The effect of alkali treatment under various conditions on physical properties of kenaf fiber

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Abstract. Alkali treatment was known as one commonly used treatment for natural fiber and obtained a good fiber matrix adhesion, thermal and mechanical properties of composite. This paper reports the effect of alkali treatment conditions on the physical properties of kenaf fiber such as density, weight loss, diameter, cross sectional and fiber morphology. In this study, kenaf fiber were treated under various conditions alkali concentration at 2, 6 and 10 (w/v%), immersion duration at 30, 240 and 480 minute and immersion temperature at 27, 60 and 100°C. The effects of alkali treatment on kenaf fiber physical properties under various conditions were explored. Alkali treatment conditions setting have an impact on kenaf bast fiber physical characteristics. In kenaf fiber density, it was found that a small increase of kenaf density value after alkali treatment compared to untreated kenaf fiber. When each of alkali treatment parameters increased, kenaf fiber density also increased slightly. Kenaf fiber weight loss also exhibit a similar pattern of small increment with the increase of treatment parameters. Additionally, kenaf fiber diameter and cross sectional area show a decline pattern after treated with alkali. Furthermore, this decline pattern was corresponding with the increasing level of alkali treatment parameters. The maximum of kenaf diameter reduction was recorded at high level of each alkali treatment parameters.

1. Introduction
The growing interest in utilization of plant fiber as environment friendly reinforcement material in polymer composite industry is mainly due to their renewable origin, low-cost and abundantly available, relative high specific strength and modulus, light weight, low density, less abrasiveness, desirable fiber aspect ratio, minimal health hazards and also good thermal, electrical and acoustic insulating character. These advantageous make plant fiber as potential replacement for synthetic fiber in composite industries [1-3]. A renaissance in the use of natural fibers as reinforcements in technical applications is taking place mainly in the automobile [4-5], packaging [6], insulation [7] and construction industries [8].

However, there still several drawbacks that limit the potential of plant fiber to be used as alternative to synthetic fibers. Most highlighted problem in dealing with natural fiber was it hydrophilic nature, which leads to an adhesion problem with hydrophobic nature of the polymer matrix [9]. Hydrophilic character of natural fiber is incompatible with hydrophobic polymer matrix and has a tendency to form aggregates. Furthermore, it exhibit poor resistant to moisture, which lead to high water absorption, subsequently resulting in poor mechanical properties and dimensional stability of the natural fiber reinforced composites [10-11]. Therefore, chemical modifications either
on natural fiber, polymer matrix or both materials are an alternative solution to overcome these challenges [12-16]. One of the common fiber treatment that extensively used by the number of researcher is alkali treatment process [17-20]. Alkali treatment was selected as a fiber treatment process in this work due to its potential to provide a good fiber matrix adhesion, thermal and mechanical properties of composites.

There are three variables involved during conducting alkali treatment process which are alkali solution concentration, immersion duration and immersion temperature. This treatment variable was set differently according to the types of fiber by the researcher. An attempt to investigate the effect of immersion time during alkali treatment at specific alkali concentration and immersion temperature on fiber was conducted by Symington et al.[21] and Obi [22]. For example, Symington et al.[21] set the immersion duration at 10, 20 and 30 minute where the alkali solution concentration was fixed as constant at 3% over room temperature condition. The tensile strength of all studied fibers was found to give a decrease pattern when the immersion time increased. On the other hand, Obi [22] used immersion duration at 1,4,8 and 8 hour with 5% alkali concentration at 30°C and found that 8 hour give a best results in improving Borassus fiber tensile properties. Another work also has been done to investigate the effect of various alkali concentrations at fixed immersion time and temperature. Mwaikambo [23] studied the tensile properties of jute fibers after treated with alkali treatment at different range of concentration. He found that jute fiber tensile properties optimized at 0.24% weight by weight (w/w) alkali concentration. Similar type of experiment was reported by Modibbo et al. [24], where alkali treatment at different range of alkali solution concentration at fixed immersion duration and temperature had been conducted to observed the bast fiber physical properties changes. Cho [20] determined pre treatment with 10% weight (wt) alkali solution give positive role in the formation of jute based carbon fiber. Boopathi et al. [25] investigated the physical, chemical and mechanical properties of alkali treated Borassus fruit fiber. The fiber was treated with 5%, 10% and 15% alkali about 30 minute at room temperature and the effect of alkali treatment on the fiber properties were explored.

Although most of the researcher focused on specific variables at one time during conducting alkali treatment, there are some works that also focus on investigating the relation between alkali treatment variables. Wang et al. [26] investigated the effect of chemical treatment process of jute fiber. The examined treatment process was sodium hydroxide concentration, treatment time, temperature, sodium silicate concentration, fiber to liquor ratio, penetrating agent concentration and degumming agent concentration. An orthogonal experiment design was used to optimize the treatment process. It was found that sodium hydroxide concentration, sodium silicate concentration and treatment time were the three most important variables for degumming process. Edderozey [27] studied the morphology and tensile strength of kenaf fiber that modified at different alkali solution concentration and temperature. Alkali concentration used was 3%, 6% and 9% for 3 hour at room temperature. Another treatment was immersion of kenaf fiber in 6% alkali concentration at 95°C. The result shows tensile strength of kenaf fiber that treated with 6% alkali solution in water bath at 95°C was better compared to other treatment condition at room temperature. This studied result has good agreement with Saha et al. [28] work which applied alkali treatment at ambient and elevated temperatures and high pressure steaming conditions. The results indicated that jute fiber uniaxial tensile strength increased up to 65% for alkali steam treatment.

Studied regarding tensile properties of kenaf fiber due to various condition of alkali treatment was reported by Mahjoub et al. [29]. They employed different alkali concentration and different immersion time. Untreated kenaf fiber was used as control unit. As a result, they found alkaline with 10% and 15% concentration solution damaged the texture of fiber as the treated fiber was more twisted, much finer and so brittle than the untreated fiber. Three methods which are system compliance method, regression method and averaging the data method were performed in their analysis work. Unfortunately, variables interaction or main effect analysis was not discussed in their work.

Natural fiber characters that commonly analyzed by researcher are fiber density, fiber diameter, fiber cross-section area and fiber surface morphology. According to Mwaikambo[30], there are two
types of density, which are absolute density and bulk density. The absolute density excludes all the pores and lumen and therefore a measure of the solid matter of the fibers. The apparent density on the other hand includes all the solid material and the pores of the fibers. Fiber apparent density is always less than the absolute density due to the buoyancy effect caused by the trapped air. The absolute density of most natural fiber is between 1.4 – 1.5 g/cm³. The common method of determining fiber apparent density is using Archimedes principle. This method involves the immersion of a known weight of fiber into a solvent of lower density than the fiber like water or benzene. The volumetric displacement was observed and the weight to volume ratio yielded the density value [25, 31]. For standard method of determining fiber density, a Technical Association of Pulp and Paper Industry (TAPPI) was used by Modibbo et al. [24] while American Society for Testing and Materials (ASTM) D 1895 was used by Jawaid et al. [32].

One of the challenges in determining natural fiber diameter is the irregularity within or between the single fibers. Mwaikambo et al. [33] calculated mean, standard deviation and standard error of hemp fiber diameter using image analysis captured by scanning electron microscope (SEM). The fiber diameter was determined along the width of the fiber bundles. Similar measuring method was used by Khan et al. [34] and Andersons et al. [35] to determine fiber diameter. However, in Anderson et al. [35] work, a fiber cross section was considered as circular. Another studied was conducted by Kabir et al. [36] which used two different approach in calculating the hemp fiber diameter. The first method used was averaged fiber widths at different locations along the fiber’s length. For this, fibers were placed horizontally under the microscope and attached with glue tag to avoid movement. The second method was measured the diameters around the breakage of the tested fibers. For this case, tested fibers were perpendicularly attached with glue tag and the equivalent diameters were obtained through image analysis.

For simplicity purposed, a typical circular fiber area assumption was widely applied during fiber diameter or cross-section measurement. Thus, it introduces a considerable error into the calculated mechanical properties. To minimize this variation, Aslan [37], studied two method of measuring cross sectional area of the flax fiber. First method was measured a fiber width along a fiber with assuming the fiber have a circular cross section area. Second method was true fiber area measurement by embedded the fiber in epoxy resin and conduct a measurement on a series of cross sectional image. The difference between the mean values suggests that the circular fiber area measured by the first method is overestimating the true fiber area by 39%. Nitta et al. [38] also conducted similar work which investigated the microstructural changes of kenaf fibers after highly concentrated alkali treatment. However, the approximated shapes of the cross-section was not only a circle but including an, ellipse, hexagon, octagon, dodecagon, and icositetragon. Micrograph observation showed each cell in the fiber cross-section changed from a polygon shape to an elliptical, accompanied with many gaps between cells. Their results indicated the tensile strength was greatly improved. Particularly, the alkali treated fiber on the condition of 15 wt % of alkali concentration for one hour is comparable to untreated fiber.

Based from above literature, it shows a number of works that used alkali treatment as chemical modification to improve natural fiber surface and it compatibility with matrix to enhance composite properties. However, there are limited work reported regarding attempts to determine the main effect and the interaction between these three variables on it effect to natural fiber properties enhancement. Therefore, it is necessary to fill this gap by conducting an appropriate experiment design. This experimental work potentially provides significant knowledge on alkali treatment variables relation and it optimum treatment condition if performance of the natural fiber in composite material form is to be maximized. Thus, this study aim to determine the effect of alkali treatment under various conditions on the physical properties of kenaf fiber such as density, weight loss, diameter, cross sectional and fiber morphology.
2. Experimental Work

2.1 Kenaf Fiber & Alkali Treatment
Bast type kenaf fibers was supplied from Kenaf Natural Fiber Industries (Malaysia) Sdn.Bhd. This fiber was subjected to water retting process before supplied to the laboratory. Sodium hydroxide (NaOH) used in this studied was supply by BDH Prolabo (UK) in 1 kg container at small pallet shape. Alkali solution concentration was prepared using weight per volume percentage (w/v %). Alkali treatment setting is according to three factors at three levels full factorial design matrix as shown in Table 1. The setting was set manually at laboratory dyeing and the mechanism of temperature control in this dyeing machine is using water. Initially, tap water was poured into water bath container until specific marking line. Temperature and time can be control using a knob at control panel. When machine is switch on, heating coils inside water bath will generate heat so that the water temperature will increase and maintain at selected temperature level. Portable infrared thermometer device was used to confirm the solution temperature. After temperature was set correctly, kenaf fiber was inserted into stainless steel container and this container was placed into dyeing machine until specific immersion time. Once treatment process is finished, kenaf fiber was taken out from container and washed in running tap water. A drop of acetic acid was dropped into a beaker that contained washed kenaf fiber to remove any excessive sodium hydroxide. This washing process was continued until pH level in distilled water inside a beaker show 7.0 ± 0.5 values. A digital pH tester was used to check the rinse solution pH value to ensure the alkali treatment process is complete. Alkali treated kenaf fiber were conditioned at 100°C ~105°C for one hour in high temperature steamer for fiber drying process.

| Table 1: Independent variables matrix of alkali treatment conditions for kenaf fiber physical properties evaluation |
|----------------------------------|-----------------|-----------------|
| Independent variables            | Actual variables value |
| X1: Alkali concentration (w/v%)   | Low  | Center | High |
| X2: Immersion time (min)          | 2    | 6     | 10   |
| X3: Immersion temperature (±1°C)  | 30   | 240   | 480  |

2.2 Fiber density
Alkali treated and untreated kenaf fiber was select randomly and cut into a nominal length of 20 mm. Then, this fiber was weighted using Mettler Toledo analytical balance (Model XS 64) to measure it weight in air and in distilled water. The fiber nominal weight was 6.0 ± 1.0 mg. Fiber density value was determined using the principle of Archimedes by calculating the different of fiber weight in air and in distilled water according to ASTM D3800-99 (2010)[39]. The fiber density measurement was replicated three times at each treatment conditions.

2.3 Fiber diameter
Kenaf fiber was select and separated from bast fiber to bundle fiber and finally to single fiber using Waltex magnifying glass as shown in Figure 1. A kenaf fiber diameter was measured at 4.5 mm interval along its length using Leica Stereo Microscopic Video Analyzer 2000 (Model 250D). The mean diameter of single kenaf fiber was measured from the average of ten fibers, in which the diameter for every fiber is the average value of the diameters measured ten times at 4.5 mm interval along the fiber length. The measurement was replicated three times at each treatment conditions.
2.4 Fiber cross-sectional area

For determining fiber cross-sectional area, kenaf fiber with no obvious defects was randomly selected as test sample under Waltex magnifying glass observation. A test specimen mounting tab according to ASTM C1557-03 [40] was prepared for each alkali treatment conditions. Kenaf fiber was assumed to have an elliptical shape with a major, \( a \) and a minor, \( b \) diameter. A kenaf fiber cross sectional area was measured at five locations in 6 mm interval of fiber length along two orthogonal directions using Leica Stereo Microscopic Video Analyzer 2000 (Model 250D). The first diameter was measured and followed by next diameter measured at about 90° from the earlier measurement. This measurement was repeated three times to get the average value and it has been replicated three times for full factorial analysis. The fiber cross sectional area, \( A \) is then calculated using Equation 1.

\[
A = \pi \frac{ab}{4}
\] (1)

2.5 Fiber morphology

The surface morphology of kenaf fiber at various alkali treatment conditions was examined using a scanning electron microscope (SEM). Kenaf fiber was randomly cut into appropriate length and placed into SEM specimen stub. Then this specimen stub was place inside a coating machine to be sputter coated with gold layer to make the surface of the samples conductive prior to SEM observations.

3. Results and Discussion

3.1. Kenaf fiber density and weight loss

In this work, apparent density approach that included all solid material and the pores of kenaf fiber was used to investigate the impact of alkali treatment condition on kenaf fiber density changes. Untreated kenaf fiber density was used as control unit and it measured value was 1.254 (g/cm³). The amount of kenaf fiber weight reduction and kenaf fiber density at different alkali treatment conditions was presented in Table 2. The result shows that there was a slight increment of kenaf fiber density value after alkali treatment process conducted. Measured responses data in Table 2 was transform into chart form as shown in Figure 2 and Figure 3 to clarify the effect of alkali treatment conditions pattern.
on kenaf fiber weight loss and density. Figure 2 shows the bar chart of kenaf fiber weight lost after alkali treatment at various conditions setting. Its indicated nearly similar range of changed (18% – 21%) at constant room temperature with various alkali concentration and immersion time. However, at 2 w/v% alkali concentration, the weight loss was 13% recorded. On the other hand, at immersion temperature 60°C and 100°C, kenaf weight loss shows an increment pattern with the increment of alkali concentration and immersion duration value.

The line graph in Figure 3 shows the kenaf fiber density mean value at different alkali concentration. It depict that kenaf fiber density value became higher when it was treated with higher alkali concentration (10w/v%) with higher immersion temperature and longer immersion time. Furthermore, kenaf fiber density at lower alkali concentration (2w/v%) exhibit nearly constant changes at room temperature and 60°C immersion temperature. However, at 100°C and longer immersion time, the kenaf fiber density value was increased slightly. The gradual increase in weight loss after alkali treatment with increasing alkali concentration and immersion time was reported by Roy et al. [41]. In their elemental analysis of untreated and alkali treated jute fiber, they suggested that the weight loss was due to leaching of lignin and/or hemicellulose. This gradual removal of hemicellulose and lignin increased the weight loss. The alkali treatment breaks hydrogen bonds between the hydroxyl groups (–OH) of the cellulose, hemicellulose and lignin and leads to defibrillation, the breakdown of the fiber bundle into smaller fibers. This change increases the effective surface area [42].

**Table 2**: Amount of kenaf fiber weight reduction and fiber density measured after various alkali treatment conditions

| Responses to the kenaf fiber properties | Time (min) | Room temperature (±27) | 60 | 100 |
|----------------------------------------|------------|------------------------|----|-----|
| Fiber weight after treatment (g)       |            | 2 6 10 2 6 10 2 6 10 2 6 10 |    |     |
| Weight loss %                          | 30         | 0.82 0.81 0.81 0.84 0.85 0.83 0.74 0.71 0.67 |    |     |
| Fiber density (g/cm³)                  | 1.262 1.270 1.276 1.268 1.269 1.280 1.272 1.273 1.281 |    |     |
| Fiber weight after treatment (g)       |            | 0.87 0.80 0.79 0.84 0.80 0.77 0.75 0.67 0.64 |    |     |
| Weight loss %                          | 240        | 0.82 0.81 0.81 0.84 0.80 0.77 0.75 0.67 0.64 |    |     |
| Fiber density (g/cm³)                  | 1.269 1.267 1.282 1.271 1.275 1.285 1.279 1.283 1.285 |    |     |
| Fiber weight after treatment (g)       |            | 0.81 0.79 0.79 0.81 0.75 0.71 0.60 0.62 0.60 |    |     |
| Weight loss %                          | 480        | 0.82 0.81 0.81 0.84 0.80 0.77 0.75 0.67 0.64 |    |     |
| Fiber density (g/cm³)                  | 1.269 1.273 1.282 1.269 1.280 1.287 1.279 1.283 1.288 |    |     |
Furthermore, the density of kenaf fiber at various alkali treatment conditions shows a gradual increment pattern at small amount with the increment of all treatment parameters value about 2.32%. On top of that, alkali treated kenaf fiber density for all conditions show a higher density value when
compared to untreated fiber at about 0.6% to 2.7% increment. This similar pattern was reported by Aziz et al. [31] for alkali treated kenaf and hemp fiber. This positive change or increment in fiber densities normally signifies cell wall densification. However, a negative change would signify cell wall damage leading to de-polymerization of the cellulose molecule. As reported by Modibbo et al. [24], when higher alkali concentration was used during treatment process, the density of kenaf fiber decreased with the increment of alkali concentration. At their work, the alkali concentration ranges was 10-25% at 5°C for 20 minutes immersion duration.

3.2. Kenaf fiber diameter

The result of kenaf fiber diameter changes after various alkali treatment conditions was presented in Table 3. At the first column of Table 3, it shows the measured responses, which are kenaf fiber diameter and standard deviation measurement values. The rest of the columns present the alkali treatment conditions and the measured responses value. Untreated kenaf fiber diameter average value was 104.69 µm with 15.5 standard deviation value. The results indicated that kenaf fiber diameter reduced after treated with alkali at all conditions. At 30 minutes constant immersion duration, the percentage of kenaf diameter decrement was 27.4% when others treatment parameter increased. Similarly, at 240 and 480 minutes immersion time, the percentage of kenaf fiber diameter decrement was 33.33% and 40.12%. This percentage increased with the increment of immersion duration. For standard deviation value, the range was small and it about 10 ~ 20. The kenaf fiber diameter was little bit larger compared to kenaf diameter reported by Mahjoub et al. in their recent studied [29] which was around 55 ~ 73 µm with 10 ~ 17 standard deviation value. Figure 4 shows the decrement pattern of kenaf fiber diameter after treated at various alkali treatment conditions. From the line graph, it was clearly understood that at constant immersion temperature and immersion time, an increment of alkali concentration reduced the diameter of kenaf fiber. Furthermore, the increment of all parameters setting value also reduced the diameter of kenaf fiber. This finding could be explained by fiber degradation and fiber delignification phenomenon that occurred in kenaf fiber as alkali treatment variables increased. As the alkali concentration, immersion time and immersion temperature increased, kenaf fiber became finer due to the leaching of non-cellulosic materials like hemicellulose, lignin and pectin [41].

Other researchers also reported the decrement pattern of fiber diameter after treated with alkali solution. Gomes et. al [43] emphasized that the decreased in fiber diameter with the increment of alkali concentration was caused by change of morphology of the treated fiber. From scanning electron microscope observation, they revealed that the fiber was not truly monofilament. It was a bundle of monofilament bonded and covered by lignin. Alkali treatment was inferred to provoke removal of a great amount of lignin. The removal of lignin reduced the fiber diameter. This statement was supported with the results from Oby [22] work, where their found that average diameter of borassus fine fiber also decreased with the increment of alkali treatment period. The alkali treatment removes certain hemicellulose and wax covering the external surface of the fiber and therefore it increases the aspect ratio (length/diameter) values. In addition, Saha et al. [28] also found that 30 minutes alkali treatment with 1% alkali solution at 90°C was contributed to fiber diameter reduction at 32%. The degradation of pectin together with lignin removed from the fiber cell wall that causing separation of the ultimate fiber which lead to the fiber diameter decreased was about between 0 to 0.03% alkali concentrations [23].
Table 3: Kenaf fiber diameter changes after various alkali treatment conditions

| Kenaf fiber diameter changes | Time (min) | Room temperature (±27) | 60 | 100 |
|-----------------------------|------------|-------------------------|----|-----|
|                             |            | Alkali Concentration (w/v %) |    |     |
|                             |            | 2 | 6 | 10 | 2 | 6 | 10 | 2 | 6 | 10 |
| Average (µm)                | 30         | 96.46 | 95.16 | 91.46 | 85.12 | 83.08 | 82.12 | 73.34 | 72.27 | 70.03 |
| STD                         |            | 15.98 | 16.17 | 18.29 | 18.94 | 10.48 | 11.55 | 19.34 | 19.54 | 15.96 |
| Average (µm)                | 240        | 95.25 | 93.03 | 91.48 | 85.49 | 80.05 | 80.79 | 70.29 | 68.86 | 63.50 |
| STD                         |            | 14.22 | 15.42 | 16.01 | 19.64 | 19.57 | 17.47 | 15.78 | 15.71 | 15.13 |
| Average (µm)                | 480        | 92.17 | 91.85 | 89.05 | 78.66 | 75.19 | 72.89 | 61.19 | 59.54 | 55.19 |
| STD                         |            | 18.03 | 16.98 | 16.20 | 19.47 | 19.72 | 11.88 | 18.07 | 18.05 | 17.27 |

STD = Standard deviation

Figure 4: Kenaf fiber diameter (µm) changing pattern after treated at various alkali treatment conditions

3.3. Kenaf fiber cross-sectional area
The result of kenaf fiber cross sectional area changes after various alkali treatment conditions was presented in Table 4. The first column of Table 4 shows the measured responses, which are kenaf fiber diameter and standard deviation measurement values. The rest of the columns present the alkali treatment conditions and the measured responses value. Untreated kenaf fiber cross sectional area.
Table 4: Kenaf fiber cross sectional changes after various alkali treatment conditions

| Kenaf fiber cross sectional changes (µm²) | Time (min) | Temperature Level (°C) |
|------------------------------------------|------------|------------------------|
|                                           |            | Room temperature (±27) | 60 | 100 |
|                                           |            | Alkali Concentration (w/v %) | 2 | 6 | 10 | 2 | 6 | 10 |
| Average                                   | 30         | 6.034                  | 5.966 | 5.849 | 5.832 | 5.794 | 5.654 | 5.612 | 5.417 | 5.351 |
| STD                                       |            | 131                    | 114 | 63 | 92 | 136 | 106 | 134 | 75 | 113 |
| Average                                   | 240        | 5.963                  | 5.870 | 5.817 | 5.806 | 5.713 | 5.637 | 5.445 | 5.233 | 5.151 |
| STD                                       |            | 84                     | 92 | 111 | 111 | 129 | 93 | 73 | 102 | 64 |
| Average                                   | 480        | 5.865                  | 5.877 | 5.775 | 5.797 | 5.718 | 5.595 | 4.841 | 4.633 | 4.604 |
| STD                                       |            | 45                     | 108 | 68 | 87 | 118 | 94 | 73 | 72 | 56 |

STD = Standard deviation value was 6472.23 µm² with 138.15 standard deviation value. The results indicated that kenaf fiber cross sectional area reduced after treated with alkali at all conditions. At 30 minutes constant immersion duration, the percentage of kenaf cross sectional area decrement was 11.32% when others treatment parameter increased. Similarly, at 240 and 480 minutes immersion time, the percentage of kenaf fiber cross sectional area decrement was 13.62% and 21.5%. This percentage increased with the increment of immersion duration. Figure 5 shows the decrement pattern of kenaf fiber cross sectional area after treated at various alkali treatment conditions. From the line graph, it shows a slight decrement pattern at constant immersion temperature, immersion time and alkali concentration. However, at 100°C immersion setting, a rapid decrement pattern of kenaf fiber cross section area was recorded when immersion time and alkali concentration increased.

Similar to the reduction of fiber diameter, the reduction of fiber cross-sectional area possibly was due to the changed of fiber morphology after alkali treatment process. Nitta et al. [38] reported that cross-section of kenaf fiber was drastically changed by the alkali treatment compared to untreated fiber. The increments of immersion duration give a fluctuated pattern where the cross-sectional area value was higher at higher alkali concentration and longer immersion time. They found that cross-sectional of alkali treated fiber was less then untreated fiber. Furthermore, each cell in the fiber cross-section was changed from a polygon shape to an elliptical one, accompanied with many gaps between cells. Thus, during measuring fiber cross-sectional area, the assumption that fiber cross-sectional is an ellipse shape will produce more accurate results compare to round shape assumption.

On the other hand, Kabir et al. [36] found that the cross section of fiber was not show a continuous decrease pattern as the alkali concentration increased. Their studied also present a contradict result where the untreated fiber cross section was less than alkali treated cross section at particular concentration.
3.4. Kenaf fiber morphology

Figure 6 (a) – (f) shows the scanning electron microscope image of untreated kenaf fiber and alkali treated kenaf fiber at different conditions. From Figure 6 (a) it appears that the surface of untreated kenaf fiber is not smooth but rather has longitudinal ridges, which could possibly enhance the mechanical interlock with the polymer matrix. It is observed that the impurities such as hemicellulose, lignin, and waxes substances were presented in untreated kenaf fiber. The white spots on the surface of the fiber may indicate impurities or localized damage of the fibers due to the handling process. Similar conditions was reported by Lai et al. [44]. From Figure 6 (b), it shows the considerable deposits of natural compounds such as hemicellulose, wax and lignin which are still present on the fiber surface after treatment with a 2% solution of alkali for 30 minute at room temperature, RT (± 27°C). This indicates that at lower setting alkali treatment conditions, the alkali treatment was not significantly effective to clean the fiber surface.

In Figure 6 (c) at lower alkali concentration at room temperature over 240 minute immersion time, the impurities is still can be detected at the fiber surface. Furthermore, delignification effect also can be observed in fiber surface image. The cleanliness and roughness in fiber surface due to fiber delignification process was observed to increase by increasing the alkali concentration, immersion time and immersion temperature as presented in Figure 6 (d), (e) and (f). This observation had good agreement with recent research work reported by Azelee et al. , which found that temperature increase in pretreatments for delignification has increase the percentage of lignin removal. Increasing temperature from 40°C to 100°C significantly increased the percentage of lignin removal to more than 70% in kenaf fiber [45]. Moreover, thermo gravimetric analysis (TGA) indicates that the kenaf fibers were thermally stable below 218°C and that, as such, the fibers could be effectively used as reinforcement when the moulding temperature was set under this temperature [46].

![Figure 5: Kenaf fiber cross sectional area (µm²) changing pattern after treated at various alkali treatment conditions](image-url)
Figure 6: (a) – (f) Scanning electron microscope image of untreated kenaf fiber and alkali treated (AT) kenaf fiber at different conditions
4. Conclusion
The effects of alkali treatment under various conditions setting on physical properties of kenaf fibers were investigated. For kenaf fiber density, it was found that a small increase of kenaf density value after alkali treatment compared to untreated kenaf fiber. When each of alkali treatment parameters increased, kenaf fiber density also increased slightly. Kenaf fiber weight loss also exhibit a similar pattern of small increment with the increase of treatment parameters. Additionally, kenaf fiber diameter and cross sectional area show a decline pattern after treated with alkali. Furthermore, this decline pattern was corresponding with the increasing level of alkali treatment parameters. The maximum of kenaf diameter reduction was recorded at high level of each alkali treatment parameters.

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