Fatigue strength of woven kenaf fiber reinforced composites

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Abstract. Nowadays, green composites provide alternative to synthetic fibers for non-bearing and load-bearing applications. According to literature review, lack of information is available on the fatigue performances especially when the woven fiber is used instead of randomly oriented fibers. In order to overcome this problem, this paper investigates the fatigue strength of different fiber orientations and number of layers of woven kenaf fiber reinforced composites. Four types of fiber orientations are used namely 0^0, 15^0, 30^0 and 45^0. Additionally, two numbers of layers are also considered. It is revealed that the fatigue life has no strong relationship with the fiber orientations. For identical fiber orientations, the fatigue life can be predicted considerably using the normalized stress. However as expected, the fatigue life enhancement occur when the number of layer is increased.

1. Introduction

It is an obvious fact that composite failure has distinct failure mechanisms compared with metals generally dominated by plastic deformation [1]. While, the toughening mechanisms during failure progressive of composite materials revealed several basic processes such as matric cracking, delamination, fiber breakage and interfacial debonding [2-7]. Fatigue strength of synthetic fiber can be found easily [8]. For example Wicaksono and Chai [9] reviewed fatigue behavior of different volume fractions of woven and non-woven glass fibers. It is found that the woven fiber resulted lower fatigue life compared with random oriented fiber reinforced composites.

Due to higher environmental awareness and sustainability aspects among researchers and industrialists, they recently utilized natural fiber to reinforce the polymeric composites. Shahzad et al. [10] studied the fatigue performances of hemp fiber reinforced composites where the fibers are randomly oriented. They also treated the fibers chemically. They found that the fiber treated chemically produced better fatigue capabilities. On the other hand, Vasconcellos et al. [11] weaved the hemp fiber to reinforce epoxy composites consisted of seven layers of hemp mats. The results exhibited that higher fatigue life can be obtained if the fiber is configured using $\pm45^0$ instead of $0/90^0$.

Liang et al. [12] investigated the flax/epoxy composites under fatigue loading. They lay-up the fibers as follows 0^0, 90^0, $0^0/90^0$ and $\pm45^0$. Their work also lead to conclude that $\pm45^0$ composites produced higher fatigue performances. Kalam et al. [13] used empty fruit bunch reinforced composites with different fiber volume fractions. In their work, the fibers are aligned uni-axially. The results obtained showing that increasing fiber fractions have significantly reduced the fatigue life. Abdullah et al. [14] investigated the fatigue performance of uni-directional kenaf fiber. However, their results inconsistence with Kalam et al. [13] where they found that fatigue life increased when fiber volume fractions are increased.

From literature review, there is a noticeable lack of information in the investigations of woven kenaf yarn fiber reinforced composites when subjected to fatigue loadings. Therefore, this work presents on the effect of fiber orientations of woven kenaf fibers. Additionally, the effects of two numbers of layers are also considered. The fatigue life is thus correlated with the fiber orientations and the number of layers before the empirical mathematical model to predict the fatigue life is formulated.

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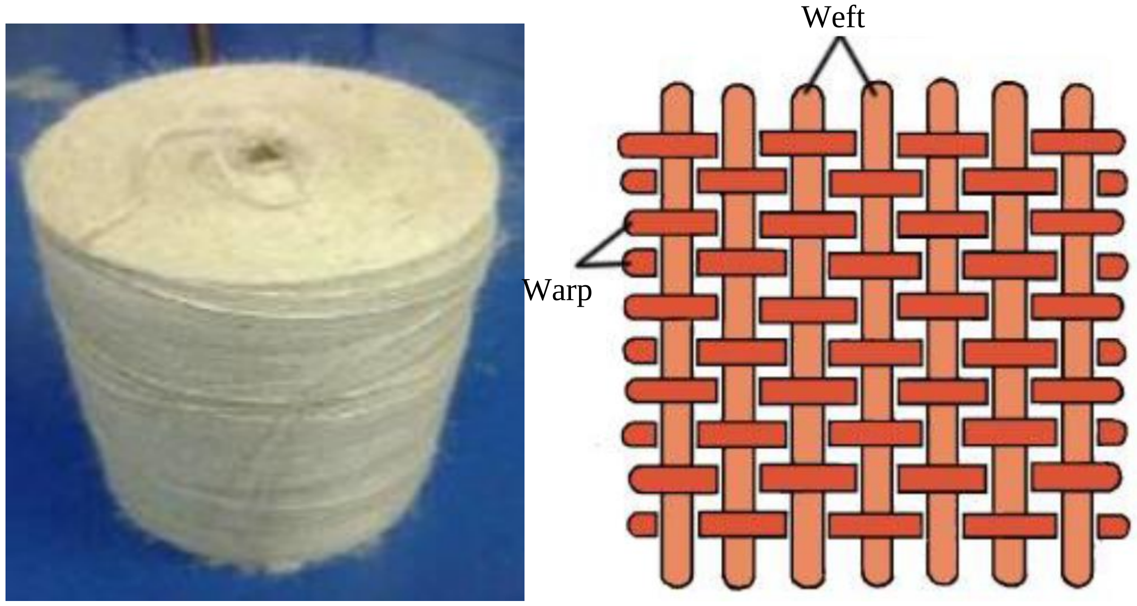
2. Experimental set up

2.1. Fiber and composite preparations

The as-received kenaf fiber (1 mm in diameter) is in the form of yarn as in Figure 1(a). This kenaf yarn is then weaved to form twill woven-type mats as in Figure 1(b). It is consisted of two sets of yarns warp and weft which is interlaced at 90^0 relative to each other to produce a balanced twill weave where the number of warp and weft is 4 x 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).



(a) (b)

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

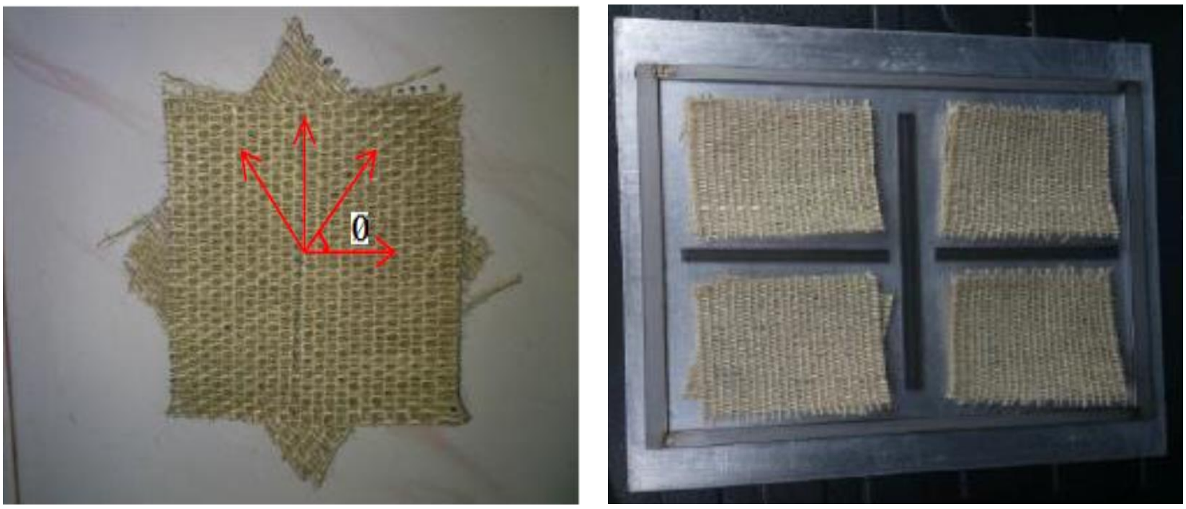
Two important parameters are considered namely fiber orientations and number of layers. Four fiber orientations are used 0^0, 15^0, 13^0 and 45^0. While single and double mat layers are produced. For double layers, the angle configurations as follows: $0^0/0^0$, $15^0/0^0$, $30^0/0^0$ and $45^0/0^0$ 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 in Figure 4.

2.2. Experimental Procedure

The hardened plates are shaped according to the standard geometry suggested by ASTM D3039. Fatigue test (Figure 5) is performed in an ambient temperature and Table 1 lists the testing parameters used in this study. Displacement-controlled fatigue test is used to examine the fatigue performances of the composites. In order to analyze the cause of failure for the composites, a scanning electron microscope (SEM) 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.

(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.

Table 1. Fatigue testing parameters

Parameter	Condition				
Loading	Tension-tension fatigue loading				
Stress ratio	0.5				
Stress level	$0.9\sigma_{ult}$	$0.8\sigma_{ult}$	$0.7\sigma_{ult}$	$0.6\sigma_{ult}$	$0.5\sigma_{ult}$
Frequency	5Hz				
Temperature	25^0C				

*σ_{ult} is an ultimate tensile strength.

3. Results and discussion

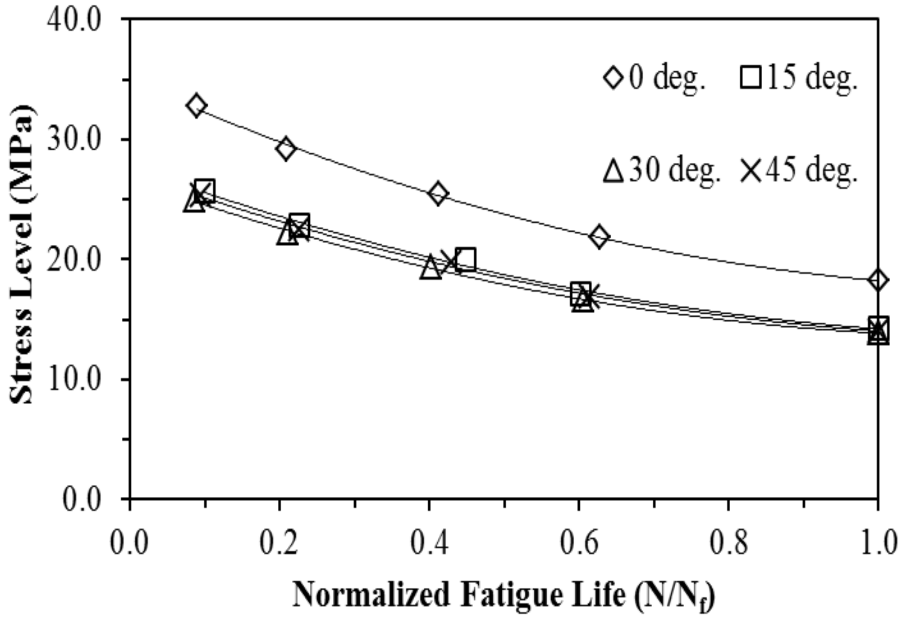
Figure 6 reveals the curves of stress against normalized fatigue life for single and double layers of woven kenaf fiber reinforced composites, respectively. Four fiber orientations and their combinations are considered. As expected, the fiber which is aligned parallel with the principal loading axis produced higher fatigue life compared with other type of composites. For single layer composites, the distributions of fatigue life are not significant where it is seemed that the life accumulated into a single fatigue life curve.

Figure 6(a) shows the fatigue life behavior of single layered woven kenaf reinforced composites. It is indicated that 0^0 oriented fibers produced higher fatigue life compared with other types of composites. For all type of composites except 0^0 fiber orientation, the fatigue curves seemed not to affect significantly where the curves are almost similar to each other. However, 30^0 fiber oriented composites show a slight reduction on the fatigue life. While Figure 6(b) on the other hand showing the behavior of fatigue life of the double layered fiber reinforced composites. In general, the curves are relatively straight and the distributions of the results are quite high especially for 0^0 fiber orientations. For other type of composites, the fatigue curves are almost identical with those in Figure 6(a). However, 300 fiber oriented composites have shifted downward obviously showing that the composite unable to resist the fatigue damage longer.

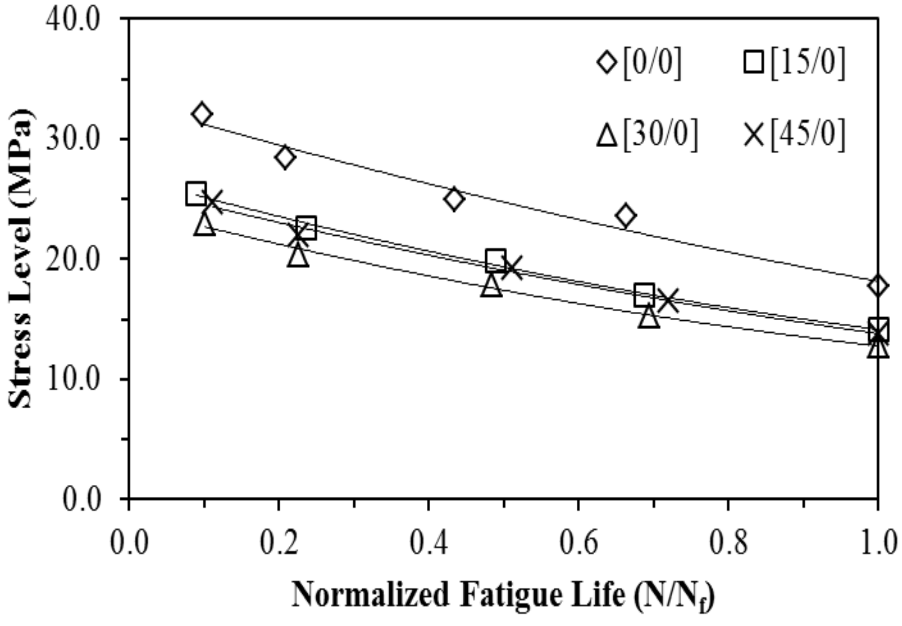
Figure 7 shows the curves of fatigue life distributions against the normalized stress for single and double layered composites. As expected, the fatigue life degraded as the normalized stresses increased for all composite conditions. The behavior of fatigue life against normalized stress shown in Figures 7(a) and 7(b) are almost identical. However, for the double layered composites, the curves reveal a slightly drop showing the composite degradations are relatively higher than that single layered composites due to the brittle effect.

Figure 8 shows the fracture mechanisms of two fiber orientations 0^0 and 15^0 for double fiber layers. For the composites which have the fibers aligned parallel with the loading axis, the most failure mechanisms found are pull-out fiber. It is responsible to produce better fatigue life. While, for the fibers which are aligned obliquely, lack of push-out mechanisms are observed instead of the fiber yarns have been peeled-off resulted lower fatigue life.

Tables 2 and 3 tabulated the mathematical model used to predict the fatigue life of single and double layered composites, respectively. These equations are formulated when the axis of fatigue life is transformed into logarithmic values against normalized stresses. Then, the regression technique is used to determine the mathematical representations with high degree of accuracies ($R^2 > 0.99$). These models can be used to predict the fatigue life of the composites as long as within the specified range of normalized stresses.

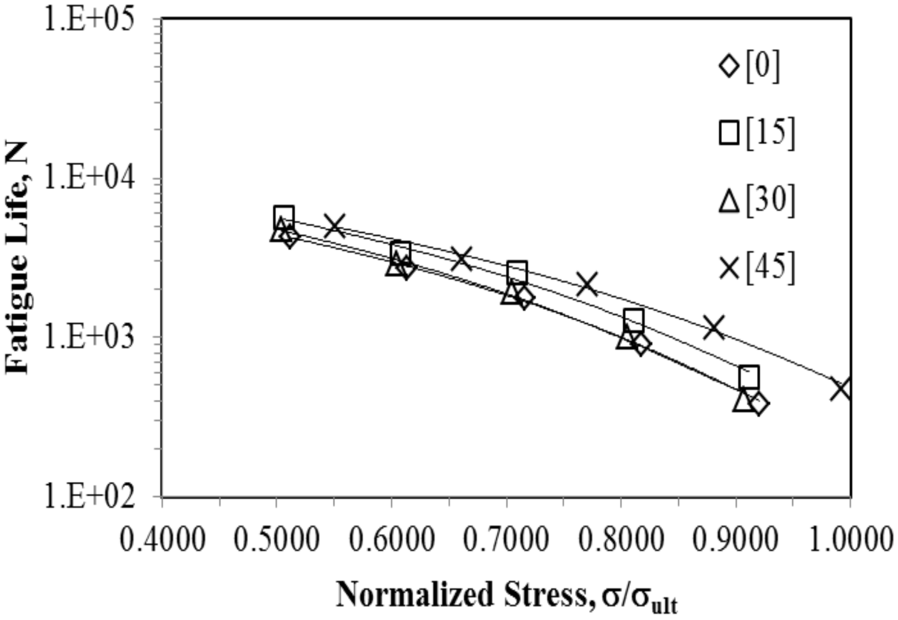


(a)

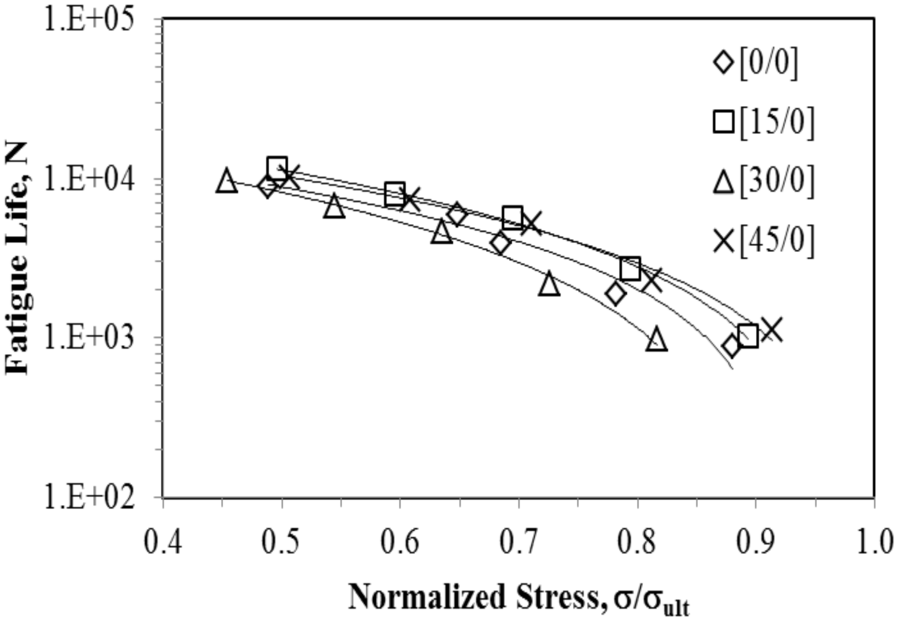


(b)

Figure 6. Fatigue life of woven kenaf fiber reinforced composites, (a) single and (b) double layers.



(a)



(b)

Figure 7. Fatigue life plotted against normalized stress level for various composites, (a) single and (b) double layers of composites.

Table 2. Mathematical model to predict fatigue life for single layered composites.

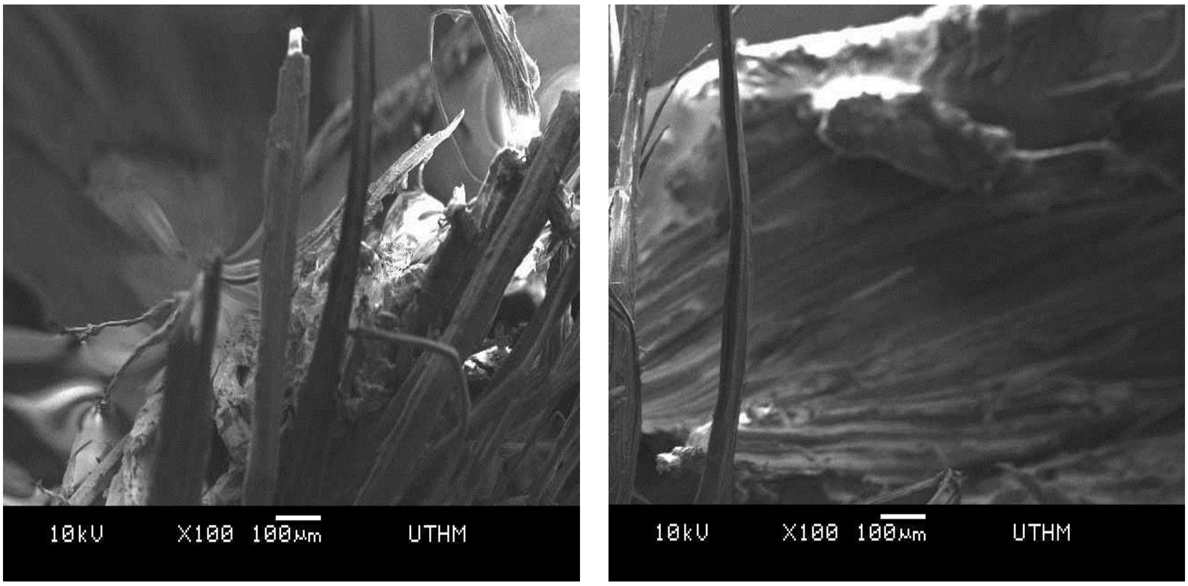
Types of Composites	Fatigue Life, N	R Square
$[0^0]$	$N = 15127\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 31021\left(\frac{\sigma}{\sigma_{ult}}\right) + 16139$	$R^2 = 0.9977$
$[15^0]$	$N = 18552\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 38379\left(\frac{\sigma}{\sigma_{ult}}\right) + 20177$	$R^2 = 0.9890$
$[30^0]$	$N = 18375\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 36421\left(\frac{\sigma}{\sigma_{ult}}\right) + 18368$	$R^2 = 0.9955$
$[45^0]$	$N = 14370\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 32176\left(\frac{\sigma}{\sigma_{ult}}\right) + 18293$	$R^2 = 0.9940$

*σ is an applied stress level and σ_{ult} is an ultimate tensile strength.

Table 3. Mathematical model to predict fatigue life for double layered composites.

Types of Composites	Fatigue Life, N	R Square
$[0^0/0^0]$	$N = 14344\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 41303\left(\frac{\sigma}{\sigma_{ult}}\right) + 25881$	$R^2 = 0.9729$
$[15^0/0^0]$	$N = 22993\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 58231\left(\frac{\sigma}{\sigma_{ult}}\right) + 34661$	$R^2 = 0.9969$
$[30^0/0^0]$	$N = 26368\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 57663\left(\frac{\sigma}{\sigma_{ult}}\right) + 30409$	$R^2 = 0.9967$
$[45^0/0^0]$	$N = 17626\left(\frac{\sigma}{\sigma_{ult}}\right)^2 - 47620\left(\frac{\sigma}{\sigma_{ult}}\right) + 29758$	$R^2 = 0.9939$

*σ is an applied stress level and σ_{ult} is an ultimate tensile strength.



(a) (b)

Figure 8. Fracture mechanisms of woven kenaf fiber reinforced composites of different fiber orientations (a) 0^0 and (b) 15^0.

5. Conclusion

In this paper, an attempt is to investigate the fatigue performances of woven kenaf yarn fiber reinforced composites. Two important parameters are considered such as fiber orientations and number of layers. After fatigue tests completed, an empirical formulation for each composite condition is developed using a simple regression technique. It can be concluded that higher fatigue life is produced when the fiber is aligned parallel with the principal loading axis. This behavior contradictorily agreed with the previous works where better fatigue life can be obtained when the fiber configuration $\pm 45^0$. The reliable empirical models are also produced and can be used as long as the normalized stress level within the range of 0.5 to 0.9.

6. Acknowledgements

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