Fracture Energy of Woven Fabric Kenaf Composite Plates with Different Fiber Orientations

Hilton Ahmad[1,a], Al-Emran Ismail[2,b]

[1]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

[2]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

[a]hilton@uthm.edu.my, [b]emran@uthm.edu.my

Keywords: Notched plate, SEN test, woven fabric, kenaf fiber, fracture energy.

Abstract. Natural fibers are potentially used as composite reinforcement in polymeric materials, but lacking of research exploration such as kenaf fibers has limited implementation in Malaysia. The advantages of natural fibers are renewable, less hazardous during fabrication and handling process and relatively cheaper as compared to synthetic fibers. The objectives of current project are to determine the fracture energy of woven fabric kenaf composite (KFRP) plates with various fiber orientations. The experiment framework includes a variation of fiber orientations as designated in testing series by using single-edge notch (SEN) testing technique. The experimental results demonstrated that testing coupons with woven fabric with 90^o fiber orientation has largest fracture toughness G_c value compared to other fiber orientations understudied. Good correlations and findings were found in other parametric studied.

Introduction

Advanced engineering materials are the key to the progress, affluence, security and leading to production of new products which open doorway to new technologies in most engineering sector. Over the past decade, there has been an increasing interest among materials engineers and scientist in using natural fibers as composite reinforcement. Natural fibers are potentially used as alternative fibers to glass fibers (in glass fiber reinforced polymer (GFRP)), motivated by advantages of low weight, cheaper, and the ecological advantages by using renewable resources [1].

Kenaf fiber composites have significantly began to attract good attention and interest among material engineers and scientist as a result to awareness in global warming by using green materials. Kenaf fiber is sustainable and renewable fibers, suggesting good alternatives to replace commercial synthetic glass fiber in low and medium load bearing applications. Benefit of natural plant fibers compared to glass fibers are acceptable specific strength (and modulus) as a result of fiber low density, less hazardous during handling, excellent biodegrability and excellent reproduce-ability to fast grown. However, the drawback is the hydrophilic properties of natural fiber during mixing stage with hydrophobic polymers (more significant with thermoplastic polymers), but with proper pre-treatment these problems can be eliminated. However, this problem is suppressed by using thermoset polymers such as epoxy resin. Good tensile strength and tensile modulus of kenaf fiber has been reported [2].

Fracture energy is regards as material parameter used as constitutive model in finite element framework to predict the structural strength of materials associated with stress raisers [3]. In material science, state-of-the-art fracture mechanics are significant parameter in order to study the resistance of materials against crack growth. There is no fracture energy datasets available in the literatures on natural fiber composites, mostly available are based on CFRP and GFRP systems. Some researchers determine fracture energy properties of natural fiber composites by calibrating datasets available from literature and known as apparent fracture energy, however, the value is not considered to be accurate. An independent experimental work is required to obtain real fracture energy parameter. Present work determines the fracture energy of different woven fabric kenaf composites following single edge notch (SEN) technique.

Experimental Framework

Fig. 1 showing the summary of working scope conducted in current project. During weaving process, two distinct sets of kenaf yarns were interlaced orthogonally in weft and warp directions to form a woven fabric layer by using handloom machine. Then, fabrication stage took place by placing and spread evenly mixed thermoset epoxy and hardener on a single woven fabric kenaf layer in a fabrication mould. Bear in mind that all testing series in current work used only a single woven fabric layer with variation fiber orientations. Compression under pressure is applied thereafter by using hydraulic compression machine for 24 hours to form fabricated panels. Cutting process was carefully done to prevent any defect along the edge of coupon with a series of testing coupon with dimensional size 250 mm length and 25 mm width. End tab with 25 mm length on each side were prepared to prevent the occurrence of slippage during mechanical testing.

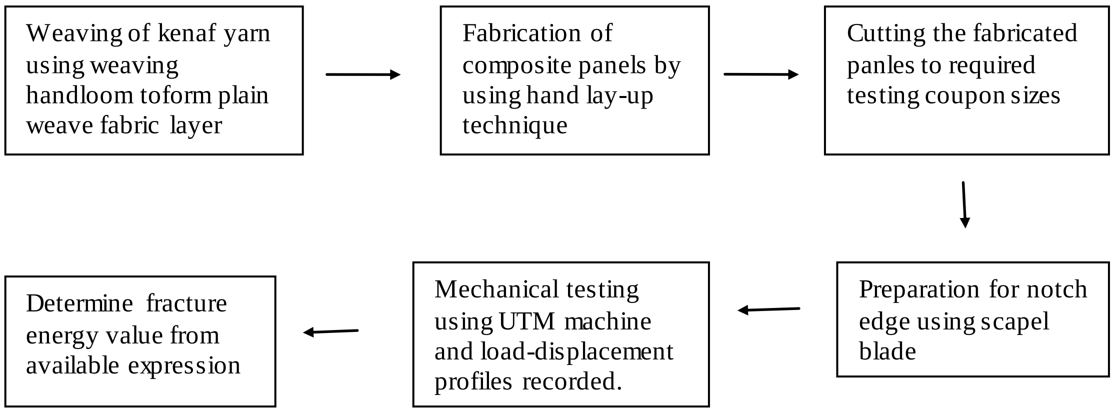

Figure 1: Flow chart of current study

The critical strain energy release rate, G_c were measured using single edge notch (SEN) technique, following recommendation practice for the toughness determination of metallic materials ASTM standard E 399-90. The edge notches were cut using a jewellers saw and sharpened prior to testing with a fresh scalpel blade. It is customary to provide a relationship between testing coupon compliance (taken as inverse in load-deflection profiles) and edge notch length for each 1 mm crack length interval up to 14 mm, and maximum load of three edge notch length (4, 8 and 12 mm) was determined separately as the fracture load, P_{max}. The fracture toughness of all fiber orientation plates are then calculated by using expression of fracture toughness, $G_c = \frac{P_{max}^2}{2B}\frac{dC}{da}$.

Table 1: Testing series of current experimental framework.

Weave type	Positive fiber orientation	Laminate designations	Negative fiber orientation	Laminate designations
Plain weave (PW)	0 °	X0	-15 °	X-15
	15 °	X15	-30 °	X-30
	30 °	X30	-45 °	X-45
	45 °	X45	90 °	X90

Five testing series were investigated in current study as given in Table 1 comprised of different plate orientation angle. There were positive and negative fiber orientations as illustrated in Fig. 2. The waft and weft directions were labeled properly to avoid confusion during woven fabric layer placing in panel fabrication stage. At least three testing coupons will be prepared for each crack length of every lay-up designations used to obtain the load-displacement profile. Then the stiffness values were determined and inversed accordingly to get compliance values prior to construction of compliance-crack length curve. Each testing coupon has 25 mm plate width and gauge length of 130 mm as shown in Fig. 2. In separate experiment testing, peak load of 4, 8 and 12 mm crack length were determined (also with three testing coupons) and associated fracture toughness are calculated and recorded as testing series datasets.

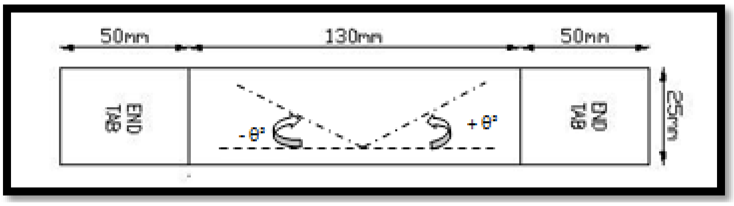

Fig. 2: Plate geometry and fiber direction orientations.

Results and Discussions

The compliance value of respective lay-up was averaged and the compliance graph was plotted as shown in Fig. 3. The equation obtained is in forth order polynomial to differentiated in order to obtain the last term, and $\frac{dC}{da}$used in accordance with aforementioned fracture energy expression, $G_c = \frac{P_{max}^2}{2B}\frac{dC}{da}$. The $\frac{dC}{da}$ term was determined by differentiating the given expression taken from the graph plotted. Substitute the term *x* with respective crack size, and we obtained the $\frac{dC}{da}$ value. The testing coupon thickness of each plate, *b* was measured by using micrometer with an accuracy of ±0.001 mm prior to mechanical testing. All compliance calibration curve obtained shown a forth order polynomial equation prior to differentiation.

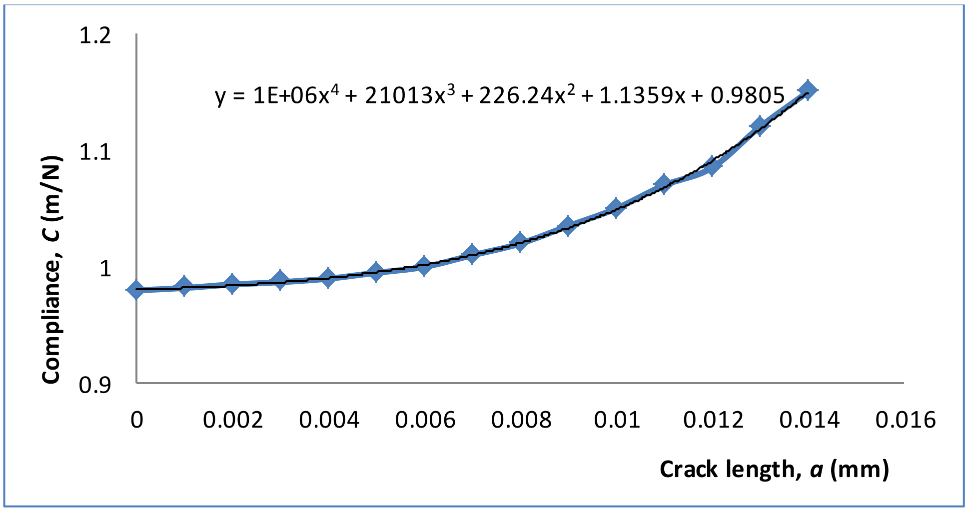

Fig. 3: Graph for compliance against crack length for X90 lay-up.

The fracture energy, G_c value was determined from an average of three testing coupons from each testing series. Table 2 shows the calculated average fracture toughness with respective of fiber orientation, showing 90 ° fiber orientation (X90) gives greatest calculated fracture toughness value, G_c with 9.56 kJ/m^2. It is followed closely by 0 ° fiber orientation (X0) with 9.12 kJ/m^2. Bear in mind that plain weave woven fabric layer is made by weaving one orthogonally yarn fibers crossing over in weft and warp direction to form a crimping region. Crimping region is always associated with plate strength degradation; however, ability of crimp to nest the cracks formation may enhance crack resistance.

The handloom machine is fixed in warp direction which allows fixed number of yarn string to form but in weft direction it is free to allow the yarn fiber spaced closely. Therefore, the thread counts in weft (90 °) direction are usually larger than warp direction (0 °). Plates with 0 ° (X0) and 90 ° (X90) fiber orientations has an equivalent stacking sequence of 0/90 and 90/0 respectively. Therefore, larger fracture toughness value in 90 ° than 0 ° fiber orientation is not surprising as applied loading gives better peak load in weft direction (more thread counts). On the other hand, 45 °(X45), 30 °(X30) and 15 °(X15) fiber orientations gives G_c value of 6.09 kJ/m^2, 5.77 kJ/m^2 and 5.08 kJ/m^2 respectively. Effective loading direction is in 90 ° fiber direction, more angle inclination from 90 ° gives smaller fracture toughness. The hypothesis that can be concluded from the datasets is the fracture toughness value is larger in the direction of larger thread counts and larger inclination from these direction may exhibit lower peak load and fracture toughness value.

The toughness measurement was carried out at every 1 mm edge notch lengths interval with an average of three testing coupons for each crack length were tested. The edge notches were prepared with a sharp scalpel blade and care should be taken in order to avoid damages at the cutting edge. We can see that smaller crack length has larger G_c value compared to the larger crack size. Moreover, the variance of crack lengths also affect the ultimate load which showed smaller crack length achieved highest maximum load, P_{max} value compared to larger crack length as seen in all fiber orientations. This is in accordance to Yasin & Siddik [4] findings that different notch-to-length ratios presented effect of notch size which the stress at maximum load (failure load divided by cross sectional area) decreased as the size was increased.

Table 2: Comparison of G_c with negative orientation cross ply lay-ups

Fiber orientations	Fracture toughness, G_c (kJ/m^2)	
	Positive orientations	Negative orientations
0 °	9.12	9.12
15 °	5.08	6.46
30 °	5.77	5.96
45 °	6.09	4.60
90 °	9.56	9.56

Table 2 show the fracture energy, G_c value for positive fiber orientations and negative orientation understudied. It was observed that both orientations are giving approximately very close fracture energy value but in a reverse trends. It is because an adverse effect of fiber angle orientation where, in positive orientation as the fiber angle is close to 90 °, better fracture energy value was found. On the other hand, negative fiber orientation gives better fracture toughness value as it is more inclined to 0 ° fiber direction as the effective loading directions has been changed to reverse direction.

It is clearly G_c of synthetic fiber composites are larger than woven fabric kenaf composites. The tensile modulus and strength of woven fabric synthetic fibers of carbon fibers [5] is excellent (to less extent. glass fibers [6]) compared to kenaf fiber. Therefore, smaller fracture energy value in woven fabric kenaf composite is much expected compared to synthetic composites. From the respective table, it is also indicated that fracture toughness, G_c value for brittle materials are usually 1–10 kJ/m^2 and higher G_c in ductile materials. This is due to the ability of ductile materials to yield prior to failure, therefore correspondingly gives higher G_c. Although woven fabric composites does not showed good fracture energy values than commercial fiber composites, however, woven fabric kenaf composites are potentially used in low and medium loading applications.

Conclusions

Experimental observation showed that the fracture and failure of testing coupons occurred at the vicinity of crack tip and the damage propagates in a self-similar manner up to catastrophic failure. The fracture toughness values are largely dependent upon parametric factor such as fiber orientations and crack length. Fracture toughness value is a material property parameter to describe the ability of a discontinuities plate to resist fracture and failure. In this study, 90 ° fiber orientations gives the largest fracture toughness value due to thread count in weft direction (90 °) is larger than warp direction (0 °). Although less fracture energy values found in woven fabric kenaf composites compared to commercial fibers and isotropic ductile materials, these materials are potentially used in low and medium load bearing applications.

Acknowledgements

The author would like to thank Universiti Tun Hussein Onn Malaysia (U245) to support this project work.

References

[1] Faruk, O., Bledzki, A.K., Fink, H.P., and Sain, M., "Biocomposites reinforced with natural fibers", *Prog. Polym. Sci.* 37 (2012) 1552–1596.

[2] Akil,H.M., Omar, M.F., Mazuki, A., Safiee, S., Ishak, Z., and Abu Bakar, A., "Kenaf fiber reinforced composites: A review", *Mater. Des.* 32(2011), 4107–4121.

[3] Ahmad, H., Crocombe, A.D., Smith, P.A., "Strength prediction of notched woven composite plates using a cohesive zone approach", Advanced Materials Reseach, 2014:845:199-203.

[4] Yasin, C., Siddik, S., "Size effect tests of different notch depth specimens with support rotation measurements", *Engineering Fracture Mechanics*, 2016:157:43-55.

[5] Belmonte, H.M.S., Ogin, S.L., Smith, P.A., Lewin, R.,. "A Physically-based Model for the Notched Strength of Woven Quasi-isotropic CFRP Laminates." *Composite Part A*, 2004: 35:763-778

[6] Belmonte, H.M.S., Manger, C.I.C., Ogin, S.L., Smith, P.A., Lewin, R.,. "Characterisation and Modeling of the Notched Tensile Fracture of Woven Quasi-isotropic GFRP Laminates." *Composites Science and Technology*, 2001: 61:585-597.