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The Effect of Alkaline Treatment on Tensile Strength and Morphological Properties of Kenaf Fibres for Yarn Production

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***Abstract*—**This paper investigates the effect of alkali treatment and mechanical properties of kenaf (*Hibiscus cannabinus*) fibre for the development of yarn. Two different fibre sources are used for the yarn production. Kenaf fibres were treated with sodium hydroxide (NaOH) in the concentration of 3, 6, 9, and 12% prior to fibre opening process and tested for their tensile strength and Young's modulus. Then, the selected fibres were introduced to fibre opener at three different opening processing parameters; namely, speed of roller feeder, small drum, and big drum. The diameter size, surface morphology, and fibre durability towards machine of the fibres were characterized. The results show that concentrations of NaOH used have greater effects on fibre mechanical properties. From this study, the tensile and modulus properties of the treated fibres for both types have improved significantly as compared to untreated fibres, especially at the optimum level of 6% NaOH. It is also interesting to highlight that 6% NaOH is the optimum concentration for the alkaline treatment. The untreated and treated fibres at 6% NaOH were then introduced to fibre opener, and it was found that the treated fibre produced higher fibre diameter with better surface morphology compared to the untreated fibre. Higher speed parameter during opening was found to produce higher yield of opened-kenaf fibres.

***Keywords*—**Alkaline treatment, Kenaf fibre, Tensile strength, Yarn production.

I. Introduction

NOWADAYS, products made from natural fibre for composite applications have yet to be seen in huge quantities. Due to the awareness of global environment problems, many alternatives are being created for new green materials and products that are compatible with the environment [1]. The advantages of natural fibres, such as low cost, low density, abundance, sustainability, recyclability, and biodegradability make them more interesting to be applied in research in order to tap their full potential. Important parameters that should be evaluated in natural fibres are the tensile and chemical properties, as both parameters play a vital role in determining the performance of fibres to be used for composites [2]. Natural fibre, which is available in materials such as cotton, kenaf, flax, jute, hemp, and pineapple, has been used as a composite for advanced applications such as aircraft and aerospace structures and for ordinary applications like consumer goods, textiles, furniture, low-cost housing, and civil structures.

The search for new high performance materials at affordable costs, which has been expanded, has also focused on developing, creating, and innovating eco-friendly materials such as recyclable and biodegradable textile materials [3]. Currently, there is a growing attention of using agricultural crops, lignocellulosic fibres, and wastes because of their properties such as renewability, abundant sources with good fibre properties. One of the potential natural fibre sources is kenaf (*Hibiscus cannabinus*). Kenaf is an old crop with many uses. The idea of making yarns from kenaf has been practiced since the early 1990s due to its properties including higher cellulose content [4], low lignin content [5], higher yields [6], and good mechanical properties [7]. However, kenaf fibre has unfavorable properties that can inhibit the development of good quality of yarn. Calamari et al. [8] claimed that the length of kenaf single fibres is only about 1-7 mm with diameter about 10-30 µm, which is too short for textile processing. Furthermore, kenaf fibres are coarse, brittle, and stiffer, which makes kenaf difficult to process with conventional yarn equipment. Thus, in order to improve the fibre properties, treatment and proper processing method is necessary to modify the fibre structures with the goal to produce acceptable quality of fibre for yarn production.

Alkaline treatment is one of the simplest and most effective chemical treatments to remove lignin or impurities on the fibre surface. Kawahara et al. [9] treated kenaf fibre using three different NaOH concentrations (1, 4, and 7%) and found that alkaline treatment produced better fibre surface. However, the tensile strength of fibre is reduced at higher concentration of NaOH, but the mechanical properties of the composites are improved. They conclude that alkaline treatment cleans the fibre surface, thus improving the bonding adhesion. On the other hand, Nitta et al. [10] treated kenaf fibre at higher level of NaOH concentration (10 and 15%) and conclude that higher concentration reduces fibre tensile strength but improves fracture strain.

One of the main processing to produce yarn is opening, apart from drawing and spinning processes. The role of opening is to separate the fibre by tearing with compressing until the fibre loosened or broke up into individual fibre [11]

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and separated into fine fibres to make them easier for the following processes. Moreover, opening also cleans the fibres by removing impurities. Ishitiaque and Kumar [12] studied the influence of different opening process, particularly roller feeder speed, drum speed, and suction air pressure. They found that air pressure has more significant influence on the mass yield, fibre diameter, and packing density compared to roller feeder and drum speed. Thus, the purpose of this study is to investigate the effect of different concentration alkaline treatment on the fibre surface and mechanical properties of kenaf fibres. The selected treated fibres are used for opening process with different opening parameters, and weight analysis, fibre diameter, and micrograph images were analysed.

II. Methodology

A. Materials

Raw kenaf fibres used in this study are supplied by Juteko Bangladesh Pvt. Ltd. and LKTN (Lembaga Kenaf dan Tembakau Negara) as shown in Fig. 1. Sodium Hydroxide (NaOH) used was supplied by Merck Sdn. Bhd.

(a) (b)

Fig. 1 Image of kenaf fibre (a) Juteko Kenaf and (b) LKTN Kenaf

B. Fibre Treatments

TABLE I
Information of Fibre Treatments

Sample Code	NaOH concentration (%)	Soaking time (hr)
UJKF	0	0
JKF3	3	24
JKF6	6	24
JKF9	9	24
JKF12	12	24
ULKF	0	0
LKF3	3	24
LKF6	6	24
LKF9	9	24
LKF12	12	24

Note: UJKF: Untreated Juteko Kenaf Fibre, JKF: Juteko Kenaf Fibre, ULKF: Untreated LKTN Kenaf Fibre and LKF: LKTN Kenaf Fibre.

Both kenaf fibres were immersed in the solution of NaOH at 3, 6, 9, and 12% concentration level for 24 hours, then the fibres were filtered out and washed with water to remove impurities. The treated fibres then were dried at elevated temperature 100 ºC for 24 hours. Kenaf fibres from Juteko are denoted as JKF and kenaf fibres from LKTN denoted as LKF. The number denoted the level of NaOH concentration as shown in Table I.

C. Fibre Surface Morphology

Diameter of the fibre was measured under MESDAN 2000 video analyzer by means of a calibrated eyepiece. All the specimens were put under the microscope with same magnification (4x MS5). Five fibres with 50-mm length at six locations were measured. Scanning Electron Microscope (SEM) model JOEL JSM – 6380LA complete with Energy-dispersive X-ray spectroscopy (EDX) was used to examine the surfaces of single kenaf fibre. The single fibre was coated with coating conductor material to allow electrons to flow through the specimen. Electron beam is applied to the image point on the fracture surfaces of examined specimens.

D. Fibre Mechanical Testing

The kenaf fibres were separated from their fibre bundles by hand, and mounted on 1-mm thick cardboard mounting cards. The single fibres were glued by PVC glue to the cardboard on either side of the two edges. A single fibre tensile test was conducted based on the ASTM D 3379 standard. All specimens for each part were tested for their tensile strength with 10-N load-cell using Universal Testing Machine (UTM) (LLOYD Instrument, LR30K), equipped with computerized data acquisition system at the room temperature. The UTM with a cross-head speed of 3 mm/min was used to determine the Young's modulus of the specimen. The mounted fibers were then gripped by the testing machine, and cut with a scissor along the cutting line with 30 mm of gauge length. Five specimens for each case were analyzed for this test. The specimens will be pulled until it fractures.

E. Fibre Diameter

About 20 g of opened kenaf fibres were drawn from each types of treatments. The fibres were examined under a stereo light microscope (Leitz DMRB) that was attached with an image analyser, and fibre diameter of randomly picked 200 fibres was measured.

F. Fibre Durability towards Machine

The treated fibres based on mechanical performance were selected. About 30 g of kenaf fibres with average length of 90-100 mm was introduced to fibre opener with three different parameters, namely V1 (roller feeder: 20 rpm, small drum: 520 rpm, big drum: 1500 rpm), V2 (roller feeder: 15 rpm, small drum: 250 rpm, big drum: 1000 rpm) and V3 (roller feeder: 10 rpm, small drum: 150rpm, big drum: 850 rpm). The weight percentage of each fibre with different parameter was determined after fibre opener.

III. Results and Discussion

A. Fibre Surface Properties

Video analyser images of untreated and treated at 6% NaOH of JKF and LKF kenaf fibre are shown in Fig. 2. Untreated kenaf fibre (Figs. 2 (a) and (c)) shows that the fibre diameters are smaller than those of the treated fibres (Figs. 2 (b) and (d)). This might be due to the swelling of cellulose when fibre is exposed to NaOH. According to Roy et al. [13], swelling of the fibre leads to increase the fibre accessibility for further process. Fig. 3 shows the SEM images of treated and untreated kenaf fibre. It can be clearly seen that some impurities were found embedded on the fibre surface (Figs. 3 (a) and (c)). The surface of ULKF fibre shows more impurities on the surface compared to JKF surface. After treated with 6% of NaOH, the fibre surface becomes 'clean' due to removal of impurities (Figs. 3 (b) and (d)). Based on the work of Sreekala and Thomas [14], NaOH has ability to remove natural fats, waxes, and impurities from the fibre surfaces. The removal of impurities from the fibre surface also improves the surface roughness, thus opening more hydroxyl groups and other reactive functional groups on the surface of the fibre [15]. Mwaikambo and Ansell [16] investigated treated fibre using NaOH at different concentrations for hemp, jute, sisal, and kapok fibres. They reported that 6% of NaOH concentration was the optimum concentration to clean the fibre bundle surfaces.

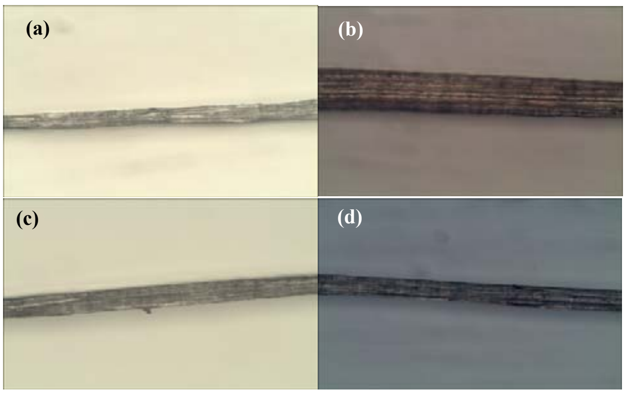

Fig. 2 Images of single treated/untreated kenaf (a) UJKF (b) JKF6 (c) ULKF (d) LKF6

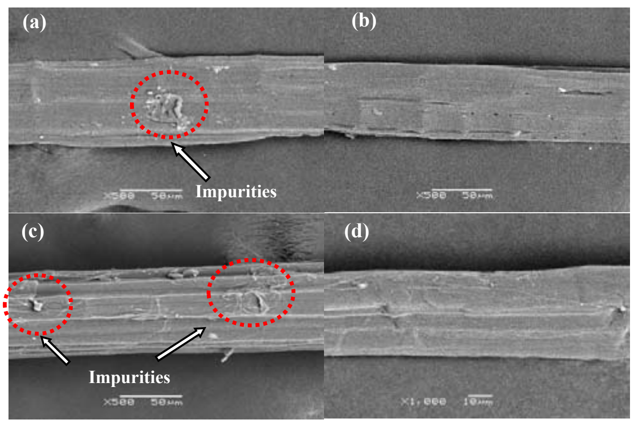

Fig. 3 SEM micrograph of single treated/untreated kenaf (a) UJKF (b) JKF6 (c) ULKF (d) LKF6

B. Fibre Mechanical Properties

The average tensile strength of untreated and treated kenaf fibres are presented in Fig. 4. In general, fibre treatment with NaOH appeared to slightly increase the tensile strength of the fibres. It can be seen that 3% NaOH treated JKF specimens gave high tensile strength values of 488 MPa as compared to treated LKF at same NaOH concentration. However, the trend was decreased when the concentration of NaOH was increased up to 6% in both fibres due to high concentration applied that yields to damage the fibres inter-laminar bonding [17]. In addition, Taha et al. [18] also claimed that the treatments with NaOH lead to an increase in the molecular orientation of the cellulose chains and result in better fibre strength. It shows that the NaOH treatment can also boost the strength of the fibre in preparation for producing yarn in which fibre strength is important to accommodate the forces applied during processing and also to produce a yarn which has high strength.

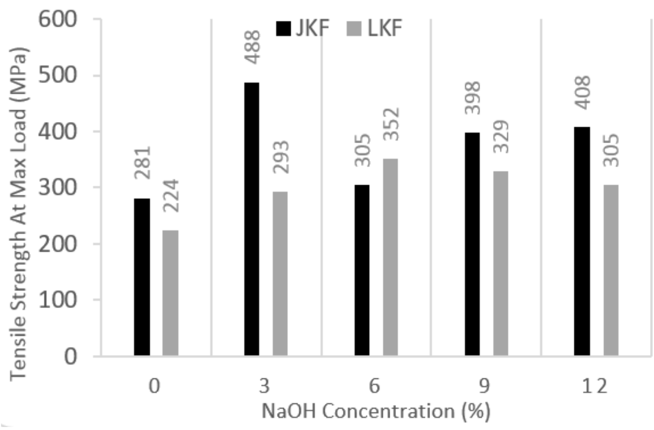

Fig. 4 Tensile strength of kenaf fibre with different NaOH concentration

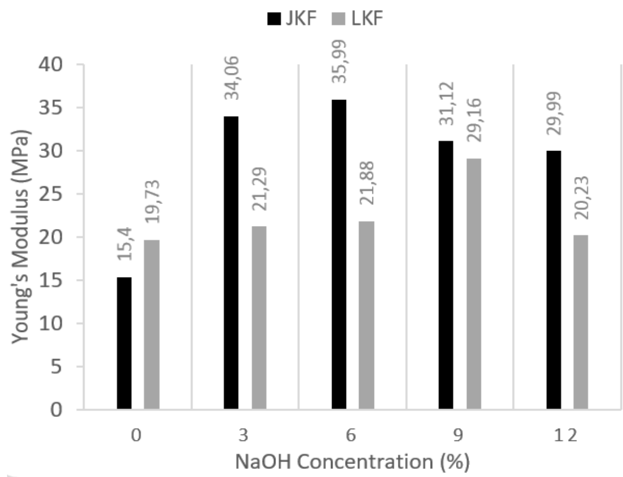

Fig. 5 Young's Modulus of kenaf fibre with different NaOH concentration

Fig. 5 displays the Young's modulus mean values of kenaf fibre as affected by the NaOH concentrations. As can be seen, the values of Young's modulus for kenaf fibre are increased with increasing of NaOH concentration up to 9%. The highest tensile strength in NaOH treatment of 35.99 MPa was observed at 6% of NaOH concentration. Charlet et al. [19] mentioned that the Young's modulus decreases with moisture content due to reduction in hemicelluloses content. Hemicellulose decreased after NaOH treatment due to the higher hydrolysis of hemicelluloses occurred. Removal of hemicellulose and lignin leads to formation of new hydrogen bonds between cellulose chains [20].

Based on the surface and mechanical properties of kenaf fibres, fibre treated at 6% of NaOH was selected for further study on the effect of opening process parameters.

C. Opened-Fibre Surface Properties

Fig. 6 shows the appearance of the fibre those treated with NaOH after opening process. It was clearly seen that opened-fibre are yellow in color, finer, and fluffy in structure compared to fibre without opening process.

(a) (b)

Fig. 6 Image of fibre before (a) and after (b) opening process

D. Diameter of Kenaf

The average values of fibre length before and after opening are presented in Fig. 7. In general, all the fibre diameters reduced after opening process in both untreated and treated fibres, and more reduction of diameter occurred in JKF with diameter range of 70 to 110 µm. The LKF6 opened-fibre showed the widest fibre diameter, while UJKF fibre before opening exhibits the thinnest fibre diameter. It was found that opening process successfully separated fibre bundles and produced finer fibers due to increase in transverse force on the fibre during opening phase. Besides, finer yarn is more suitable to develop yarn and to be woven due to interfibrillar adhesion. Also, treatment using NaOH is one of the ways to produce finer fibres with the help of fibre opener to develop fine yarn.

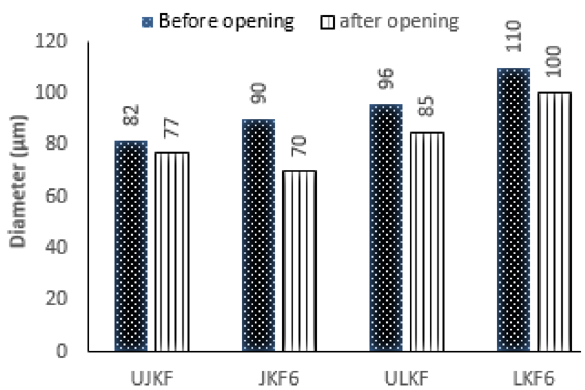

Fig. 7 Diameter of single kenaf with different NaOH concentration treatment

E. Fibre Durability towards Machine

Table II tabulated the weight percentage of opened-fibre at different velocities of drum and roller feeder. It can be noticed from the table that using NaOH produced fibre with higher weight percentage, and the higher output percentage is at high speed of drum and roller (V3). According to [12], higher opening roller speed leads to increase carrying factor, i.e. effective number of wire points fibre that results in better yield with the better fibre opening. Additionally, in this process, fibres with higher durability are capable of withstanding the process, while low-durable fibres are usually crushed into short fibres or dust and they will be eliminated as waste.

IV. Conclusion

Alkaline treatment has removed the impurities on fibre surface with the improvement of mechanical properties, where Juteko fibre is much better than the LKTN fibre. The fiber treated at 6% NaOH was found to have the optimum concentration of NaOH to produce acceptable fibre properties for opening process. Opening process produced small diameter fibre, and the treated fibre is finer than untreated fibre. Higher velocity in opening machine operation produced higher opened-fibre yields than lower velocity.

TABLE II
WEIGHT ANALYSIS PERCENTAGE

Sample	Weight Analysis (%)		
	Roller feeder : 20 Small drum : 520 Big drum : 1500 (V1)	Roller feeder : 16 Small drum : 250 Big drum : 1000 (V2)	Roller feeder : 10 Small drum : 150 Big drum : 850 (V3)
UJKF	95.3	91.6	90.6
JKF6	92.9	98.2	91.6
ULKF	92.1	86.7	90.1
LKF6	89.8	89.7	92.3

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