

EFFECT OF FIBRE TREATMENT ON LONGITUDINAL AND TRANSVERSE TENSILE PROPERTIES OF UNIDIRECTIONAL KENAF COMPOSITE

Norhashidah Manap, Aidah Jumahat*, Napisah Sapiai

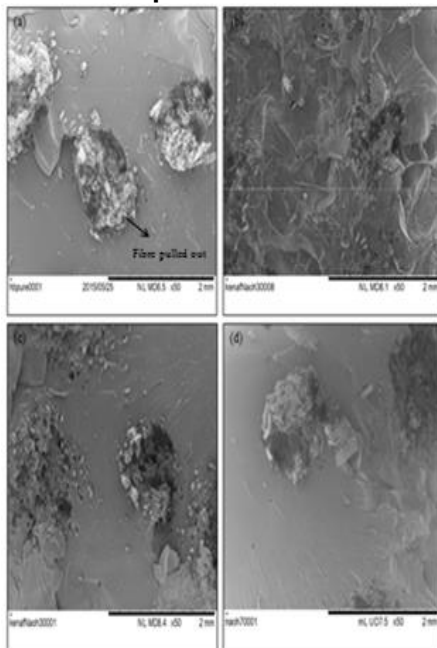
Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

Article history

Received
15 February 2015
Received in revised form
30 April 2015
Accepted
30 June 2015

*Corresponding author
aidahjumahat@salam.uitm.edu.my

Graphical abstract



Abstract

Kenaf fibre has become one of the best candidates to be used as reinforcement material in polymer composite. However, the adhesion between natural fibre and polymer is weak due to different polarity of natural fibre and hydrophobic polymer. This affects the properties of the composite. One of the method to overcome this compatibility issue is by treating the fibre using sodium hydroxide (NaOH). This study is aimed to evaluate the effect of NaOH treatment on longitudinal and transverse tensile properties of kenaf composites using three different concentration (3, 5, and 7 wt. % NaOH). The kenaf composite test specimens were prepared using filament winding and vacuum bagging techniques. The 0° and 90° tensile tests were conducted in accordance to ASTM standard D3039 in order to obtain longitudinal and transverse tensile properties of treated and untreated kenaf composites. The fracture surfaces of the specimens were observed using scanning electron microscope in order to identify fracture mechanisms involved during tension. NaOH treatment on kenaf fibre resulted in a significant improvement in longitudinal tensile modulus, strength and failure strain. This also indicates an improvement in toughness property as this can be observed through a larger area under graph of tensile stress-strain curve. The SEM micrographs showed that the interfacial adhesion between kenaf fibre and epoxy matrix was improved when the kenaf fibre was treated using NaOH. Therefore, NaOH treatment give positive effects on longitudinal and transverse tensile properties of kenaf composites. Kenaf composite treated with 7wt% NaOH showed the highest tensile strength for both longitudinal and transverse fibre directions.

Keywords: Kenaf treatment, tensile properties, kenaf composites, nanosilica, polymer composite.

© 2015 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

The studies on polymer composites have attracted many researchers, scientist, engineers and academician due to the properties of composite materials can be tailored according to the required application. In polymer composites, one of the most important materials is reinforcement fibre. It acts as load barrier, carrier and transfer. It significantly affects the properties of the composites. The mechanical properties of fibre reinforced polymer composite materials mainly depend on properties of

reinforcing fibre, properties of matrix, fibre direction or alignment of the continuous fibre, fibre volume fraction and void content. Most of the fibres used in polymer composites are synthetic fibres for example, carbon fibre, glass fibre and Kevlar fibre [1]-[2]. They possess good strength for load barrier and have been used in many critical applications which require light-weight and high-strength materials. Recently, emerging of interest in natural fibre has become new phenomenon since it has promising properties to be used in future industries for structural and non-structural industries. Other than ecological and

environmentally friendly, the fibres have low density and good specific modulus and strength properties and can be obtained at lower price when compared to the synthetic fibres [1]–[5]. However the major drawback of using natural fibre in polymer matrix composites is poor bonding between the fibre and matrix which results in lower mechanical properties of the composites when compared to those of synthetic fibre composites. The high moisture absorption of natural fibre makes the fibre tend to swell when incorporated with polymer thus the composite is debonded when cured. In order to fully utilize the natural fibre in polymer composite, a treatment should be done on the fibre whether physically or chemically [6]–[10]. Mercerization is one of the techniques of chemical treatment. It is one of most widely used to treat natural fibre because of its simplicity. This chemical treatment aims to increase surface roughness other than increasing the amount of cellulose that exposed on the surface fibre. Therefore, the number of possible reaction sites in between fibre and matrix is increased. This study is aimed to evaluate the effect of sodium hydroxide (NaOH) treatment on tensile properties of continuous kenaf fibre reinforced polymer composites using three different concentration (3, 5, and 7 wt. % NaOH).

2.0 EXPERIMENTAL

2.1 Materials

The epoxy resin and hardener used for this study were supplied by Miracon (M) Sdn Bhd. The sodium hydroxide used was supplied by R & M chemicals in pellet forms. It was used in three different weight percentages (3, 5 and 7 wt. %). The kenaf fibres yarn was supplied by Innovative Pultrusion Sdn. Bhd.

2.2 Kenaf Treatment

The treatment of kenaf fibre started with soaking the kenaf yarn into distilled water at temperature of 70°C for 2 hours. The fibre was then dried in oven at temperature of 105°C for 12 hours before soaked into 3 different weight concentration of sodium hydroxide (NaOH) (3, 5, 7wt%). Kenaf bundle was then soaked in the solution for 2 hours at room temperature. After that, the fibres were washed using distilled water with drops of acetic acid to neutralize back the pH of the fibre for several times until the pH of the solution was neutralize to pH 7. Then the fibres were left for 2 days to dry at room temperature before once again oven dried at 80°C for another 6 hours to make sure the fibres are completely dry. Figure 1 illustrates the process of kenaf treatment started from chemical treatment using NaOH until the fibres were wound onto aluminium frame for preparation of kenaf composite plate.

2.3 Fabrication of Kenaf Composite Specimens

The treated continuous kenaf fibres were wound onto 430 x 300 mm aluminium plate frame. The wound fibres were impregnated in polymer matrix. Polymer matrix used was an epoxy resin which consists of Miracast 1517 A/B DGEBA epoxy resin and amine-curing agent (hardener). The ratio of epoxy and hardener used was 100:30. The impregnated fibres frame were vacuumed and left to cure at room temperature and 515Pa pressure for 24 hours. Finally, the samples were post cured at 60°C for 2 hours, followed by 80°C for 2 hours, 100°C for 2 hours and 120°C for 2 hours. After curing, the kenaf reinforced polymer (KFRP) composite plate was obtained by cutting-off the frame.



Figure 1 Treatment process of kenaf fibre

2.4 Longitudinal and Transverse Tensile tests

The KFRP composite plates were cut into two different dimensions for longitudinal tensile test at 0° fibre direction and transverse tensile test at 90° 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° and 90° 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 were used to record the applied load and elongation data. The tensile tests were conducted at a crosshead speed of 2 mm/min.

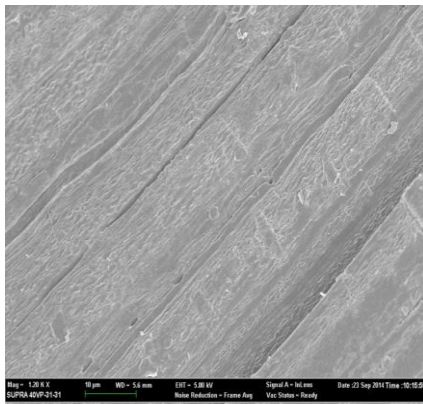
2.5 Observation on fibre and fractured surface

The Field Emission Scanning Electron Microscope (FESEM), SUPRA 40 VP (Carl Zeiss) was used to observe the morphology of fibre surface and to identify the fracture mechanisms involved during tensile test of KFRP composite specimens. The fracture surfaces perpendicular to the loading direction or the longitudinal splits were observed by sectioning the area of interest and mounted onto suitable holder. Sections were mounted onto aluminum stubs using carbon adhesive patch. The specimens were then coated with thin layer of platinum using sputter coater.

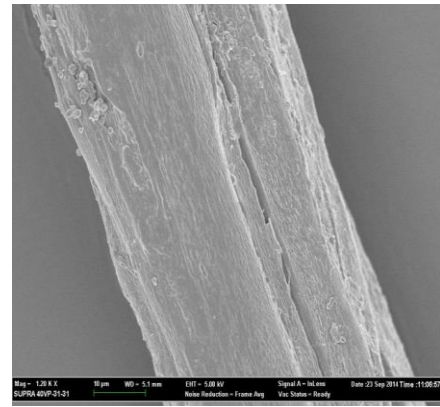
3.0 RESULTS AND DISCUSSION

3.1 Morphological structure of kenaf fibre surface

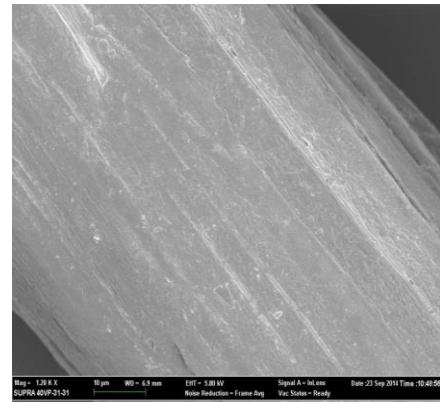
As received kenaf fibre and treated kenaf fibre were observed under FESEM to view their microstructure at 1200x magnification. It was shown that in Figure 2, kenaf fibres were smoother and cleaner for 3 and 5 wt% of NaOH treatment (see Figures 2b and 2c) when compared to the untreated fibre (see Figure 2a) due to lignin removal. When the fibres were treated at high percentage of NaOH (at 7 wt%, see Figure 2d), the microstructure of kenaf fibre surface has become rougher when compared to the fibres treated with lower NaOH weight percentages.



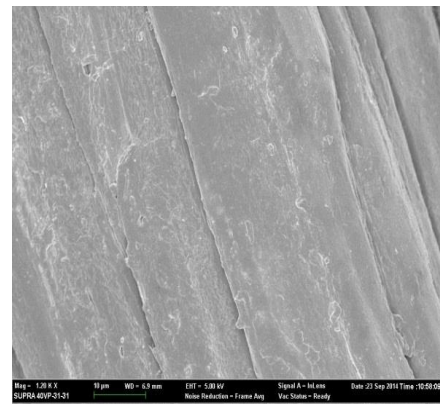
(a)



(b)



(c)



(d)

Figure 2 SEM micrographs showing four different kenaf fibre surfaces (under 1200x magnification): (a) as received kenaf, (b) 3wt.% NaOH treated kenaf, (c) 5wt.% NaOH treated kenaf and (d) 7wt.% NaOH treated kenaf

The morphological structures of fibres as observed under FESEM showed that kenaf treatment has removed impurities on fibre surface and it is believed that the hydrogen bonding of natural fibre has also been removed. Rough surface due to NaOH treatment of kenaf fibre may provide mechanical interlocking between fibre and matrix thus improving the interfacial bonding.

3.2 Longitudinal Tensile Properties

Figure 3 illustrates the typical longitudinal stress-strain curves of as-received kenaf fibre composites (K) and NaOH treated kenaf fibre composites with three different weight percentages (3, 5 and 7 wt% NaOH) which denoted by 3Na/K, 5Na/K and 7 Na/K. The graphs show bilinear pattern where an identical graph pattern was also reported by Fiore et. al [6]. Un-treated kenaf composites shows stress increases linearly proportional to the strain of up to 0.1% strain with modulus of elasticity of about 5 GPa. After 0.1% strain the graph shows a slight reduction in modulus of elasticity of about 3 GPa. The untreated kenaf composites fails at about 1.2% failure strain and 40MPa failure stress. When the fibre surface was treated with 7wt% NaOH, the first linear line and second linear line of the graph indicate improvement in modulus of elasticity values when compared to those of untreated kenaf composites. The 7Na/K graph shows that the stress increases linearly proportional to the strain of up to 0.22% strain with modulus of elasticity of about 6.5 GPa. After 0.22% strain the graph shows a slight reduction in modulus of elasticity of about 4 GPa. The untreated kenaf composites fails at about 1.6% failure strain and 65 MPa failure stress. Based on these typical longitudinal tensile stress-strain curves, as shown in Figure 3, it can be seen that the treatment on fibre surface using high percentage of NaOH (7wt%) contributes to a better properties of kenaf composites. This may be due to a stronger interfacial bonding in between kenaf fibre and epoxy matrix as contributed by a rougher fibre surface as shown in Figure 2d. As mention in the previous subsection, a rough surface due to NaOH treatment of kenaf fibre may provide mechanical interlocking between fibre and matrix. This contributes to a better interfacial bonding.

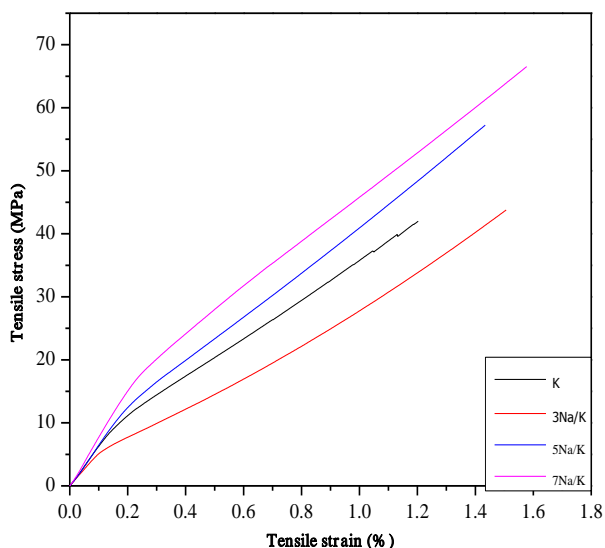


Figure 3 Typical longitudinal tensile stress-strain curves of untreated kenaf composites (K) and 3, 5 and 7 wt% NaOH-treated kenaf composites (3Na/K, 5Na/K and 7Na/K)

The longitudinal tensile tests were conducted on a minimum of 5 samples for each system. The average data on tensile properties were then calculated. The average longitudinal tensile properties of untreated and treated kenaf composites are given in Figures 4, 5 and 6. The results of average longitudinal tensile modulus of kenaf composite is shown in Figure 4. Figure 4 shows that the longitudinal tensile modulus of as received kenaf composite is 5.39 GPa. The modulus was slightly decreased when treated with 3 wt.% sodium hydroxide (3Na/K). The tensile modulus increased to 5.45 GPa for 5wt. % kenaf treated composite (5Na/K) and 5.6GPa for 7wt. % kenaf treated composite (7Na/K). Figure 5 shows the average longitudinal tensile strength of kenaf composite. Longitudinal tensile strength of kenaf composite shows that the tensile strength of as received kenaf composite is 53.36 MPa. The longitudinal tensile strength of kenaf composite has increasing trend when treated with sodium hydroxide. Tensile strength of 3Na/K is 59.84MPa and 64.82MPa for 5Na/K. 7Na/K shows the highest longitudinal tensile strength which is 79.18MPa. Figure 6 shows the average longitudinal tensile strain for kenaf composites. Longitudinal tensile strain at break of K is 1.49% and increased by 23.49% for 3Na/K. Longitudinal tensile strain of 5Na/K shows 1.78%. 7Na/K shows the highest value of tensile strain which is 2.31%.

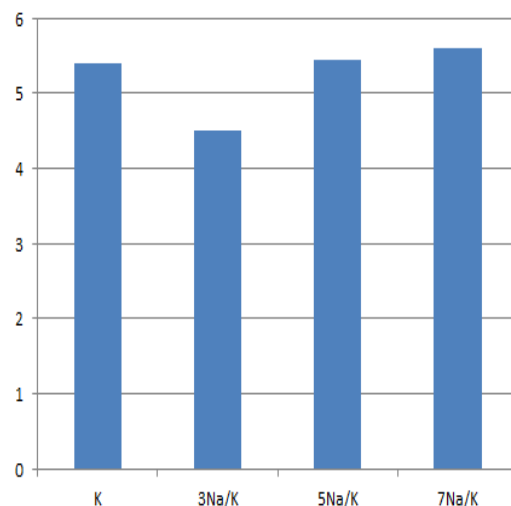


Figure 4 Longitudinal tensile modulus of kenaf composites

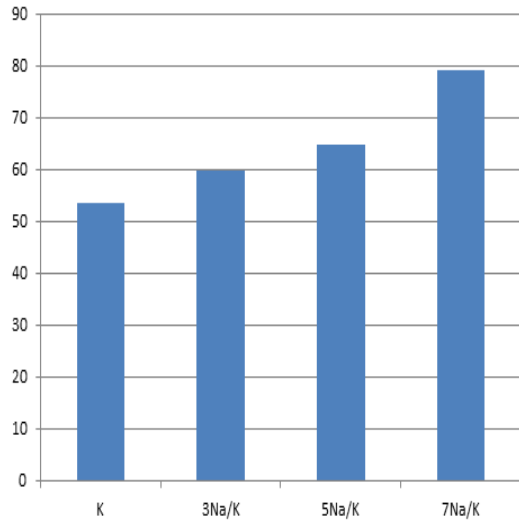


Figure 5 Longitudinal tensile strength of kenaf composites

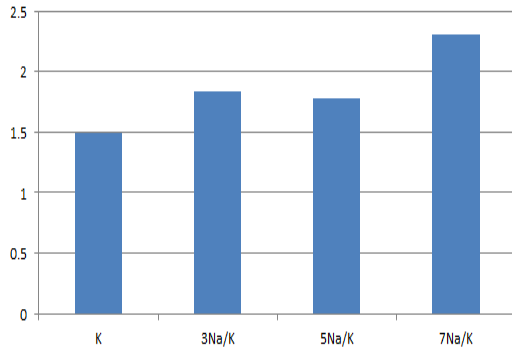


Figure 6 Longitudinal tensile strain at break (failure strain) of kenaf composites

3.3 Transverse Tensile Properties

Figure 7 shows the typical transverse tensile stress-strain curves of as-received kenaf fibre composites (K) and NaOH treated kenaf fibre composites with three different weight percentages (3, 5 and 7 wt% NaOH) which denoted by 3Na/K, 5Na/K and 7 Na/K. The graphs show a similar pattern as observed in longitudinal tensile stress-strain curve. Figure 7 shows a bilinear curve pattern. In general it can be seen that the treatment of kenaf fibre using 7 wt% NaOH results in improvement of Elastic modulus, Tensile strength and failure strain of kenaf composite as indicated in the graph, 7NaK curve compared to K curve. The transverse tensile tests were conducted on a minimum of 5 samples for each system. The average data on transverse tensile properties were then calculated. The average transverse tensile properties of untreated and treated kenaf composites are given in Figures 8, 9 and 10.

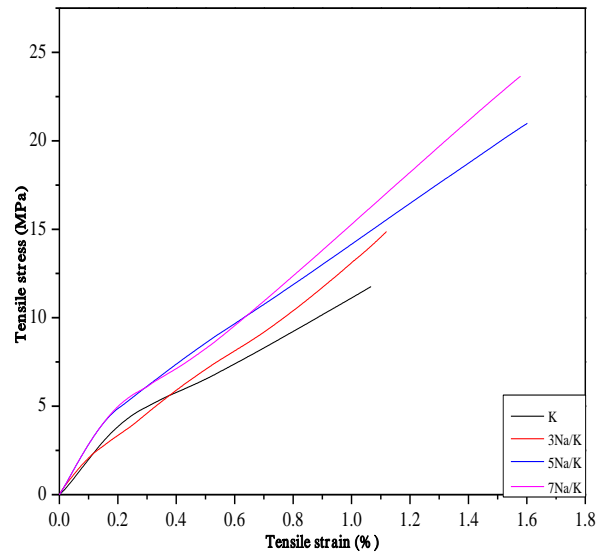


Figure 7 Typical transverse tensile stress-strain curves of untreated kenaf composites (K) and 3, 5 and 7 wt% NaOH-treated kenaf composites (3Na/K, 5Na/K and 7Na/K)

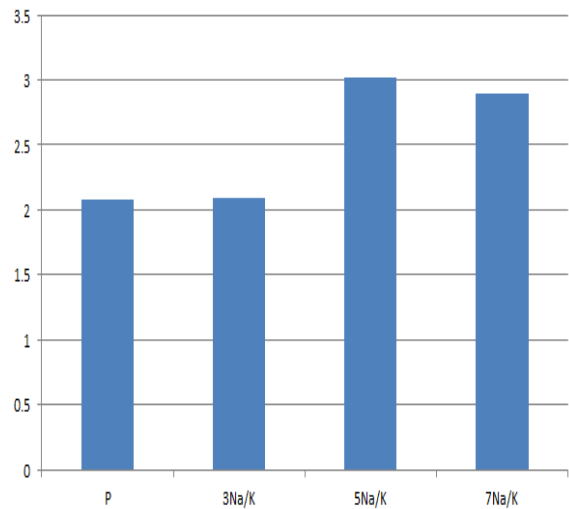


Figure 8 Transverse tensile modulus of kenaf composite

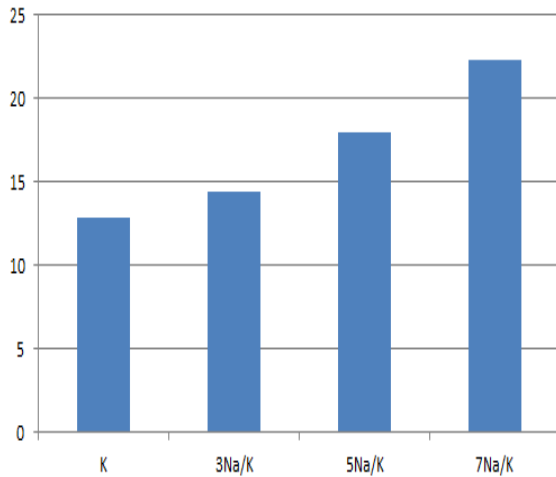


Figure 9 Transverse tensile strength of kenaf composite

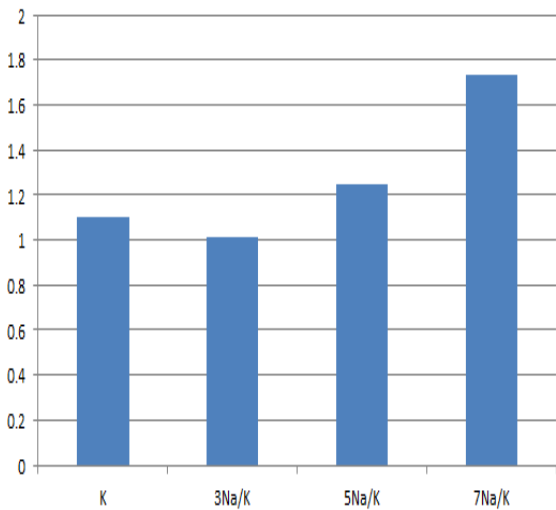


Figure 10 Transverse tensile strain of kenaf composite

Average transverse tensile modulus of kenaf composite is shown in Figure 8. Transverse tensile modulus of untreated kenaf composites, K is 2.081GPa. The transverse tensile modulus of kenaf composites increases when the fibre is treated with sodium hydroxide. Transverse tensile modulus of 3Na/K is 2.09GPa and 3.02GPa for 5Na/K. The transverse tensile modulus of 7Na/K is 2.9 GPa. These results showed that the sodium hydroxide treatment give positive effects on transverse tensile modulus. Average transverse tensile strength of kenaf composite is given in Figure 9. Transverse tensile strength of kenaf composite shows an increasing trend with increasing of sodium hydroxide concentration of kenaf treatment. Tensile strength for untreated kenaf composite, K is 12.74MPa. Treated kenaf composites showed higher transverse tensile strength values of 14.4 MPa for 3Na/K and 17.94MPa for 5Na/K. 7Na/K has the highest transverse tensile strength which is 22.19MPa. It shows that the sodium

hydroxide treatment gives positive effects on both longitudinal and transverse tensile strength properties. Figure 10 shows the average transverse tensile strain for kenaf composites. Transverse tensile strain at break of K is 1.1% and drop by 8.18% for 3Na/K. Transverse tensile strain of 5Na/K improved about 13% when compared to K. Transverse tensile strain at break of 7Na/K showed the highest value of transverse tensile strain at break which was 1.73% and about 57% higher than transverse tensile strain at break of K.

Tables 1 and 2 illustrate the summary of longitudinal and transverse tensile properties of four different systems of kenaf composites. The tables show the percentage of error of each average data. The data were taken based on a minimum of 5 test samples of each composite system.

3.4 Scanning Electron Microscope

Figure 11 shows the fracture surface of longitudinal fibre direction kenaf composite under scanning electron microscope at 50x magnification. Figure 11(a) shows the fracture surface of untreated kenaf composite, K. It can be seen that the fibre being pulled out from the matrix. This failure mode is a clear indication of ineffective load transfer between the matrix and the fibre. Figure 11(b) shows the fracture surface of 3Na/K composite. It can be seen that the interface between kenaf and epoxy is better compared to K where the kenaf debonding can be seen less than K. Kenaf fibre pull out was also decreased in the fracture surfaces of 5Na/K (Figure 11(c)) and 7Na/K (Figure 11(d)). These micrographs showed that the adhesion between kenaf fibre and epoxy for treated kenaf composite systems were better than the untreated kenaf composite system, K. For treated kenaf composite systems, the micrographs showed that epoxy matrix strongly adhered onto kenaf fibre surfaces.

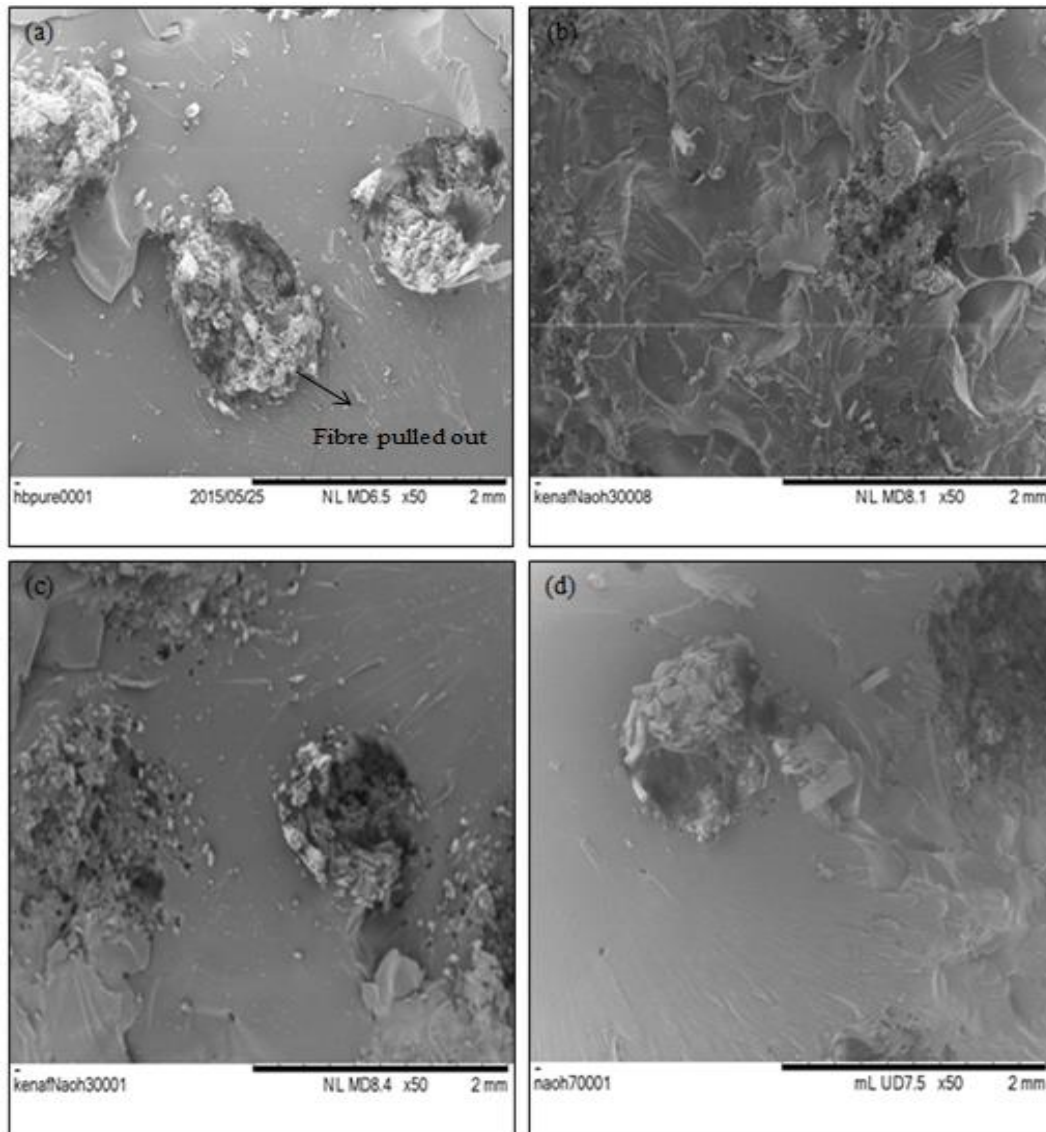
Figure 12 shows the fracture surfaces of transverse fibre direction kenaf composite observed under scanning electron microscope at 50x magnification. It can be seen that the transverse strength of untreated kenaf composites, K depends on the properties of epoxy matrix as shown in Figure 12(a). The fracture surface describes that the kenaf fibres unable to bear load in transverse direction where the fracture surface shows that the fracture occur at the matrix without involvement of fibres. It can be seen that the properties of matrix play important role for this untreated kenaf composite system. This result indicates that the strength of the composite depends mainly on the properties of the matrix. The fracture surfaces of 3Na/K, 5Na/K and 7Na/K (Figure 12 (b-d)) show the matrix failure and fibres debonding at interfaces in fibre direction. Kenaf fibres tend to support the transverse load and try to retain its shape. Fracture surfaces of 5Na/K and 7Na/K show that the failure occurs between the fibre and matrix interface. Therefore, this indicates good interfacial bonding between the treated kenaf fibre and matrix.

Table 1 Summary of longitudinal tensile properties of untreated and NaOH (3, 5 and 7 wt%) treated kenaf composites

| Material properties | K | 3Na/K | 5Na/K | 7Na/K |
|------------------------------|------------|-------------|------------|------------|
| Tensile modulus, (GPa) | 5.39±0.214 | 4.5±0.859 | 5.45±0.49 | 5.6±0.2 |
| Tensile strength, (MPa) | 53.36±8.5 | 59.84±10.36 | 64.82±7.78 | 79.18±1.69 |
| Tensile strain at break, (%) | 1.49±0.2 | 1.84±0.14 | 1.78±0.35 | 2.31±0.45 |

Table 2 Summary of transverse tensile properties of untreated and NaOH (3, 5 and 7 wt%) treated kenaf composites

| Material properties | K | 3Na/K | 5Na/K | 7Na/K |
|------------------------------|------------|-----------|------------|------------|
| Tensile modulus, (GPa) | 2.081±0.22 | 2.09±0.53 | 3.02±0.14 | 2.9±0.05 |
| Tensile strength, (MPa) | 12.74±1.43 | 14.4±2.21 | 17.94±2.69 | 22.19±2.23 |
| Tensile strain at break, (%) | 1.1±0.15 | 1.01±0.28 | 1.25±0.29 | 1.73±0.1 |

**Figure 11** Fracture surface of kenaf composite loaded in longitudinal fibre direction under tensile testing.

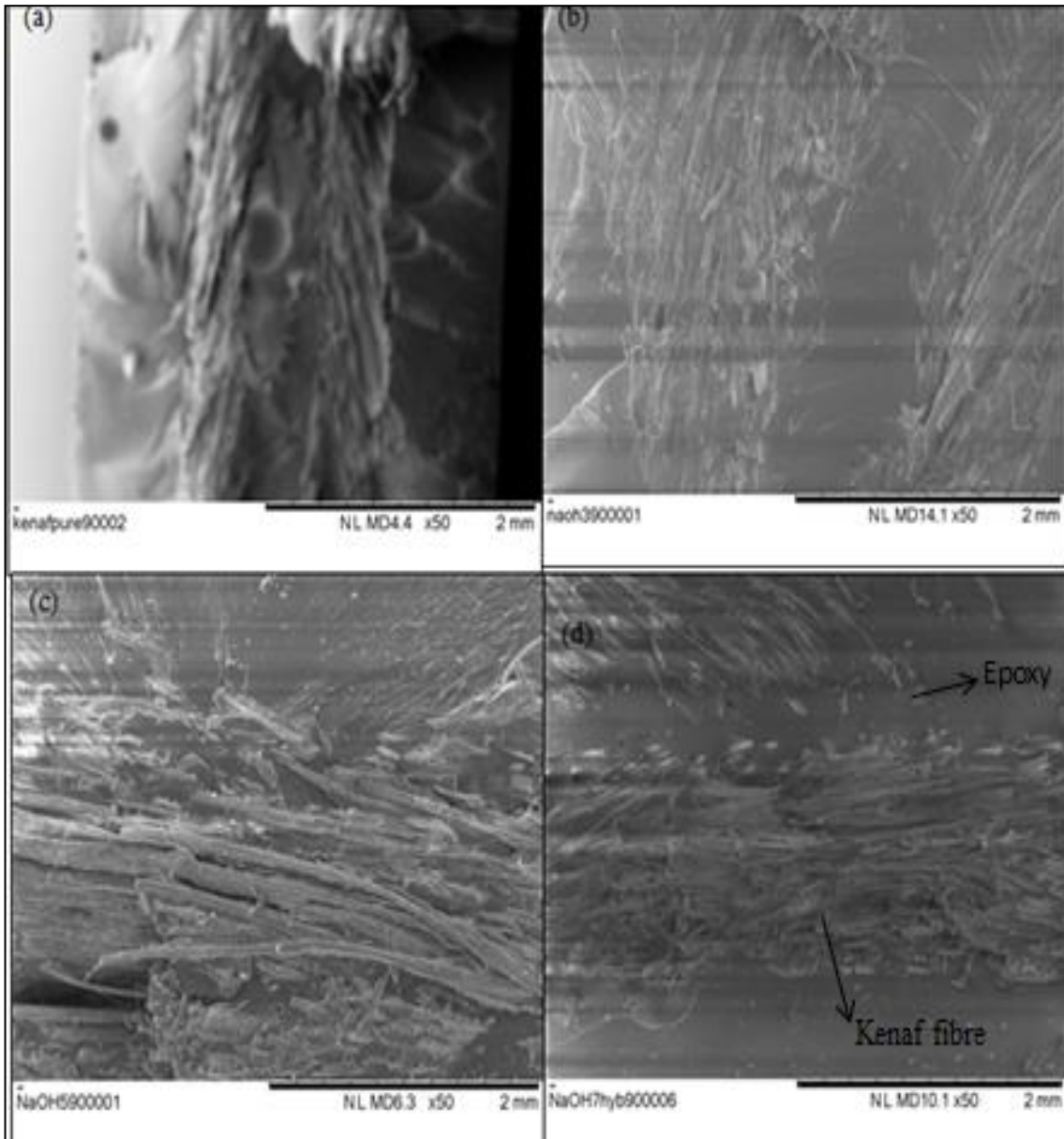


Figure 12 Fracture surface of kenaf composite loaded in transverse fibre direction under tensile testing

4.0 CONCLUSION

Sodium hydroxide treatment gives positive effects on longitudinal and transverse direction of kenaf composite under tensile loading. 7Na/K shows the highest tensile strength for both longitudinal and transverse fibre directions which are 79.18MPa and 22.19MPa respectively. SEM micrographs showed that the interfacial adhesion between kenaf fibre and epoxy matrix was improved when the kenaf fibre was treated using NaOH. The stronger interfacial adhesion leads to better tensile strength and modulus for both fibre directions, longitudinal and transverse.

Acknowledgement

The authors would like to thank Research Management Institute (RMI) Universiti Teknologi MARA (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. This research work is performed at the Faculty of Mechanical Engineering, UiTM Malaysia under the support of Research Acculturation Collaborative Effort (RACE) no: 600-RMI/RACE 16/6/2(7/2013) and Fundamental Research Grant Scheme (FRGS) no: 600-RMI/FRGS 5/3 (145/2014).

References

- [1] Faruk, O., Bledzki, A. K., Fink, H.-P. and Sain, M. 2014. Progress Report on Natural Fiber Reinforced Composites. *Macromol. Mater. Eng.* 299(1): 9–26.
- [2] Bakar, N. H., Hyie, K. M., Ramlan, A. S., Hassan, M. K. and Jumahat, A. 2013. Mechanical Properties of Kevlar Reinforcement in Kenaf Composites. *Appl. Mech. Mater.* 465: 847–851.
- [3] Manap, N., Jumahat, A. and Ludin, A. 2014. Tensile and compressive properties of glass reinforcement in kenaf reinforced epoxy composite. *Advances in Environmental Biology.* 8(8): 2673–2681.
- [4] Sapiai, N., Jumahat, A. and Hakim, R. N. 2014. Tensile and Compressive Properties of Hybrid Carbon Fiber / Kenaf Polymer Composite. *Advances in Environmental Biology.* 8(8): 2655–2661.
- [5] Sapiai, N., Jumahat, A., Mahmud, J. 2015. Flexural And Tensile Properties Of Kenaf/Glass Fibres Hybrid Composites Filled With Carbon Nanotubes. *Jurnal Teknologi.* 76(3): 115–120.
- [6] Fiore, V., Di Bella, G. and Valenza, A. 2015. The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. *Compos. Part B Eng.* 68: 14–21.
- [7] Atiqah, A., Maleque, M. A., Jawaid, M. and Iqbal, M. 2014. Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications. *Compos. Part B Eng.* 56: 68–73.
- [8] Herrera-Franco P. and Valadez-González, A. 2004. Mechanical properties of continuous natural fibre-reinforced polymer composites. *Compos. Part A Appl. Sci. Manuf.* 35(3): 339–345.
- [9] Valadez-Gonzalez, A., Cervantes-Uc, J. M., Olayo, R. and Herrera-Franco, P. J. 1999. Effect of fiber surface treatment on the fiber–matrix bond strength of natural fiber reinforced composites. *Compos. Part B Eng.* 30(3): 309–320.
- [10] Yan, L., Chouw, N. and Yuan, X. 2012. Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment. *J. Reinf. Plast. Compos.* 31(6): 425–437.