International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Flexural Strength, Fracture and Impact Toughness Analysis of Kenaf/Woven Fibreglass Polyester Composite

Z. Salleh, Y. M. Taib, S. Kushairi, S. Yunus, A. Kalam

Abstract**:** ***Natural fibers may be obtained from plant, animal and mineral sources. They are becoming a promising high potential reinforcement material for composites and thus have drawn attention from many researchers. Apart from their well-known benefits such as environmental friendly, low cost and biodegradability compared to synthetic fibres, they also have low density, minimal abrasive wear to machinery, high specific strength and modulus and can be recycled thermally. In recent years, kenaf fibres have appeared as one of the outstanding materials being used in the textile, building, plastics and automotive industries. However, it cannot be used in heavy applications. Thus hybridization with fibreglass may improve the overall mechanical properties of the composite materials. Kenaf/woven fibreglass unsaturated polyester composites was fabricated using a combination of hand lay-up and cold-press methods. A sandwich configuration with the skin being fibreglass and the core made of kenaf fibre is employed in this work. It can be surmised that the flexural strength, fracture and impact toughness of this hybrid material are influenced by fibreglass at skin layer rather than matrix strength.***

Keywords : Kenaf fibre, fiberglass, polyester composite, flexural, impact.

I. INTRODUCTION

There are three classifications of composite by its matrix material, namely metal matrix composite (MMC), ceramic matrix composite (CMC) and polymer matrix composite (PMC) [1]. However, natural fibre reinforced polymer composite materials is the most rapidly growing both in terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable, and biodegradable [2]. The natural fibre that was used in this study is one of the celebrated constituents of natural fibre reinforced plastic composites in Malaysia which is Kenaf fibre. Kenaf (Hibiscus cannabinus, L.), belongs to the family of Malvaceae and originating from Africa [3] has been regarded as an industrial crop. In spite of that, they have some weaknesses such as poor moisture resistance especially absorption and low strength compared to synthetic fibre. Kenaf fibre composites are still unsuitable for heavy load application especially when dealing with impact loading condition [4].

Hybridization with fibreglass might be helpful to improve mechanical properties of the composite system. Stronger and tougher fibreglass in the composite system thus improved the relatively poor impact properties of the kenaf-composite materials [5]. Maya Jacob John et al stated that the behaviour of hybrid composites is a weighed sum of the individual components in which there is a more favourable balance between the inherent advantages and disadvantages [6]. Besides that, anything less in one type of fibres will be complemented by the advantages of another fibre.

The effect of stacking sequence on the mechanical properties of the hybrid composite is investigated in this work, namely with long kenaf fibres sandwiched between fibreglass of the kenaf/glass fire polyester composite laminates.

II. PROCEDURE FOR PAPER SUBMISSION

A. Materials

Kenaf fibres were supplied in long fibres form and used without any surface treatment. Meanwhile, a standard unsaturated polyester resins and woven fibreglass were used.

B. Preparation of hybrid composite

A combination of hand lay-up and cold-press method was used in the fabrication of the composite laminates. A steel frame mould having dimensions of 350 mm x 260 mm was used in making the laminates. The long kenaf fibres were coiled around the mould and a layer of woven fiberglass having dimensions of 300 mm x 210 mm was placed on both upper and lower part of the coiled kenaf fibres. Then, a mixture of the unsaturated polyester resins and catalyst in a weight ratio of 100:1 were poured onto the kenaf fibres and woven fiberglass in the mould.

Manuscript published on November 30, 2019.
* Correspondence Author
Z. Salleh*, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
Y. M. Taib*, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
S. Kushairi, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
S. Yunus, Mechatronics Section, Electrical Engineering Department, German Malaysian Institute (GMI), Kajang, Selangor, Malaysia.
A. Kalam, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

This type of configuration is called as sandwich configuration which the skin being fibreglasss and the core made of kenaf fibres. Layers of the hybrid composite are as follows (Fig. 1 and 2):

i. Single layer of woven fibreglass
ii. Horizontal (0°) kenaf fibre layer
iii. Vertical (90°) kenaf fibre layer
iv. Vertical (90°) kenaf fibre layer
v. Horizontal (0°) kenaf fibre layer
vi. Single layer of woven fibreglass

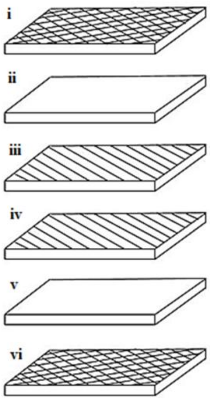

Fig. 1: Layers of the hybrid composite

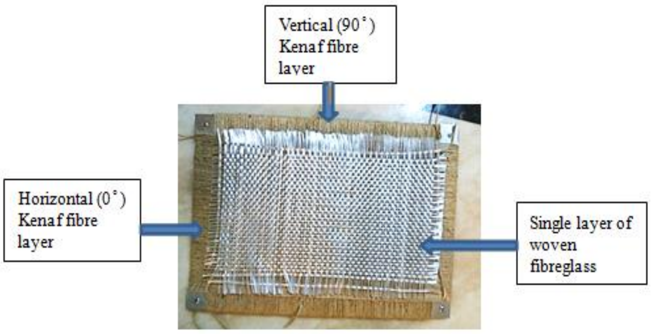

Fig. 2: Layers of the hybrid composite

The mould was covered by a plastic film which before that it was sprayed with a WD-40 lubricant for easy removal and to give the surface of the laminate a smooth finish. A cold press of approximately 10 kN of load was applied by using a press machine for 20 minutes at room temperature to ensure the homogeneity of the end product with no bubble formation. Then, the mould was removed from the machine and cured under for 24 hours at room temperature.

C. Flexural test

Flexural test specimen having dimensions of 125 mm x 12 mm with parallel edges were made from the laminates. The three-point bending test was performed according to ASTM D 790 standard test method using the Instron 8802 testing machine. The length of support from middle point was set to 25 mm. Load was gradually applied with crosshead speed of 1.5 mm/min. The test was conducted on six specimens.

D. Fracture toughness test

The maximum value of the stress intensity factor was determined via the SENB test specimen (Fig. 3) machined based on the ASTM D 5045 standard. Notch of depth 1 mm was made using an emery stick and pre-crack was introduced by sliding a sharp razor blade across the notch root. An optical microscope with a 4x objective lens was used to measure the pre-crack length, *a*. Load was applied at crosshead speed of 10 mm/min. The load and load line displacement were recorded from the built-in data acquisition system of the machine.

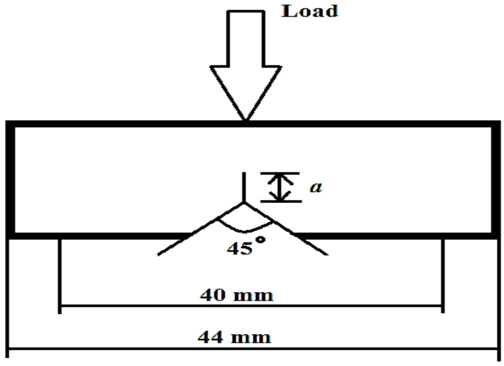

Fig. 3: SENB test specimen

E. Izod impact test

The Izod impact specimens were cut from the laminates having dimensions of 55 mm x 10 mm. All Izod specimens were notched similar to SENB specimens but without a pre-crack. The Izod impact test was conducted by using the Izod impact tester with a load equal to R3=1.813 kg in accordance to BS ISO 179:1996 standard.

F. Falling weight impact test

The falling weight impact specimens were cut from the laminates according to the ASTM D3763 standard in size of 100 mm x 100 mm. The test was carried out by using an instrumented drop weight test system, DYNATUP 9250. The amount of load used was 13 kg. Three categories of specimens were required to be obtained in this test as follows:

i. Early penetration specimen
ii. Half penetration specimen
iii. Full penetration specimen

Value of height for each category was recorded.

III. RESULT AND DISCUSSION

A. Load vs extension for flexural test

After completion of the flexural testing, the flexural properties obtained are presented in Table I. Fig. 4 shows the graph of load vs extension for the flexural test for six similar specimens. It can clearly be seen that all plots exhibit similar trends. From the load extension plot, the specimen experienced large plastic deformation immediately after elastic region.

Table I: Flexural properties

Number of specimen	Max Flexure Load (N)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Strain to failure
1	670.163	65.446	2.238	0.088
2	643.913	62.882	2.468	0.089
3	713.341	69.662	2.308	0.222
4	715.773	69.900	2.609	0.063
5	707.134	69.056	2.806	0.222
Average		67.389	2.486	0.137
SD		3.096	0.230	0.078

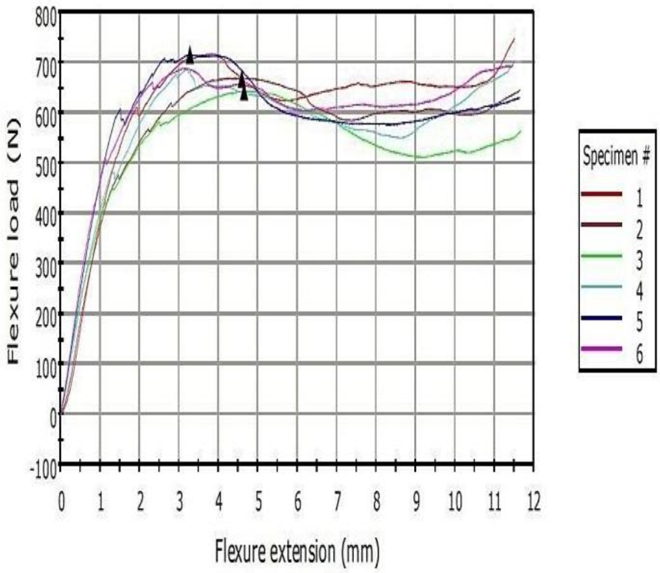

Fig. 4: Load-extension curve for flexural test of hybrid composites

The maximum flexural strength obtained is 69.900 MPa and its corresponding modulus is 2.609 GPa. Flexural strength and modulus were affected by the strength of the reinforcement. It was not possible from load-extension curve to trace the exact beginning of fibre failure of composite materials because of the non-linear behaviour of kenaf fibre reinforced polymer composites under flexural load. The crack initiates on the tension side of the specimen and then slowly propagates in an upward direction. The modulus is sensitive to the matrix or fibre interfacial bonding.

Fibreglass is tougher and stronger than kenaf fibre. The mechanical interlocking of the woven fibreglass has improved the load carrying capacity of the composite this is clearly shown by short elongation under load. It be observed from Fig. 5 that the specimen did not break but still remains intact, this indicates that this hybrid composite is still useable.

Fig. 5: Side view of the specimens under flexural load

B. Results of fracture toughness Test

Fig. 6 shows the stress vs strain for SENB test for ten specimens. The value of stress increases proportionally to the strain. SENB test is exactly similar to flexural test, thus the graph obtained also show a similar trend. However, the the stress dropped rapidly after reaching its maximum value due to pre-crack ahead of the notch

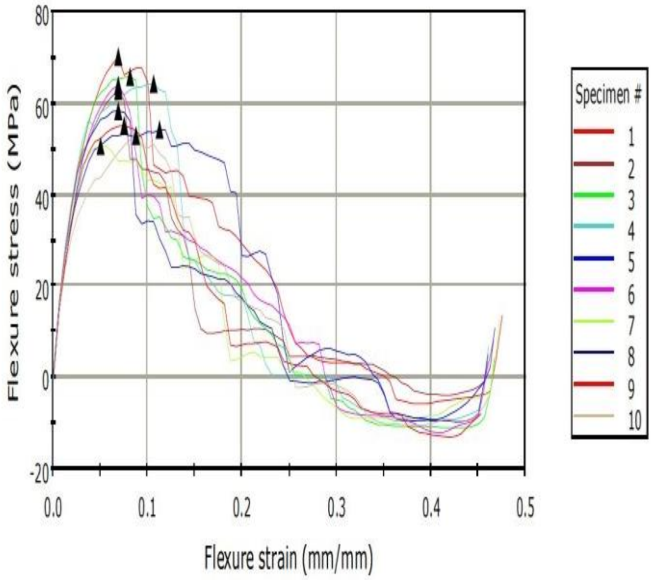

Fig. 6: Stress-strain curve for SENB test of hybrid composites

Fig. 7 shows the side view of the specimens after undergoing fracture toughness test. It can clearly be seen that the fibreglass layers prevent the specimen from breaking into halves. The values of flexural strength and K_{IC} are presented in Table II.

Fig. 7: Side view of the specimens after undergoing SENB test

Table II: Maximum flexure load and critical stress-intensity factor of kenaf/woven fibreglass reinforced polyester composite

Specimen	Maximum flexure load (N)	Critical stress-intensity factor, K_{IC} (MPa $\sqrt{mm}$)
1	732.600	118.789
2	768.848	124.666
3	750.305	121.660
4	633.850	102.777
5	746.069	120.973

From Table II, it shows that the critical stress-intensity factor increases as the flexure load increases. This means that the material was being more resistive as the applied load was increased and it can hold a load up to 768.848 N with its corresponding critical stress-intensity factor of 124.666 MPa $\sqrt{mm}$.

In order to ensure the validity of these results, they are compared to the results obtained in previous study [7]. Generally, the K_{IC} values in the study were higher than there are in Table II. This is due to the environmental differences where the K_{IC} values obtained in aqueous environment will be higher compared to the K_{IC} values obtained in room temperature environment since the voids and cracks in the composite allows the water to be absorbed, thus reducing the strength between the matrix and fibres. If a material has a large value of fracture toughness, it will probably undergo ductile fracture. Otherwise, the material will have brittle fracture characteristic with a low value of fracture toughness [8]. Therefore, the results in Table II proves that the material undergo brittle fracture while the results in previous study have ductile fracture. Table III shows the values of flexural strength, modulus and strain to failure for SENB test.

Table III: SENB test data

Number of specimen	Tensile Strength (MPa)	Tensile Modolus (GPa)	Strain to failure
1	62.794	1.758	0.069
2	65.901	1.703	0.082
3	64.312	1.538	0.107
4	54.330	1.234	0.113
5	63.949	1.660	0.069
Average	62.257	1.579	0.088
SD	4.569	0.209	0.021

C. Izod impact test results

Table IV shows the tabulation of data for Izod impact test results for 5 specimens. The aim of this test was to purposely break the specimen and thus, the impact energy were measured and tabulated in the table. On impact side, the specimen deforms elastically until yielding takes place (plastic deformation), and a plastic zone develops at the notch. The stress and strain in the plastic zone was increased. Therefore, the specimen experienced crack at the middle of its length and finally were broken into two.

Table IV: Izod impact test data

Specimen	Impact energy (J)	Impact angle (°)
1	6.4	76
2	7.3	67
3	6.5	75
4	5.5	85
5	6.3	77
Average	6.4	76
SD	0.64	6.403

In this testing, one end of the specimen was fixed vertically with the aid of a vice. The energy absorbed by the specimen during the striking process is known as the breaking energy which is also called as impact energy. The breaking energy is the parameter that indicates a material's impact resistance.

From Table IV, it can be seen that the energy are inversely proportional to the hammer angle. The maximum energy obtained is 7.3 J with 67° impact angle. Lower impact angle means the material is stronger to resist the impact compared to the material that has higher angle. Therefore, lower impact angle corresponds to higher impact energy. For hybrid composite, a sandwich configuration with the skin being fibreglasss and the core made of kenaf fibres are fit for high impact resistant [9].

As can be seen, there are very big gap between the average and standard deviation values. The reason that might affect the differences is that the thickness of all specimens was too high compared to the standard thickness. This happened since hand lay-up technique was used to fabricate the specimen and it involved six layers of fibres. Therefore, it was hard to get the perfect thickness. In this testing, most specimens were completely broken into two which reflects a failure process involving fibre breakage and delaminating. The material has high brittleness and need to be improved for future research.

D. Falling weight impact test

Results of the impact for three different categories of specimens namely; early penetration, half penetration and full penetration, prepared at different values of height are summarized in Table V.

Table V: Falling weight impact test data

Specimen	Height (cm)	Impact energy (J)
1 (Early penetration)	35	43.871
2 (Half penetration)	45	64.567
3 (Full penetration)	55	79.539

From Table 5, the trend can be clearly observed where the value of height affect the depth of penetration on the specimen. The impact energy also increases as the height increases. The impact energy has higher value compared to the other study that did the same experiment. This is because the skin of the hybrid composite in this study was fibreglass which has stronger and tougher properties when compared to kenaf fibres being the skin of the hybrid composite.

Fig. 8 and 9 show the damage zone for the hybrid composites as the height value was increased. On the front surface of the impacted specimen, it can be seen that the fibre-matrix debonding occurred by cracks running parallel to fibres. Meanwhile, on the back surface of the impacted specimen, matrix cracking was observed where these cracks have circular shape which may be the result of the propagation of tensile strain waves during impact [10].

Z. Salleh et al. [9] stated that the relatively poor fibre-matrix interfacial bonding of the composites in this research suggest that most of the impact energy absorbed will be through fibres. It can be concluded that the composite fracture was contributed mostly by the fibre strength rather than the matrix strength.

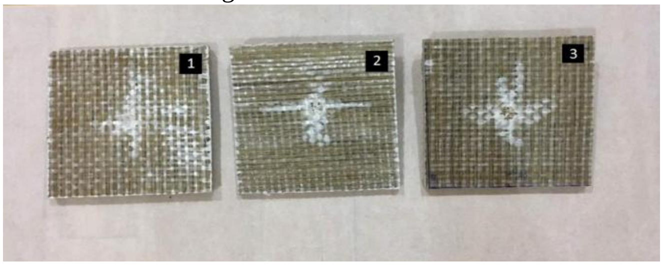

Fig. 8: Impact damage on the front surfaces of hybrid composites

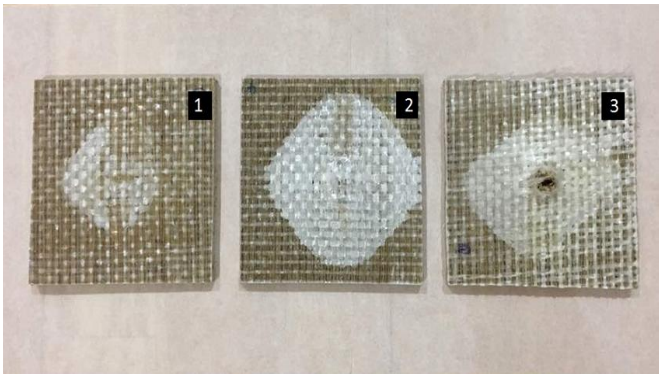

Fig. 9: Impact damage on the back surfaces of hybrid composites

IV. CONCLUSION

The effect of using long kenaf fibers, woven fiberglass, unsaturated polyester and a sandwich configuration with the skin being fibreglass and the core made of kenaf fibers have been successfully investigated. As expected, the hybrid composites exhibit the non-linear behaviour under flexural load which involve the composites to deform plastically immediate after elastic deformation. The hybrid composites tested for impact in this research showed that the composite fracture was contributed mostly by the fiber strength rather that matrix strength.

REFERENCES

1. Yang Y, Boom R, Irion B, et al. (2012). Recycling of composite materials. Chem Eng Process 51, 53–68.
2. Chandramohan, D. and Marimuthu, K. (2011). A Review on Natural Fibers. International Journal of Recent Research and Applied Studies, 8, 194-206.
3. Abdalla A. Ab. Rashdi, S. M. (2009). Review of Kenaf Fiber Reinforced Polymer Composites. Polimery 11/12, 775-888.
4. Z. Salleh, K. M. (2014). Residual Tensile Stress of Kenaf Polyester and Kenaf Hybrid under Post Impact and Open Hole Tensile. Procedia Technology 15, 856-861.
5. Z. Salleh, K. M. (2013). Effect of Low Impact Energy on Kenaf Composite and Kenaf/Fiberglass Hybrid Composite Laminates. Applied Mechanics and Materials 393, 228-233.
6. M. J. John, and R. D. Anandjiwala (2009). Chemical modification of flax reinforced polypropylene composites. Composites Part A: Applied Science and Manufacturing 40(4), 442-448.
7. Z. Salleh, Y. M. Taib, K. M. Hyie, M. Mihat, M. N. Berhan, and M. A. A. Ghani (2012). Fracture Toughness Investigation on Long Kenaf/Woven Glass Hybrid Composite Due To Water Absorption Effect. Procedia Engineering 41, 1667-1673.
8. ASTM D5045-14, Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials, ASTM International, West Conshohocken, PA, 2014.
9. Z. Salleh, K. M. Hyie, M. N. Berhan, Y. M. Taib, M. K. Hassan, and D. H. Isaac (2013). Effect of Low Impact Energy on Kenaf Composite and Kenaf/Fiberglass Hybrid Composite Laminates. Applied Mechanics and Materials 393, 228-233.
10. T. Yuanjian and D. H. Isaac (2008). Combined Impact and Fatigue of Fibreglass Reinforced Composites. Composites: Part B 39, 505-512.

AUTHORS PROFILE

Zuraidah Salleh is currently a Senior Lecturer at Faculty of Mechanical Engineering, Universiti Teknologi MARA. She received her Bachelor Degree in Mechanical Engineering from Universiti Teknologi MARA and her MSc. from Universiti Sains Malaysia (USM). Her research interests include composites, coating and welding.

Ya'kub Md Taib is currently an Associate Professor at the Faculty of Mechanical Engineering, Univerity Teknologi MARA. He received his Bachelor Degree in Mechanical Engineering from ITM, Malaysia and his M. Phil from Swansea University, Wales, U.K. His research interests include composites and fracture mechanics of engineering materials.

Sahril Kushairi is currently senior lecturer at Faculty of Mechanical Engineering, Universiti Teknologi MARA. He received his Bachelor Degree in Mechanical Engineering from University of Bradford, United Kingdom and his M. Phil from ENAC and ENSICA University, Toulouse, France. His research interests include multibody dynamics and control system.

Syarifah Yunus is Technical Training Officer in Mechatronics Section, Electrical Engineering Department, German Malaysian Institute (GMI), Kajang, Selangor. She received her Bachelor Degree and MSc in Mechanical Engineering from Universiti Teknologi MARA. Her research interests include natural fibre composites and fracture mechanics of engineering materials.

Anizah Kalam is currently a Senior Lecturer at the Faculty of Mechanical Engineering, Universiti Teknologi MARA. She obtained her Ph.D from Universiti Teknologi MARA in 2010. Her research interests include natural fiber composites and material characterization.