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The Effect of Nanoclay and Carbon Nanotubes Addition on Fracture Toughness Properties of Chopped Kenaf Fibres Reinforced Composites

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Abstract*: *In this study, the chopped kenaf fibres composites were incorporated with 1wt%, 3wt% and 5wt% of nanoclay and 0.5wt%, 1.0wt% and 1.5wt% of carbon nanotubes (CNT). The composites samples were fabricated using a combination of three roll milling and hand lay-up processes. The fracture toughness test was conducted according to ASTM D5045. The addition of the nanoclay and CNT significantly enhanced the fracture toughness properties as well as critical stress intensity (K_{IC}) and critical strain energy (G_{IC}) of the composites. In particularly, the results show that chopped kenaf fibres composites incorporated with 1wt% of nanoclay (1NCKF) and 0.5 wt% of CNT (0.5CNTKF) exhibited the highest fracture toughness properties of about 50% and 19%, respectively as compared to pure chopped kenaf fibres. However, it was found that the addition of CNT more than 0.5wt% (1CNTKF and 1.5CNTKF) decreased the (K_{IC}) and (G_{IC}) properties as compared to pure kenaf composites.

Index Terms*: *Nanoclay, Carbon nanotubes, chopped kenaf fibres composites, fracture toughness

I. INTRODUCTION

Chopped or Short fibres reinforced polymer composites (SFRPCs) have been widely used especially in the automotive applications due to excellent corrosion resistant with sufficient strength and stiffness. SFRPCs have some advantages over continuous fibre composites which are lower cost, higher manufacturing rate and easy to shape especially in complex geometries [1][2]. Natural fibres are increasingly being recognized as an alternative reinforcement in polymer composites to substitute conventional glass and carbon fibres. There are a lot of advantages of natural fibres over man-made glass and carbon fibres which are low cost, low density, comparable specific tensile properties, non-abrasive to the equipment, non-irritation to the skin, reduced energy consumption, less health risk, renewability, recyclability and biodegradability [3]–[7].

Kenaf fibres, which is made from the kenaf plant possess outstanding properties such as good modulus, excellent stability, good chemical resistance, high mechanical strength and high temperature resistance, and easy to produce [8]–[12]. The literature reveals that there are many studies focusing on different characteristics of continuous or chopped kenaf fibres reinforced polymeric composites. Even though the kenaf fibres composites have good potential for commercialization, certain limitation arises with respect to fracture toughness properties when epoxy resins used as a matrix. The usage of the epoxy resins had been reported to decrease the mechanical performance of the composites due to brittleness of the epoxy resin in nature. Consequently, significant efforts have been made to enhance the fracture toughness and strengths of chopped fibres reinforced composites. One such approach is to modify the epoxy resin with incorporation of nanomaterials such as nanoclay and CNT [[8], [13]–[18]]. It is well known that the presence of nanofillers may induce several toughening mechanisms in epoxy resin such as crack deflection, plastic deformation and crack front pinning. Equally important is the fact that nanofillers may influence the matrix structure resulting from interactions between fillers and the polymer. The surface functionality of the nanoparticles, may then participate in the epoxy curing process which may result in different epoxy network structures. This contributes to the toughening effecting due to strong bonding adhesion, thus enhancing the mechanical properties of composites system.

H. Yaghoobi and A.Fereidoon [19] reported that the incorporation of 1 wt% CNT with kenaf/PP enhanced the tensile strength, flexural strength and notched impact strength about 13.8%, 15.6%, and 11.4%, respectively. TGA result shows the highest thermal stability when incorporated with 2 wt% of CNT. However, the higher content of CNT caused the reduction of mechanical properties of CNT/kenaf/PP composites. Xiaorong Liu et al. [20] found that the addition of halloysite nanotubes (HNTs) with kenaf/soybean meal composites markedly enhanced the thermal stability, bonding strength and toughness of composite. N. Sapiai et al. [13] in their study reported that the CNT with surface treatment (acid and silane) improved the mechanical properties of unidirectional kenaf composite. A limited study was reported on the effect of the nanofillers on fracture toughness behaviour of the kenaf or natural fibres composites. However, the effectiveness of nanofillers on fracture toughness behaviour has always been discussed when incorporating with synthetic fibres i.e. carbon and glass fibres.

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Therefore, this study is aimed to incorporate nanofillers i.e. nanoclay and CNT in chopped kenaf fibres composites in order to improve the fracture toughness behavior.

II. EXPERIMENTAL SET UP

A. Materials

In the present study, the kenaf fibres was supplied by Innovative Pultrusion Sdn.Bhd., Malaysia. The epoxy used was miracast 1517 A/B that was supplied by the MIRACON Sdn. Bhd, Malaysia. Miracast 1517 A is a diglycidyl ether of Bisphenol A (DGEBA) type of epoxy, while Miracast 1517 B is amine-curing agent that used as a hardener with the ratio of 100:30 (epoxy: hardener). The Flo Tube 9000 Series Multi-Wall Carbon Nanotubes was purchased from CNano Technology, Beijing, China. The nanoclay used was the commercially available organo-montmorillonite, Nanomer I30 E, which modified with an octadeyl amine modified, provided by Nanocor Inc.

B. Fabrication of Chopped Kenaf Fibre Composites

To prepare the chopped kenaf fibres reinforced composites, the kenaf fibres was chopped into lengths of 1-3mm by grinder, as shown in Figure 1 (a). In modified system, the epoxy resin was mixed with nanoclay and carbon nanotubes (CNT) using three roll milling machine, as shown in Figure 1 (b). After that, the chopped kenaf fibres was subsequently added to the modified epoxy resin. The mixture was evenly mixed before being placed in silicone mould, as shown in Figure 1 (c). The mixture of fibres and resins was then cured at room temperature for 24 hours. The process was repeated in fabricating chopped kenaf fibre modified with various concentration of nanoclay (1wt%, 3wt% and 5 wt%) and CNT (0.5wt%, 1.0wt% and 1.5). Table 1 shows the description and designation of chopped kenaf fibre composites that were fabricated in this study.

Table 1 The designation of chopped kenaf composites systems

Designation	Kenaf Fibres (wt%)	Nanoclay (wt%)	CNT (wt%)
KF	15	-	-
1NCKF	15	1	-
3NCKF	15	3	-
5NCKF	15	5	-
0.5CNTKF	15	-	0.5
1CNTKF	15	-	1
1.5CNTKF	15	-	1.5

Fig 1 (a) Chopped kenaf fibres (b) Three roll shear milling machine and (c)Mixure of kenaf and epoxy resin is placed in the silicone mould

C. Fracture Toughness Test

The fracture toughness test was conducted according to ASTM D5045 with specimen size of 5 x 10 x 80 mm as illustrates in Figure 2. The notch was sharpened by sliding a razor blade across the sample with 4.5 mm initial crack length. The SENB specimens were tested using the three-point bending test and the specimen was placed symmetrically on the two supports of span=40 mm as illustrated in the Figure 3. A force was applied at midspan with a crosshead speed of 1 mm/min. The 100kN INSTRON 3382 Universal Testing Machine was used to conduct the fracture toughness test and analyzed using Bluehill 2 software. Figure 4 shows three-point bending test set-up for fracture toughness test.

From the applied load and corresponding deflection that obtained during the test, the graph of force (F) versus Displacement (s) was plotted and the value of critical stress intensity factor, K_{IC} and critical energy release rate, G_{IC} were analyzed. The K_{IC} and G_{IC} were calculated using equations 1 and 2:

$$K_{Ic}(Pa.\sqrt{m}) = f(a/w)\frac{F_Q}{h\sqrt{w}} \quad (1)$$

where, $f(a/w)$ is a calibration factor, F_Q is a maximum load , a is a original crack initiation w is a width of specimen and h is a thickness of specimen.

$$G_{Ic}\,(J/m^2) = \frac{W_B}{h \times w \times \emptyset(a/w)} \qquad (2)$$

Where, W_B is a Energy to break, $\emptyset(a/w)$ is a calibration factor, a is an original crack initiation, w is a width of specimen and h is a thickness of specimen.

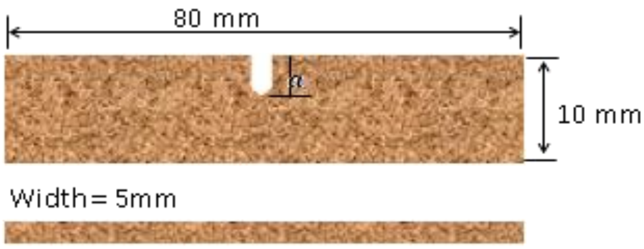

Fig 2 Specimen size of chopped kenaf fibres

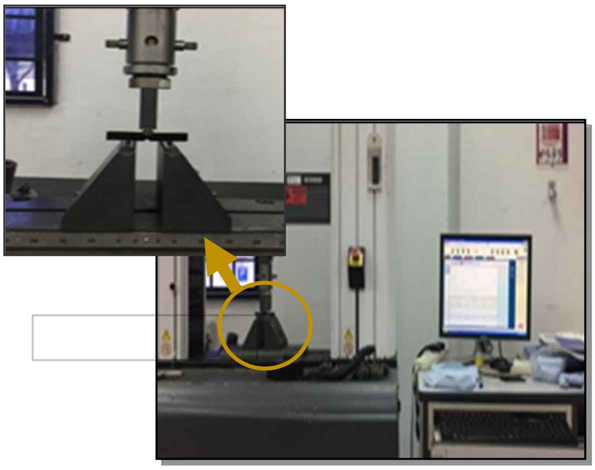

Fig 3 Three-point bending test set-up for fracture toughness test

III. RESULT AND DISCUSSION

Fracture toughness properties, i.e. critical stress intensity factor (K_{IC}) and critical energy release rate (G_{IC}), were determined from the applied load and corresponding deflection that obtained during the experiment. Fig 4 shows the properties of K_{IC} and G_{IC} of kenaf composites with addition of nanoclay. Fig 5 shows the properties of K_{IC} and G_{IC} of kenaf composites with addition of CNT. As shown in Figure 4, the curve clearly recorded that the addition of 1 wt% of nanoclay into kenaf composites (1NCKF) had increased the K_{IC} and G_{IC} by 50% and 90%, respectively as compared to pure kenaf composite. The K_{IC} is slightly increased with addition of 3 wt % (3NCKF) and 5 wt% (5NCKF) nanoclay, about 2.9% and 8.5% increment, as compared to pure kenaf composites. However, the K_{IC} for both 3NCKF and 5NCKF was lower than 1NCKF. Similar result trend was found for G_{IC} properties except the 3NCKF, which was reduced as compared to pure kenaf composites. The incorporation of nanoclay leads to the enhancement of fracture toughness properties. However, it is suggested that the amount of nanoclay addition is not more than 1wt%. Reduction in fracture toughness at high nanoclay content was also reported by several researchers, in which the higher the amount of nanofiller, the lower the quality of the composites [20] [21]. At high nanoclay content, the tactoid and intercalated structures of clay nanoplatelet may become a stress concentrator, thus limit the intrinsic properties of nanoclay to obtain the desired properties of composites.

The addition of 0.5 wt% of CNT increased the K_{IC} and G_{IC} about 19% and 30%, respectively as compared to pure kenaf composites as shown in Fig 5. When increase the amount of CNT of up to 1 and 1.5 wt%, the K_{IC} and G_{IC} properties show reduction. The G_{IC} properties decreased by 40% and 42% for 1CNTKF and 1.5CNTKF, respectively. As reported in a previous study, the mechanical properties as well as fracture toughness were influenced by the amount of incorporated CNT [13], [22], [23]. Although CNT could improve the properties, the higher the amount of CNT added, the higher the viscosity of the resin, thus high possibility for the CNT to clump together. It is also reported that, the CNT has an extremely large surface area due to its nanoscale diameter and high aspect ratio (> 1000), hence further clarify on high tendency of CNT to clump together [13], [22], [23]. In this research, the decreasing of K_{IC} and G_{IC} properties in 1CNTKF and 1.5CNTKF was due to agglomeration of CNT as observed on the fractured surface. The agglomerated CNT regions acted as failure concentrated points that lead to further reduction of fracture toughness properties. Similar findings were also reported by Sapiai et al. [13].

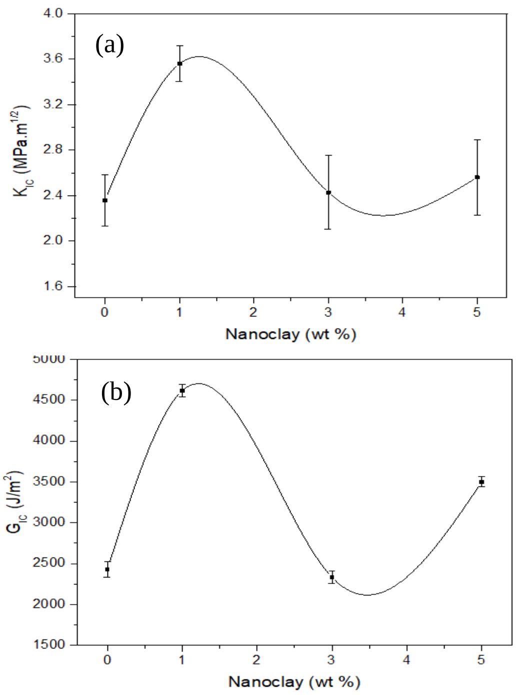

Fig 4 Fracture toughness properties (a) K_{IC} and (b) G_{IC} of kenaf composites with different nanoclay content

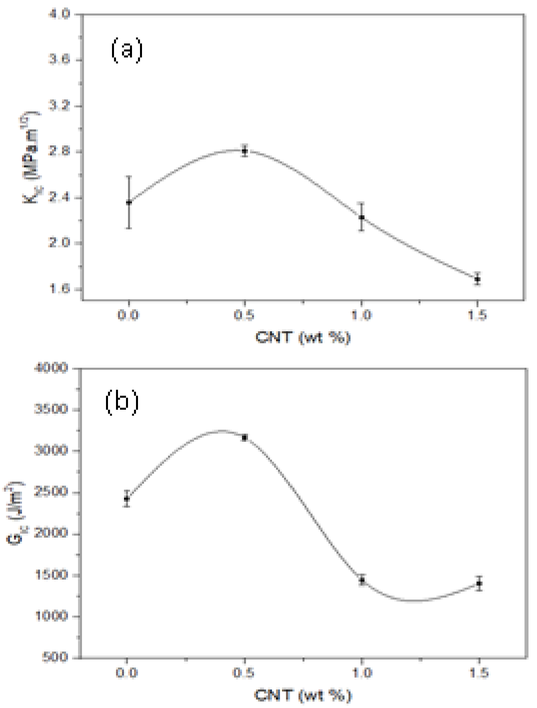

Fig 5 Fracture toughness properties (a) K_{IC} and (b) G_{IC} of kenaf composites with different CNT content

Table 2: Fracture toughness properties of kenaf composites with different nanoclay and CNT contents

Samples	F_{max} (N)	K_{IC} (MPa.√m)	G_{IC} (J/m^2)
KF	129.24 ±15.26	2.36 ±0.23	2428.50 ±92.32
1NCKF	194.84 ±14.06	3.56 ±0.16	4618.07 ±78.94
3NCKF	132.85 ±17.73	2.43 ±0.32	2333.29 ±72.49
5NCKF	140.09 ±13.41	2.56 ±0.33	3502.33 ±64.58
0.5CNTKF	153.48 ±2.64	2.81 ±0.05	3167.88 ±41.50
1CNTKF	122.19 ±1.12	2.23 ±0.12	1445.41 ±63.69
1.5CNTKF	92.49 ±2.88	1.69 ±0.05	1404.49 ±87.86

IV. CONCLUSION

Kenaf fibres composites have high potential and the best candidate to replace petroleum based –composites due to environmental problem and depletion of resource. However, brittleness of thermoset polymer that was used as the matrix limits their applications. The incorporation of nanoclay and CNT to the epoxy matrix improved the toughness of kenaf fibres composites. However, this requires significant additions of nanoclay and CNT for improving the fracture toughness. The results concluded that small amount of nanoclay (1 wt%) and CNT (0.5 wt%) had significantly improved the fracture toughness properties as compared to pure kenaf composites. Meanwhile, the higher amount of CNT (1CNTKF and 1.5CNTKF) reduced the fracture toughness properties of kenaf composites. Although a lot of challenges happened during processing and incorporating nanofillers (clay and CNT) such as high viscosity of resin and wetting of resin in fibres, this method is effectively and significantly enhanced the fracture toughness properties.

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Dr. Aidah Jumahat has a PhD degree in Mechanical Engineering from the University of Sheffield United Kingdom, a MSc (Mechanical Engineering) degree and a B.Eng. (Hons.) Mechanical and Materials Engineering degree from the Universiti Kebangsaan Malaysia. She joined the Faculty of Mechanical Engineering UiTM as a lecturer in 2001. Currently, she is an Associate Professor at the Faculty of Mechanical Engineering and the Director at Community of Research Frontier Materials and Industrial Application (CoRe FMIA) Institute of Research Management and Innovation (IRMI) Universiti Teknologi MARA Shah Alam Selangor Malaysia. Dr. A Jumahat has been lecturing on Composite Materials, Finite Element Method, Mechanics of Materials, Manufacturing Processes, Product Design and Advanced Materials, which happens to be her areas of research interest. She has published more than 100 technical papers in journals and conference proceedings locally and internationally in these research areas. She is an esteemed member of the panel of judges for the International Invention, Innovation & Technology Exhibition (ITEX) since 2012 and an executive member of several professional bodies

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