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Fracture toughness of woven kenaf fibre reinforced composites

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Abstract. This paper presents the role of fibre orientations on the woven-type kenaf fibre reinforced composites. According to literature survey, lack of information regarding to the fracture toughness of woven kenaf fibre reinforced composites. Fracture toughness tests were performed using ASTM D5045. Four fibre orientations were used such as 0/15/0/-15/0, 0/30/0/-30/0, 0/45/0/-45/0 and 0/90/0/-90/0 and on the other hand virgin polyester and unidirectional fibre reinforced composites were also used for comparisons. Based on the experimental works, woven-typed composites produced lower fracture toughness compared with the unidirectional fiber composite. Fracture toughness obtained from different fibre orientations composites are almost identical however 0/30/0/-30/0 and 0/90/0/-90/0 produced higher toughness relative with others. Fracture mechanisms revealed that as expected the fibres aligned along the stress direction capable to sustain better mechanical deformation and therefore producing higher fracture toughness.

1. Introduction

Natural fiber reinforced composites are increasingly used especially in automotive industries however these composites are limited for non-load bearing applications. This is due to the fact that natural fibers have their own disadvantages such as uncertainties of mechanical performances. In order to overcome these obstacles, a single strand of kenaf fibers are combined together to form a kenaf yarn and then it is weaved to produce a woven kenaf mat. This technique is hopefully capable to produce mechanical strength with a higher degree of certainty. Fracture toughness is one of the indicator of mechanical performances can be used to characterize the composite materials. Salleh et al. [1] studied the effect of water absorption on the fracture toughness of long kenaf/woven glass hybrid composites. They found that the exposure of environmental conditions capable to decrease the fracture toughness of the composites. Radif and Ali [2] studied the fracture toughness of kenaf mat polyester composite. Both experimental and numerical investigations are conducted and found that they are well agreed. Kumar et al. [3] studied experimentally the fracture toughness under modes I and II for sisal/borassus polyester composites. They found that randomly oriented fiber composites have constant stress intensity factor under mode I loading. It is also found that the mode II analysis of hybrid composite shows high energy release rate compared to individual fiber composites. Harikrishnan et al. [4] performed experimental and numerical analyses to study mode I fracture toughness of jute/glass fiber hybrid composites. Different volume fractions of composites are shaped into compact tension specimens. It is found that the volume fractions of 0.75 glass and 0.25 jute or 0.5 glass and 0.5 jute capable to produce better fracture toughness. Another works on the woven kenaf fiber composites can be found elsewhere in [5, 6].

Based on the literature survey, lack of information available in investigating the effect of fiber orientations of woven kenaf fiber reinforced composites. In a similar topic, Radif and Ali [2] also investigated the fracture toughness of kenaf fiber reinforced composites. On the other hand, their works used randomly oriented fibers in fabricating the composites. However, this paper presents the fracture toughness of woven kenaf fiber reinforced composites where the samples are prepared according to ASTM D5054 standard for plain strain fracture toughness test. Different fiber configurations are produced and tested in order to study their effect on the fracture toughness performances. The role of fiber loading on the composite capabilities are also observed and discussed.

2. Methodology

Yarn kenaf fiber of 1mm in diameter as shown in Figure 1(a) is used in this work. The fiber is weaved according to the plain woven technique where the identical wrap and weft fibers are aligned perpendicularly to take a crisscross pattern. The weaving process is performed using an in-house facility as in Figure 1(b) and the final woven mat is revealed in Figure 1(c). Table 1 tabulates the types of materials used in this work. Weaved kenaf mats are then arranged or stacked according to the specific fiber orientations. The geometries and dimensions of samples are based on the ASME D 5045 for plain strain fracture toughness test as in Figure 1(d). The composites are produced manually using handy layout where the fiber mats are firstly submerged or covered with polyester resin before they are stacked together and compressed to squeeze out the excessive resin. After 24 hours, the materials hardened and they are shaped according to the standard shape and geometry where each sample is notched to produce a pre-crack with different length. Figure 2 shows the pre-notched materials for virgin polyester and 0/90/0/-90/0 fiber orientation composite, respectively.

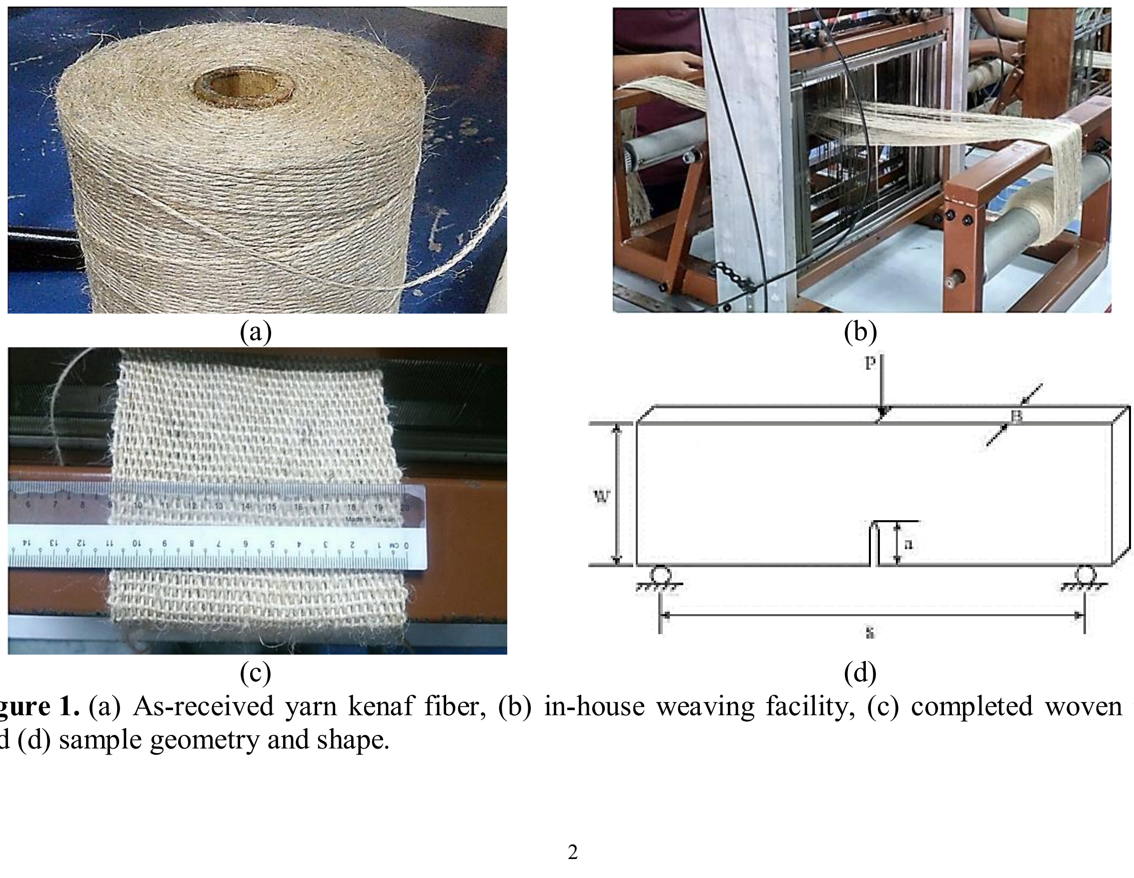


Figure 1. (a) As-received yarn kenaf fiber, (b) in-house weaving facility, (c) completed woven mat and (d) sample geometry and shape.

Table 1. Types of materials used.

No.	Type of material/fiber orientations	Height, *W* (mm)	Length, *L* (mm)	Half of span, *S* (mm)	Thickness, *B* (mm)	Pre-crack length, *a* (mm)
1	Virgin polyester	12	54	48	6	6
2	Unidirectional fibers	12	54	48	6	6
3	0/15/0/-15/0	18	81	72	9	9
4	0/30/0/-30/0	18	81	72	9	9
5	0/45/0/-45/0	18	81	72	9	9
6	0/90/0/-90/0	14	63	56	6	7

(a) (b)

Figure 2. Pre-notched samples (a) virgin polyester and (b) 0/90/0/-90/0 fiber orientations.

Fracture toughness test is conducted according to the Figure 1(a) where they are simply-supported at both ends and the force is applied quasi-statically at the center using a constant cross-head displacement 1mm/min. Plain strain fracture toughness, K_{IC} is determined according to the Eq. (1):

$$K_{IC} = 6\sqrt{x}\left(\frac{P_Q}{B\sqrt{W}}\right)\left[\frac{1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2}{(1+2x)(1-x)^{1.5}}\right] \quad (1)$$

where $x = 0 < \frac{a}{W} < 1$.

3. Results and Discussion

Figure 3 shows the responses of pre-notched samples under quasi-static three-points bending moment. In this work, virgin polyester and unidirectional fiber reinforced composite are also included as a comparison on the role of different weaving fiber orientations. It is revealed that without any reinforcement, virgin polyester failed in brittle manner. On the other hand, unidirectional fiber composite showed the most reliable configuration. This is due to the fact, the fibers are arranged perpendicularly with the applied force therefore it is capable to sustain higher stress. However, if the force is applied oppositely the result may different. In order to overcome this problem, woven fibers are introduced. It is indicated that the force-displacement responses of the configurations of 0/15/0/-15/0, 0/45/0/-45/0 and 0/90/0/-90/0 are almost identical. However, the 0/30/0/-30/0 fiber orientations revealed that their responses are almost similar with unidirectional fiber composite especially in the region of elastic deformation. Once the deformation reached 2mm, the composites showed the first sign fiber breakages. In comparison with unidirectional fiber reinforced composites, the sign of fiber breakages are not obviously observed.

Figure 4 shows the effect of fiber orientations on the maximum forces. The virgin polyester produced the lowest force while the unidirectional fiber composite sustained the highest maximum force. However when the woven configurations are introduced, the forces are slightly reduced comparing with unidirectional composite. It is also revealed that different fiber configurations resulted almost similar maximum forces except for the case of 0/30/0/-30/0. Figure 5 indicates the role of fiber orientations on the time responses. The responses can generally be divided onto three categories according to the fiber configurations. For a virgin polyester, the failure process is relatively faster compared with the reinforced polyester indicating the present of defect capable to degrade the material strength. For woven type composites, the time responses in the linear elastic region are almost similar except for the case of first maximum force dropped. This is indicated that the fiber configurations capable to strengthen the composites and therefore holding higher forces. Lastly the composite reinforced with unidirectional fibers, it is capable to hold the longest failure time compared with other composites. This is due to the fact that the fiber strain to failure is higher than the virgin polyester.

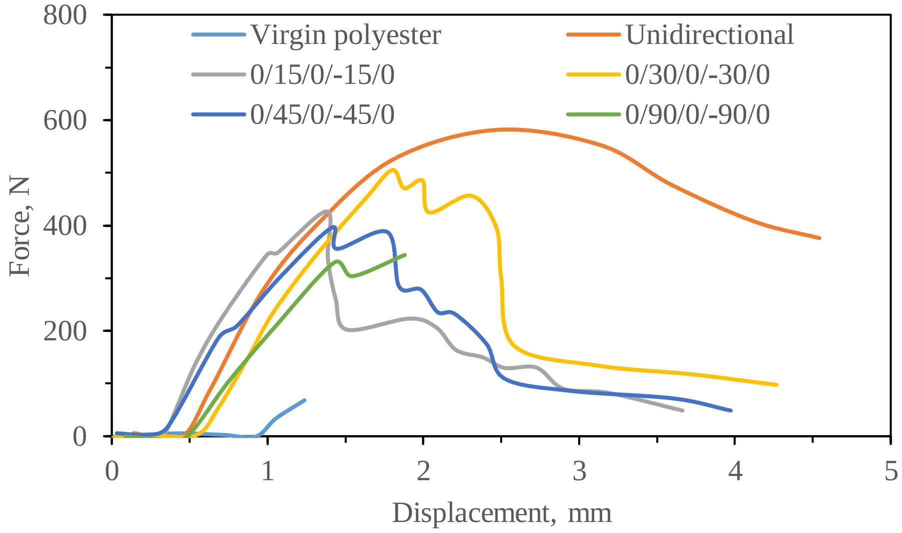


Figure 3. Force-displacement curves of different fiber configurations.

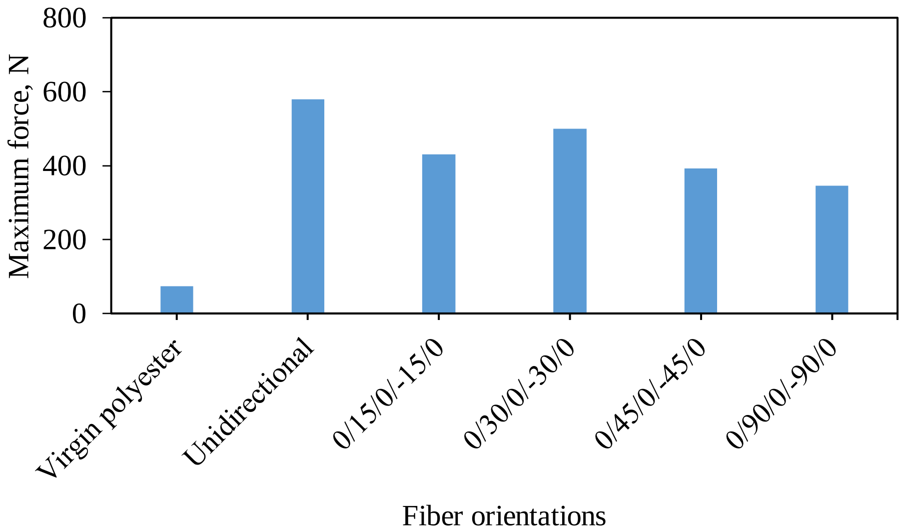


Figure 4. Effect of fiber configurations on the maximum forces.

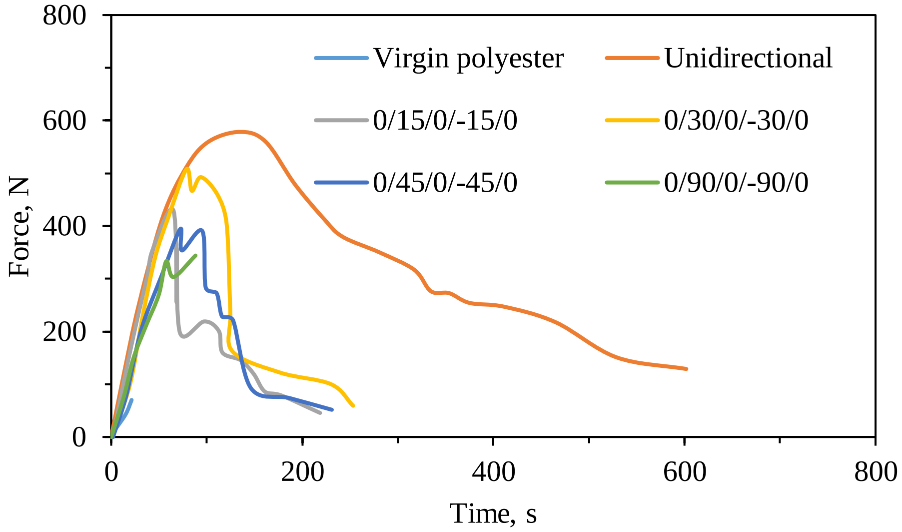


Figure 5. Force-time curves for different fiber configurations.

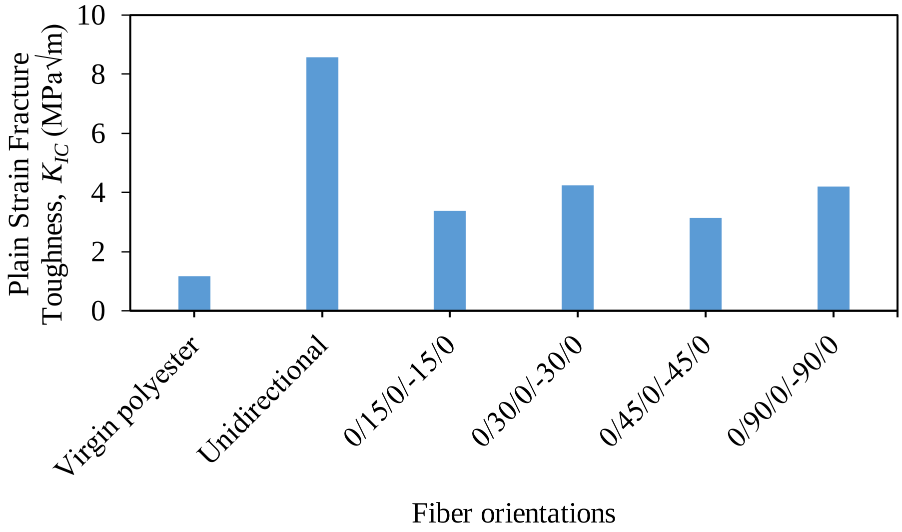
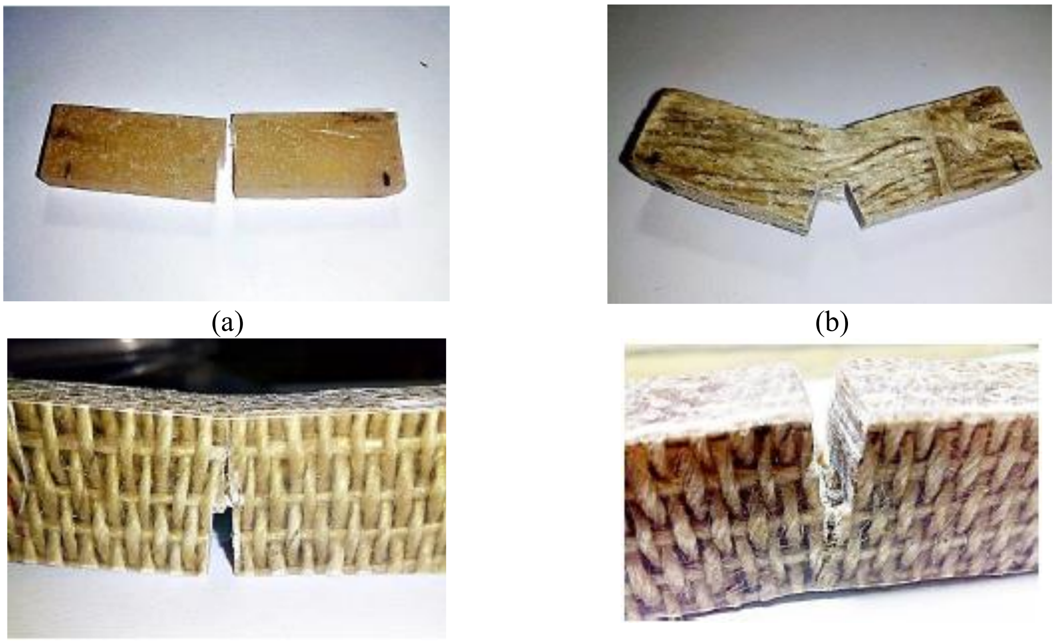


Figure 6. Effect of fiber configurations on the plain strain fracture toughness.

Figure 6 reveals the effect of fiber orientations on the plain strain fracture toughness. It is showed that the unidirectional composite produced the highest K_{IC} compared with other type of material conditions. Woven fiber reinforced composites produced almost identical values of fracture toughness with small fluctuations. On the other hand, the orientations of 0/30/0/-30/0 and 0/90/0/-90/0 produced slightly higher fracture toughness compared with others. This is indicated that the woven type composites capable to produce almost similar value of fracture toughness even different fiber orientations are used. Fracture toughness is strongly related with the maximum forces where higher the maximum force produced higher toughness. Instead of showing the highest toughness, the unidirectional composite also produced the lowest toughness if the induced stress is perpendicular to the direction of fibers due to the weak interfacial bonding between fiber and the polyester.

Figure 7 shows the fracture mechanisms of different types of composites. Figure 7(a) indicates the failure of virgin polyester sample. The failure path is almost straight indicating that the crack propagation has no strong resistance and therefore producing the lowest fracture toughness. Figure

7(b) reveals the failure condition of unidirectional fiber reinforced composite. In this composite, all unidirectional fibers strengthened the composite where this type of composite capable to withstand higher force. Figures 7(c) and 7(d) indicate the failure mechanisms of woven fiber reinforced composites. It is clearly shown that the crack path is also almost straight. However, the presence of fibers resisted the deformation and therefore higher forces compared with the virgin polyester sample.



(a) (b) (c) (d)

Figure 7. Fracture mechanisms of (a) virgin polyester, (b) unidirectional fiber, (c) 0/45/0/-45/0 and (d) 0/30/0/-30/0.

4. Conclusion

This work presents an experimental work to investigate the role of fiber configurations on the plain strain fracture toughness. Pre-notched materials are subjected to three-points bending moment as specified by ASTM D5054. Based on the experimental works, several conclusions care drawn:

1. The responses of force-displacement curves of unidirectional fiber reinforced composites are better than the woven-type fiber composite since the fibers are mostly aligned in the direction of stresses.
2. Woven-typed composites showed that the force-displacement curves are almost identical however the composites containing 30^o fiber orientation produced relatively higher response compared with others.
3. The effect of fiber configurations on the plain strain fracture toughness has no strong relationship where the fracture toughness is almost similar however the composite containing 30^o fiber orientation showing an obvious peak of fracture toughness.
4. Both maximum force and fracture toughness for unidirectional fiber reinforced composite is higher than the woven-typed composites.

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