

Tensile strength of woven yarn kenaf fiber reinforced polyester composites

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ABSTRACT

This paper presents the tensile strength of woven kenaf fiber reinforced polyester composites. The as-received yarn kenaf fiber is weaved and then aligned into specific fiber orientations before it is hardened with polyester resin. The composite plates are shaped according to the standard geometry and uni-axially loaded in order to investigate the tensile responses. Two important parameters are studied such as fiber orientations and number of layers. According to the results, it is shown that fiber orientations greatly affected the ultimate tensile strength but it is not for modulus of elasticity for both types of layers. It is estimated that the reductions of both ultimate tensile strength and Young's modulus are in the range of 27.7-30.9% and 2.4-3.7% respectively, if the inclined fibers are used with respect to the principal axis.

Keywords: Kenaf yarn; tensile strength; natural fiber composites; woven kenaf fibers.

INTRODUCTION

Several studies have focused on the development of eco-friendly bio-composite to replace non-biodegradable fiber reinforced composites [1-7]. The use of natural fibers as reinforcements in polymer composites to replace synthetic fibers such as glass fiber is receiving an increasing attention because of the cost effectiveness, low density, high specific strength as well as their availability as renewable resources [4, 8-11]. According to previous works [9-13], it is found that the studies on the behavior of tensile strength of natural fiber composites are almost established. Most of these studies concern the randomly oriented fibers [8-10]. However, there is a lack of available information regarding the behavior of tensile strength fabricated using properly aligned fiber for example using woven fiber [1-5, 8-11, 14-16]. For example, Sapuan et al. [11] studied the tensile and flexural behavior of woven banana fiber reinforced composites while Khan et al. [17] investigated the influence of woven structures and direction on the mechanical behavior such as tensile, flexural and impact tests. The results show that the woven structures exhibited an excellent mechanical behavior for all tests compared to non-woven fabric composites. However, none of these studies examined the influence of fiber orientations and number of layers. From literature review, it is found that woven-type kenaf fiber reinforced composites are not properly understood. Therefore, this paper presents the experimental results on the tensile behavior of woven-type kenaf fiber reinforced composites. There are two important parameters used, namely fiber orientations and the number of layers. Then, the composites are produced and tested according to the ASTM standard. Finally, the tensile behaviors are discussed in terms of these two parameters with an assistance of fracture surface observation and analysis.

EXPERIMENTAL SET UP

Fiber and Composite Preparations

As-received kenaf fiber (1 mm in diameter) is in the form of yarn as in Figure 1(a). Then, this kenaf yarn is weaved to form twill woven-type mats as in Figure 1(b). It consists of two sets of yarns warp and weft, which is interlaced at 90° relative to each other to produce a balanced twill weave where the number of warp and weft is 4×4 (4 yarns in warp and 4 yarn in weft directions per 10mm^2). Woven kenaf mats are produced manually using in-house machine as in Figure 2(a) and the kenaf mat produced is shown in Figure 2(b). Two important parameters are considered, namely fiber orientations and number of layers. Four fiber orientations are used: 0° , 15° , 13° and 45° . For double layers, the angle configurations are as follows: $0^{\circ}/0^{\circ}$, $15^{\circ}/0^{\circ}$, $30^{\circ}/0^{\circ}$ and $45^{\circ}/0^{\circ}$ as in Figure 3(a). The mats are then placed into a rectangular steel mold (Figure 3(b)) before polyester resin is poured and compressed in order to squeeze the excessive resin out as shown in Figure 4(a). Once the composite plates hardened as in Figure 4(b), they are then shaped into geometry as specified in ASTM standard for tensile test.

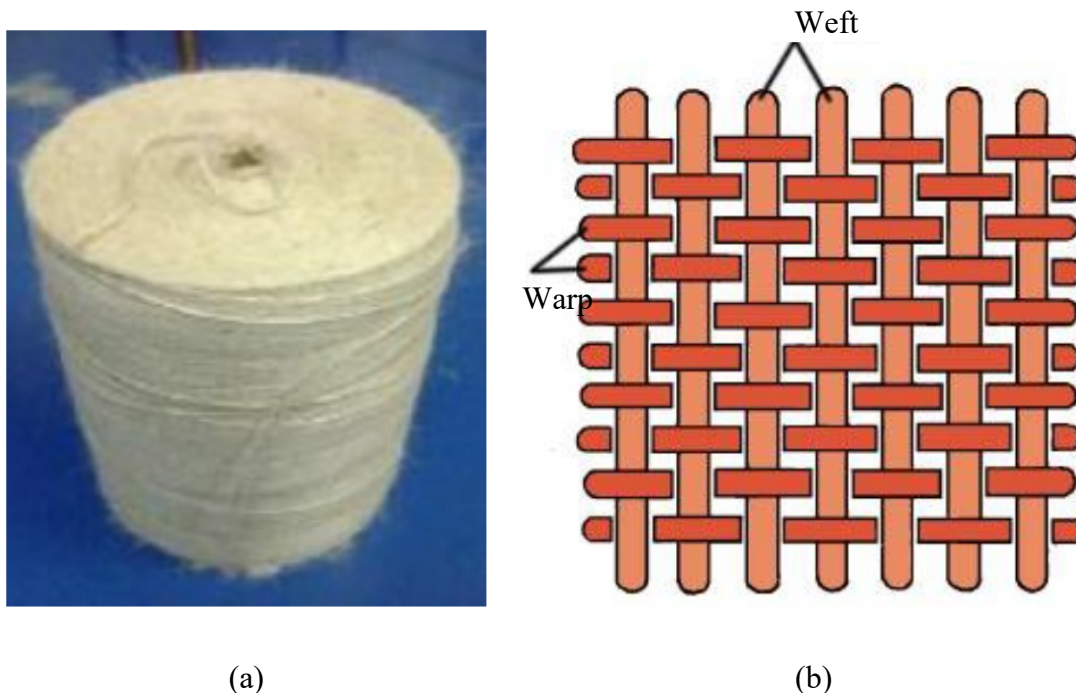


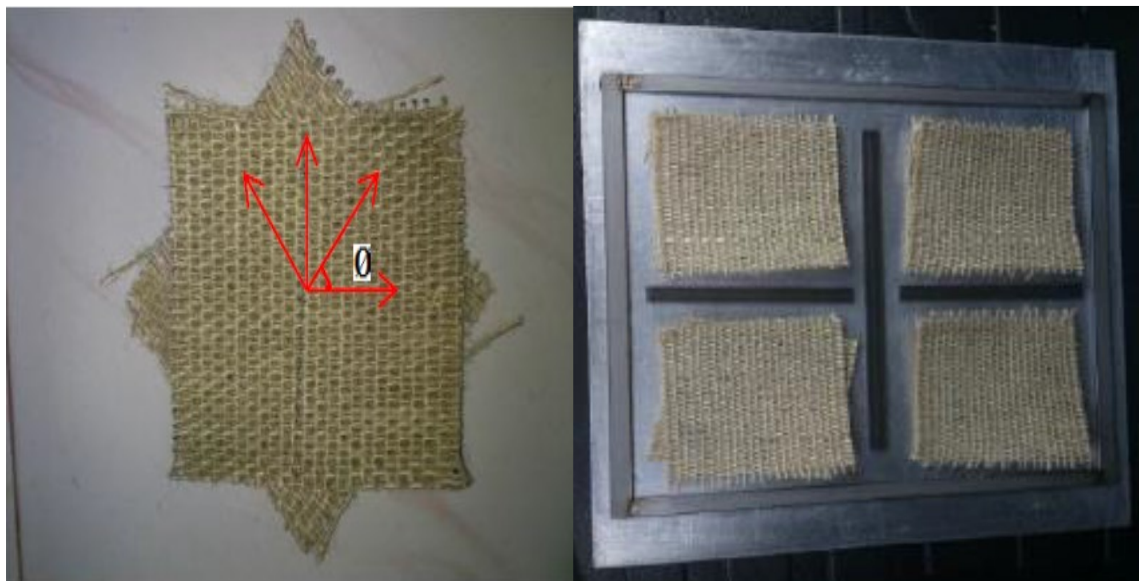
Figure 1. (a) As-received kenaf yarn fiber and (b) Twill-type woven mat.

Experimental Procedure

The hardened plates are shaped according to the standard geometry suggested by ASTM D3039. Tensile test (Figure 5) is performed in an ambient temperature and then quasi-statically stressed at a constant cross-head displacement of 2 mm/min. The composite response in terms of force and displacement is recorded automatically and then converted into stress versus strain diagram. In order to analyze the cause of failure for the composites, an optical microscope is used.



(a) (b)
Figure 2. (a) In-house weaving machine and (b) Finished woven type fiber mats.

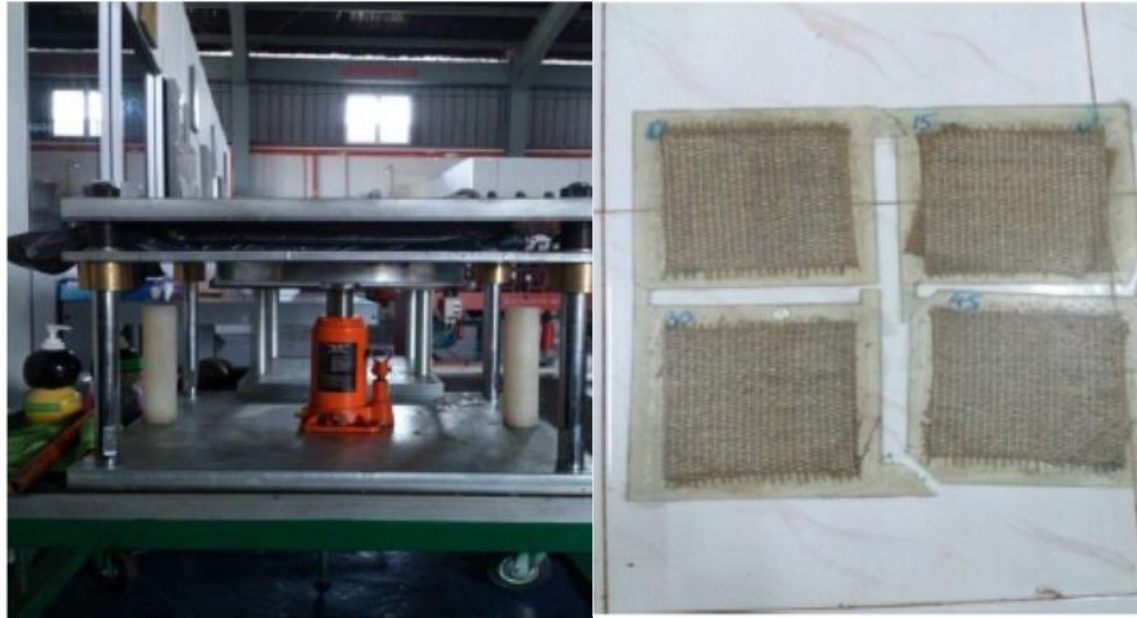


(a) (b)
Figure 3. (a) Fiber mat configuration and (b) Fiber mat placement in a mold.

RESULTS AND DISCUSSION

Figure 6 reveals the stress versus strain diagram of the single and double layers of woven kenaf reinforced composite subjected to uni-axial tensile test, respectively. Figure 6(a) shows the stress against strain curves of single layered composites when different fiber orientations are used. The curves generally can be divided into three regions. The first region is for linear elastic deformation where the stress is proportionally related with

strain. The second part occurs when the application of large strain slightly increases the stress. Once the strains are in the range of 4-5%, the stress suddenly drops, indicating that the composites are unable to sustain any further loading. It is also shown that 45° fiber orientations produced higher strain before failure compared to other types of composites.



(a)

(b)

Figure 4. (a) Fiber mats and resin is under compression and (b) The hardened composite plates.

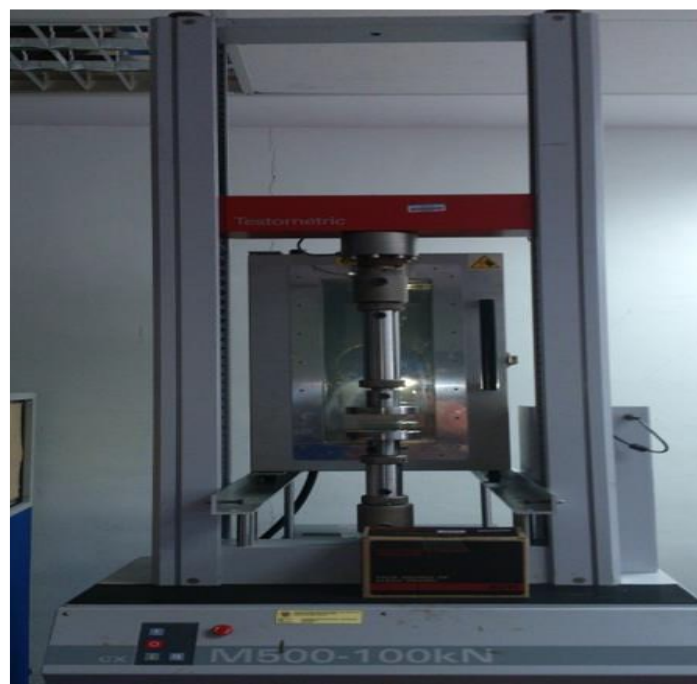


Figure 5. Universal tensile test machine with a high temperature chamber.

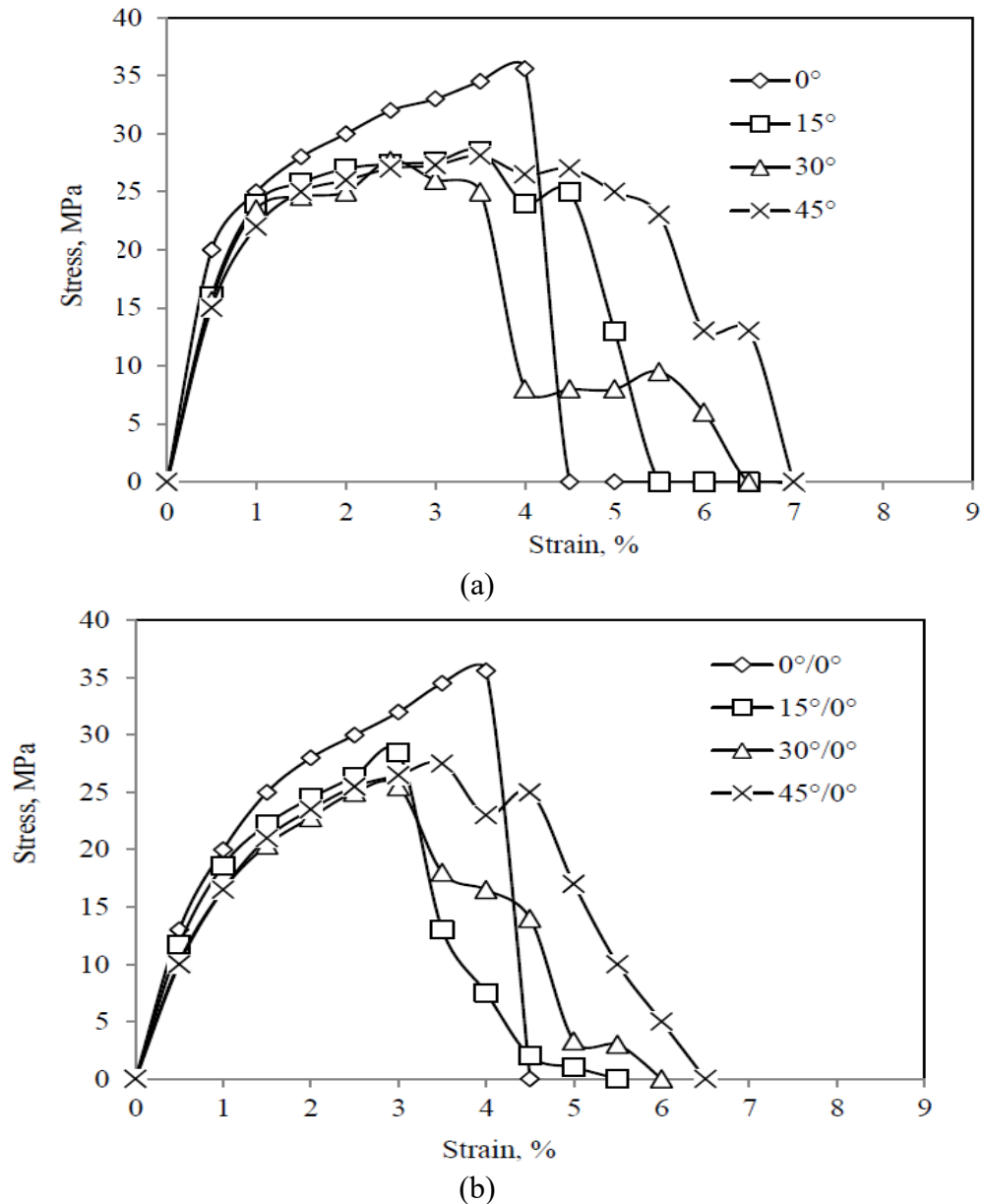
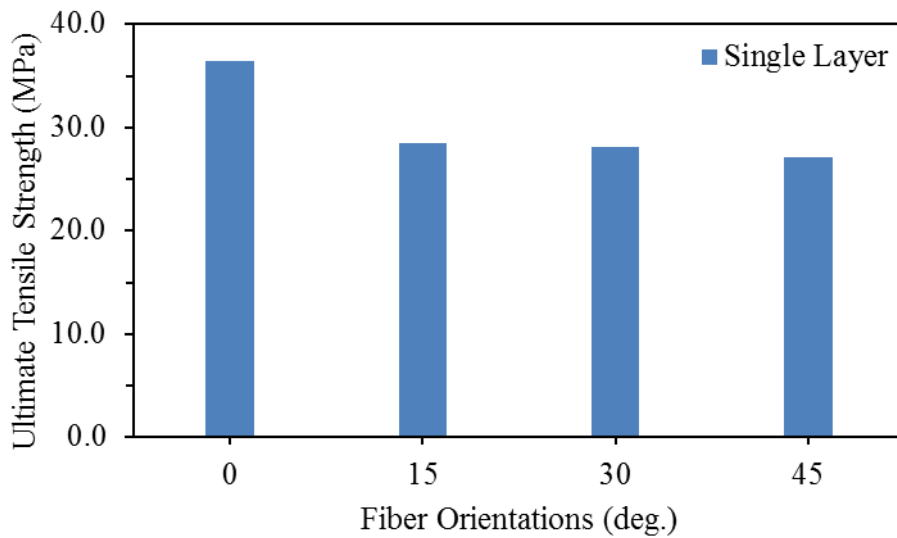


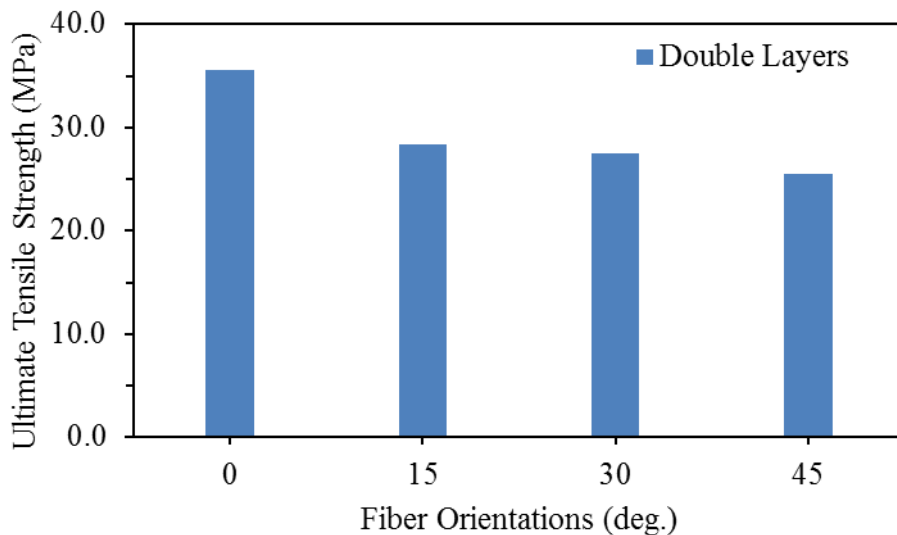
Figure 6. Tensile strength of woven type kenaf fiber reinforced composites for (a) single and (b) double layers when fiber orientations are varied.

Similar stress versus strain curves behavior can be observed for double-layered composites as in Figure 6(b); however, it fails in brittle manner. According to the shapes of the curves, only two deformation stages can be observed; the first one is the linear elastic deformation and the other one is in the failure stage. For these composites, the failure strain occurs within the range of 3-4%, which is less than the curves in Figure 6(a). The maximum stress for double-layered composites, however, slightly increased compared to the single-layered composites. The ultimate tensile strength and the Young's modulus are then determined for the stress-strain curves as shown in Figures 6 and 7. These two important parameters are plotted against their respective fiber orientations. Figure 7 shows the distribution of ultimate tensile strength against fiber orientations. Two types of layers are used, which are single- and double-layered composites as in Figures 7(a) and 7(b) respectively. It is indicated that fiber orientation plays an important role in

determining the ultimate tensile strength. As expected, the fiber aligned parallel to the loading axis produced higher ultimate tensile strength compared to other types of fiber orientations. This is due to the fact that the fibers which are aligned parallel with the axis of loading are capable of strengthening the composites. Meanwhile, for the case of two fiber layers, the ultimate tensile strength is not significantly affected by the angles. Similar distributions on the effect of fiber orientations on the modulus of elasticity can be observed in Figure 8. However, the Young's moduli for single layer composites are higher than the double layers due to the fact that lower strain to failure occurred as a result of brittle failure mechanism for the double-layered composites. Table 1 lists the ultimate strength and modulus of elasticity of the composites in terms of fiber orientations for two types of layers.

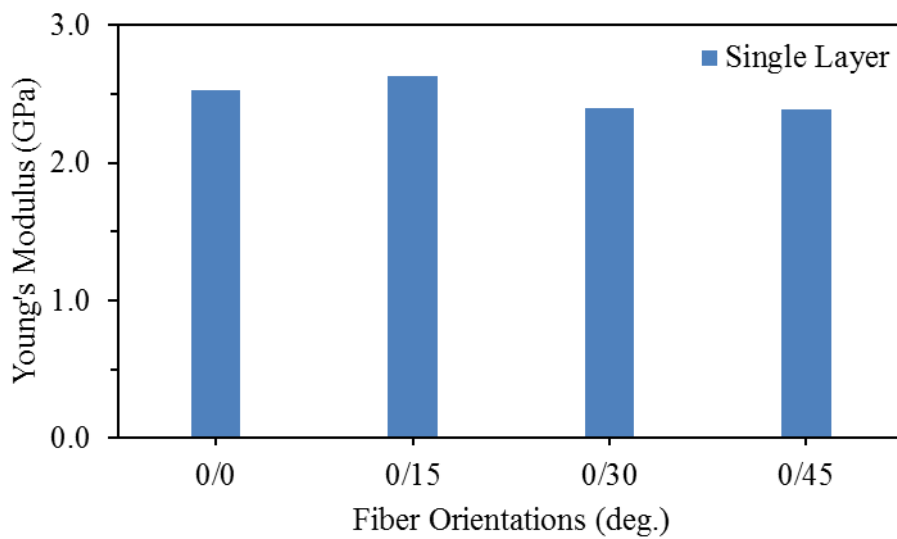


(a)

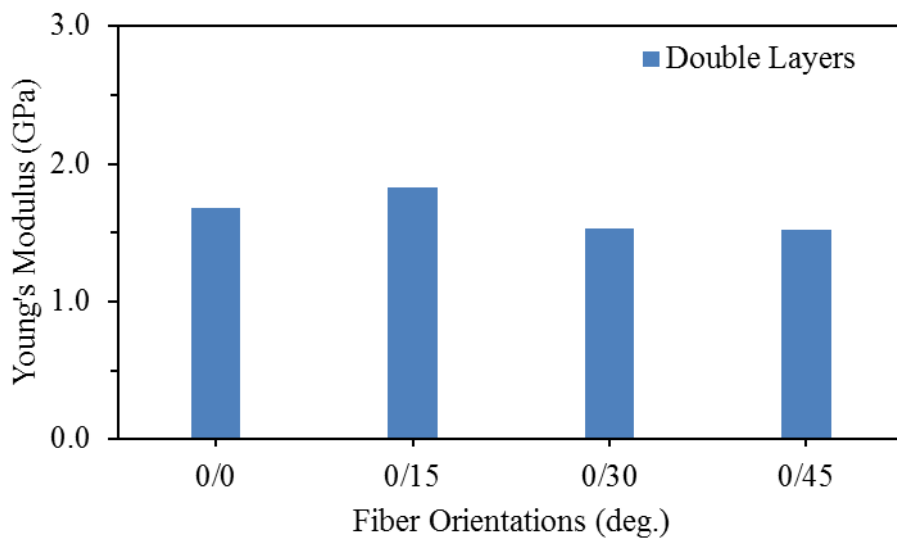


(b)

Figure 7. Effect of fiber orientations on the ultimate tensile strength, (a) single and (b) double layers.



(a)



(b)

Figure 8. Effect of fiber orientations on the ultimate tensile strength, (a) single and (b) double layers.

Table 1. Tensile behavior of woven fiber reinforced composites.

Fiber orientations.	Double layers		Single layer	
	Ultimate tensile strength (MPa)	Young's modulus (GPa)	Ultimate tensile strength (MPa)	Young's modulus (GPa)
0 ⁰	36.4	2.53	35.6	1.68
15 ⁰	28.5	2.63	28.3	1.83
30 ⁰	28.1	2.40	27.5	1.53
45 ⁰	27.1	2.39	25.5	1.52

Failure modes are greatly dependent on the fiber orientations as shown in Figure 9 and therefore affecting the mechanical performances. For fibers aligned at 0⁰, the failure

path is perpendicular with respect to loading axis. However, when the fibers are obliquely aligned, the failure paths are also changed. This characteristic therefore reduced the mechanical capability of the composites. Figure 9(a) indicates the failure mechanism of 0° oriented fibers. It is also revealed that the failure path is almost flattened where it is perpendicular to the axis of loading. If the fiber orientation is increased to 15° , the failure pattern is slightly oblique as in Figure 9(b). Similar crack pattern can also be observed for other types of fiber orientations as in Figures 9(c) and 9(d). According to Ismail et al. [18-20], when there are cracks positioned and/or loaded eccentrically, not only one failure mode occurred but two, which are mode I (an opening mode) and mode II (a sliding mode). Consequently, this condition accelerates the damaging process and therefore reduces the mechanical performances.

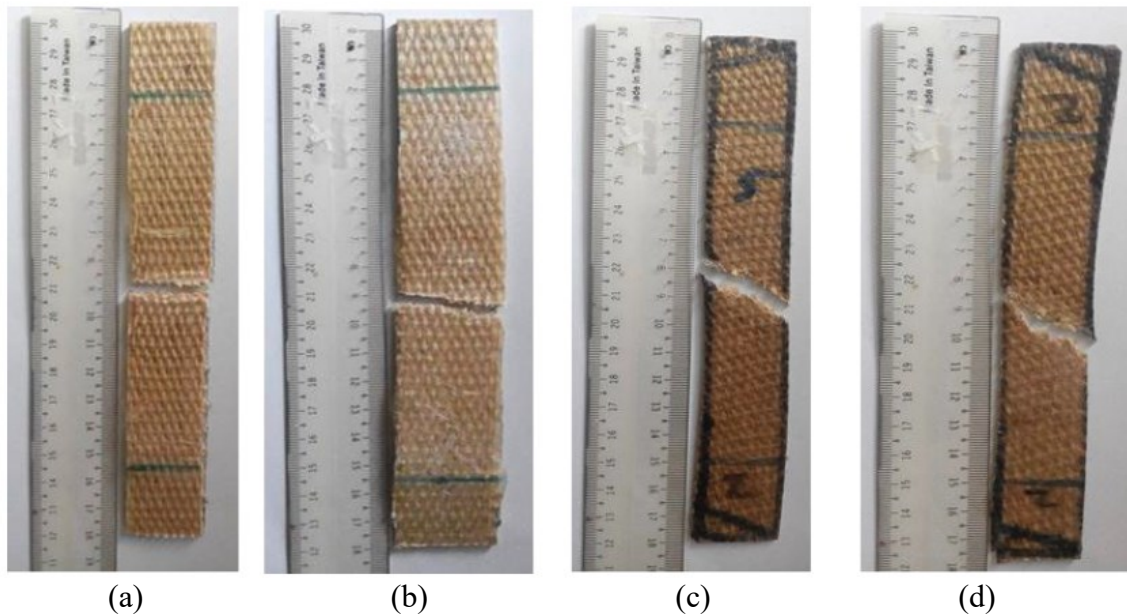


Figure 9. Failure modes of woven kenaf fiber reinforced composites of different fiber orientations, (a) 0° , (b) 15° , (c) 30° and 45° .

CONCLUSIONS

This paper attempted to study the tensile responses of the woven type fiber reinforced composites. Two important parameters are used, namely fiber orientations and number of layers. According to the present results, it is indicated that fiber orientations played an important role in determining the ultimate tensile strength. When the fiber orientations increased, the decrement of ultimate tensile strength is estimated in the range of 27.7-30.9%. The change in fiber orientations insignificantly affected the modulus of elasticity, which is less than 4%. This is due to the fact that when the crack path is inclined, the formation of new crack is accelerated. It is assisted by the induction of two types of failure modes. On the other hand, insignificant increment of tensile strength has been observed if the numbers of layers are increased.

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