Jurnal Teknologi

Tensile Behaviour of Kenaf Fiber Reinforced Polymer Composites

Hafizah, N. A. K.[a], Hussin, M. W.[a], Jamaludin, M. Y.[b]*, Bhutta, M. A. R.[a], Ismail, M.[a], Azman, M.[c]

[a]Contruction Research Centre (UTM CRC), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Structures and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Department of Engineering, Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, International Campus, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
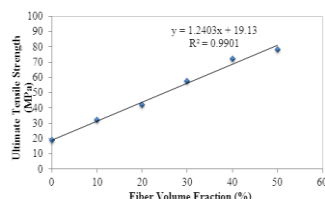
*Corresponding author: jamaludin@utm.my

Graphical abstract

Abstract

Natural fiber is usually used as reinforcement in polymeric materials, and short fibers are commonly used for non-structural applications. However, the lack of studies on long fiber reinforced polymeric materials, especially kenaf fiber, has limited its usage in Malaysia. This paper presents the experimental results of a series of tensile tests conducted on continuous kenaf fibers produced with different types of thermoset resin (epoxy, polyester, and vinyl ester) arranged longitudinally. A total of 75 kenaf fiber reinforced polymer composites containing up to 50% fiber volume fraction including 15 neat samples as control samples were produced. Then, the samples were tested using Universal Testing Machine to obtain their tensile behaviour. Results indicated that the composites' performance increased gradually with every increment of fiber volume fraction. Factors affecting the tensile behaviour of kenaf fiber reinforced polymers are also explained and discussed. In conclusion, kenaf fiber can be used as reinforcing materials in polymeric materials.

Keywords: Kenaf fiber; natural fiber; kenaf fiber reinforced polymer composites

◼1.0 INTRODUCTION

The tensile properties of natural fibers are very important in the rule of mixture of composites as the addition of fibers with higher strength and stiffness than those of composite material's polymer matrix can markedly improve its tensile properties.[1] Munawar *et al.* (2007)[2] performed their experiments in a universal testing machine and obtained an average tensile strength and modulus of 357 MPa and 9.1 GPa, respectively. Table 1 summarizes the tensile strength and modulus of fibers that have been tested by previous researchers.

Netravali (2004)[3] also proved that unidirectional (longitudinal) composites are stronger than transverse composites and since they are stronger than steel on per weight basis, the author concluded that unidirectional orientation is preferable for structural applications. The author also suggested short fiber composites for non-structural applications while long fiber composites are applicable for structural uses. This was supported by Aziz and Ansell (2004)[4] in which unidirectional (longitudinal) long kenaf fibers and randomly arranged short fibers were compared in terms of the tensile properties of kenaf fiber composites. The flexural strength, flexural Young's modulus, and toughness of the long fiber composites were superior to the short fibers composites. Albuquerque *et al.* (2000)[5], on the other hand, prepared unidirectional jute roving reinforced polyester composites by aligning the jute fibers in post tension and this

resulted in excellent tensile properties. Such properties have also been enhanced by the development of textile technologies such as weaving because continuous orientation of fibers is no longer restricted at any point.[6]

In general, higher fiber content is desirable for the purpose of achieving high performance of biocomposites. Hajnalka *et al.* (2008)[12] observed that the Young's modulus (stiffness) of the hemp fiber PP composites improved when the fiber content increased, reaching a maximum value at 50% of hemp fiber loading, but then decreased gradually at 70% of hemp fiber loading. Liew (2008)[9] also studied oil palm fiber polyester composites; the presence of fiber (10%-30%) as reinforcement elevated the tensile strength and Young's modulus of biocomposites. However, theoretically, the maximum fiber volume fraction should be around 80%.[15] The experimental and theoretical results differed due to the characterization of fibers and viscosity of resin. Therefore, the effect of fiber content on the tensile properties of biocomposites is one of particular interest and significance to many researchers.

Current researches on kenaf that deals with short fiber characterizations are widespread, but researches on kenaf in the form of yarn or long fibers for the production of reinforced polymer composites, together with its characterizations, are considerably lesser. The aim of this study is to investigate the tensile behaviour of various kenaf fiber reinforced polymer composites. The ultimate tensile strength, Young's modulus and

strains at failure were obtained from the tensile stress-strain behaviour. Factors affecting the tensile behavior of kenaf fiber reinforced polymer composites and their effects will also be explained and discussed.

■ 2.0 EXPERIMENTAL

The kenaf fiber used in this study was obtained from MARDI, Selangor (Figure 1). The existing moisture content in kenaf fiber was less than 6%, as shown in Figure 2. The fibers were extracted from the bast through a bacteria retting process. The maximum length of the kenaf fibers from the manufacture is 1.5 meter and the preparation of kenaf fibers for composites depends on the size of the mould, which in turn is dependent on the volume fractions for fabrication of the kenaf fiber composites (2.31 g every 10% of fiber volume fraction). The strength of kenaf fiber was simply obtained using the universal testing machine with the capacity of 2.5 kN in accordance to ASTM D3379-75.[16] The cross head rate in this study was 3 mm/min and the gauge length was fixed at 30 mm.

Three types of resins were used in this study, namely epoxy (density: 1.11 g/cm^3), polyester (density: 1.12 g/cm^3), and vinyl ester (density: 1.1 g/cm^3). The selected resins are suitable for hand lay-up process and are durable for future study. These resins are chosen as they are commonly used in the industry.[1]

Figure 1 Kenaf fiber

Table 1 Summary of tensile strength and young's modulus for various of natural fibers from previous researchers

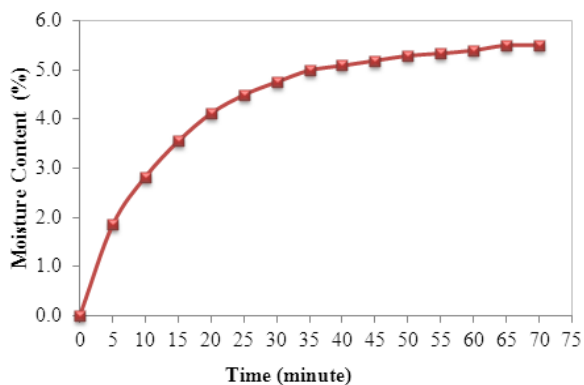| Type of fiber	Diameter (mm)	Average ultimate tensile Strength (MPa)	Young's modulus (MPa)	References
Kenaf	0.04-0.16	18-180	-	[7]
Kenaf	0.081	250	4300	[8]
Jute	0.082	345	2200	[8]
Jute	0.04-0.35	29-312	-	[7]
Oil palm	0.448	58.37	477.51	[9]
Oil Palm	0.25-0.61	71	1703	[10]
Coir	0.04-0.1	15-327	-	[7]
Sisal	0.05-0.2	568-640	9400-15800	[11]

Figure 2 Moisture content of kenaf fiber

A rectangular specimen was shaped according to ASTM D 3039/D[13] with dimension of 25 mm x 6 mm x 200 mm. This stage is required to investigate the tensile properties of kenaf fiber reinforced polymer composites with different types of thermoset matrices, i.e., epoxy, polyester, and vinyl ester resin. The kenaf fibers were tested only in the longitudinal direction as a review on published literature has shown that such orientation can greatly enhance the tensile properties of the fibers as well as the kenaf fiber reinforced polymer composites produced after that. The composites were categorized according to their fiber volume fractions (10%, 20%, 30%, 40% and 50%). Strain gauges were applied onto the sample's surface before the tensile test was conducted. The samples were tested for their tensile properties as well using the universal testing machine, which had a capacity of 50 kN, as shown in Figure 3. The fiber volume fraction in this study was limited to 50% because, physically, this was the maximum fiber content that could be included to produce the composites

Figure 3 Tensile test

■3.0 RESULTS AND DISCUSSION

The tensile behaviour of the Kenaf/Epoxy composites, Kenaf/Polyester composites, and Kenaf/Vinyl Ester composites are as shown in Figure 4, Figure 5, and Figure 6. Generally, the figures depicted that all samples were brittle and their strength increased gradually when the fiber volume fraction increased. The ultimate tensile strength, strain at failure, and Young's modulus of all kenaf fiber reinforced polymer composites were obtained from the stress strain curves. From the results, the tensile strength for Kenaf/Epoxy composites, Kenaf/Polyester composites, and Kenaf/Vinyl Ester composites were 3.1 times, 4.7 times, and 5.4 times respectively higher as compared to those of neat resin and this was clearly influenced by the type of resin used. Further analysis was carried out to investigate the effects of fiber volume fraction on the composites strength.
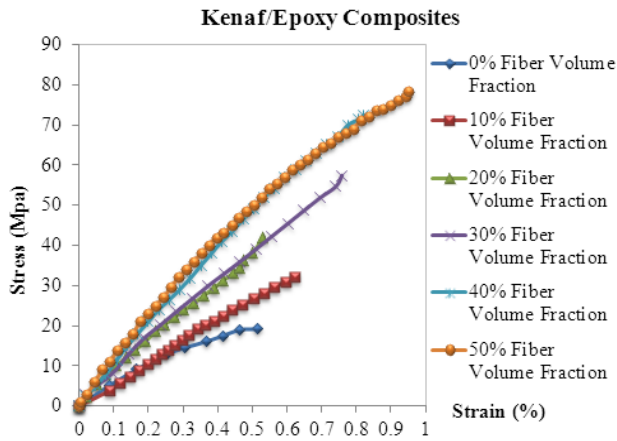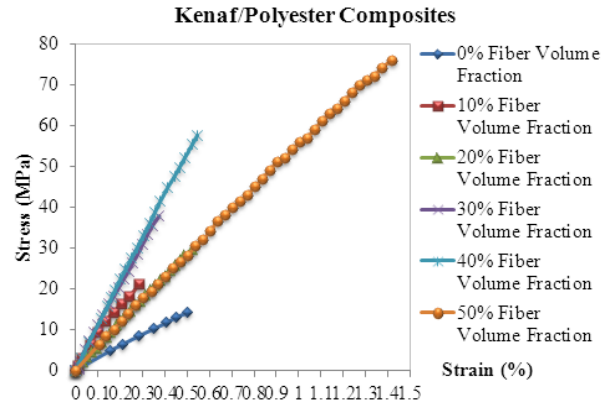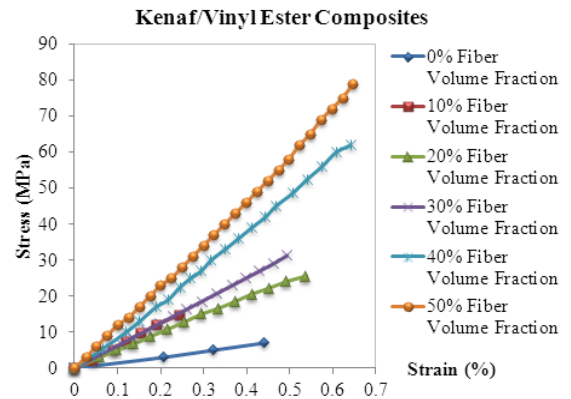

Figure 5 Kenaf/Polyester composites

Figure 6 Kenaf/Vinyl ester composites

The strain development of the kenaf fiber reinforced composites varied according to the type of resins used and the fiber volume fraction. Inconsistent development of strain in voids had further induced stress concentration and fiber misalignment during failure. However, a better workmanship had been practiced in this study and only the best five samples were chosen to be tested in terms of thickness consistency.

Figure 7, Figure 8, and Figure 9 show the effects of fiber volume, in percentage, on the ultimate tensile strength (UTS) of the kenaf fiber reinforced composites; the ultimate tensile strength of all composites increased gradually with every increment of fiber volume fraction. The regression, R^2, of all kenaf fiber reinforced composites was above 0.9, which reflected that the fabrication process was consistent and had been properly done. Similar trend had been reported in the study done by Albuquerque *et al.* (2000)[5] on the Jute reinforced polyester composites.

The Kenaf/Epoxy composites had higher ultimate tensile strength than Kenaf/Polyester composites and Kenaf/Vinyl Ester composites when the fiber content was up to 40%. However, all composites showed similar ultimate tensile strength at 50% fiber content; the Kenaf/Epoxy composites had an ultimate strength of 78.34 MPa, whereas the Kenaf/Polyester composites and Kenaf/Vinyl Ester composites exhibited 76.67 MPa and 78.92 MPa, respectively. Overall results showed that Kenaf/Epoxy had the highest ultimate tensile strength as epoxy resins are superior to the others. Additionally, the results also showed that, generally, the tensile strength of all kenaf composites increased

Figure 4 Kenaf/Epoxy composites

with increasing fiber content. Similar findings were also observed by Ku *et al.* (2011)[1] and Seki (2009)[14].
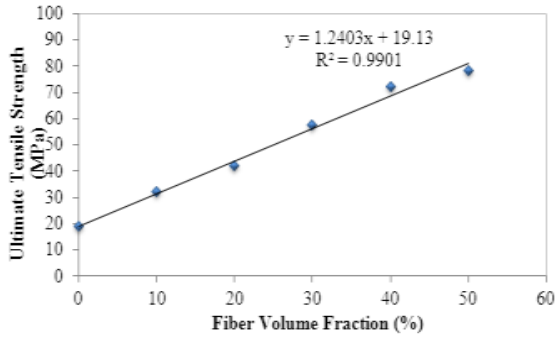

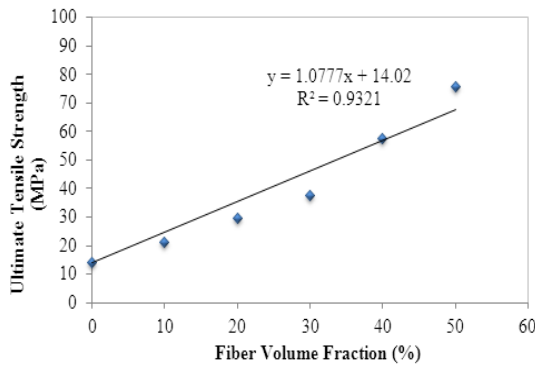**Figure 7** Ultimate tensile strength of Kenaf/Epoxy composites

Figure 8 Ultimate tensile strength of Kenaf/Polyester composites
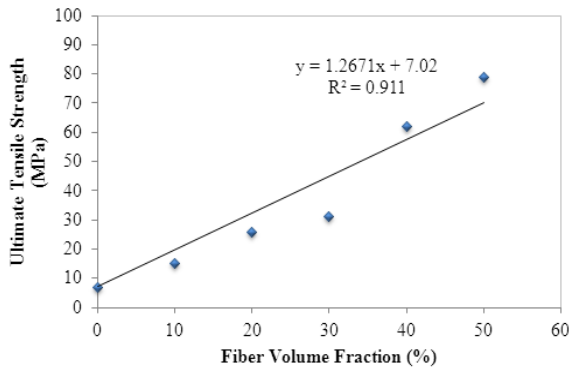

Figure 9 Ultimate tensile strength of Kenaf/Vinyl Ester composites

Figure 10 shows the Young's modulus, *E*, of Kenaf/Epoxy composites. The curve showed an increment in Young's modulus for every increment in fiber content and at 50% of fiber volume fraction, there was a drastic increment from 16.53 GPa (40% fiber volume fraction) to 35.9 GPa (50% fiber volume fraction); the difference is about 1.17 times. This was caused by the arrangement of the fibers during composite fabrication; the fibers were post tensioned before the resin was poured into the mould to ensure that the fibers were in unidirectional orientation. This method was important to avoid the 50% fiber volume fraction and resin from moving out of the mould, and such arrangement had apparently enhanced its Young's modulus.
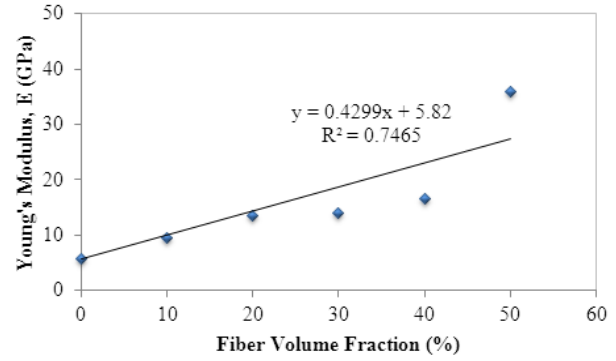

Figure 10 Young's modulus of Kenaf/Epoxy composites

Figure 11 shows the Young's modulus, *E*, of Kenaf/Polyester composites. The pattern showed continuous increment of Young's modulus for almost every increment of fiber content, except at 40% (8.87 GPa) of fiber volume fraction where it decreased about 2.6% from 9.11 GPa (30% fiber volume fraction). The Young's modulus continued to decrease at 50% (7.13 GPa) of fiber volume fraction as it reduced 19.62% from the previous fiber volume fraction. Some researchers had encountered contradicting trend where the composite strength did not decrease at all for every increase in fiber content. In this study, however, it is postulated that since the density of polyester (1.12 g/cm^3) and its viscosity are higher than epoxy and vinyl ester resins, the flow rate of resin to penetrate the spaces between fibers might have been reduced during the curing period. This has led to slipping between the resin and fiber substances. In other words, the fiber-matrix interface could not transfer the stress effectively. As a result, the strength properties of the composites were reduced.
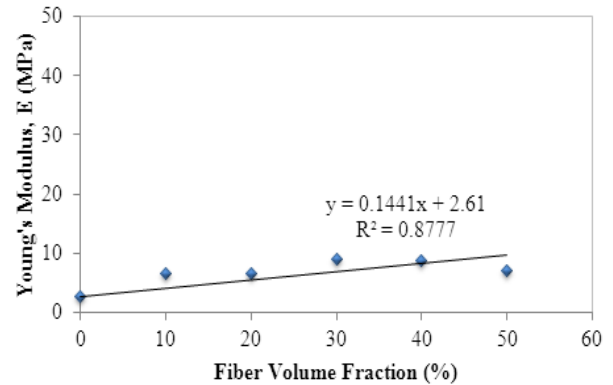

Figure 11 Young's modulus of Kenaf/Polyester composites

Figure 12 shows the Young's modulus, *E*, of Kenaf/Vinyl Ester composites. The curve showed that the Young's modulus increased gradually with increasing fiber content and their regression, R^2, was more than 0.9. The Young's modulus increased up to 30% fiber volume fraction for all the composites. However, for more than 30% of fiber content, the Young's modulus started to fluctuate due to the effect of fiber arrangement and viscosity of resins.
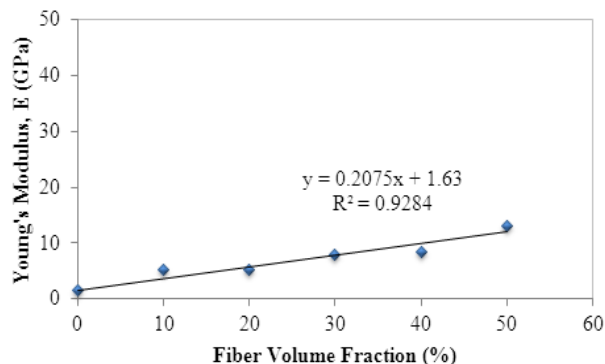
Figure 12 Young's modulus of Kenaf/Vinyl Ester composites

■**4.0 CONCLUSION**

The following conclusions could be drawn from the experimental results of this study:

  i.   All Kenaf/Epoxy, Kenaf/Polyester, and Kenaf/Vinyl Ester composites were brittle materials.
  ii.   The tensile strength of Kenaf/Epoxy composites, Kenaf/Polyester composites, and Kenaf/Vinyl Ester composites were 3.1 times, 4.7 times and 5.4 times respectively higher as compared with those of neat (control) resins.
  iii. The Kenaf/Epoxy composites had the highest ultimate tensile strength. All composites' strength gradually increased when the fiber volume fraction increased.
  iv.   Kenaf/Epoxy composites had the highest Young's modulus up to 50% fiber volume fraction. Meanwhile, the Young's modulus of Kenaf/Polyester composites and Kenaf/Vinyl Ester composites were approximately the same. The Young's modulus for all composites then fluctuated due to the effect of fiber arrangement and viscosity of resins.

References

[1]   Ku, H., Wang, H., Pattarachaiyakoop, N. and Trada, M. 2011. A Review on the Tensile Properties of Natural Fiber Reinforced Polymer Composites. *Composites:Part B*. 42(4): 856–873.
[2]   Munawar S. S., Umemura K, Kawai S. 2007. Characterization of the Morphological, Physical and Mechanical Properties of Seven Nonwood Plant Fiber Bundles. *Journal of Wood Science*. 53: 108–113.
[3]   Netravali, A. N. 2004. Ramie Fiber Reinforced Natural Plastics. In Frederick T. Wallenberger and Norman E. Weston. *Natural Fibers Plastics and Composites*. United States America: Kluwer Academic Publishers. 321–343.
[4]   Aziz, S. H. and Ansell, M. P. 2004. The Effect of Alkalization and Fibre Alignment on the Mechanical and Thermal Properties of Kenaf and Hemp Bast Fibre Composites: Part 1–Polyester Resin Matrix. *Composites Science and Technology*. 64: 1219–1230.
[5]   Albuquerque, A.C., Joseph, K., Carvalho, L. H. and Almeida, J.R.M. 2000. Effect of Wettability and Ageing Conditions on the Physical and Mechanical Properties of Uniaxially Oriented Jute-Roving-Reinforced Polyester Composites. *Composites Science and Technology*. 60: 833–844.
[6]   John, M. J. and Thomas, S. 2008. Biofibers and Biocomposites. *Carbohydrate Polymers*. 71: 343–364.
[7]   Ramakrishna, G. and Sundararajan, T. 2005. Studies on the Durability of Natural Fibres and the Effect of Corroded Fibres on the Strength of Mortar. *Cement & Concrete Composites*. 27: 575–582.
[8]   Lee, B. H., Kim H. J. and Yu W. R. 2009. Fabrication of Long and Discontinuous Natural Fiber Reinforced Polypropylene Biocomposites and Their Mechanical Properties. *Fibers and Polymers*. 10(1): 83–90.
[9]   Liew, S. C. 2008. *Characterization of Natural Fiber Polymer Composites for Structural Application*. Master of Civil Engineering. Universiti Teknologi Malaysia, Skudai.
[10] Mohd Zuhri, M. Y. 2008. *Mechanical Properties of Oil Palm Fibre Thermoset Composites.* Master of Science. Universiti Putra Malaysia, Selangor.
[11] Satyanarayana, K. G., Sukumaran, K., Mukherjee, R S., Pavithran, C. and Pillai, S. G. K. 1990. Natural Fibre-Polymer Composites. *Cement & Concrete Composites*. 12: 117–136.
[12] Hajnalka, H, Racz, I. and Anandjiwala, R.D. 2008. Developement of Hemp Fibre Reinforced Polypropylene Composites. *Journal Thermoplastic Composite Materials*. 21: 165–174.
[13] American Society of Testing and Materials (1995). *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*. United States: ASTM D 3039.
[14] Seki, Y. 2009. Innovative Multifunctional Siloxane Treatment of Jute Fiber Surface and Its Effect on the Mechanical Properties of Jute/Thermoset *Composites. Materials Science and Engineering A*. 508 (1009): 247–252.
[15] Gibson, R. F. 1994. *Principle of Composite Material Mechanics*. United States of America. McGraww-Hill.
[16] American Society of Testing and Materials. 1975. *Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials*. United States: ASTM D 3379.