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

# Flexural Properties of Chopped Kenaf and Carbon Fibre Reinforced Polymer Composites Embedded with Carbon Nanotubes

**Ummu Raihanah Hashim, Aidah Jumahat, Nur Syarah Iffah Azizi**

***Abstract*: An experimental study was performed to investigate the flexural behaviour of chopped kenaf and carbon fibre reinforced polymer composites embedded with carbon nanotubes (CNT). The fibre content in the composites was 10 wt.% with three different CNT loadings, which were 0.5wt.%, 1.0wt.%, and 1.5wt.%. The CNT were dispersed in the epoxy resin using the mechanical stirrer and three-roll mill machine and mixed with the chopped fibres before being poured into the designated mould. Three-point bending tests were conducted with a specimen thickness and width of 4 mm and 10 mm, respectively, and a standard specimen length of 20% longer than the support span. The flexural test results showed that the chopped carbon fibre reinforced polymer (CFRP) with 0.5wt.% CNT exhibited the highest flexural strength and modulus (42 MPa and 2.9 GPa, respectively) compared to other composites with 1.0wt.% and 1.5wt.% CNT loading. The chopped kenaf fibre reinforced polymer (KFRP) composite with 0.5wt.% CNT loading showed the highest increase in the flexural strength and modulus, at 30 MPa and 2.8 GPa, respectively. Hence, it was concluded that the addition of CNT improved the flexural properties and 0.5 wt.% CNT was the ideal loading to enhance the flexural properties of chopped fibre-reinforced polymer composites.***

***Keywords* : Carbon fibre, Carbon nanotubes, Chopped fibre, Flexural properties, FRP Composites, Kenaf fibre.**

## I. INTRODUCTION

The usage of composite materials in various applications, such as the automotive, marine, construction, and sports industries, has expanded for years. Fibre Reinforced Polymers (FRP) are composite materials consist of high strength fibres as the reinforcement and a polymer as the matrix. In the FRP composites, the function of the polymer matrix is to provide protection to the fibres, while the reinforcing fibres contribute to the mechanical performance of the composite [1], [2]. There are two types of polymers, which are thermoplastics and thermosets. Epoxy resin is one of the most versatile established thermosets because of its remarkable advantages as the main polymer matrix selection for fibre reinforced composites. It is frequently used in high demand performance-driven industrial sectors, such as the aerospace, marine, automotive, and construction industries [3]. However, the main constraint of this material is the low compressive strength and highly brittle nature, which causes the material to be used only as a secondary material in high-end applications. Hence, to improve the strength of this polymer matrix, the use of nanofillers such as silica, clay, and carbon nanotubes, are emphasize to the polymer to increase the modulus as well as to improve their strength [4]–[6]. The addition of a nanofiller increases the stiffness of the matrix and enhances the flexural modulus and strength. Carbon nanotubes (CNT) are one of the most attractive fillers for polymer nanocomposites because of its superior mechanical properties. The unique properties and structure of CNT make it ideal as a reinforcing material in epoxy matrices [7].

Reinforcing fibres can be categorized into two groups, which are synthetic fibres (carbon, glass, Kevlar, etc.) and natural fibres (basalt, kenaf, bamboo, etc.) [8], [9]. Synthetic fibres are made from chemical processes, usually via extrusion, and are widely used in various applications, such as in the automotive, marine, sports, and building construction industries, because of their excellent mechanical properties. Carbon fibre has been used in high-end applications because of its excellent strength and stiffness. However, this fibre is expensive due to its high strength. Hence, because of the depletion of petroleum resources and the increase in environmental awareness, research has focused on sustainable, environment friendly, and renewable materials for fibre reinforced polymer composites [10]–[13].

The emergence of natural fibres, which are derived from natural resources, i.e., plant-, animal-, or mineral-based resources, have led them to be considered an alternative material to synthetic fibres with a proper development process. Natural fibres were introduced because of their biodegradability, low cost, lightweight and renewable nature, high specific modulus, and abundant availability [14]–[16]. Studies have been conducted on the use of natural fibres to fulfill the demands of producing composites, which has made high-end applications more viable. The most common natural fibres used are hemp, jute, flax, kenaf, sisal, pineapple leaves, oil palm fruit bunch, and bamboo [17]–[19].

Manuscript published on November 30, 2019.
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In the engineering field, the flexural resistance is the one of the most important mechanical properties in the design of structural materials to ensure safety. Jumahat et al. [20] showed that the flexural strength of a composite with 5wt.% nanoclay exhibited a remarkable improvement (80%) compared with neat glass fibre-reinforced polymer composites. Hossain et al. [21]studied the flexural behaviour of short and bi-directional carbon/epoxy (CFRP) composites and found that the mechanical properties of bi-directional CFRP composites were enhanced with an increase in the fibre loading compared with a short fibre-reinforced epoxy composite. Dorigato and Pegoretti [22] studied the flexural properties of CFRP composites modified with 0.3 wt.% multi-walled carbon nanotubes (MWCNT) and 2 wt.% nanoclay, and the results were compared with unmodified CFRP composites. It was found that the flexural strength and flexural modulus of all of the composites were increased when the nanoparticles were correctly incorporated into the system.

The use of short/chopped fibres is efficient in terms of cost reduction and processability, and it can be employed using most extrusion techniques with thermoplastics as compared with long fibres [23]. Several studies have reported on chopped fibre-reinforced polymers, but there is still limited information about the effect of CNT on the flexural properties of chopped fibre-reinforced polymer composites.

Hence, the aim of this study was to evaluate the flexural properties of chopped kenaf and compare them with carbon fibre-reinforced polymer epoxy filled with CNT.

## II. EXPERIMENTAL DETAILS

### A. Materials

In this study, the commercial epoxy resin Miracast 1517 part A and B was supplied by Miracon (M) Sdn. Bhd. (Selangor, Malaysia). The kenaf fibre yarn was supplied by Innovative Pultrusion Sdn. Bhd. (Seremban, Malaysia). The carbon fibre was supplied by Vistec Technology Sdn. Bhd. (Selangor, Malaysia) in the form of continuous long fibres. The fibres were cut into shorter lengths before being crushed to obtain a length of 4 mm to 5 mm. Multi-wall CNT (Flo Tub 9000 Series) was synthesized via a catalytic vapour deposition process with an average diameter of 11 nm and length of 10 µm. The CNT was supplied by CNano Technology Ltd. (Beijing, China). The CNT loading used were 0.5wt.%, 1wt.%, and 1.5wt.%.

### B. Preparation of nanomodified epoxy

The CNT-modified epoxy polymer was prepared using a mechanical stirrer (AM-120Z-H, Meditry Instrument Co. Ltd., Shanghai, China) and three-roll mill machine to disperse the nanofiller in the epoxy resin. A series of 0.5wt.%, 1.0wt.%, and 1.5wt.% CNT nanofillers were mixed together with the epoxy resin using a mechanical stirrer at 400 rpm for 1h at 80°C. The mixture was then milled using a self-fabricated three-roll mill machine by pouring the nanofiller-epoxy mixtures in between the feed and centre rollers. The material from the apron was collected and fed back into the feed and centre rollers after each complete cycle. The whole cycle was repeated five times to ensure a proper dispersion of CNT in the epoxy resin. Then, the mixtures were degassed using a vacuum oven for 1 h, followed by the addition of hardener with 100:30 ratio (epoxy:hardener). The degassification process was conducted to remove air trapped during the composite fabrication.

### C. Fabrication of the chopped fibre-reinforced polymer nanocomposites

The 10wt.% chopped fibre was weighed and added into the epoxy resin to produce the neat FRP. For the nanomodified composite, 10wt.% fibre was added into the nanomodified resin and stirred using a mechanical stirrer until the fibres were uniformly distributed in the epoxy resin. Then, the mixture was poured into a silicon mould (4 mm × 10 mm × 78 mm) to get the desired size. The mould was then placed on a flat surface under a load to ensure good surface finishing. After that, the mould was left for 24h to completely cure before being used for testing.

### C. Flexural test

The flexural test was conducted according to ASTM D790, using a rectangular specimens with a thickness of 4 mm, width of 10 mm, and length 20% longer than the support span length of 60 mm (distance between the two supporting pins). The specimen was arranged in the three-point bending test configuration. A 100-kN Instron 3382 universal testing machine (Instron, Massachusetts, USA) was used to run the flexural test. Using the flexural load and deflection data obtained from the test, the flexural stress and strain were calculated for each specimen. These values were used to plot the stress-strain curve to obtain the flexural modulus of the composites. A minimum of five specimens for each composite system were tested to determine their properties.

## III. RESUTLS AND DISCUSSION

### A. Flexural Properties of the CNT-Kenaf/Epoxy Composites

Fig. 1 shows the flexural stress-strain curves of CNT-kenaf (C-KFRP) epoxy composites compared with the neat KFRP epoxy composite while Table I shows their flexural properties calculated from the stress-strain curves. From the curves, C-KFRP composites system with 0.5wt.% CNT displayed the highest flexural strength with 74% increment, followed by C-KFRP system with 1.0wt.% CNT with 54% and 1.5wt.% CNT with 42% improvement as compared to the neat KFRP system. The flexural modulus was calculated from the slope of the curve at 0.1% to 0.25% strain value. The slope of the graph reflect modulus of the system; indicating the stiffness of the system where steeper curve showed more stiffer system. From the graph, it can be observed that 0.5wt% C-KFRP system exhibited the highest modulus; where the calculated value showed an increment of 183% corresponding to the neat system. The addition of 1.0wt% CNT improved the modulus by 178% and addition of 1.5wt% CNT improved the modulus by 47%, respectively. This proves that the existence of CNT nanofiller in the system enhanced the flexural properties by preventing the deformation to propagate through the system.

Despite of the improvement by the CNT existence, it is also important to take note on the dispersibility of the CNT, where for the C-KFRP system with higher CNT loading, the mechanical properties were slightly lower than C-KFRP system with less CNT. This could have been caused by the agglomeration of CNT in the epoxy matrix, which occurs at higher CNT loadings owing to the strong van der walls forces between the CNT.

In order to overcome this agglomeration problem, it is suggested to the functionalization on the CNT surface to improve the interfacial bonding between the CNT, fibre and the epoxy matrix. Sapiai et al. [24] found that the functionalization of the CNT using silane modification had proven to be beneficial in enhancing the dispersibility and reducing agglomeration of CNTin the epoxy matrix. Other than the functionalization, the solvent could be used to enhance the dispersibility of the CNT in the epoxy resin as conducted by U. R. Hashim et al. [25] where the mechanical properties was improved due to effective dispersion technique.

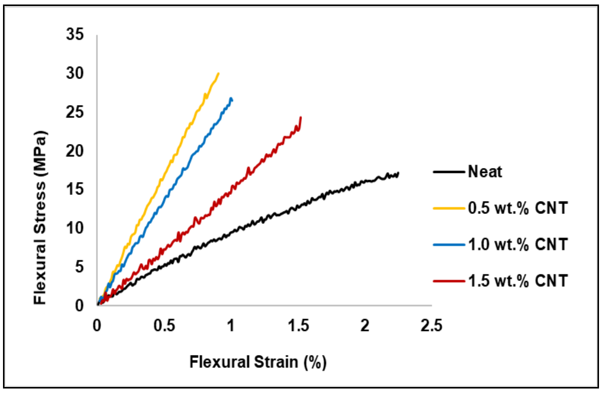


**Fig.1. Flexural stress-strain curves of the C-KFRP epoxy composites**

**Table-I: Flexural properties of the C-KFRP epoxy composites**

| CNT Content | CNT-filled KFRP Composites | | |
|---|---|---|---|
| | ***Flexural Strength ($\sigma_f$) (MPa)*** | ***Flexural Strain ($\varepsilon_f$) (%)*** | ***Flexural Modulus ($E_f$) (GPa)*** |
| Neat | 17.1657 ± 2.321 | 2.261 ± 0.013 | 0.992 ± 0.077 |
| 0.5 wt.% | 29.941 ± 4.423 | 0.931 ± 0.133 | 2.810 ± 0.072 |
| 1.0 wt.% | 26.452 ± 6.843 | 1.018 ± 0.121 | 2.767 ± 0.286 |
| 1.5 wt.% | 24.289 ± 6.811 | 1.543 ± 0.029 | 1.462 ± 0.317 |

## B. Flexural Properties of the CNT-Carbon/Epoxy Composites

Fig. 2 shows the flexural stress-strain curve of CNT-Carbon (C-CFRP) epoxy composites as compared to the neat CFRP epoxy system. The flexural properties, such as the flexural strength, flexural strain at break, and flexural modulus, were calculated and tabulated in Table II. There was a major increase in the flexural strength of the 0.5wt.% C-CFRP composite system with 29% improvement compared to the neat CFRP composite. This system showed the highest flexural strength as compared to other systems. Different trend with the C-KFRP system was observed for flexural strength of the C-CFRP, where 0.1wt% C-CFRP showed an improvement by 18%, meanwhile the reduction of 6% was observed for the 1.5wt% C-CFRP system. This might be attributed to the improper dispersion and aggregation of CNT that acts as the stress concentrators in the polymer matrix which lead to the drop in the flexural strength of the latter system. Similar condition were observed for the flexural modulus values where 0.5wt% C-CFRP showed the highest modulus values with 40% improvement, followed by 1.0wt% C-CFRP with only 4% improvement. On the other hand, the 1.5wt% C-CFRP system showed the reduction in modulus by 40%. The reduction in the flexural modulus of 1.5wt% C-CFRP system could be due to the improper wetting of the composite specimen. This outcome was similar to the finding of Yue et al. [26] which indicated that the addition of 0.5 wt.% CNT is the optimum value to increase the flexural strength of the FRP composites. In terms of strain, the addition of CNT reduced the strain where this showed that the system had become more brittle as compared to the neat KFRP as well as CFRP system.

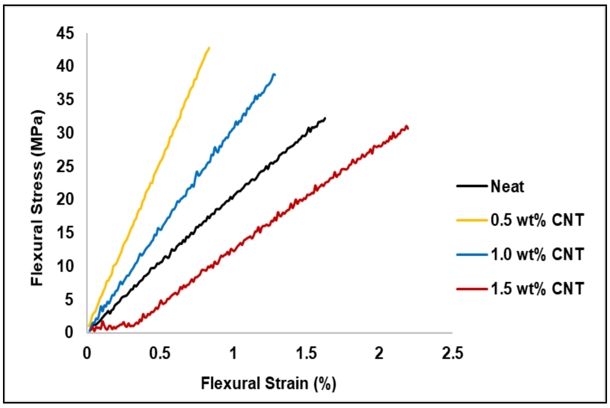


**Fig. 2. Flexural stress-strain curves of the CNT-Carbon/Epoxy**

**Table-II. Flexural Properties of the CNT-Carbon/ Epoxy Composites**

| CNT Content | CNT-filled CFRP Composites | | |
|---|---|---|---|
| | ***Flexural Strength ($\sigma_f$) (MPa)*** | ***Flexural Strain ($\varepsilon_f$) (%)*** | ***Flexural Modulus ($E_f$) (GPa)*** |
| Neat | 32.856 ± 3.393 | 1.660 ± 0.316 | 2.078 ± 0.285 |
| 0.5 wt.% | 42.256 ± 16.069 | 0.912 ± 0.249 | 2.901 ± 0.341 |
| 1.0 wt.% | 38.754 ± 2.179 | 1.310 ± 0.229 | 2.151 ± 0.356 |
| 1.5 wt.% | 30.597 ± 7.216 | 2.217 ± 0.619 | 1.240± 0.168 |

In order to compare the flexural properties of the C-KFRP and C-CFRP composites, it could be deduced that the CFRP properties are not in the same league as the KFRP due to its much higher strength correponding to the KFRP. However, as for the alternative purposes, KFRP could be considered as a strong potential to be used as an alternative natural material, based on the positive results of the flexural strength and modulus.

Moreover, the addition of CNT improved their mechanical properties by utilizing a proper mixing process to avoid agglomeration of the nanofillers, which led to stress concentration and a reduction in the mechanical properties of the systems.

## IV. CONCLUSION

Chopped FRP composites with the addition of CNT nanofiller were successfully developed in this study. The flexural properties of C-KFRP and C-CFRP were investigated and analyzed. Several conclusions are drawn and outlined as follows:

1. The addition of CNT in the chopped FRP composites showed detrimental effects on their flexural properties. The proper incorporation of CNT into the epoxy composites remarkably improved the flexural strength and modulus of the kenaf and carbon systems. The results showed that the 0.5 wt.% CNT loading caused the greatest improvement in the carbon and kenaf composites, in terms of the flexural strength and modulus.
2. Kenaf fibre composite have a strong potential to be used as an alternative material to commercial fibres because of the promising mechanical properties specifically in flexural as compared to the synthetic fibres.

## ACKNOWLEDGMENT

The authors would like to thank the Universiti Teknologi MARA (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is conducted at the Faculty of Mechanical Engineering, UiTM, Malaysia under the support of Research Entity Initiative (REI) grant no: 600-IRMI/DANA 5/3/REI (11/2017).

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