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Article

Fatigue Behavior of Kenaf Fibre Reinforced Epoxy Composites

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Abstract. Towards green material, fatigue life of epoxy and its unidirectional kenaf fibre reinforced epoxy composites were investigated. These specimens were hand lay-up made. The specimens were cycled to tension-tension fatigue loading at stress ratio of 0.5 and 5 Hz of frequency to determine the fatigue life and its life characteristic at given 5 stress levels. Fibre content ratios were found to affect fatigue life strongly on the low cycle fatigue regime as illustrated with stress level versus cycles to failure. It is found that kenaf fibre reinforced epoxy composites with higher fibre content posses higher load carrying capacity and degradation rates. The existing models developed by Mandell, Manson-Coffin and Hai-Tang were adopted to predict the fatigue life. Some of the models show minor similarities with the experimental data, but not universally applicable to predict the fatigue life when it comes with various amount of fibre volume.

Keywords: Polymer matrix composites, kenaf fiber, general fatigue.

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1. Introduction

Nowadays, the uses natural fibres have become attention by many researchers throughout the world as reinforcement in polymer matrix composites. This abandoned fibre, low cost and essential from renewable resources provides sustainability and advantages for the environmental preservation and economical issues. Good interfacial adhesion between the matrix and natural fibre is one of the main requirements in composites [1]. The ability of hydroxyl groups to create great hydrogen bond between the polymer and natural fibre essential in directing chains to group together [2-3].

Many investigations in the past deal with the performance of the natural fibre reinforced in thermoplastic and thermosetting composites. This includes the uses of treated and untreated fibre [4], the effect of natural fibre strength in composites [5], manufacturing process [6] and growth condition of plant [7]. The positive outcome of the results indicates natural fibres are good candidates to substitute glass fibre reinforced in polymer composites [8].

Although it is quite promising, current generation of natural fibre reinforced composites may not warrant their use in load demand application. Natural fibres and its composites may suffer from fatigue loads as many others composites too. In addition, the uses wide range of application obliged researchers to realize the important of fatigue phenomena even for structures where fatigue was not considered an issue. Because of few in literature, this paper is intended to be preliminary and exploitation with the fatigue life of epoxy and its kenaf reinforced composites made from two different fibre volume ratios. There are numerous of fatigue models that have been developed by researchers in order to predict the fatigue life of metallic and composites. Nevertheless, none of these fatigue models deals with the fatigue life of natural fibre reinforced composites. Fatigue models developed by Mandel [9], Manson-Coffin [10] and Hai Tang [11] are used because of their simplicity and can be related to the polymer composites. The constant stress base models shown below are compared with the experimental results to determine how well these models in predicting the fatigue life of kenaf polymeric composites. Mandel proposed equation as follows:

$$\sigma = \sigma_{UTS} + b.\log(N_f) \tag{1}$$

where σ is the cyclic tensile stress, σ_{UTS} is the ultimate tensile stress, N_f is cycle to failure and b is material constant. While Manson-Coffin relation as follows:

$$\ln\left(\frac{\Delta\sigma}{2}\right) = \ln(\sigma_{UTS}) + b.\ln(N_f) \tag{2}$$

where $\Delta\sigma$ = cyclic stress range (maximum stress - minimum stress). Recent Hai-Tang's model developed in 1998 is given as follows

$$S_{\max}^{11.40}(N_f) = \frac{13.11}{1+\frac{8}{f}} \tag{3}$$

where $S_{\max}$ = normalized stress respective to static ultimate tensile strength ($|S_{max}| \leqslant 1$), and f is frequency.

2. Experimental Procedure

2.1. Materials

The kenaf fibres were harvested from Shenzen, China. The fibres were alkaline treated with Sodium Hydroxide (NaOH) solution prior to composite fabrication. Fibres were soaked in 6% Sodium Hydroxide (NaOH) solution in water at room temperature for 6 hours. The fibres were rinsed and left to dry at room temperature overnight before being put in oven for 2 hour at 50°C temperature setting. The treated kenaf fibre is shown in Fig. 1. The Diglycidyl Ether of Bisphenol-A (DGEBA) epoxy resins and amine-based hardener for curing agent were supplied by Miracon (M) Sdn Bhd (Malaysia). The volume ratio of mixing epoxy and hardener is 1:0.2 respectively that is equal to 100 ml epoxy resin with 20 ml hardener for application use.

Fig. 1. The treated kenaf fibres.

The fibre volume fractions, Vf were 0% (Pure epoxy), 15% and 45%, determined by combustion of the matrix. The flat laminate was constructed from the stretched unidirectional kenaf fibre. The fibres were impregnated with matrix material inside a steel mould cavity. Then, the steel mould cover was placed above the mould and the pressure was applied vertically from the top of the mould cover. The composite was cured under the pressure of mould cover overnight before it can be taken out from the mould. Coupon having dimension of 23 cm long x 1.6 cm wide x 0.5 cm thickness with a 15 cm gauge length thick were cut from a 23 cm long x 17 cm wide plate. The edges of specimens were sanded to ensure uniformity and aluminum tabs were bonded with a filled epoxy material to minimize any chances of slippage during the loading. The specimen dimensions are shown below.

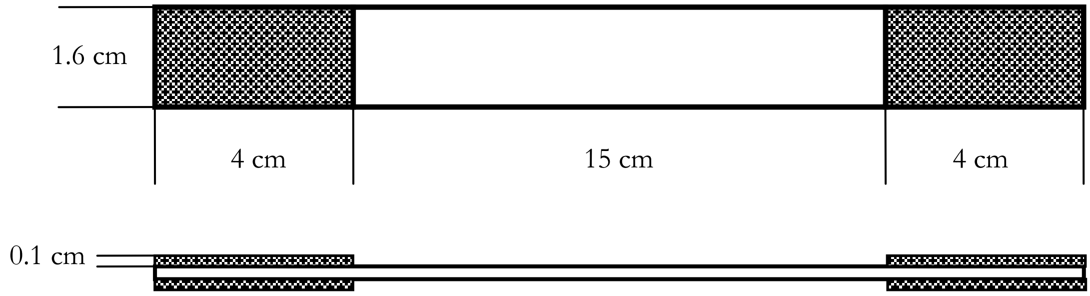

Fig. 2. Coupon dimensions with a thickness of 0.5 cm for tensile and fatigue loading.

2.2. Tensile Test

Tensile properties were obtained for each batch of preconditioned specimens prior the fatigue loading. A 20.0 x 10^4 N load MTS Bionix 858 servo-hydraulic system was used to measure the tensile strength as shown in Fig. 3. The specimens were loaded at a constant cross head rate of 2 mm per minute up to fracture at ambient temperature of 25±2 ºC in accordance to ASTM D3039. The tensile test measured the σ_{UTS} and Young's modulus.

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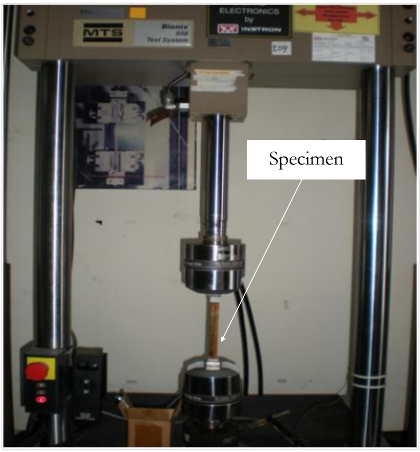

Fig. 3. A specimen loaded onto MTS Bionix 858 test system.

2.3. Fatigue Test

Fatigue experiments were in accordance to ASTM D3479 and conducted under the following conditions:

1) Loading mode: tension-tension fatigue
2) Stress Ratio, *R* (minimum stress to maximum stress ratio) = 0.5
3) Stress level (S_{max}): 90 %, 80 %, 70 %, 60% and 50% of ultimate tensile strength
4) Test frequency: 5 Hz
5) Test temperature: 22^{o}C

All fatigue specimens were tested using the same machine from previous tensile test. The machine cycles the specimens to failure and the number of cycles-to-failure was recorded by computer data acquisition system.

2.4. Surface Morphology

A surface morphology study was conducted using a Phillips XL 30 ESEM scanning electron microscope (SEM). The fractured surfaces of specimens were coated for 24 hours; to eliminate the moisture effect prior to the surface morphology study in the SEM. A setting of 10.0 kV and 0.8 Torr was used to examine the fracture composites.

3. Result and Discussion

The following Table 1 presents the mechanical properties. This table showed a 58% and 175% increases of ultimate tensile strength at 15% V_f and 45% V_f specimens, respectively, as compared to the epoxy specimen. The corresponding increases in tensile modulus are 34% and 166% respectively.

Table 1. Mechanical properties of pure epoxy and its kenaf reinforced composite.

Mechanical Properties	**Pure**	**15%**	**45%**
Ultimate tensile strength (MPa)	36.56	57.95	100.56
Young's modulus (GPa)	2.92	3.96	7.78

The fatigue tests were conducted using various stress level. Table 2 show the fatigue life obtained in terms of number of cycles to failure. It shows that the fatigue life is increasing when the lower stress level is applied.

Table 2. Fatigue Life Data of Epoxy and Its Composites.

Epoxy		15% V_f		45% V_f	
Stress (MPa)	N_f (Cycle)	Stress (MPa)	N_f (Cycle)	Stress (MPa)	N_f (Cycle)
32.9	6	52.2	55	90.5	300
29.3	18	46.4	44	80.4	4247
25.6	120	40.6	1209	70.4	63110
22.0	200	34.8	75950	60.3	113521
18.3	686	29.0	550010	50.3	758963

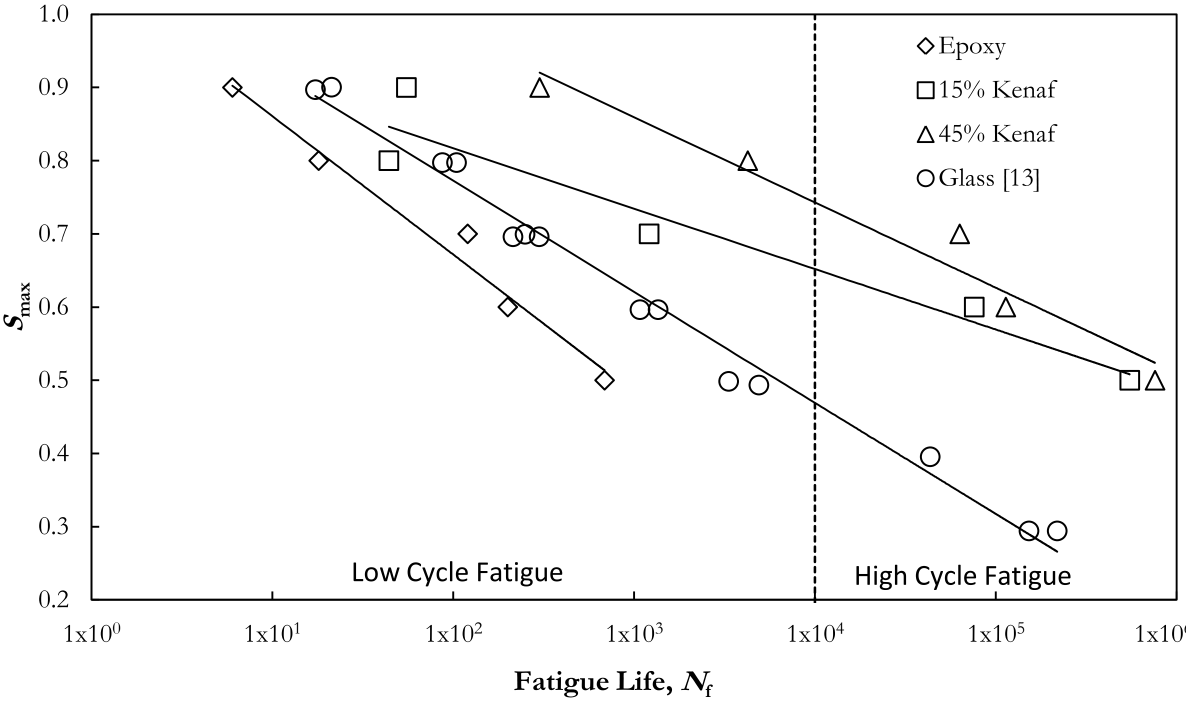

Fig. 4. The S_{max}-N_f curves of all tested specimens and a reference data of unidirectional glass/epoxy composites obtained from Harik and co-worker [13].

From the results in Table 2, a stress level versus fatigue life graph (Smax -Nf) is plotted to view the significant difference of fatigue life at different fibre volume ratios as in Fig. 3. Let the Smax to be 0.9, the fatigue life seems to be sensitive on fibre volume ratios where the fatigue life increases along with fibre volume ratios and this trend continues until the final Smax. This result is contrary to the previous research done by Kalam and co-worker [14]. The increasing of oil palm fruit bunch fibre ratio in their composites have significantly reduces the fatigue life and the tensile strength. The present investigation indicates that the fibre-matrix interfacial is unaffected when the fibre volume ratio increases. The good fibre-matrix interfacial is seen in Fig. 5. There is no gap existed between the fibre's surface and epoxy matrix. Moreover, a fibre still intact with the epoxy matrix although there is a matrix cracking formation, the cracked epoxy matrix unintentionally a little upraised above by chances. According to Gu and co-worker [12], the increasing of fibre volume ratio in composite creates more area within the fibre-matrix interfacial and therefore, the stress concentration can be distributed efficiently among the fibres from matrix. For every cycle in fatigue loading, higher fibre volumes ratio in composites could sustain more damages and lead to longer fatigue life in composites.

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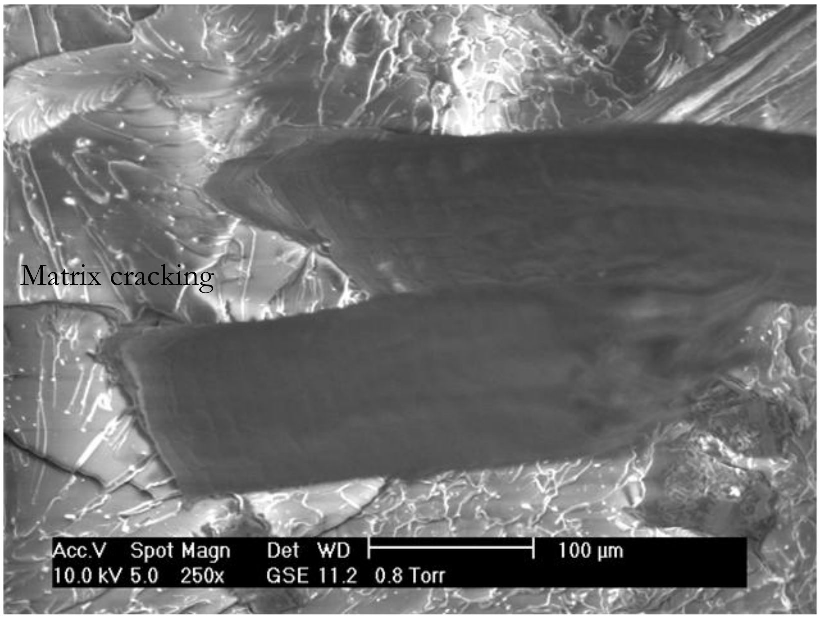


Fig. 5. SEM micrograph (250x) of the kenaf reinforced composites shows the fibre-matrix interfacial.

The fatigue life of the specimens in Fig. 4 can be described into two regions namely low cycle fatigue (LCF) regime and high cycle fatigue regime (HCF), taking 1x104 cycles and Smax to be 0.5 as proposed by Harik and co-worker [13]. The LCF criteria are applicable when an application needs high longitudinal stiffness (e.g sporting rods and consumer product) and considered to estimate the reliability for safety, insurance risk and life cycle costs. The HCF on the other hand is involved in many structural designs (e.g poles for power line). While most of data including the epoxy specimens fall within in this LCF region, the remaining of data shifted into HCF region; from Smax 0.7 and Smax 0.8 for 15% Vf and 45% Vf specimens respectively. This finding is similar to a reference data of unidirectional glass/epoxy composites from Harik and co-worker [13] in which contained that two regions. This characteristic indicates natural fibres could be beneficial in application that requires good fatigue life, while remain cheap but perform similar to that synthetic fibre.

The slope of the S–N fatigue curve characterizes the degradation rate of the expected fatigue life [9]. It can be seen the degradation rate of epoxy specimens is highest and followed by its kenaf reinforced composites. Perhaps, the addition of fibre volume ratios up to 45% may not necessary where the degradation rates are higher as compared to the 15% specimens. The similar results also obtained by Kalam [14]. The effects can be seen clearly in the curves between the LCF and HCF regions. The 45% specimens experienced highest load carrying capacity and fatigue life in the LCF region. Nevertheless, the fatigue life of this specimen may not give any significant in the HCF region; the 15% specimens could offer similar fatigue resistance in the HCF region or beyond. The higher degradation rates received by the 45% kenaf composites may be resulted from poor dispersion level of fibre in epoxy matrix compared to the 15% kenaf composites as shown in Fig. 6. The fracture surfaces particularly on kenaf fibre is getting brushier appearance, dislodging and rough surfaces once the amount of fibre volume ratio increases. A more in-depth in SEM analysis shown in Figs. 7(a) and 7(b) confirmed that poor dispersion level of fibre in epoxy matrix received by the 45% kenaf composites. Too much fibre volume ratios has resulted less matrix encapsulation in the composite in some certain areas. Moreover, the present of voids in 45% kenaf composites due to hand lay-up made also could contributes higher degradation rates in composites. It is therefore, higher amount of fibre ratios could be beneficial for application that requires higher load carrying capacity and ultimately, improves fatigue life in the LCF regime. The fatigue life in HCF region is conversely not affected by the amount of fibre volume ratios.

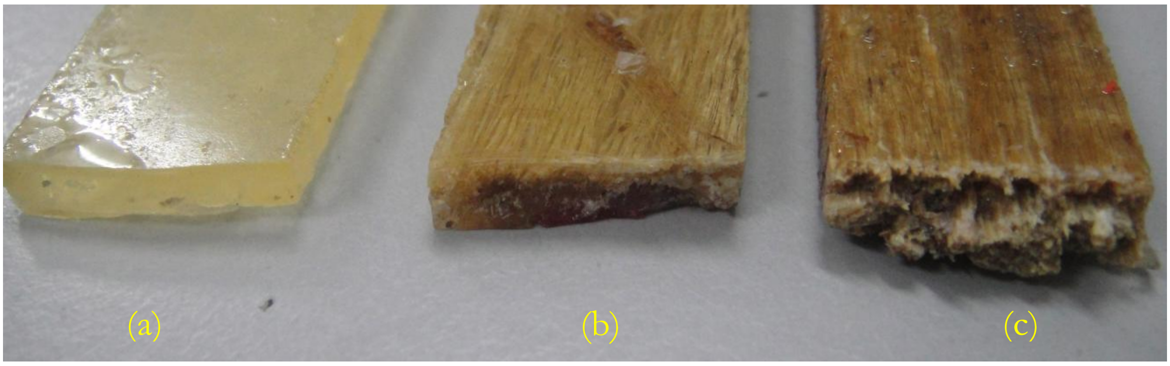
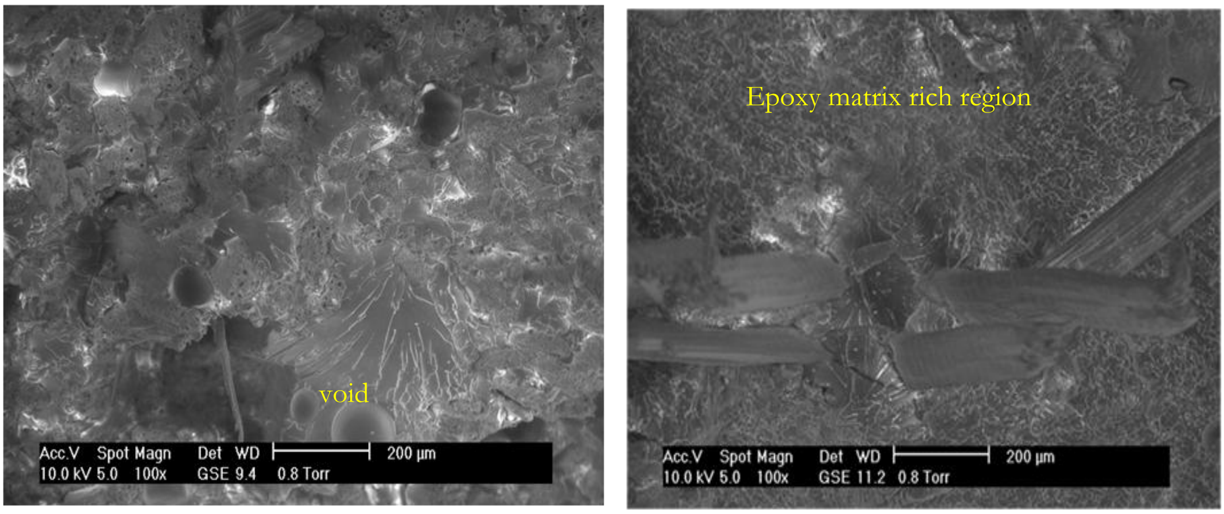


Fig. 6. Fracture specimens after fatigue failure. (a) Epoxy specimens (b) 15% kenaf reinforced composites and (c) 45% kenaf reinforced composites.



(a) (b)

Fig. 7. SEM micrograph (100x)of the kenaf reinforced composites that shows fibre-matrix dispersion level (a) 45% kenaf reinforced composites and (b) 15% kenaf reinforced composites.

Figure 5 shows comparison between experimental data and selected fatigue model. In Fig. 5(a), Mandel's model was the closes to mimicking the fatigue life of the epoxy specimens followed by Manson-Coffin's model. The models were well plotted within LCF regime except some data in Hai Tang's model. Hai Tang's model was meant to be composite, not for isotropic material such as pure epoxy specimens and therefore, the right shifted curve was expected. Figure 5(b) showed an interesting finding when all the models were closes to mimicking the fatigue life of 15% specimens within LCF regime as compared in pure specimens. Nevertheless, once again, Mandel's model was the closes to mimicking fatigue life of 15% specimen at the HCF regime. Figure 5(c) describes the all the models were lag behind with the experimental data but the fatigue models remain closes among them. The comparison between fatigue models and obtained experiment data suggests that there are no applicable models to predict fatigue life because these materials response differently on fatigue loading and the complexity of natural fibre itself, in which poorly understood. It is therefore, development of fatigue model for this material is highly recommended.

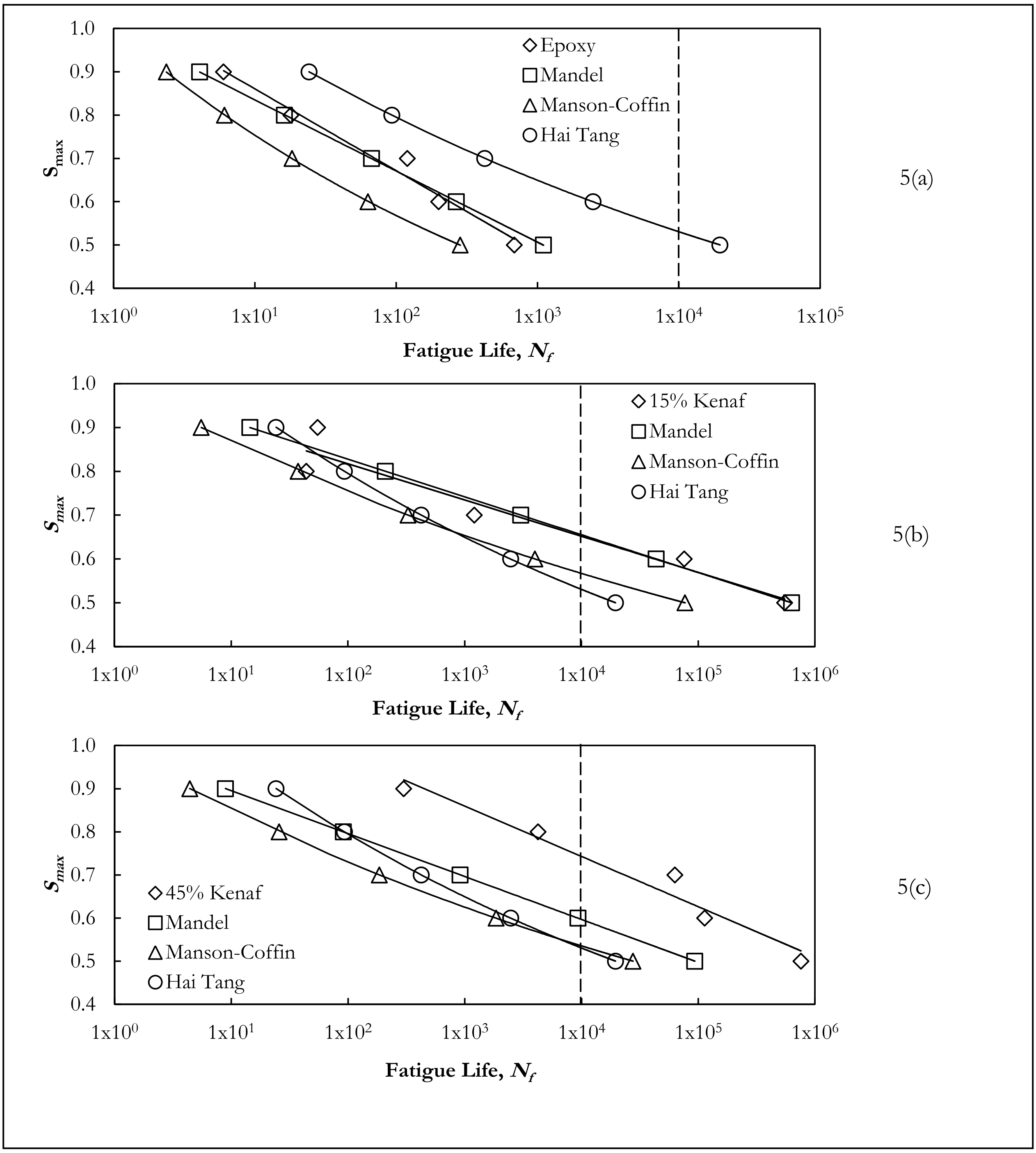


Fig. 8. Comparison between experimental data and selected fatigue model. 5(a) Pure epoxy specimens, 5(b) 15% kenaf reinforced epoxy composite and 5(c) 45% kenaf reinforced epoxy composite.

4. Conclusion

This paper presented epoxy and its kenaf reinforced composites subjected to tension-tension fatigue loading. The fatigue life is affected by the amount of fibre volume ratio but it may not show any significant improvement at very high number of cycles. Further investigation is made by comparing experimental data with three simple fatigue models. The results indicate that there are no applicable models close to mimicking the fatigue life of this composite.

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References

[1] J. Gassan, "A study of fibre and interface parameters affecting the fatigue behavior of natural fibre composites," Journal of Applied Science and Manufacturing, vol. 3, no. 33, pp. 369-374, 2000.
[2] H. Dalvag, C. Klason, and H. E. Stromvall, "The efficiency of cellulosic fillers in common thermoplastics.part II, filling with processing aids and coupling agents," *Intern. J. Polymeric Mater.*, vol. 11, pp. 9-38, 1985.
[3] B. V. Kokta, R. G. Raj, and C. Daneault, "Use of wood flour as filler in polypropylene: studies on mechanical properties," *Polym. Plast. Tecnol. Eng,* vol. 28, pp. 247-259, 1989.
[4] A. M. M. Edeerozey, H. M. Akil, A. B. Azar, and M. I. Z. Ariffin, "Chemical modification of kenaf fibres," *Mater. Lett.*, vol. 61, no. 10, pp. 2023-2025, 2007.
[5] I. S. Aji, S. M. Sapuan, E. S. Zainudin, and K. Abdan, "Kenaf fibres as reinforcement for polymeric composites: a review," *International Journal of Mechanical and Materials Engineering*, vol. 4, no. 3, pp. 239-248, 2009.
[6] A. K. Mohanty, A. Wibowo, M. Misra, and L. T. Drzal, "Effect of processing engineering on the performance of natural fibre reinforced cellulose acetate biocomposite," *Composites Part A*, vol. 35, no. 3, pp. 363-370, 2004
[7] S. Ochi, "Mechanical properties of kenaf fibers and kenaf/PLA composites," *Mech. Mater.*, vol. 40, pp. 446-452, 2008.
[8] T. Nishino, K. Hirao M. Kotera, K. Nalamae, and H. Inagaki, "Kenaf reinforced biodegradable composite," *Compos. Sci. Technol*, vol. 63, no. 9, pp. 1281-1286, 2003.
[9] J. F. Mandell, "Fatigue behavior of fiber-resin composites," in *Developments in Reinforced Plastics 2,* G. Pritchard (Eds.), London, United Kingdom: Applied Science Publishers, pp. 67-108, 1984.
[10] B. Claude, "An engineering point of view about fatigue of polymer matrix composite materials," *International Journal of Fatigue*, vol. 28, pp. 1094–1099, 2006.
[11] T. Hai, N. Tinh, C. Tze-jer, C. Joannie, and L. Jack, "A Fatigue Model for Fiber-Reinforced Polymeric Composites in Civil Engineering Applications," in *Composites Engineering, 5th Internatioonl Conference, Proceedings. International Community for Composites Engineering and College of Engineering,* New Orleans, pp. 881-882, 1998.
[12] W. Gu, H. F. Wu, S. L Kampe, and G.-Q. Lu, "Volume fraction effects on interfacial adhesion strength of glass-fiber-reinforced polymer composites," *Journal of Materials Science and Engineering*, vol. A277, pp. 237-243, 1999.
[13] V. M. Harrik, J. R Klinger, and T. A Bogetti, "Low-cycle fatigue of unidirectional composites: Bi-linear S-N curves," *International Journal of Fatigue*, vol. 24, pp. 456-462, 2002.
[14] A. Kalam, B. B. Sahari, Y. A. Khalid, and S. V. Wong, "Fatigue behaviour of oil palm fruit bunch fibre/epoxy and carbon fibre/epoxy composites," *Journal of Composite Structures*, vol. 71, no. 1, pp. 34-44, 2005.