechanical strength, and low density [2,3]. Kenaf fiber from a plant known as *Hibiscus cannabinus* seems one of the best natural fibers for embedded reinforcement owing to comparable mechanical strength, excellent biodegradable properties, and low density [4,5]. Moreover, the availability of kenaf which can rapidly grow becomes another factor that contributes to the utilization of kenaf fiber [6]. As reported from the previous study, the tensile modulus of kenaf fiber reinforced polypropylene is quite close to glass fiber reinforced polypropylene, which is 8.3 GPa and 9.0 GPa, respectively [7].

Despite all the advantages offered by natural fiber, high moisture absorption has limited its potential in most structural engineering applications [8]. Besides, the long-life cycle of synthetic fibers after the end-of-services contribute to the difficulty in the recycling process can lead to environmental issues. Thus, to overcome this problem a hybridization system was introduced by combining two different fibers with one matrix phase to form a hybrid composite. Thus, considering the mechanical performances of a composite system concurrently with environmental sustainability, hybrid composites from kenaf/carbon with epoxy resin were fabricated via vacuum infusion technique. The selection of vacuum infusion as a fabrication method due to its ability in promoting better interfacial bonding between fibers and matrix phases that consequently produced a composite material with outstanding mechanical properties [9].

Materials and Methods

Materials

There are three main materials employed in this project including fine kenaf fabric, woven carbon fiber, and epoxy resin. Kenaf fiber was supplied by SBJ Innovation Services Sdn. Bhd. (Selangor, Malaysia). Meanwhile, woven carbon fiber supplied by Vistec Technology Services Sdn. Bhd and epoxy resin was obtained from Sky Tech Enterprise Sdn. Bhd. (Kuala Lumpur, Malaysia). Table 1 summarizes the properties of these materials given by the suppliers.

Table 1. The properties of main materials (data from the supplier)

Properties	Materials		
	Kenaf Fiber	Carbon Fiber	Epoxy Resin
Density (g/cm^3)	1.22	1.77	1.122
Tensile Strength (MPa)	200	1380-2070	78
Elongation at break (%)	1.6	1.5	4.5
Type	Fine fabric	2x2 Twill	Viscous liquid

Fabrication of Hybrid Composite

Carbon and kenaf fibers were cut having a dimension of 230mm x 280mm and 260mm x 280mm, respectively. The interlacing arrangement was applied in this study wherein the outer layer occupied with carbon fiber. Both samples with 40:60 and 50:50 fiber-to-matrix ratio consists of six layers of carbon and five plies of kenaf fiber. The amount of epoxy resin needed for both samples was obtained using a rule of mixture concept. Then, fibers were placed on the mold and the setup for vacuum infusion was prepared accordingly. The vacuum pump was switched on to remove all the trapped air inside the vacuum bagging system. The resin was flowed from the inlet, then spread evenly along the surface of fibers until reaching the outlet chamber. The hybrid composite underwent a curing process for 24 hours at room temperature. After curing, the samples were cut to the desired size according to the respective ASTM standard.

Characterization

The tensile test was carried out according to ASTM D390 with the dimension of $250\,mm \times 25\,mm$ using The Universal Testing Machine (Instron 5582) with a crosshead speed at 2 mm/min and 50 mm of a gripping length. A flexural test was performed using the same machine based on ASTM D790 with the dimension of $127\,mm \times 13\,mm$ at the crosshead speed of 2 mm/min and a gauge length of 25 mm. The fracture failures from the tensile test were evaluated using a scanning electron microscope (SEM) JEOL JSM-5600 where the Quarom SC7620 Sputter Coater was used to coat the sample with palladium (Pd). The mode of failures from the flexural test was examined under Nikon Measuring Microscope Trinocular Head, model MM-TRF.

Results and Discussion

Morphology of Raw Materials

Fig.1 (a-b) represents the morphology of carbon and kenaf fibers observed under a scanning electron microscope (SEM). Based on Figure 1(a), kenaf fiber exhibits a plain weave pattern wherein it can be observed that the gap between warp and weft yarns not too tight. Meanwhile, from Figure 1(b), carbon fiber shows a twill weave pattern. This pattern displays the diagonals shape where all the sequences are synchronized. Besides, the gap between warp and weft yarns was very small and tight. Therefore, the twill weave tends to exhibit good strength compared to a plain pattern.

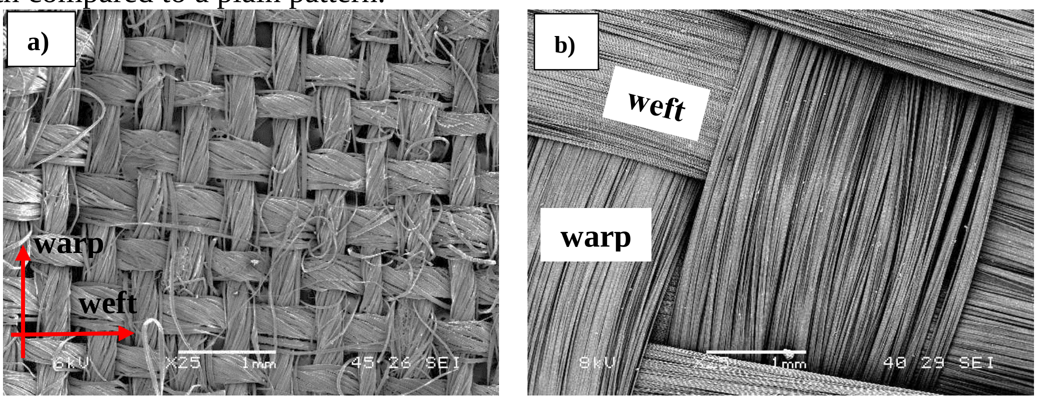

Fig. 1. SEM surface morphology (a) kenaf fiber and (b) carbon fiber at $\times$ 25 magnification

Tensile Properties

Table 2 shows the variation of the tensile properties obtained from fabricated hybrid composites when fiber/matrix loadings were varied to 40:60 and 50:50. Based on Table 2, tensile strengths of sample A and sample B gained at 325.70 MPa and 259.40 MPa, respectively. It should be noted that from this result the tensile strength of a hybrid composite increased by 20.36% when 40:60 vol.% of fiber/matrix employed in a hybrid system as compared to the one with 50:50 vol.%. The introduction of kenaf fiber as reinforcement into sample A and sample B reduced the tensile strength compared to samples C and D (without kenaf fiber). This phenomenon supported by the fact that higher carbon content resulted in high tensile strength because carbon fiber has good resistance to mechanical damages when they are subjected to efforts of tension [10]. A hybrid composite from sample A also displays the higher value in tensile modulus than sample B whereby both values obtained at 4.21 GPa and 3.92 GPa, respectively. In terms of elongation, the adoption of kenaf fiber inside the composite material improves the elongation at break. The highest elongation stated in sample B with 25 vol.% of kenaf fiber contents. It is supported by the fact that kenaf fiber exhibits good stiffness which affects the elongation at break compared to carbon fiber [11].

Table 2. Summarization of tensile properties. **K (kenaf fiber), C (carbon fiber), E (Epoxy matrix)*

Properties / Sample	Fiber/matrix ratio (vol.%)	Tensile strength (MPa)	Tensile Modulus (GPa)	Elongation at break (mm)
A	*(K/C/E) 20:20:60	325.70	4.21	5.69
B	(K/C/E) 25:25:50	259.40	3.92	6.15
C	(C/E) 40:60	496.44	7.16	3.34
D	(C/E) 50:50	420.50	5.56	3.46

Flexural properties

Fig. 2 shows the flexural properties of carbon/kenaf hybrid composite. It should be noticed that flexural properties also exhibit the same trend as tensile properties. The highest value of flexural strength is 345.23 MPa belongs to sample A (40:60). Meanwhile, for sample B the flexural strength was obtained at 223.06 MPa. The addition of kenaf fiber from 20 vol.% to 25 vol.% decreased the flexural strength by 35.39%. This phenomenon occurred due to the adhesion factor between fiber and matrix whereby 40:60 fiber/matrix ratio (sample A) possess better adhesion which leads to the effectiveness of load transfer between a matrix and reinforcement inside a composite system. As a result, a high value of flexural strength can be obtained from a sample A compared to sample B. The same result reported in the previous research [12] in which increasing the volume fraction of fiber beyond 40 vol.% results in reducing of flexural modulus. It is because the addition of fiber beyond 40 vol.% contributes to insufficient fiber wetting which can promote interfacial defects and acts as a stress concentrator. For this reason, it was found that fiber wettability gives a great influence on the flexural properties of composites.

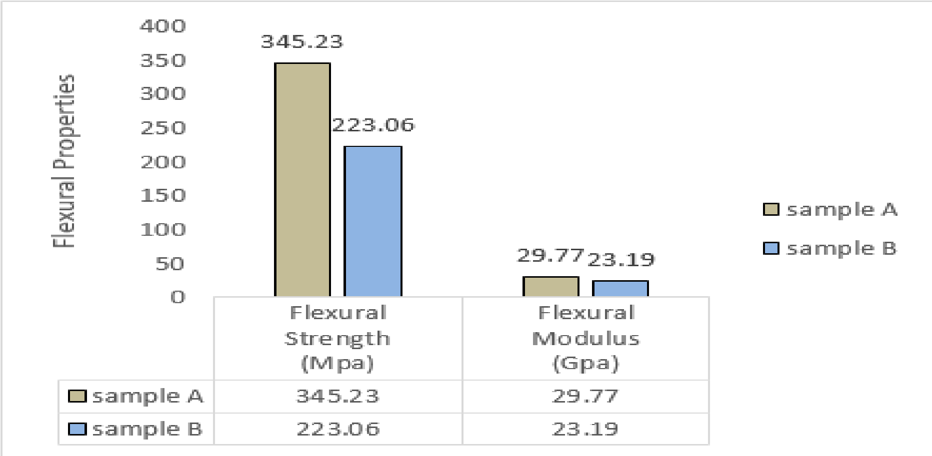

Fig. 2. Flexural properties of carbon/kenaf hybrid composites

Characterization Mode of Failure of Hybrid Composite

Fig.3 (a,b) represents the morphology for both sample A and sample B before performing a test. From the microstructure, sample A (Fig. 3(a)) shows the good adhesion between fiber and matrix and less matrix cracking. This indicates one of the main reasons that contribute to the high performance of tensile and flexural properties of sample A. Fig.3 (b) illustrates the microstructure of sample B where it clearly shows that sample B experienced fiber-pulled out phenomena that give a great influence on the tensile properties.

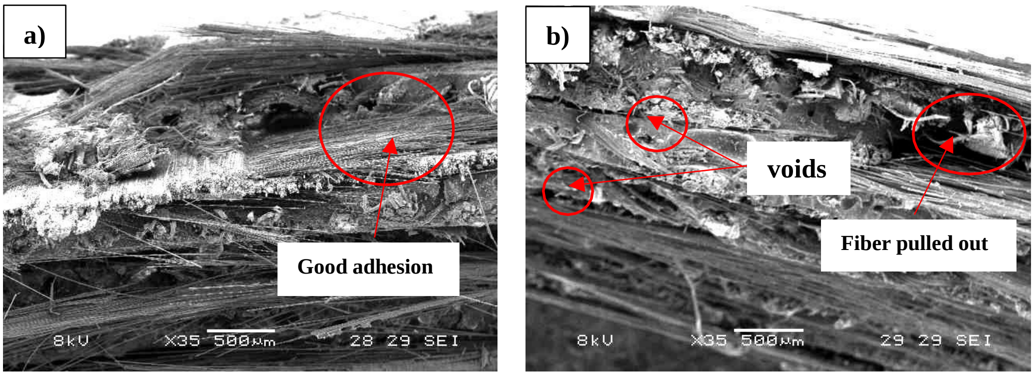

Fig. 3. SEM micrograph of (a) sample A and (b) sample B before testing at $\times$ 35 magnification

From the morphology images, a hybrid composite experienced several fracture failures when loads were applied to the samples either through the tensile or flexural test. Fig. 4 (a-b) represents the fracture failure for both samples A and B after performing a tensile test. From the microstructure images, it can be observed that fiber failures such as fiber pull-out, fiber breakage are the major fracture failures during tensile test. It should be noted that sample B exposes more fiber breakage compared to sample A.

Fig.5 (a,b) shows the optical micrographs for sample A and sample B. From the Fig.5 (a), the appearance of microcrack in sample A due to the application of load during bending test. The microcrack emanate when the crack was initiated from the load transfer, then the crack starts to propagate before experiencing permanent failure.

This type of failure occurs due to the weak adhesion bonding between fiber and matrix. Thus, laminate kenaf fiber in sample B unable to provide sufficient barrier as a load receiver, as a result, the load receiver needs to be carried by a weak epoxy matrix that consequently leads to poor flexural properties.

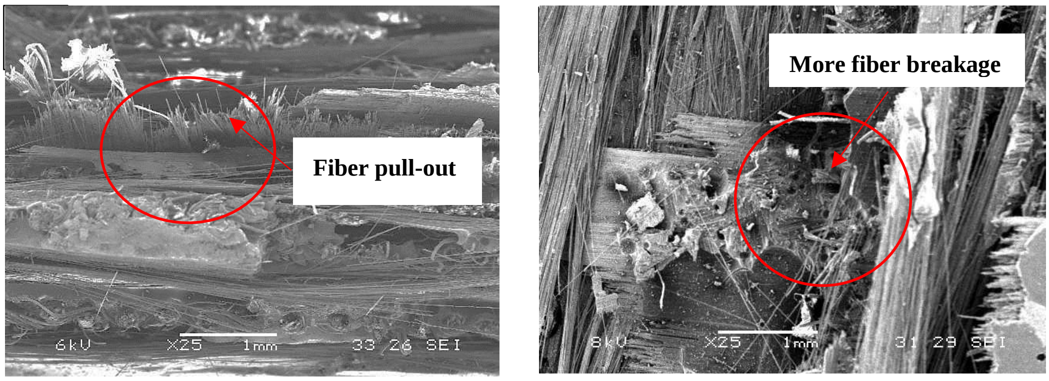

Fig. 4. SEM micrograph of the tensile fracture surface (a) sample A, and (b) sample B at × 25 magnification

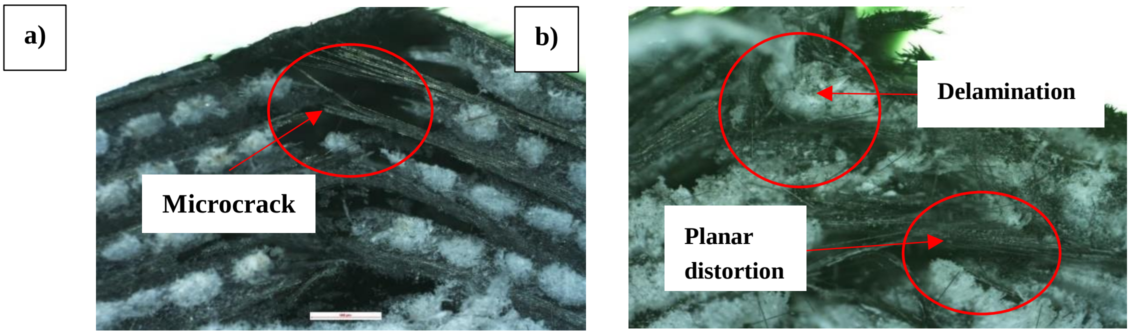

Fig.5. Optical morphology of flexural fracture surface (a) sample A and (b) sample B

Conclusion

The mechanical properties of carbon/kenaf hybrid composite were studied. From this research, it can be concluded that:

1) The highest tensile strength and modulus obtained by composite with 40/60 fiber-to-matrix ratio due to the strong adhesion bonding between fiber and matrix which can be clearly observed under SEM.
2) The flexural properties show the same trend as tensile properties. Sample A with 40/60 fiber/matrix content possess the highest flexural properties than sample B.
3) Both tensile and flexural properties decrease as the fiber content inside the hybrid system increases.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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