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EFFECTS OF GAUGE LENGTH AND CHEMICAL MODIFICATION ON THE TENSILE PROPERTIES OF KENAF FIBRE

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Abstract
An experiment was conducted to study the effect of gauge length and chemical modifications on the tensile properties of kenaf fibres. Measurement of fibre linear density and tensile properties such as strength, elongation-at-break and tenacity were performed using three different gauge lengths of 10 mm, 15 mm and 20 mm on a universal testing machine. The fibres were chemically treated with 6 % NaOH for 3 hrs, the NaOH treated kenaf was further treated with 1 % Aminosilane prepared in aqueous solution of ethanol and water at ratio of 1:95:4 respectively and the kenaf was surface coated with epoxy resin. Fourier Transform Infrared Spectrometry (FTIR) and Scanning Electron Microscopy (SEM) studies were performed to examine the changes in functional group and morphology of the fibres respectively. The results showed that gauge length and chemical treatment has a significant influence on the tensile properties and performance of natural fibres. The strength and tenacity of kenaf fibres increased with increase in gauge length and inversely decreased in elongation at break. The NaOH treatment gave the best results for the tensile properties but with a lower linear density. The epoxy coated fibres yielded better tensile properties than silane treated samples while the tensile properties of the fibre decreased for silane treatment with respect to the untreated. The FTIR result for epoxy coated kenaf, sodium hydroxide and silane treated kenaf fibres showed significant reduction in peak intensity which are indication of their low hydrophilic characteristics compared to the untreated. The SEM result showed an improved surface quality for all the treatments.

Key word: *Chemical treatment, Epoxy coating, Silane treated kenaf, Sodium hydroxide treated kenaf, Gauge length*

1.0 INTRODUCTION

Fibre count (linear density), fibre length, fibre tenacity and fibre elongation are important tensile properties of textile materials as these properties do not only determine the processibility of the material but also its performance. Performance of fibres under different forces and deformations, which are applied along its longitudinal axis, are defined as the tensile properties of fibres. Due to their shape, the most studied and, in many applications, the most important mechanical properties of fibres are their tensile properties.

Natural fibres are not homogeneous in their physical properties and dimensions. Their maturity, diameter, and fineness are different from fibre to fibre. Sometimes, even alongside the length of a fibre, there is a variation in physical properties, such as cellulose density. Thus, the tensile properties are affected by the test length (gauge length or distance) due to weak-link effect theory.

Kenaf fibre is obtained from stems of plants Hibiscus cannabinus (Bharath *et al.,* 2015) closely related to cotton and jute. Historically, kenaf has been used as a cordage crop to produce twine, rope and sackcloth (Mohd Edeerozey 2007). Nowadays, there are various new applications for kenaf including paper products, building materials, absorbents and animal feeds. The fibre is getting attention of industries and researchers, as they are utilized in different polymer composites for automotive, sports industries, food packaging and furniture industries. Kenaf is in its advanced position when compared with other lingocellulose fibres which make it suitable for various applications (Bharath *et al.,* 2015: Nur Inani *et al.,* 2014). According to researchers, the kenaf

fibres possess superior mechanical and thermal properties (i.e. long fibres, toughness and aspect ratio) in comparison with other natural fibres.

Various chemical treatments have been used to improve the mechanical performance of the natural fibre including jute and hemp by many researchers in the past (Mohd Edeerozey *et al.,* 2007; Bharath *et al.,* 2015; Nimmo *et al*., 2002). Edeerozey *et al.* (2007) investigated the chemical modification of kenaf fibres using NaOH at different concentrations and discovered that the alkalization treatment of kenaf can improve its mechanical properties significantly as compared to untreated fibre through its morphology and structural changes.

Juliana *et al.,* (2012) found that kenaf fibres are widely considered as suitable biological resources and potential substitute for fossil fuels and wood-pulps. Some studies (Xue *et al.,* 2007; Symington *et al.,* 2009) conducted on the tensile properties of kenaf bast fibres indicated that the average tensile strength of kenaf fibres ranges from 157 MPa to 600 MPa. Bharath *et al*., (2015) reported that tensile properties of kenaf fibres are comparably superior to those of other natural fibres such as jute, flax and bamboo for use in natural fibre reinforced composites due to its good mechanical properties, low cost, and good thermal stability of kenaf fibre compared to other natural fibres (Aji *et al.,* 2009). Kenaf's superior properties combined with excellent tensile strength that makes it the material of choice for a wide range of extruded, moulded and non-woven products (Mohd Edeerozey *et al.,* 2007). Kenaf are also used as reinforcement in Polymer Matrix Composites (PMCs) as an alternative to glass fibre due to some advantages over traditional reinforcement materials such as glass fibre in terms of cost, density, renewability, recyclability, abrasiveness and biodegradability.

The aim of this work is to study the effect of gauge length and chemical modifications on the tensile properties of kenaf fibres by the measurement of fibre linear density and tensile properties.

2. Materials and Methods

2.1 Materials

Raw kenaf fibres were supplied by Malaysian Agricultural Research and Development Institute (MARDI). The supplied fibres were combed and dried at ambient temperature for 48 hours before tensile testing. Sodium hydroxide (MERCK), silane (Dow Corning), ethanol (C_2H_5OH) (supplied by RCI Labscan Ltd) and acetic acid (CH_3COOH) (supplied by SYSTERM) were used for surface treatment of kenaf fibres. The epoxy resin/hardener (supplied by Oriental Option Sdn. Bhd.) and acetone (C_3H_6O) (supplied by SYSTERM) were used for surface coating of kenaf fibres.

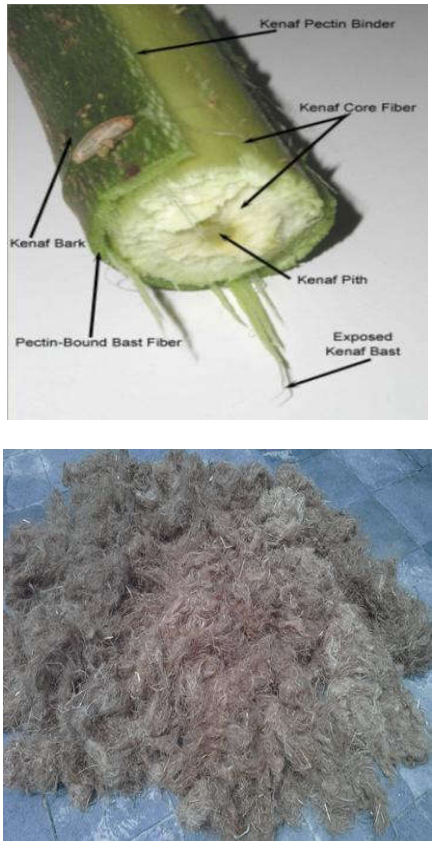


Plate 1: Kenaf fibre (Mohd Edeerozey 2007; Owen *et al.,* 2018)

2.2 Methods

2.2.1. Tensile testing of kenaf fibres

Ten samples were randomly selected from the bale of kenaf fibres according to their maturity, fineness, and length. The linear density in tex was measured and the fibres were subjected to a tensile strength test at three different gauge lengths of 10 mm, 15 mm and 20 mm using Schimadzu Universal Testing Machine, Japan. These gauge lengths were chosen because they are ranges of minimum lengths with the probabilities of having at least a weak point along the fibre length.

2.2.2. Measurement of Linear Density (Count) of Kenaf Fibres

Measurement of fibre linear density for the tensile properties was performed by measuring 10 centimetre of each single fibre bundle randomly selected from the bale of kenaf fibres. Ten samples were measured and weighed on an electronic weighing balance (Shimadzu, Japan). The linear density of the fibre was determined in Tex unit of measurement using the established direct measuring system for fibre fineness (Count) using the following equation:

$$\text{Tex} = \frac{W}{L} \times 1000$$

where Tex is the unit measurement for linear density of textile fibres, W is the weight (gram) of the fibre and L is the measured length. Fibre fineness is being expressed in millitex.

2.3 Fibre surface treatments and Coating

2.3.1 NaOH treatment

Kenaf fibres (KF) were immersed in 6wt% concentration of NaOH solution for 3 hours at room temperature, the fibres were then washed repeatedly with distilled water to remove excess NaOH and neutralized with 100 % acetic acid and finally rinsed thoroughly with distilled water until neutral pH was obtained and NaOH treated fibres were oven dried at 70 °C for 12 hours.

2.3.2 Silane treatment

The silane treatment was a combination of 6 % NaOH and 1 % silane (NaOH-silane) concentrations for 3 hours and 30 mins respectively. NaOH-treated fibres (NKF) were further treated with 1 % Aminosilane prepared in aqueous solution of ethanol and water at a ratio of 1:95:4 respectively (Ahmad and Muhammed, 2016). Acetic acid was added to the silane solution to maintain the pH value between 3.0 and 5.5, KF fibre that has been pretreated with 6 % NaOH solution for 3 h was immersed in the silane solution for 30 mins before it was removed and left to dry at room temperature then followed by oven dried at 70 °C for 48 hours (Jafirin *et al.,* 2013; Asumani *et al.,* 2012).

2.3.3 Epoxy Coating of Kenaf fibres

The epoxy resin and hardener of ratio 2:1 mixture respectively was used for surface coating of the untreated fibres (KF), NaOH-treated fibres (NKF) and Silane-treated fibres (SKF). The epoxy was dissolved in acetone at an optimised ratio of 1:5 epoxy to acetone. The KF, NKF and SKF fibres were immersed in the diluted epoxy solution (of very low viscosity dissolved in acetone) for 2-3 mins dipping time. The epoxy coated fibres EKF, ENKF and ESKF were finally cured at high temperature of 80 °C for 24 hours.

Chemical treatment of kenaf fibre

Surface treatment and coating of the kenaf fibres was performed at two stages. The first stage was by impregnating the fibres in 6 % concentration of sodium hydroxide (NaOH) solutions for 3 hours. The fibres were then washed and neutralized with 100 % acetic acid and finally washed thoroughly with distilled water until neutral pH was obtained and NaOH treated fibres were oven dried at 70 °C for 12 hours.

The second stage was a combination of 6 % NaOH and 1 % silane (NaOH-silane) for 3 hours and 30 mins respectively. Silane was used to reduce the number of -OH groups in cellulose (Jafirin *et al.,* 2013; Asumani *et al*., 2012). NaOH treated fibres were further treated in 1 % by weight of silane coupling agent relative to the weight of kenaf fibre) 2-Aminosilane prepared in aqueous solution of ethanol and water at a ratio of 1:95:4 respectively for 30 minutes (Ahmad and Muhammed, 2016). The pH of the solution was maintained in the range of 3.5-5.5 using acetic acid and stirred continuously for 5 minutes. The silane treated fibres was again oven dried at 70 °C for 48 hours.

2.3.4. Fibre Bundle Tensile Test

Tensile properties of different treated kenaf fibre bundle as well as untreated fibres were measured and the results are shown in Figures 2(a-d).

Plate 2: Tensile sample of single fibre testing

Plate 2 shows the sample preparation for testing. The fibres were attached and glued to the tab shape of cardboard which was designed with the gauge length of 10 mm, 15 mm and 20 mm and tested using the Universal Testing Machine (UTM) (Shimadzu, Japan) (Plate 2), according to ASTM D 3379 standard test method for single fibre tensile test with speed of 1 mm/min. Tests were conducted at a standard laboratory atmosphere of 23 °C and 50 % relative humidity. For every set of treatment (NaOH, silane and epoxy coated), 10 specimens were tested and the average of every set of specimen representing the fibre bundle tensile properties are summarized in Table 1 and Figure 1

Plate 3: Tensile testing of kenaf fibres

2.4 Fibre Characterization.

2.4.1. Fourier Transform Infrared Spectrometry (FTIR)

FTIR study of both untreated and treated (NaOH, silane and epoxy coated) and uncoated kenaf fibres were carried out using an FTIR machine (Perkin Elmer Spectrum 1A, Perkin Elmer Inc., USA). The samples were analysed over the range of 4000 to 600 cm^{-1}.

2.4.2. Optical microscopic Analysis

The optical images of the untreated, chemically (NaOH and Saline) treated and epoxy coated kenaf fibres were analysed on an Optical microscope (Olympus BX51TRF model, Japan) fitted with optic cam computer program and magnifications of 10x was used.

Plate 3: Optical microscope (Olympus BX51TRF model, Japan)

2.4.3. Scanning Electron Microscopy (SEM)

SEM analysis of fibre surface was conducted using Hitachi Scanning Electron Microscope model (TM 3030 PLUS Japan) to examine the effect of chemical (NaOH and Saline) treatment and epoxy coating on morphological changes of kenaf fibres at an accelerating voltage of 5–20 kV and magnifications of 500x.

3.0 Results and Discussion

3.1 Effect of fibre length (gauge length) on the tensile properties of kenaf fibre.

Table 1: Count, gauge length, breaking force, tenacity and elongation of kenaf fibre

Fibre Count		**Gauge length (mm)**	**Force (N)**	**Tenacity**		**Elongation (%)**
(millitex)	(tex)			(N/millitex)	(N/tex)	
0.0386	0.386	10	27.63	715.76	71.576	7.78
		15	51.55	1335.41	133.541	6.12
		20	69.75	1807.02	180.702	6.37

Table 2: Count, breaking load, tenacity and elongation of chemically modified kenaf fibre

Sample	**Fibre Count (millitex)**	**Breaking Load (N)**	**Tenacity (N/millitex)**	**Elongation (%)**
Untreated	0.0386	27.62	715.76	7.78
NaOH (6%)	0.0239	44.22	1850.21	12.72
NaOH - Silane (1%)	0.039	17.46	447.69	4.42
Epoxy coated (1:6)	0.0298	29.78	999.33	6.64

From the results obtained Figures 1a and 1b, It was observed that the gauge length has a significant effect on the tensile properties of kenaf fibres, the breaking load of kenaf fibres increase as the gauge length increases, the highest breaking load (69.75 N) was obtained with a gauge length of 20 mm, followed by 15 mm and lowest breaking load of 27.63 N recorded with 10 mm

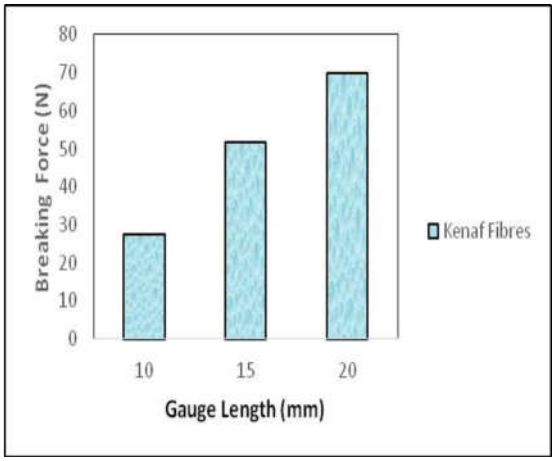
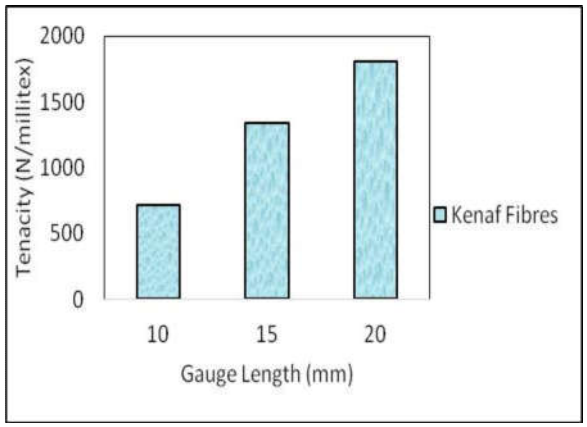


Figure 1a: Effect of fibre length (gauge length) on the breaking strength of kenaf fibre.

Edeerozey *et al*., 2007 obtained an average unit break single fibre bundle value of 215.4 N/mm^2 with a gauge length of 40mm. Asim *et al.* (2016) also obtained a single fibre strength of 282.60 MPa with a gauge length of 20 mm. This is in view of the fact that bast kenaf fibres are long staple natural fibres with each single fibre bundle consisting of large amount of element fibres along with matrix of lignin and hemicelluloses (Asim *et al.* 2016).



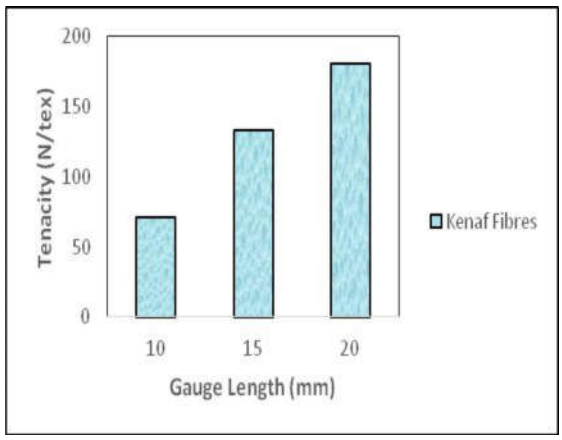


Figure 1b: Effect of fibre length (gauge length) on the tenacity of kenaf fibre.

The trend is the same for tenacity, tenacity increased with gauge length, the highest tenacity was obtained with the gauge length of 20 mm and was followed with 15 mm, while the least value obtained with 10 mm gauge length.

However, a reversed trend was observed with elongation of kenaf fibre, elongation at break decreased with increase in gauge length. The highest percentage (7.78 %) elongation at break was obtained with a gauge length of 10mm, and a drop as the gauge length increased to 15mm. The reason might be attributed to the irregular structure (shape) of natural fibres and non-uniformity in their thickness (Asim *et al.,* 2016). In a related study with varieties of cotton fibres with respect to tenacity and length, Murali *et al*., (2007) also found that tenacity and breaking extension increased with increasing length of fibre.

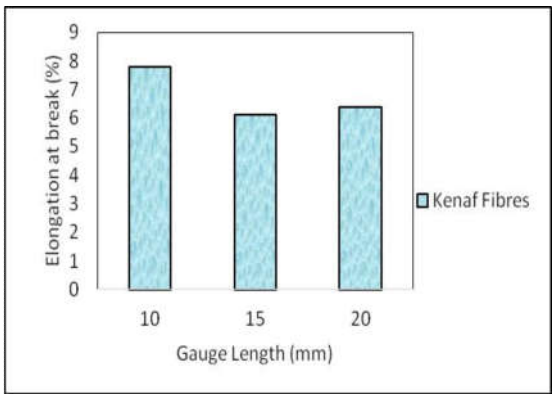


Figure 1c: Effect of fibre length (gauge length) on elongation at break of kenaf fibre.

Generally, the results have showed that fibre length (gauge length) has a significant influence on the tensile properties and performance of natural fibres, it can be concluded that tensile properties of kenaf

fibres such as breaking load, tenacity increase with increase in gauge length and decrease in elongation at break.

3.2. Effect of Chemical treatment on the tensile properties of kenaf fibre.

The results of the chemical treatment and coating of kenaf fibres with its effect on the tensile properties are shown in Table 2 and Figures 2a - 2d.

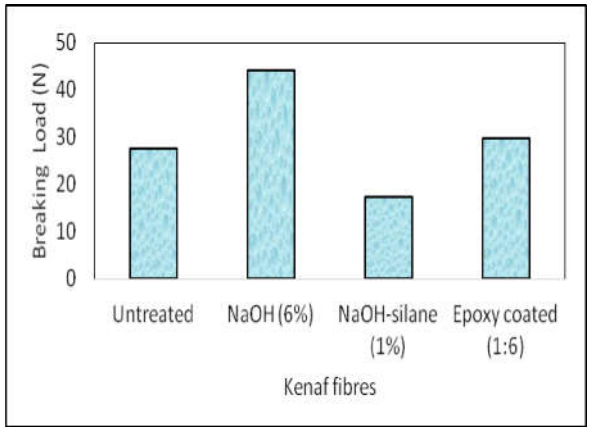


Figure 2a: Effect of chemical treatment on the breaking strength of kenaf fibres

From Figure 2a, the breaking load of NaOH treated kenaf fibres is the highest overall compared to the untreated, NaOH-silane treated and epoxy coated kenaf fibre bundle, followed by epoxy coated. The reason is attributed to the effectiveness of the concentration of NaOH used in the cleaning process of the fibres thereby yielded better tensile properties. Similar result was reported by Asim *et al.,* (2016) on NaOH treated Kenaf with 6 % concentration. It was however established that the effective removal of impurities and its effect on tensile strength depends on the concentration of NaOH and soaking time. Edeerozey *et al*. (2007) reported that treated kenaf with 6 % concentration also resulted in effective removal of all impurities from the fibres. This present result has confirmed that chemical treatment enhances the tensile properties of fibres with 6 % NaOH yielded the best result. NaOH-silane treated fibres yielded the lowest tensile strength among all the treated fibres, and was even lower than that of untreated fibres. Similar result was also found by Asim *et al.* (2016) with NaOH (6 %)-silane (2 %) treated kenaf in which the tensile strength was much lower than the untreated but latter showed better interfacial bonding with the matrix because the lignin and hemicellulose were removed, they concluded that higher chemical concentration may remove impurity efficiently but may decrease tensile strength due to lignocellulose degradation and rupture of fibre surfaces (Asim *et al.,* 2016). In the case of coated kenaf fibres, there was a significant improvement on the tensile strength compared to NaOH-silane treated and 7.2 % improvement compared to the untreated fibres.

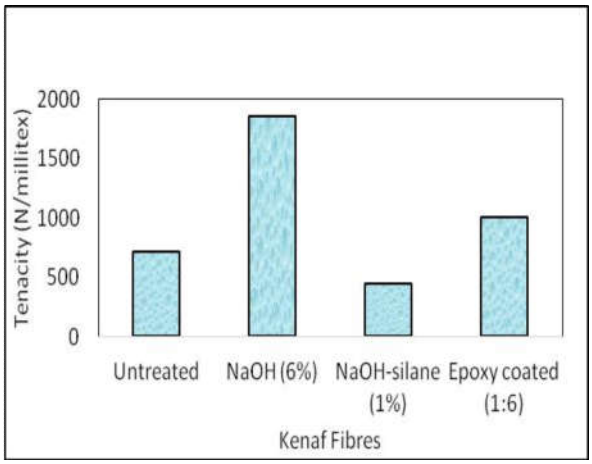


Figure 2b: Effect of chemical treatment on the tenacity of kenaf fibres

Similar trend was found on tenacity in Figure 2b. The maximum tenacity was recorded with NaOH treated kenaf fibres and followed by epoxy coated fibres. While NaOH-silane treated fibres revealed very low tenacity compared to the untreated fibres.

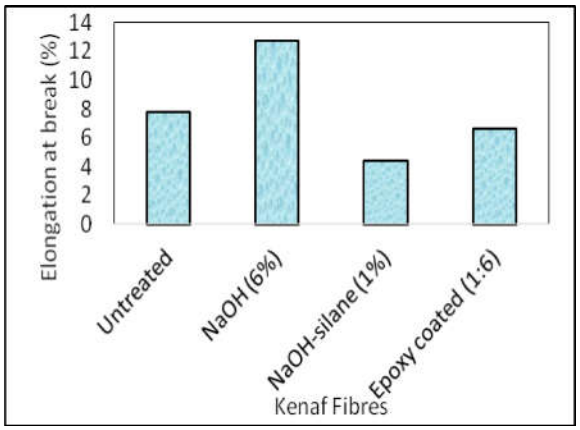


Figure 2c: Effect of chemical treatment on the elongation-at-break of kenaf fibres

The result of elongation-at-break of kenaf fibres as shown in Figure 2c also clearly showed that elongation of NaOH treated fibres were comparatively the highest overall while the elongation of NaOH-silane fibres dropped significantly compared to the untreated. However, an improvement in elongation with epoxy coated fibres was obtained compared to the NaOH-silane treated fibres. Combine NaOH-silane treatment and epoxy

coating has generally resulted in a significant reduction in elongation of the fibres compared to the untreated.

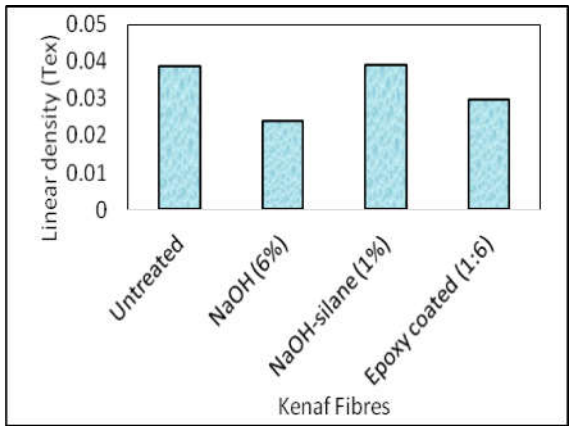


Figure 2d: Effect of chemical treatment on the linear density (Count) of kenaf fibres

In Figure 2d, it is clearly showed a reduction in linear density of NaOH treated fibres up to 3.8 % compared with the untreated fibres due to the effective removal of the impurities from the fibre surface, which has induced the separation of fibre bundles into individual fibres (Asim *et al.,* 2016; Edeerozey *et al.,* 200; Kargarzadeh *et al.,* 2012). Jafirin *et al*. (2013) also reported significant physical changes in the fibre (e.g. reduction in diameter) after different stages of treatment. Similar reduction was found with the coated fibres up to 22.8 %. However, Silane treatment has no obvious effect on the linear density in comparison with other treatment (Asim *et al.,* 2016).

Generally, it can be concluded that 6 % NaOH treatment has effectively enhanced the kenaf fibre bundle tensile properties (tensile strength, tenacity and elongation) with highest values overall than other treatment. The fibre bundle tensile properties decreased with silane treatment and recorded very lower values than that of the untreated fibres. Epoxy coating improved the NaOH-silane treated fibre bundle tensile properties to some extent.

3.3 Fourier Transform Infrared Spectrometry (FTIR)

FTIR results of both untreated, treated (NaOH and Silane) and epoxy coated kenaf fibres which were carried out using an FTIR machine (Perkin Elmer Spectrum 1A, Perkin Elmer Inc., USA) to investigate the changes in functional groups on the surfaces and analysed over spectra range of 4000 cm^{-1} to 1000 cm^{-1} are illustrated in Figure 3. The FTIR spectra results show that, for untreated kenaf fibres, the vibration peaks at 1028 cm-1750 cm^{-1} revealed the typical broad peaks of cellulosic fibres with presence of lignin and hemicellulose structure respectively (Asim *et al*., 2016).

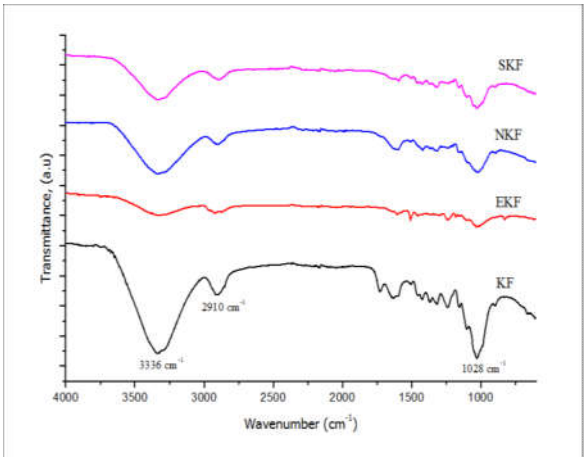


Figure 3: FTIR Spectra of Untreated Kenaf (KF), NaOH-treated (NKF), Silane-treated (SKF) and Epoxy-coated kenaf (EKF).

Figure 3 shows the FTIR Spectra of Untreated Kenaf (KF), NaOH-treated (NKF), Silane-treated (SKF) and Epoxy-coated kenaf (EKF). Observations from the FTIR results indicates that the peaks between 1250 cm^{-1} to 1500 cm^{-1} revealed absorption of water (Asim *et al*., 2016). The peak at 2910 cm^{-1} corresponds to the C-H stretching vibration from $–CH_2$ group of cellulose and hemicelluloses. The broad band ranging from 3000 cm^{-1} to 3500 cm^{-1} were because of hydrogen bonded –OH vibration of the cellulosic structure Epoxy coated kenaf (EKF) showed a reduction in peaks intensity at from 1028 cm^{-1} to 1750 cm^{-1} and 2910 cm^{-1} and 3336 cm^{-1} compared to NaOH and Silane treated kenaf (NKF) due to coating effects (encapsulation) of the fibres surfaces by epoxy resin. An indication of the epoxy resin able to improve wetting of the fibre by coating (hydrophobizing) the fibre surface and promoting interfacial bonding by diffusion of the chain segments of the epoxy molecules (Aji *et al.,* 2009). The result indicates that epoxy coating has helped to reduce water absorption and did not affect the chemical composition of the fibres. The vibration peak at 1750cm^{-1} revealed ester carbonyl group (Razak *et al*., 2014). Another peak at 2910 cm^{-1} mostly arose from C-H stretching (Asim *et al.,* 2016), whereas the vibration peak at 3400cm^{-1} indicated O-H frequency.

NaOH treated KF was more or less same as Silane treated KF. The vibrations indicated that huge amount of the lignin were removed (Asim *et al*., 2016). For NaOH and Silane treated KF, another peak was shifted to 1750 cm^{-1}, this peak revealed the carbonyl group of the acetyl ester in hemicellulose and the carbonyl aldehyde in lignin. Silane treated kenaf (SKF) showed similar graph as NaOH-treated

kenaf (NKF) graph revealed low intensity peak compared to untreated kenaf and its effect on lignin and hemicelluloses. The low intensity at peaks of 1028 cm^{-1} to 1500 cm^{-1} due to Si-C stretching bond revealed silane presence on the kenaf surface (Asim *et al.,* 2016), which was an indication of very good interfacial interaction between the silane coupling agent and the surface of the kenaf fibre. The silanol reacted with the hydroxyl group of the fibre, resulted in the formation of stable covalent bonds to the cell wall that are chemisorbed on to the fibre surface (Akil *et al.,* 2011). The vibration peaks at 1028 cm^{-1} and 1750 cm^{-1} indicated N-H and C-H bonding respectively, stretching vibration of carboxylic acid or ester invisible in the spectrum of Silane –treated kenaf.

Both treated KF with NaOH and Silane removed hemicellulose, wax content and lignin effectively. NaOH removed some cellulosic materials also, which may affect strength of fibres. These chemical treatments helped to reduce water absorption of both fibres. Silane treatment did not affect a good proportion of the chemical composition. Asim *et al.,* (2016) reported that by assumption, the absence of lignin, hemicellulose and wax containing chemicals on the fibre surface enhances the compatibility between fibre and polymer matrix and will not affect the mechanical strength of fibres. The FTIR spectra in Figure 3 showed that epoxy coated kenaf fibre and coated NaOH and silane treated kenaf fibres both showed significant reduction in peaks intensity at from 1028 cm^{-1} to 1750 cm^{-1} and 2910 cm^{-1} and 3336 cm^{-1} which are indications of their low hydrophilic characteristics compared to untreated kenaf (KF) due to effects of surface treatment and coating on the fibres.

3.4 Optical microscopic Analysis

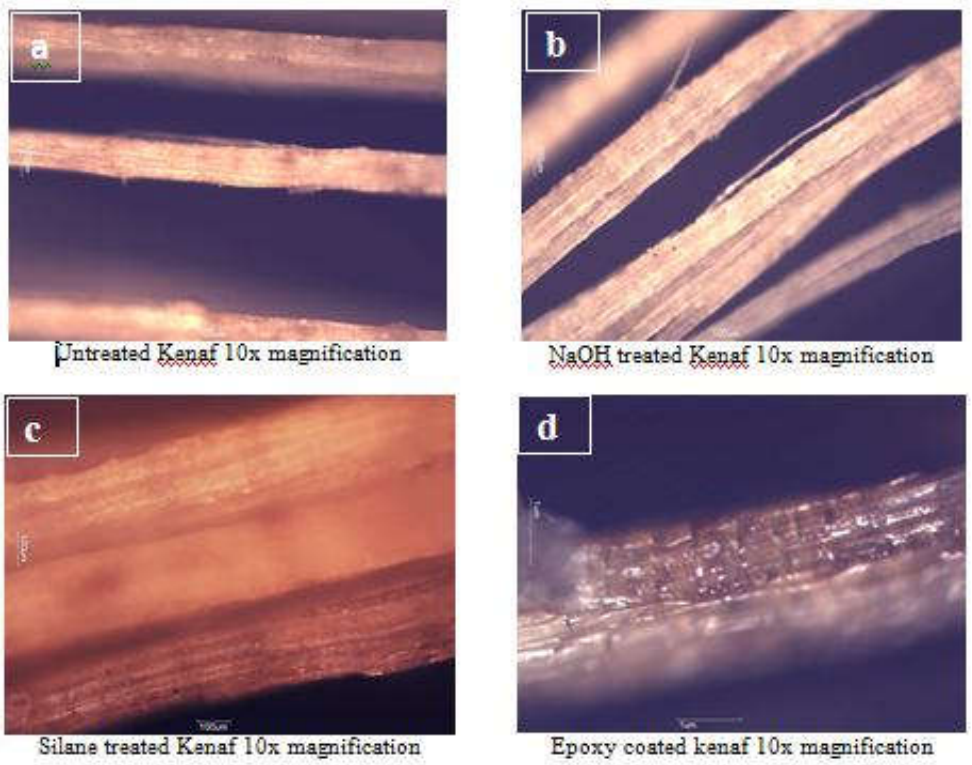


Figure 4: Optical micrographs of fibre surface morphology of (a) untreated KF, (b) NaOH-treated KF, (c) silane-treated KF and (d) Epoxy-coated KF at 10x magnifications respectively.

Figure 4a-d show the optical micrographs of chemically treated and epoxy coated fibres that were examined on the optical microscope. The morphological studies performed on the kenaf samples showed some noticeable morphological changes occurred after chemical treatment and epoxy coating on kenaf fibre samples as shown in Figure 4a-d. These observed structural changes may be due to internal modification or structural changes of chemical bonding which occurred during the chemical treatment resulting in partial dissolution of hemicellulose, lignin and pectin (Owen *et al.,* 2018).

The optical micrograph of epoxy coated fibre in Figure 4d revealed the presence of uniform coating of crosslinked epoxy and formation of thin coating layers around the surface of the epoxy particles formed due to an increased cellulose-epoxy reactions. Figure 4c revealed a smooth surface for saline treated sample resulted from reduction in the amount of -OH group on the surface of the fibres as compared with untreated kenaf fibre in Figure 4a with evidence of impurities presence on the surface of the fibre (Owen *et al*., 2018).

3.5. Scanning Electron Microscopy (SEM) Analysis of kenaf fibres

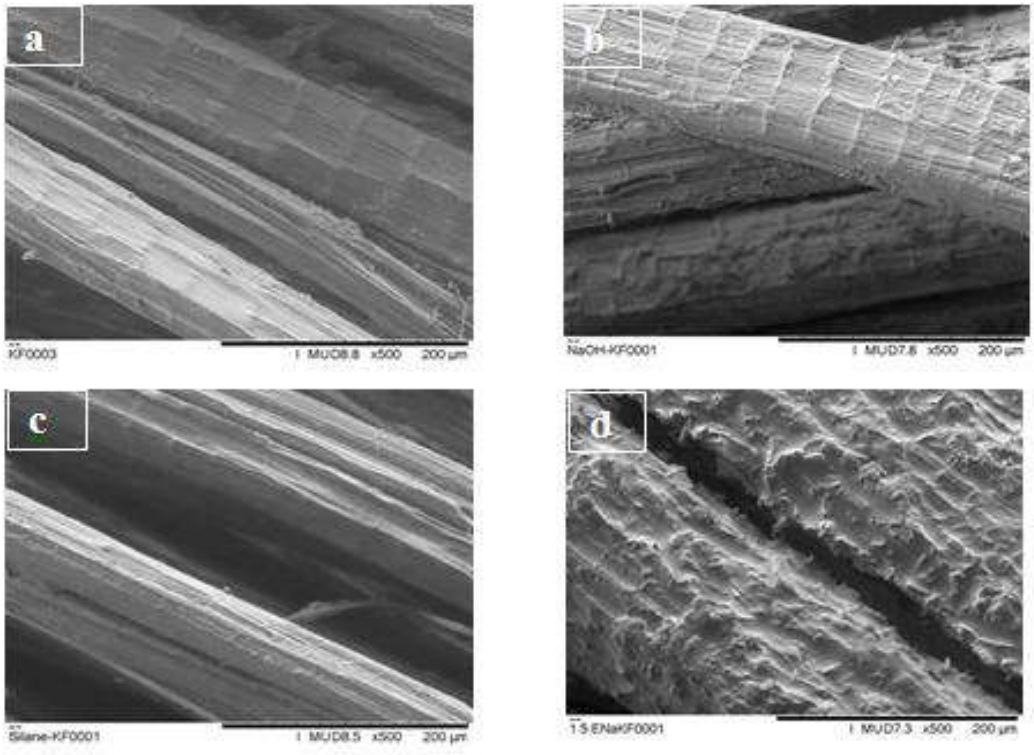


Figure 5: SEM micrographs of fibre surface morphology of (a) untreated KF, (b) NaOH-treated KF, (c) silane-treated KF and (d) Epoxy-coated KF at 500x magnifications respectively.

Figure 5a shows the SEM micrographs of untreated KF with evidences of impure materials on the surface of untreated fibres resulting to uneven surface compared to treated samples as reported in previous studies (Owen *et al*., 2018). Figure 5b shows NaOH-treated KF with some structural changes that occurred upon NaOH treatment, indicating that KF treated with 6 % conc. of NaOH was effective in removing impurities from the fibres, resulted in rough surfaces topography and more visible micropores due to effect of NaOH treatment on KF resulting in good tensile performance as compared to untreated and other treated samples (Owen *et al.,* 2018; Edeerozey *et al*., 2007; Tan *et al*., 2011). Silane-treated KF in Figure 5c shows very clean and smooth surfaces compared to untreated and the NaOH-treated KF, indicating that silane treatment have removed impurities from the fibres, resulting to improved surface quality compared to NaOH-treated KF. The smooth surface suggests absence of impurities and other foreign materials on the surface such as lignin and hemicellulose compared to NaOH-treated fibres (Asim *et al*., 2016). Figure 5d shows epoxy-coated KF with the presence of epoxy resin encapsulation of the KF, increased surface area and rougher structure compared to untreated, NaOH-treated and silane-treated fibres. The SEM micrograph of fibre surface of epoxy-coated KF showed the porous structure being covered by a layer of epoxy resin on the fibre surface and have resulted in strong fibre-matrix bonding and improved thermal stability of the fibres (Owen *et al.,* 2018).

4.0 CONCLUSION

An experiment on effect of gauge length and chemical modifications on the tensile properties of

kenaf fibres was conducted and the following conclusions were drawn from the study:

1. Tensile strength and tenacity of kenaf fibres increased with increase in gauge length and inversely decreased in elongation at break.

2. NaOH treatment gave the best results for the tensile properties but with a lower linear density. The epoxy coated fibres yielded better tensile properties than silane treated samples while the tensile properties of the fibre decreased for silane treatment with respect to the untreated.

3. The FTIR result for epoxy coated kenaf, sodium hydroxide and silane treated kenaf fibres showed significance reduction in peak intensity which are indication of their low hydrophilic characteristics compared to the untreated.

4. The SEM result showed an improved surface quality for all the treatments.

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