*International Journal of Engineering & Technology*, 7 (4.18) (2018) 60-64

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

*Research paper*

# Unidirectional and Transverse Tensile Properties of Nanoclay Filled Kenaf/Glass Fibre Hybrid Composites

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## Abstract

Nowadays, hybrid continuous natural and synthetics fibre reinforced polymer nanocomposites have attracted substantial attention among researchers due to various benefits possesses by the natural fibres, synthetics fibres and nanofillers. Kenaf fibre is a natural fibre that has become one of the high potential candidates to replace synthetic fibres in polymer composite. Kenaf fibre exhibits good strength and modulus properties, low density, and non-abrasive during processing and biodegradable. Glass fibre composite has comparable modulus and strength to weight ratio properties to natural fibre composite. This study is aimed to evaluate the effect of nanoclay on longitudinal and transverse tensile properties of unidirectional (UD) kenaf/glass fibre hybrid composite (KGC). The UD KGC samples were prepared based on three different nanoclay content; i.e. 1, 3 and 5 wt. %. The $0^o$ and $90^o$ tensile tests were conducted in accordance to ASTM standard D3039 in order to obtain longitudinal and transverse tensile properties of unmodified and nanoclay-modified kenaf/glass composites. The results showed that the addition of nanoclay produced a substantial increase in UD tensile modulus, strength and failure strain of the KGC. UD tensile modulus, strength and strain of the KGC improved significantly by 120%, 76.4% and 68.73%, respectively, with the addition of 3wt% nanoclay when compared to the unmodified system. However, it was found that the transverse tensile properties of the KGC showed a slight increase in transverse tensile modulus, strength and strain by 16.12%, 21.85% and 30.77%, respectively, with addition of 3wt% nanoclay.

**Keywords**: *Natural fibre composites; Hybrid composites; Nanocomposites; Tensile properties*

## 1. Introduction

Hybridization is a method to combine the features of different types of materials[1][2][3]. In composites structures, natural fibres have become one of emerging interests of scientists, researchers and engineers to implement products that are environmental friendly[4][5][6]. Natural fibres are low cost materials that have low density and good strength. It also produces less pollution during production thus resulting in minimal health hazards and eco-friendly nature. Composites reinforced with natural fibres have a short lifetime when it comes to degradation with limited environmental damage whereas, synthetic fibres have a negative impact due to degradation pollution [7]. However, because of the nature of natural fibre which possess high polarity to absorb the liquid form of polymer, the bonding between the fibres and polymers will become weak after the polymer for example epoxy has been set or cured [8]. Therefore, to improve the overall features of this type of composites, hybridization of natural fibre with synthetics fibres should be employed [9][10]. This improvement will widen the application of natural fibres composites to be use in more critical applications, other than reducing the usage of synthetics fibre in certain application. Other than that, the impregnation of nanofibers in polymer composites has been proven to provide additional features of this composites and giving its unique properties.

In this paper, the focus of the research is on the effect of nanoclay in glass fibre-kenaf hybrid composites (KGC) on its tensile properties. It is important to note that the dispersion of nanoclay is an important criterion to exploit its nanoform features. Therefore, in this experiment, the mixture of nanoclay and epoxy has been dispersed using three roll mills to improve its dispersion. Kenaf is one type of the natural fibres that has been research widely. It is an annual fibre crop, which is one of the advantages, it can be produced all year long. It can grow up to 3-4 metres height and takes about 3-4 months to achieve the maturity. The tensile strength of kenaf is reported between 195-666 MPa with tensile modulus of 60-66 GPa. Kenaf has been used to make ropes and animal consumption for at least 4,000 years [11].

Glass fibre is among the oldest fibre used in polymer composites. The density and strength properties of glass fibre are comparable to those of natural fibre composite. It has high strength to weight ratio and low corrosion resistance [12]. Addition of nanofibre has been studied extensively for the last decades. From the previous research, the nanoform structured fibres has significantly improves the overall properties of reinforced fibre composites[13][14]. Plate-like montmorillonite is the most commonly used nanoclay in materials applications. It is a low cost with high elastic modulus nanoplate to be added in composites. In this paper, the unidirectional and transverse tensile properties of the composites are studied.

## 2. Materials and Method

### 2.1 Materials

Figure 1 shows the materials used in this study. The epoxy resin and hardener used for this study were supplied by Miracon (M) Sdn Bhd, Malaysia. Nanoclay (I30)) were used as filler where these materials supplied by Nanocor Inc.USA. Nanoclay I.30E is an onium surface modified montmorillonite mineral. While the yarn kenaf fibres (as shown in Figure 1) was supplied by Innovative Pultrusion Sdn. Bhd, Seremban, Malaysia. The unidirectional glass fibre was supplied by China Nationa lBuilding Materials (Group) Corporation,Composite Division.N196 is an E glass direct roving. Materials used and suppliers are summarized in Table 1.


**Fig. 1 :** Materials used ; (a) glass roving; (b) kenaf yarn; (c) montmorillonite clay; (d) epoxy

**Table 1:** List of materials used

| Materials used | Source of Materials |
|---|---|
| Kenaf Fiber | Innovative Pultrusion Sdn Bhd. |
| Unidirectional Glass Fiber (N196 E glass Direct Roving) | China National Building Materials (Group) Corporation, Composite Division |
| Epoxy (Miracast 1517 Part A) | Miracon (M) Sdn Bhd. |
| Hardener (Miracast 1517 Part B) | Miracon (M) Sdn Bhd. |
| Nanoclay (Montmorillonite clay, I30E) | Nanocor |

### 2.2 Fabrication of Composite

The continuous kenaf fibres were wound onto 430 x 300 mm aluminum plate frame. After kenaf being wound on the aluminum frame, glass fibre roving is wound onto kenaf plate. The wound fibres were impregnated in polymer matrix. The ratio of epoxy and hardener used was 100:30. Before the impregnation of the polymer, the epoxy first was degassed under high vacuum machine for 1 hour, followed by adding the hardener at ratio 100:30 (epoxy: hardener). Degasification process was employed to remove entrapped air during the composite fabrication Polymer matrix used was an epoxy resin which consists of Miracast 1517 A/B DGEBA epoxy resin and amine-curing agent (hardener). The impregnated fibres frame was then left to cure at room temperature and 515Pa pressure for 24 hours. Finally, the samples were post cured at 60$^{o}$C for 2 hours, followed by 80$^{o}$C for 2 hours, 100$^{o}$C for 2 hours and 120$^{o}$C for 2 hours. After curing, the kenaf glass reinforced polymer (KGC) composite plate was obtained by cutting-off the frame. Figure 2 shows KGC plate before it was cut into specific specimen for testing. For nanomodified composites, the nanoclay was added in the epoxy before inserted into three roll mills (as shown in Figure 2) to increase the dispersion of nanoclay in epoxy. After that the same process was done to produce nanomodified composite. 3 different weight percentage of nanoclay was chosen to be added into the epoxy polymer (1, 3 and 5%) to the study the effect of different percentage of nanoclay added towards its properties. Table 2 shows the lists if composite systems that are fabricated in this study.

**Fig. 2 :** Cured Kenaf Composite plate

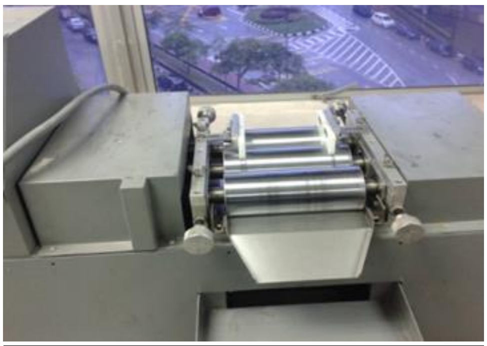

**Fig. 3 :** three roll mills

**Table 2 :** Lists if composite systems that are fabricated in this study

| Composite systems | Abbreviation |
|---|---|
| Hybrid Kenaf/Glass fibre reinforced polymer composite | KGC |
| 1 wt% nanoclay in hybrid Kenaf/Glass fibre reinforced polymer composite | 1cKGC |
| 3 wt% nanoclay in hybrid Kenaf/Glass fibre reinforced polymer composite | 3cKGC |
| 5 wt% nanoclay in hybrid Kenaf/Glass fibre reinforced polymer composite | 5cKGC |

### 2.3 Tensile Test

In longitudinal and transverse tensile tests, the composite plates were cut into two different dimensions for longitudinal tensile test at $0^o$ fibre direction and transverse tensile test at $90^o$ fibre direction. Longitudinal tensile tests were conducted on rectangular specimens of 15 mm width x 250 mm overall length (with 56 mm tab length) and 4.5 mm average thickness. Transverse tensile tests were conducted on rectangular specimens of 25 mm width x 175 mm overall length (with 25 mm tab length) and 4.5 mm average thickness. The tests were conducted in accordance to ASTM Standard D3039 using an Instron Universal Tester machine and the BlueHill data acquisition software. Tensile tests were conducted on unidirectional (UD) laminates at $0^o$ and $90^o$ fibre directions to determine longitudinal and transverse tensile stress, tensile strain, maximum load, extension at maximum load and Young's modulus. A 100 kN load cell and 25 mm gauge length clip-on extensometer was used to record the applied load and elongation data. The tensile tests were conducted at a crosshead speed of 2 mm/min. Table 3 shows the list of sample dimension for unidirectional and transverse tensile test.

**Table 3 :** List of samples dimension

| ASTM 3039 | Size |
|---|---|
| Tensile Test ($90^o$) | 25mm x 175mm x 4mm |
| Tensile Test ($0^o$) | 15mm x 250mm x 4mm |

### 2.4 Density Test

The density of the composite was determined using Archimedes' Principle. 200ml of water is prepared in a beaker. The temperature of the water is measured to determine the density of the water used. The water-filled beaker is placed onto a scale. A receptacle was used to hold the specimen while measuring both its dry and wet weight. Three samples were used for each specimen in this test to determine its density. The density of specimen of size 15×15 mm was calculated using equation (1):

$$\rho_{sample} = \frac{A}{A-B} \times [(\rho_{water} - d) + d] \quad (1)$$

Where

| | |
|---|---|
| $\rho_{sample}$ | Density of specimen |
| $\rho_{water}$ | Density of water **(0.99754 g/cm$^3$)** |
| **A** | Weight in air |
| **B** | Weight in liquid |
| **d** | Density of air **(0.001 g/cm$^3$)** |

## 3. Materials and Method

### 3.1 Unidirectional and Transverse Tensile Test Results

Referring to Figure 4, it is shown that, the unidirectional tensile modulus for natural fibre/glass composites increases with the inclusion of nanoclay. It presented that the unidirectional tensile modulus for kenaf /glass composite without additional of nanoclay (KGC) is 6.17 Gpa. The tensile modulus for longitudinal direction of fibres in the composites increase linearly with increasing nanoclay percentage in the composite. Tensile modulus for 1wt% nanoclay in kenaf/glass composites (1cKGC) is 13.58 GPa while 3wt% nanoclay in kenaf/glass composites (3cKGC) is 13.95 GPa and 5wt% nanoclay in kenaf/glass composites (5cKGC) is 14.37GPa. It is revealed that with the addition of nanoclay in kenaf glass reinforced polymer composite, the tensile modulus of increased significantly from 6.17 GPa to 13.58 GPa, which is increased about 120%. The tensile modulus keeps increasing with the additional of more weight percentage nanoclay platelet in the kenaf glass reinforced composite.

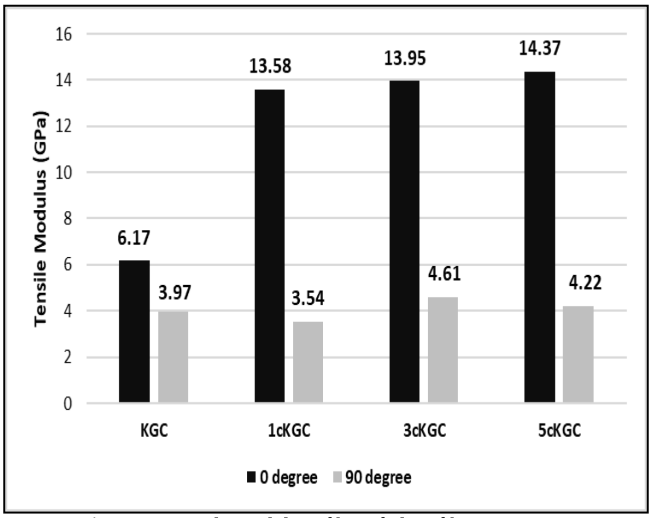


**Figure 4:** Tensile modulus of kenaf glass fibre composite

For transverse direction of fibres, the tensile modulus of KGC is 3.97 GPa, while 1cKGC is 3.54 GPa. However, further increase in the amount of nanoclay improved the transverse tensile modulus where the modulus for 3cKGC and 5cKGC is 4.61 GPa and 4.22 GPa, respectively. This shows that the addition of nanoclay in KGC does not significantly improved the transverse tensile modulus as compared to the UD tensile modulus.

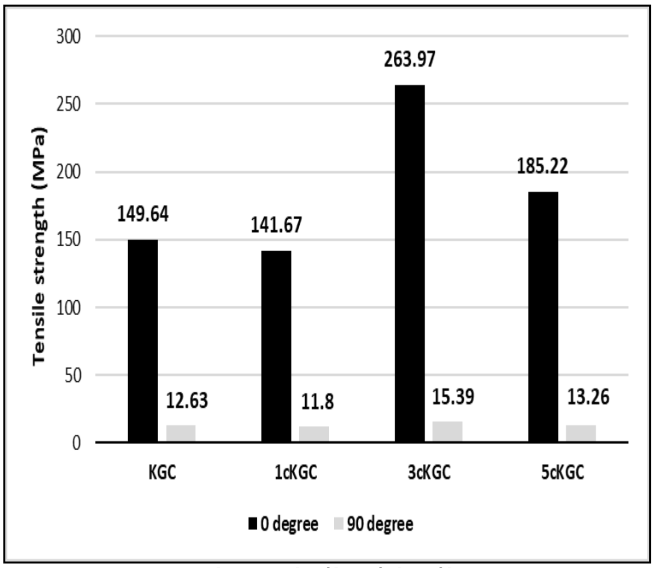


**Figure 5:** Tensile strength of kenaf glass fibre composite

Figure 5 shows the effect of nanoclay addition on tensile strength of KGC. It is displayed that the tensile strength for KGC without nanoclay inclusion for unidirectional fibre direction is 149.64 MPa. The tensile strength decreases by 5% with the inclusion of 1wt.% nanoclay, which can be concluded as an insignificant change. The strength, however, increased by 76.4% when 3wt% of nanoclay was added into the KGC. The UD tensile strength of 3cKGC is 263.97 MPa. The UD tensile strength of 5cKGC is 185.22 MPa, though the strength of 5cKGC is lower compare to 3cKGC but it is higher than KCG by 23.77%. This may be due to the presence of nanoclay agglomeration in the polymer matrix that deposited on the fibre surface at a high nanoclay content (of 5wt%). This causes lower adhesion strength between nanoclay and epoxy matrix. It is exposed that with the addition of nanoclay platelet in kenaf glass composites, the tensile strength for unidirectional fibre increases, especially for 3wt% of nanoclay. For transverse fibre direction, the transverse tensile strength is 12.63 MPa for KGC, 11.8 MPa for 1cKGC, 15.39 MPa for 3cKGC and 13.26 MPa for 5cKGC. It can be seen that, the addition of nanoclay in kenaf glass composites slightly improved the transverse tensile strength, where the biggest difference between the transverse strength of KCG and 3cKGC is about 21.85%.

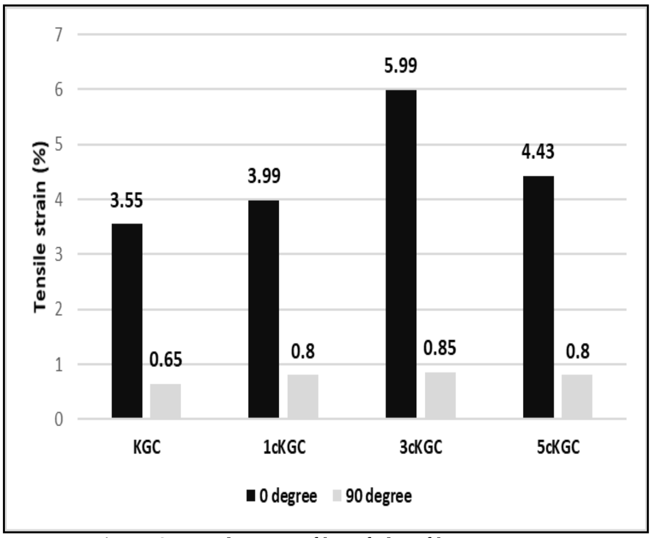


**Figure 6:** Tensile strain of kenaf glass fibre composite

Figure 6 shows the tensile strain for KGC with nanoclay addition. Tensile strain for UD KGC is 3.55% and increases with the inclusion of nanoclay. The UD tensile strains are 3.99, 5.99 and 4.43 for 1cKGC, 3cKGC, and 5cKGC, respectively. While tensile strain for transverse fibre direction for KGC is 0.65 and increases with the inclusion of nanoclay. The strains are 0.80, 0.85 and 0.80 for 1cKGC, 3cKGC, and 5cKGC respectively. It can be concluded that, with the addition of nanoclay, the materials become less brittle. When compared, the change between UD tensile strain of KGC and 1cKGC is 12.39%, KGC and 3cKGC is 68.73% and 24.78% between KGC and 5cKGC. For transverse tensile strain, the difference between KGC and 1cKGC is 23.07%, 30.77% between KCG and 3cKGC, and 23.07% between KGC and 5cKGC. Therefore, the nanoclay addition is insignificantly affect the UD and transverse tensile strain.

### 3.2 Density Result

The densities of each specimen are as in Table 4. The density of KGC is 1.244g/cm$^3$, 1cKGC is 1.25g/cm$^3$, 3cKGC is 1.312g/cm$^3$ and 1.269g/cm$^3$ for 5cKGC.

**Table 4:** Density of kenaf glass composite

| Specimens | Density (g/cm$^3$) |
|---|---|
| KGC | 1.244 |
| 1cKGC | 1.250 |
| 3cKGC | 1.312 |
| 5cKGC | 1.269 |

The difference is 0.48% between KGC and 1cKGC, 5.466% between KGC and 3cKGC, 2% between KGC and 5cKGC. It can be observed that the density of the composite increases as the percentage of nanoclay increases. However, there is no significantly change in density since the amount of nanoclay added into the KGC composite system is small. The drop of density from 1.312 g/cm$^3$ for 3cKGC to 1.269 g/cm$^3$ for 5cKGC shows the evidence of air entrapped or microvoids inside the composite. This may be the reason of declining values of unidirectional and transverse tensile modulus and strength of the composites added with 5wt% nanoclay. The presence of microvoids reduces the load transfer between fibre and the matrix hence reduces the properties of the composites.

## 4. Conclusion

From the results, it can be concluded that the addition of nanoclay in kenaf/glass hybrid composites increases the unidirectional tensile modulus where the significance difference between KGC and 5cKGC is by 132.9%. However, addition of nanoclay in KGC shows slight improvement in transverse tensile modulus. Addition of nanoclay in kenaf glass composites also significantly increases the unidirectional tensile strength. The biggest difference is between 3cKGC and KGC, which is 76.4%. Although the strength decreases for 5cKGC by 26.8% compared to 3cKGC, but value is still higher when compared to KGC. It may be due to agglomeration of nanoclay that causes an incomplete wetting process and also the presence of microvoids due to a high viscosity of resin at a very high nanoclay content (of 5wt%). These defects interrupt the interface between epoxy and fibre and therefore, the fibre unable to fully bear the load given. Density of kenaf glass composites increases with the addition of nanoclay. However, a slight decrese in density occurs from 1.312 g/cm$^3$ for 3cKGC to 1.269 g/cm$^3$ for 5cKGC. This shows the evidence of the presence of microvoids in the composites. This defect reduces the load transfer between fibre and the matrix hence reduces the properties of the composites at a very high nanoclay content (5wt%). In general, it can be concluded that, addition of 3wt% nanoclay in kenaf glass hybrid composites significantly improves the unidirectional tensile modulus, strength and strain and slightly improves the transverse tensile modulus, strength and strain.

## Acknowledgement

The authors would like to thank the Institute of Research Management and Innovation (IRMI), Universiti Teknologi MARA (UiTM), Institute of Graduate Studies (IPSIS) UiTM and Ministry of Education Malaysia for the financial support. This research work was performed at the Faculty of Mechanical Engineering, UiTM ShahAlam Selangor Malaysia under the support of BESTARI research grant no. 600-IRMI/DANA5/3/BESTARI (0007/2016).

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