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The Effect of Alkaline Treatment On the Schizostachyum Grande Fibre for Textile Applications

Anis Amirah Nor Anuwar[1,2], Azrin Hani Abdul Rashid[1,2*], Suzi Salwah Jikan[3], Mohd Nazrul Roslan[1,2], Abdussalam Al-Hakimi Mohd Tahir[1,2], Nurul Husna Zolkifflee[1,2] and Fathee Aizat Mohd Razal[4]

[1]Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600, Muar, Johor, MALAYSIA

[2]Bamboo Research Centre (BambooRC),
Universiti Tun Hussein Onn Malaysia, 84600, Muar, Johor, MALAYSIA

[3]Faculty of Applied Sciences and Technology,
Universiti Tun Hussein Onn Malaysia, 84600, Muar, Johor, MALAYSIA

[4]Hangterrabamboo Sdn. Bhd., Bandar Amanjaya, 08000, Sungai Petani, Kedah, MALAYSIA

*Corresponding Author

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Abstract: Among commercial Malaysian bamboo species, Schizostachyum Grande species are characterised by their longest internode and thinner culm wall, which allow more attainable fibres during the extraction process. However, the chemical composition of bamboo fibres is higher than any other natural fibre, resulting in coarse and stiff fibres that require alkaline treatment to develop fine fibres. This paper presents the effect of alkaline treatment concentration and soaking time on the physical properties and tensile properties of bamboo fibres. The bamboo fibre was treated with an alkaline solution at 4 and 8 wt.% concentration for 6, 12, 18, and 24 hours. The diameter and fineness of bamboo fibre were evaluated to determine if alkaline concentration and soaking time affected the fibres. Results showed that the treated fibre diameter decreased by 23.2% to 66.51 μm at 8 wt.% alkaline concentrations for 12 hours of soaking time compared to the untreated bamboo fibre of 86.56 μm. The fibre fineness of 11.96 tex was produced at 24 hours of soaking time and 8 wt.% alkaline concentrations. Alkaline treatment was effective in causing a decrease in fibre diameter and produced the finest fibre. Thinner and finer fibre was produced as alkaline concentration and soaking time increased. The highest tensile strength of treated bamboo fibre was 1.42 GPa at a 4 wt% alkaline concentration and 6 hours of soaking time. Elongation at break and tenacity improved remarkably when the alkaline concentration and soaking time were increased, which were 3.11% and 45 cN/Tex, respectively, at 8 wt% alkaline concentrations for 12 hours of soaking time. Moreover, the 8 wt% alkaline concentration was the best for bamboo fibre because the treatment was effective in causing a decrease in fibre diameter and produced the finest fibre. The elongation at break and tenacity of fibres were also improved at 12 hours of soaking time. The tensile strength and modulus of fibre were reduced at longer soaking times at high alkaline concentrations of more than 18 hours.

Keywords: Alkaline treatment, natural bamboo fibres, fibre fineness, fibre morphology, tensile properties.

1. Introduction

Natural cellulose fibres include flax, jute, sisal, kenaf, hemp, banana, and oil palm fruit bunch cellulose fibre. Plants that produce cellulose fibres are classified as bast fibres (jute, flax, ramie, hemp, and kenaf), seed fibres (cotton,

*Corresponding author: azrin@uthm.edu.my

coir, and kapok), leaf fibres (sisal, pineapple, and abaca), grass and reed fibres (rice, corn, and wheat), and core fibres (hemp, kenaf, and jute), along with others (wood and roots) [1]. Natural fibres such as silk, wool, lignocellulosic fibres, and synthetic fibres are used by textile makers for various applications. Natural fibres such as cotton and linen have long been sought after by industry. New materials that may match their performance are now being explored. Since cotton production consumes more than a quarter of the total insecticides used worldwide each year, cotton production is harmful to the environment [2]. Synthetic fibres are derived from petroleum, which is not renewable, and they use substantially more energy than renewable fibres [2]. Therefore, the textile industry has recently begun exploring and utilizing all aspects of the bamboo plant for yarn application [3].

In manufacturing of textile products, the discovery of alternative sources of raw materials and natural resources is required because of the limited availability and high price of raw materials. In Malaysia, where a tropical rainforest environment prevails throughout the year, the accessibility and plentiful supply of bamboo fibres are addressing the sustainable technology that may overcome the drawbacks of synthetic fibres by providing an alternative [4]. Bamboo is one of the fastest-growing plants in the world, with a peak growth rate of up to 100 cm per day, which is far higher than the growth rate of all other types of wood, which is normally 0.1-0.4 cm per day [5]. However, bamboo as lignocellulosic fibres are coarse and stiff, requiring specialized processing techniques to develop fine and soft yarns that can be used in value-added goods [6]. Aside from that, this initiative is in accordance with the Malaysian Timber Industry Board's (MTIB) efforts to promote the bamboo industry through the formation of the Bamboo Industry Development Action Plan 2021-2030 [7].

Numerous bamboo species are grown in forest regions, but they are also found on farms, riverbanks, roadsides, and suburbs [8]. In Peninsular Malaysia, *Schizostachyum grande* species has the second-highest distribution after *Gigantochloa levis*, according to the distribution of six bamboo species based on forest status, followed by *Gigantochloa scortechinii, Gigantochloa wrayi, Dendrocalamus asper, Schizostachyum zollingeri* [9]. *S grande* is the only species with longer internodes than any other commercial Malaysian bamboo. Among thirteen commercial bamboo species, *S. grande* has a larger value in density, radial and tangential shrinkage. These characteristics of *S. grande* species allow it to be used in various fibre production processes, particularly during mechanical extraction [10]. Due to the biological nature of bamboo, its mechanical, physical, and natural durability attributes vary according to various factors, including growth conditions and genetics [11]. Detailed studies on the properties of numerous bamboo species have been conducted, as in [10,12,13], where researchers focused on the physical and mechanical properties of bamboo species that are commercially viable in Malaysia.

There have been lots of research studies on the physical properties of natural fibre based on spectroscopy and microscopy. Salih et al. [14] discussed that single-cellulosic bamboo fibre scanning electron microscopy (SEM) analysis revealed that the fibre surface had a high number of regularly spaced holes or pits and became significantly rougher following alkaline treatments due to the elimination of hemicellulose, fatty substances, and other surface impurities. Rocky and Thompson [15] discovered that all bamboo species analysed possess comparable structures in which fibres are linked and coated by lignin and other non-fibrous material. The key structural parameters of textile fibres in technical processes and fabric physical attributes are length, diameter, fineness, cross-sectional shape, and major heterogenetics [16]. Aaditaa et al. [17] discovered that increasing NaOH concentrations enhanced physical properties such as fineness, resulting in the elimination of more impurities from fibres. Many studies have been conducted on mechanical performance testing of natural textile fibres including bamboo [4,15,18] and other plant fibres such as kenaf [19] and pineapple leaf fibres (PALF) [20,21] by measuring tensile properties including its tensile strength, Young's modulus, percentage of elongation, and tenacity.

Bamboo fibre extraction is often carried out using three primary methods, which are mechanical, chemical, or a combination process of chemical and mechanical extraction [22-25]. Alkaline treatment, also known as mercerization, is a common method for producing high-quality fibres. It involves the removal of non-structural components such as fats, ash, and waxes from the fibres [26]. Bamboo fibres are comprised of cellulose and hemicellulose, with 45 to 55% and 20 to 25%, respectively. Bamboo fibres are stiff due to their high lignin content of 20-30% lignin [27]. Apart from that, the impurities in the fibres make them coarse and give them a murky white appearance. Due to the coarse nature of the fibres, yarn spinning, and fabric manufacture are complicated [17]. As a result, a scouring procedure is required to remove contaminants from bamboo fibres and separate them to make them appropriate for textile applications. Sodium hydroxide (NaOH) is a versatile treatment that reduces strength and weight without affecting the fibre shape and crystalline structure. Alkaline treatment affects the chemical composition of the fibres, resulting in changes to the mechanical properties of the fibre surface roughness, crystallinity, and thermal behaviour [28].

The fineness of fibres is a critical feature that impacts their behaviour during the yarn and fabric manufacturing processes. Additionally, the enhanced fineness leads to softer fibres and greater fibre pliability [17,29]. Studies found that alkaline treatment with NaOH dissolves the cementing agent of the fibre. The percentage reduction depends on the soaking time and temperature as well as the mixture ratio and NaOH concentration. Single bamboo fibres had a multi-layered wall structure made of large cell walls, a small-scale lumen with pits, and a tiny microfibril angle [30]. However, only a few studies in the literature examine how alkaline concentration and soaking duration affect bamboo fibre diameter and fineness in terms of spinnability [31].

Natural fibres often range in diameter from 6 µm (silk) to 15 µm (cotton) to 70 µm (thick wool). In contrast, man-made fibres may be produced in any diameter and cross-sectional form [32]. Different types of bamboo have different lengths, diameters, chemical compositions, and lumen sizes for their fibres [14]. The diameter of the fibre influences not only its strength, elongation, stiffness, and elasticity but also its hand feel, style, and processing of the yarn and textile. The smaller the fibre diameter, the greater the friction between the fibres and the larger the yarn formed due to the increased number of fibres contributing to the yarn strength [33]. Fibre diameter is an important characteristic since a smaller diameter indicates a greater thread count and a silky feel [34]. Based on previous research, different techniques and chemicals in suitable conditions may help extract fine natural bamboo fibre suitable for textile and apparel applications [15,18,35]. The advantages of extraction processes and the effect of chemical treatment on fibre diameter and fineness will provide a baseline for future research on spinnability potential. This research aims to determine the effect of alkaline concentration and soaking time on the diameter, fineness, tensile properties, and tenacity of bamboo fibres.

2. Methodology

2.1 Materials

The present investigation used a cultivated Schizostachyum grande species, commonly referred to as Buluh Semeliang, which was obtained from Hangterra Bamboo Sdn Bhd. Mechanical extraction with a decorticator machine was used to convert this bamboo strip to fibre prior to alkaline treatment. The fibre extracted from the bamboo culm were hand combed using a hackling tool to eliminate short fibres, impurities, and neps while smoothing and parallelizing the fibres. The sodium hydroxide (NaOH) in the pallet form utilized in this study was from HmbG Chemicals, which comes in 1 kg plastic bottles. The alkaline solution concentration was prepared using weight per volume percentage (w/v%).

2.2 Bamboo Fibre Extraction Process

The flow of the fibre preparation process is illustrated in Fig. 1. Each raw bamboo culm in Fig. 1(a) was cut into 4 to 5 strips as feed material prior to the decorticator machine process, as shown in Fig. 1(b). The strips were water retted for 3 to 7 days before being crushed using a decorticator machine to obtain fibres. The decorticated fibres in Fig. 1(c) remained adherent and showed a low degree of fibre opening. Therefore, the decorticated fibres were hand combed before being subjected to an alkaline treatment. Alkaline treated fibres were entangled and intact after treatment, as shown in Fig. 1(e), because of their wet form. Hence, combing was necessary after drying so the fibres were more open and parallel, as shown in Fig. 1(f). Fibre extraction is based on the procedure established by [12]. As shown in Fig. 1(g), the fibre samples for testing and analysis were cut into the same standard length of 100 mm. Fibre specimens were collected randomly from the top, middle, and basal of each part of the processed bamboo internodes. Untreated bamboo fibre was utilized as a control sample to isolate the effect of the experimental treatment.

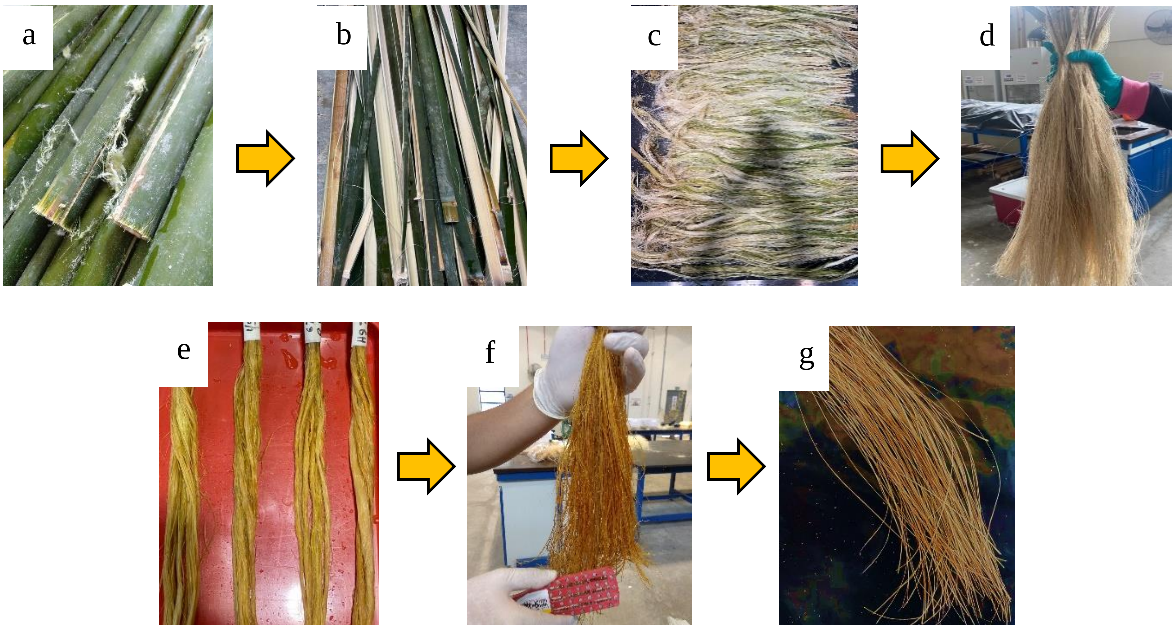


Fig. 1 - Sample preparation process (a) bamboo culm; (b) bamboo strips; (c) decorticated bamboo fibre; (d) combed fibre; (e) alkaline treated fibre; (f) combed treated fibre; (g) testing sample

2.3 Alkaline Treatment of Bamboo Fibre

Decorticated bamboo fibre was combed before being subjected to alkaline treatment. Salih et al. [14] reported insufficient alkali solution reduced tensile properties, whereas an excessively high NaOH solution easily eroded the fibers. In this study, the processed bamboo fibre was treated with different alkaline aqueous solutions at two levels of concentrations of 4 and 8 wt.% at room temperature for 6, 12, 18, and 24 hour soaking times at 5-hour intervals were selected based on literature [14,36] to remove hemicellulose and surface impurities. After the treatment, the fibres were washed and neutralised with 10 wt.% of magnesium chloride ($MgCl_2$) solution to remove the alkaline content and retain the softness imparted to them. The fibres were thoroughly cleaned and dried at room temperature for a day, then dried in a 60 °C oven for 24 hours. After drying the bamboo fibre, it was enclosed in a plastic bag to prevent water absorption from the atmosphere prior to testing.

2.4 Fibre Diameter

The bamboo fibre diameter was measured using an Olympus Advanced Microscopic (BX53M model). The lens was adjusted to 5x lens magnification used for diameter measurement. Ten fibre samples with 10 mm length were sorted of each different treatment condition. The diameter was measured 10 times along its length as the average of the diameters (Fig. 2). ASTM D2130-90 is a standard test method used for measuring the diameter of representative sampling fibres under high magnification of microscope.

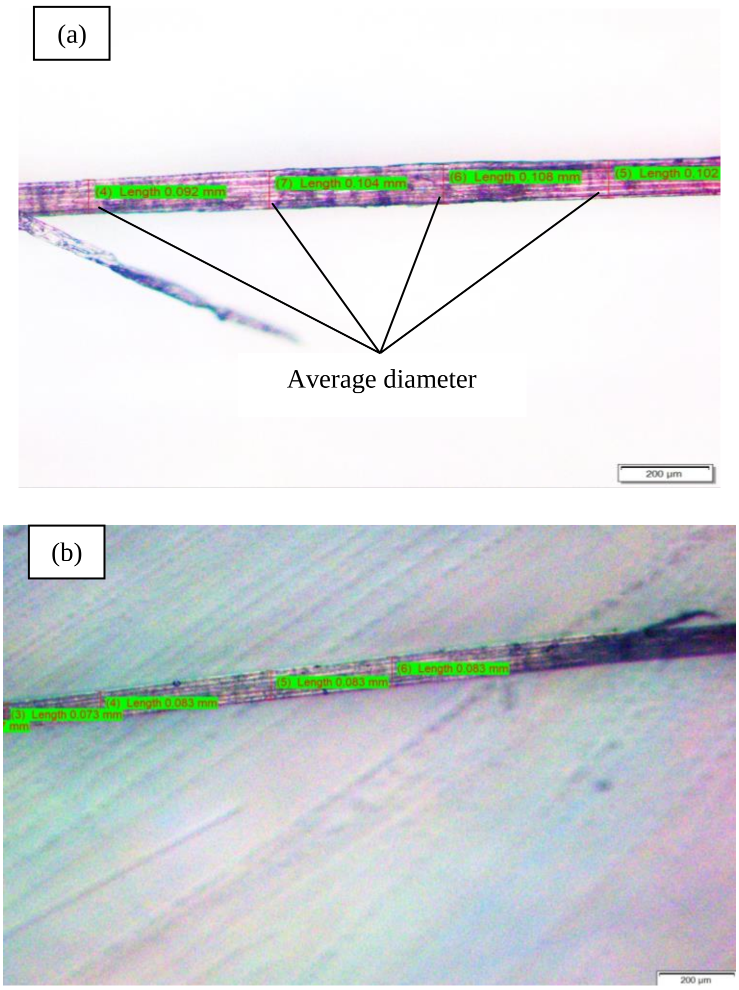


Fig. 2 - Diameter measurement of (a) untreated bamboo fibre; (b) treated bamboo fibre under the microscope

2.5 Fibre Fineness

The fineness of fibre, which was frequently expressed as mass per unit length, was measured using the standard gravimetric method (cut and weight method) in accordance with ASTM D1577. The samples were cut into 10 cm and weighed using a calibrated balance with a precision of 0.001 g. The results were expressed in Tex. An average of three readings were taken. The coarser the fibre, the higher its tex value, which is inversely proportional to its fineness.

2.6 Fibre Morphology

The surface morphology of the bamboo fibre before and after different alkaline treatment conditions was examined with a Hitachi SU1510 Scanning Electron Microscope (SEM). The fibre samples were used for surface observations on an SEM instrument operated at an accelerating voltage of 15 kV.

2.7 Fibre Tensile Properties

The Lloyd Instruments Universal Testing Machine LR30K model was used to determine bamboo fibre tensile properties in compliance with ASTM (C1557-03). Natural fibres, such as kenaf, were tested using this standard approach by Hashim et al. [37]. A single bamboo fibre was cut and glued at each end of the fibre to the paper frame to avoid it sliding out of the grip area during testing. A single fibre was 40 mm in total length and 20 mm in gauge length. The tensile speed was set to 1.0 mm/min. Fig. 3(a) shows a sample of bamboo single fibres that have been tightly clamped on a tensile testing machine. Fig. 3(b) shows a diagram of the paper frame that is used to test tensile specimens. The analysis was conducted on fibres that had been treated with NaOH at concentrations of 0, 4, and 8 wt%. Twenty samples were gathered from each condition throughout the assessments. The average values were determined by averaging the maximum of ten readings and excluding the samples that broke at the edges of the clamps from the calculation.

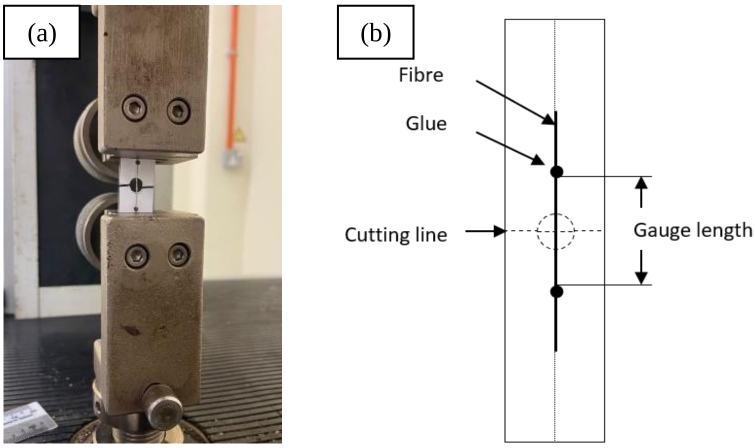


Fig. 3 - Tensile testing (a) tensile test of a single bamboo fibre sample; (b) specimen dimension schematic diagram for a single fibre tensile test

2.8 Fibre Tenacity

Tenacity refers to the force required to break the fibre in relation to its linear density. As indicated in Equation (1), the force required to break the fibre, cN, was divided by the tex value.

$$Tenacity = \frac{Load\ required\ breaking\ specimen}{Linear\ Density} \quad (1)$$

Unit of tenacity: cN⁄tex

3. Results and Discussion

3.1 Fibre Physical Properties

Table 1 shows the impact of alkaline concentration and soaking time on bamboo fibre diameter and fineness. Untreated bamboo fibre has the highest diameter when compared to treated bamboo fibre. Based on the results, untreated bamboo fibre had an average diameter of 86.56 µm. In contrast, treated bamboo fibre had a diameter ranging from 66.51 to 78.95 µm. Based on previous research by Tamanna et al. [38], it was found that the bamboo fibre diameter was higher than that of cotton (11 to 22 µm) and the pineapple leaf fibre (53 to 62 µm). However, kenaf (65 to 71 µm) and jute fibre (40 to 350 µm) were found to be comparable to the bamboo fibre diameter. The fineness was found to have a decreasing tex value after each treatment condition. Untreated bamboo fibres exhibit the highest fineness with 23.84 tex. The lowest fineness of 11.96 tex for treated bamboo fibres was found in 8 wt.% NaOH after 12 hours of soaking time, which is within the range of 9.68 to 93.3 tex of previous research. Based on the results, the fineness obtained was higher than the range of 0.05 to 0.20 tex reported for cotton fibres in the previous study. Despite having a higher tex value than cotton fibres, natural bamboo fibres can be processed to produce coarser yarns or finer counts [15]. Based on the results from a previous study, it was observed that 2.5 wt.% NaOH treatment at a soaking period of 24 hours resulted in finer bamboo fibre at 18 tex, compared to 32 tex for untreated bamboo fibres [39]. The alkaline treatment approach utilized in this study was significantly improved to approximately a 50% increment in the fineness of the bamboo fibre, which is 11.96 tex.

Table 1 - Diameter and fineness properties of bamboo fibre

Alkaline Concentration (wt.%)	Soaking Time (hours)	Diameter (µm)	Fineness (tex)
0	0	86.56 ± 9.40	23.84 ± 0.86
4	6	78.20 ± 7.51	19.75 ± 0.88
	12	70.80 ± 5.50	16.54 ± 0.60
	18	71.99 ± 6.57	14.50 ± 0.83
	24	78.95 ± 6.12	14.09 ± 0.63
8	6	72.40 ± 3.67	12.76 ± 0.66
	12	66.51 ± 4.84	12.66 ± 0.65
	18	76.11 ± 5.79	12.14 ± 0.46
	24	77.93 ± 4.89	11.96 ± 0.33

The average diameter of bamboo fibres is depicted in Fig. 4. As the alkaline concentrations and soaking time increase, the diameter of the fibre decreases. The alkaline treatment caused the hemicellulose, lignin, and other impurities in the fibre to dissolve, which reduced the diameter of the fibre [40]. However, concentrations of more than 18 hours of soaking time for 4 and 8 wt.% indicate a distinct pattern. When soaking time and alkaline concentration are increased, fibre diameter increases. The alkaline solution permeation process occurs concurrently with hemicellulose dissolution, which causes the bamboo fibres to swell, which increases fibre diameter [5]. Alkaline treatment is important in the separation of fibres in lignocellulosic material. To obtain a good degree of fibre extraction, a high concentration of alkaline or a high temperature treatment is necessary [35].

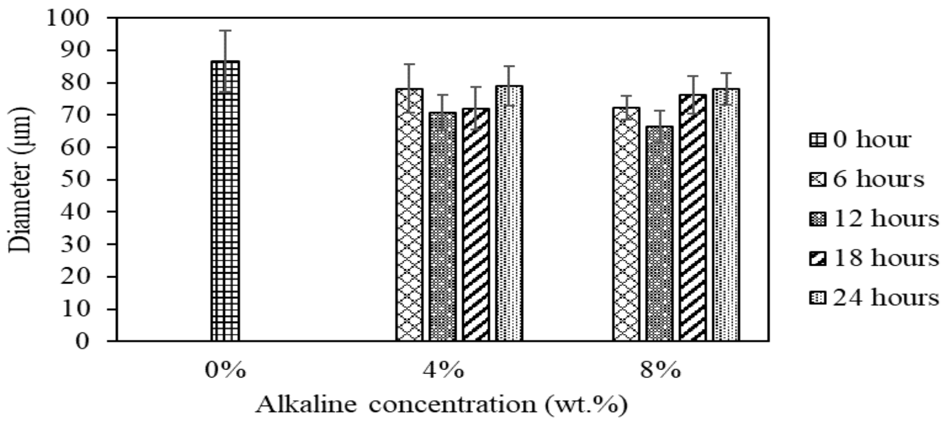


Fig. 4 - The diameter of the bamboo fibre subjected to different alkaline concentrations for various soaking times

As displayed in Fig. 5, the fineness showed a decreasing trend. Treated bamboo fibre is finer than untreated bamboo fibre, since the tex value is proportional to the fineness of the fibre, with a greater tex value indicating coarser fibres. The tex values decrease as the alkaline concentration increases. Additionally, as the soaking time increased, the fineness of the bamboo fibres also increased. This is because increases in alkaline concentration and soaking time result in a gradual loss of cementing materials such as lignin, hemicellulose, and pectin [41].

3.2 Fibre Morphology

Fig. 6 depicted the SEM image of untreated bamboo fibres under 250x and 1000x magnification. The surface morphology of untreated bamboo fibres shows the presence of impurities and wax on the surface of the fibre as shown in Fig. 6(b). Table 2 compares the surface morphologies of treated bamboo fibre that have been treated with 4 and 8 wt.% alkaline concentrations at various soaking times. Visual inspection at 250x magnification in Table 2 showed that alkaline treated bamboo fibre diameter was reduced compared to the untreated bamboo fibre diameter (Fig. 6(a)). The diameter of the treated fibre decreased with increasing NaOH concentration after 12 hours of soaking. The surface of the untreated fibre was covered by a superficial layer of impurities, which may include lignin, pectin, and other debris [4]. Most of the hemicellulose, lignin, and other extractives were removed from the alkali-treated fibre surface, and the separation of cemented fibres reduced the fibre diameter [4].

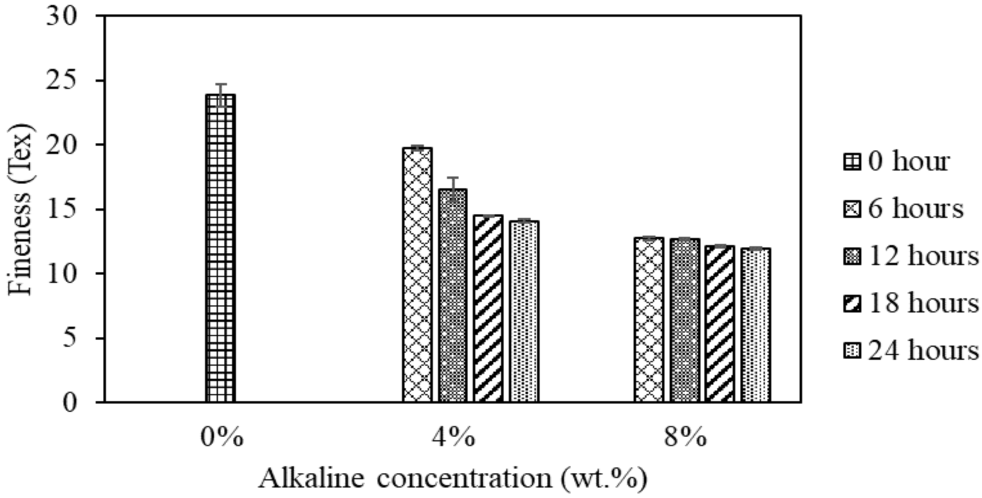


Fig. 5 - Fineness of the single bamboo fibre subjected to different alkaline concentrations for various soaking times

However, when the fibres are steeped in 18 and 24 hours of soaking time, the findings revealed a slight increment in the fibre diameter, as indicated in Table 1, as could be observed by the morphology analysis, as shown in Table 2. It is commonly accepted that the transport of liquid inside the cell wall happens mostly at the elementary fibril level of hemicellulose, and in most cases, the contraction and swelling processes also occur primarily at this level of the cell wall structure [42]. According to Table 2, the image under 1000x magnification shows that untreated bamboo fibre appears to have longitudinal ridges rather than a smooth surface. The presence of white spots on the surface of the fibre may be an indication of impurities. Untreated bamboo fibre was discovered to contain impurities like hemicelluloses, lignin, and wax substances on the fibre surface. Significant natural compounds like hemicellulose, wax, and lignin remain deposited on the surface of the fibres after 6 hours of treatment with 4 and 8 wt.% alkaline concentrations at room temperature. This suggests that at lower alkaline treatment conditions, the fibre surface was not significantly cleaned. In addition, a delignification effect can be seen in the fibre surface image. The increasing in the alkaline concentration and soaking time results in an increase cleanness and roughness due to the fibre delignification process. Pectin and lignin are broken down when they are taken out of the cell wall of the fibre during treatment. This separates the final fibre and makes it thinner. According to Hashim et al. [43], the authors have noted that the change in the morphology of the treated fibre was the cause of the decrease in fibre diameter that occurred alongside the increase in alkaline concentration. They discovered that the fibre was not truly monofilament after using a scanning electron microscope to examine it. It was a lignin-covered bundle of monofilament bonded together. Due to their solubility in NaOH solution, waxy impurities were removed more effectively. Some impurities are still visible on the surface of treated fibres after 24 hours of soaking in a 4 wt.% alkaline concentration. This may be due to the low concentration of alkaline. Treated fibre with 8 wt.% NaOH concentration for 24 hours revealed great amount of impurities and lignin removal.

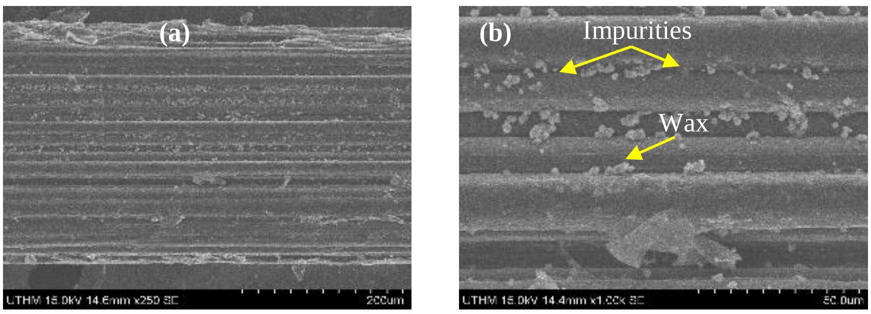


Fig. 6 - SEM image of untreated bamboo fibre under (a) 250x; (b) 1000x magnification

3.3 Tensile Properties

Tensile properties of untreated and treated bamboo fibres were determined using various alkaline treatment conditions, as shown in Table 3. In this study, the average tensile strength of the single bamboo fibre was found to be in the range of 0.81 to 1.49 GPa. Bamboo fibres, with an average tensile strength of 0.14 to 1.69 GPa, have garnered much interest and attention due to their outstanding mechanical properties [44,45]. When compared to treated bamboo fibre, untreated bamboo fibre has the highest tensile strength. The highest tensile strength obtained after alkaline treatment was 1.42 GPa after soaking for 6 hours at 4 wt% alkaline concentrations. As shown in Table 3, the elongation at break of bamboo fibre ranged from 1.7 to 3.11%. Similar observation by Rocky et al. [15] found that natural bamboo fibre has a breaking elongation of 2.06 to 2.46% but less than cotton fibres, which have a breaking elongation of 4 to 8%. Treated bamboo fibres have a lower Young's modulus than untreated bamboo fibres. The Young's modulus of a single bamboo fibres with an average diameter of 67.03 to 83.31 μm was discovered to be between 0.39 and 0.85 GPa, which is less than the 5.5 to 12.6 GPa recorded for cotton fibres. The tenacity of bamboo fibre determined was in the range of 30.56 to 45 cN/Tex. Compared to other natural textile fibres such as jute, flax, and cotton, their tenacity ranges from 29-56 cN/Tex, 25-26 cN/Tex, and 28-48 cN/Tex, respectively [46]. The textile fibres must possess a minimum strength of 6 cN/tex and a minimum elongation of 1 to 2% [47]. In this study, the elongation at break and tenacity improved remarkably when the alkaline concentration and soaking time were increased.

Table 2 - SEM image of untreated bamboo fibre and 4 and 8 wt.% alkaline treated bamboo fibre at various soaking times under 250x and 1000x magnification

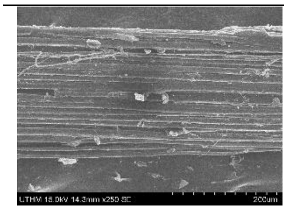
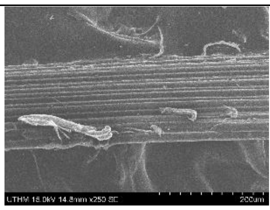
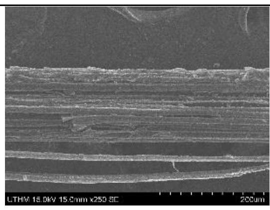
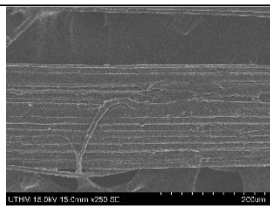
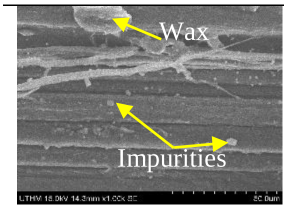
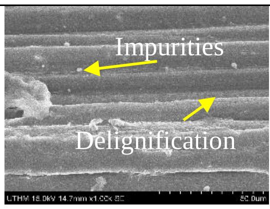
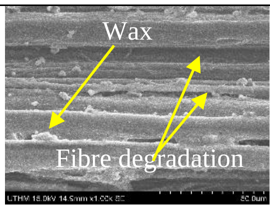
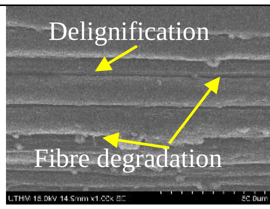
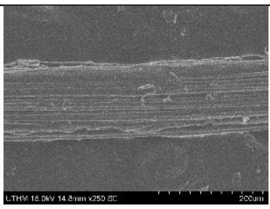
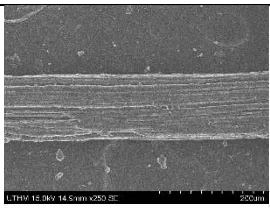
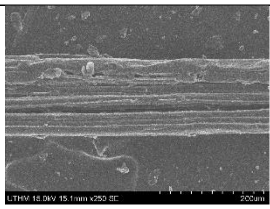
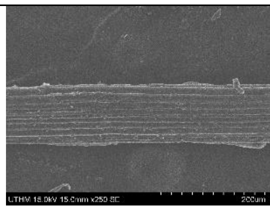
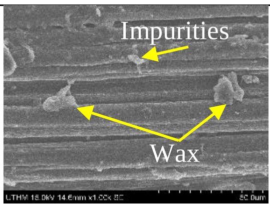
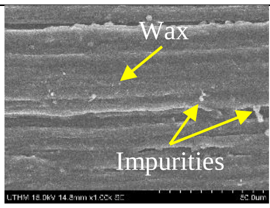
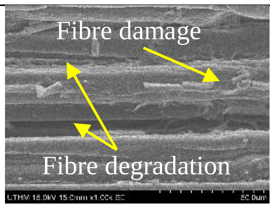
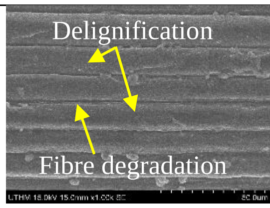
NaOH %	Soaking Time (hours)			
	6 hours	12 hours	18 hours	24 hours
	250x magnification			
4 wt.%				
	1000x magnification			
				
	6 hours	12 hours	18 hours	24 hours
	250x magnification			
8 wt.%				
	1000x magnification			
8 wt.%				

Table 3 - Tensile properties of bamboo fibre

Alkaline Concentration (wt.%)	Soaking Time (hours)	Tensile Strength (GPa)	Elongation at break (%)	Young's Modulus (GPa)	Tenacity (cN/tex)
0	0	1.49 ± 0.12	1.81 ± 0.41	0.85 ± 0.81	34.15 ± 1.25
4	6	1.42 ± 0.25	1.91 ± 0.19	0.75 ± 0.21	35.90 ± 1.60
	12	1.37 ± 0.13	2.48 ± 0.30	0.56 ± 0.11	36.01 ± 1.30
	18	1.35 ± 0.12	1.70 ± 0.19	0.79 ± 0.05	41.53 ± 2.32
	24	1.32 ± 0.18	2.00 ± 0.52	0.68 ± 0.13	40.45 ± 1.82
8	6	1.30 ± 0.10	2.24 ± 0.42	0.60 ± 0.14	42.73 ± 2.20
	12	1.26 ± 0.05	3.11 ± 0.81	0.42 ± 0.09	45.00 ± 2.44
	18	0.81 ± 0.09	2.24 ± 0.62	0.39 ± 0.12	30.56 ± 1.10
	24	0.81 ± 0.08	2.09 ± 0.39	0.40 ± 0.08	31.93 ± 0.88

Tensile strength results for untreated and treated single bamboo fibres under different treatment conditions are shown in Fig. 7. The tensile strength of the treated bamboo fibre gradually decreased when the alkaline concentration and soaking time increased. According to Ibrahim et al. [48], high alkaline concentrations weaken the fibres because the treatment removes impurities, causing lignocellulosic degradation and rupturing the fibre surface, all of which are detrimental to fibre performance [14]. A study conducted by Salih et al. [49] revealed that when compared to fibre treated with the other chemical techniques, NaOH-treated fibre demonstrated the maximum tensile strength of 1.45GPa. Depending on the species, a single bamboo fibre can have tensile strengths of more than 1.43 GPa to 1.69 GPa [50]. In this study, the tensile strength of the 4 wt% alkaline concentration for various soaking times did not show much decrement, whereas the 8 wt% alkaline concentration at 18 and 24 hour soaking times fall significantly to the lowest value. Most likely, this was because the 4 wt% alkaline concentration partially removed lignin, hemicelluloses, and cellulose from the fibres.

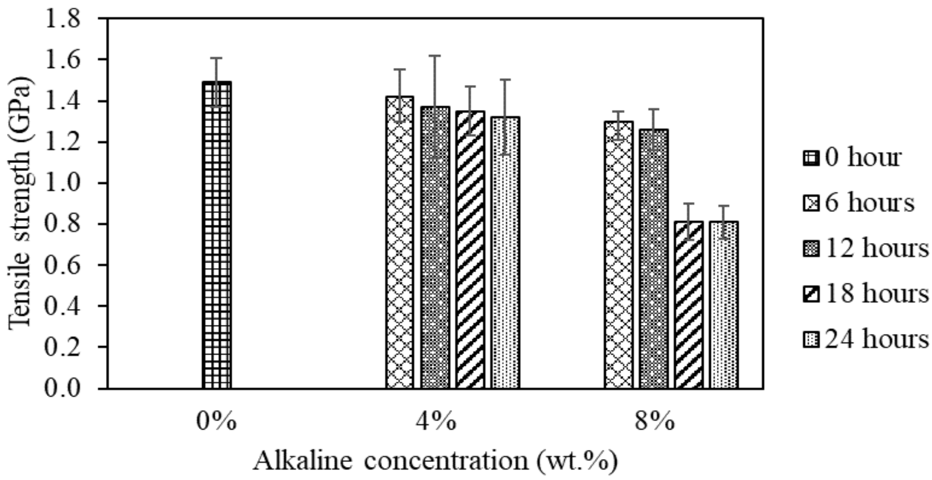


Fig. 7 - Tensile strength of single bamboo fibre subjected to different alkaline concentrations for various soaking times

As illustrated in Fig. 8, all examined fibres displayed an increasing pattern of elongation at break as the alkaline concentration increased. The elongation at break for the untreated bamboo fibre was 1.81% and improved by approximately 45% to reach the highest elongation at break of 3.11% when treated with 8 wt% alkaline concentrations. It is obvious that when alkaline concentration increases, intermolecular or interchain hydrogen bonds loosen at the expense of bundle strength, resulting in an increase in the percentage of elongation [51]. Bamboo fibres were modified from brittle to ductile as alkaline concentration was increased using NaOH, showing that alkaline treated bamboo fibres had a promising application in textiles [44]. However, with longer soaking times of 18 and 24 hours, the elongation at break dropped significantly after 4 and 8 wt% alkaline concentrations. The highest elongation at break of fibres was at 8 wt% alkaline concentration soaked for 12 hours, while the lowest elongation at break was soaked for 18 hours at 4 wt% alkaline concentrations.

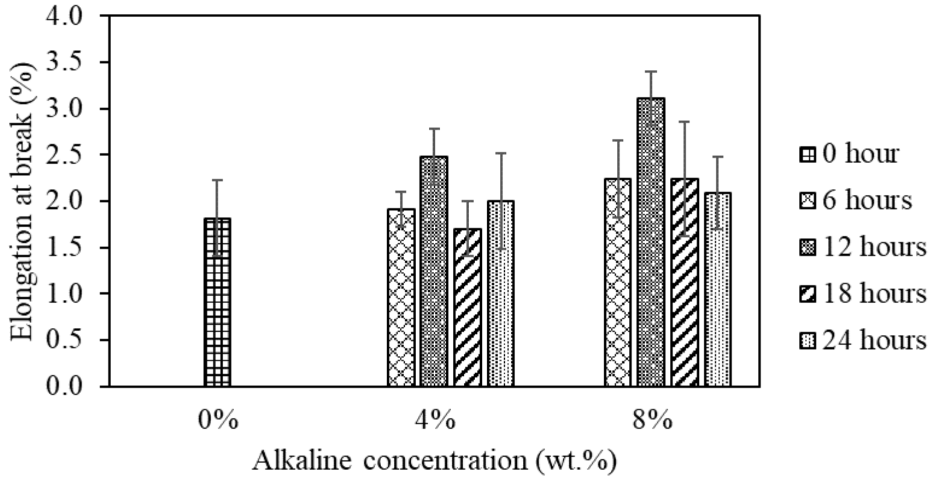


Fig. 8 - Elongation at break of the single bamboo fibre subjected to different alkaline concentrations for various soaking times

Fig. 9 shows that the Young's modulus decreased significantly as the alkaline concentration increased. Untreated bamboo fibres had a modulus of 0.85 GPa, which was reduced by 54% to the lowest modulus of 0.39 GPa when treated with an 8 wt% alkaline concentration for 18 hours. Cellulose transformation caused by aqueous alkaline may have a significant impact on modulus decline [52]. However, only slight variations in modulus trend were observed as treated bamboo fibre exhibits a 29% increase after 18 hours of soaking in a 4 wt% alkaline concentration, and then slightly decreased to 13% was observed for 24 hours of soaking time. The modulus was significantly reduced after an increase in alkaline concentration and soaking time. The degradation of hemicellulose and lignin in bamboo fibres results in a decrease in the modulus and hardness of the fibres [53]. When compared to untreated bamboo fibres, alkaline treatment reduces tensile strength and Young's modulus, but increases elongation at break. Chen et al. [54] reviewed a similar study, which found that increasing the NaOH concentration reduces the tensile strength and tensile modulus of bamboo fibres while increasing their ductility.

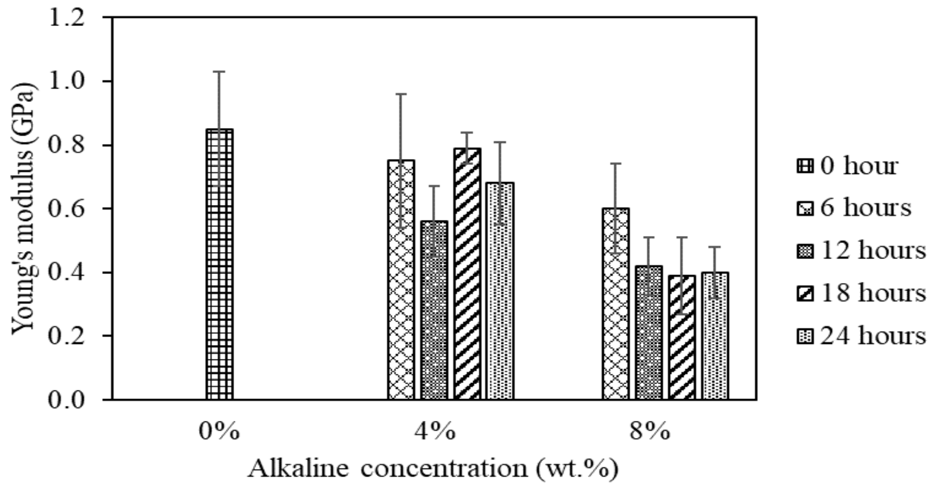


Fig. 9 - Young's modulus of single bamboo fibre subjected to different alkaline concentrations for various soaking times

Fig. 10 shows the tenacity of untreated bamboo fibre compared to that of bamboo fibre that has been treated with different alkaline concentrations and soaking times. The tenacity of treated bamboo fibre was found to be greater than that of untreated fibres. It can be observed that the higher the alkaline concentration, the higher the tenacity of bamboo fibre. However, soaking time of 8 wt% alkaline concentrations for more than 18 hours results in a significant decrease in fibre tenacity when compared to a similar soaking time in a 4 wt% alkaline concentration. This is because when NaOH concentration and soaking time in the treatment were increased, the breaking strength and fineness of the fibres decreased. Increased treatment soaking time resulted in a decrease in tenacity of 32% for more than 18 hours at an alkaline concentration of 8 wt%. The researchers discovered that although the tenacity of the fibres treated with a lower quantity of NaOH was high, the elimination of impurities from the fibres was less effective [17]. It resulted in a decrease in tenacity because of the elimination of non-cellulosic material [27].

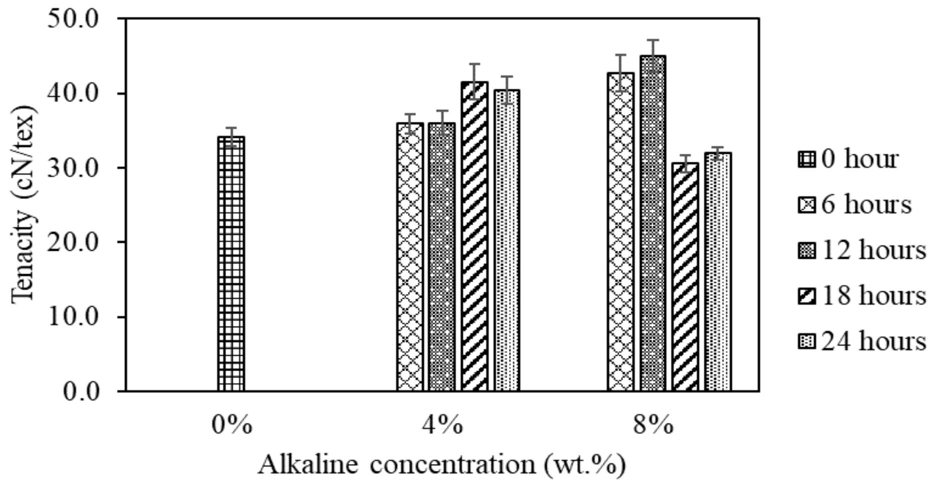


Fig. 10 - Tenacity of a single bamboo fibre subjected to different alkaline concentrations for various soaking times

4. Conclusion

The diameter and fineness of bamboo fibres were determined in this research. It was discovered that the different alkaline concentration and soaking times influenced the diameter and fineness of the fibres. The diameter of the bamboo fibre gradually decreased as the alkaline concentration and the soaking time increased. The diameter was reduced by approximately 23.2% to 66.51 μm after being treated with alkaline treatment. The fineness of treated fibres decreased in tex value by almost 50% after alkaline treatment. The finest treated fibres were achieved after treating with the highest concentration and longest soaking time, which is 11.96 tex. Based on the results, the optimum concentration was 8 wt.% alkaline concentrations, with 24 hours of soaking time yielding the finest fibre. It was discovered that the different soaking times influenced the tensile properties of the fibres. Tensile properties were best achieved with soaking times of less than 12 hours, whereas longer soaking times resulted in the weakest results. The tensile strength of the bamboo fibre gradually decreased as the alkaline concentration and soaking time increased. Furthermore, after being treated with an 8 wt% alkaline concentration for 12 hours, the tensile modulus and tenacity of the bamboo fibre were found to be greatly enhanced. This study provides technical information on bamboo fibre modification and effective treatment that can be used in future research on fibre selection for the spinning process.

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References

[1] Keya, K. N., Kona, N. A., Koly, F. A., Maraz, K. M., Islam, M. N., and Khan, R. A. (2019).Natural Fiber Reinforced Polymer Composites: History, Types, Advantages, and Applications, Materials Engineering Research, 1, 69-87.

[2] Tesfaye, T., Sithole, B., and Ramjugernath, D. (2018).Valorisation of Chicken Feather Barbs: Utilisation in Yarn Production and Technical Textile Applications, Sustainable Chemistry and Pharmacy, 8, 38-49.

[3] Akinlabi, E. T., Anane-Fenin, K., and Akwada, D. R. (2017).*Bamboo*, Springer International Publishing, Cham.

[4] Tong, F. S., Chin, S. C., Mustafa, M. T., Ong, H. R., Khan, M. M. R., Gimbun, J., and Doh, S. I. (2018).Pengaruh Rawatan Alkali Terhadap Sifat-Sifat Fizikal-Kimia Serat Buluh Malaysia: Satu Kajian Awal, Malaysian Journal of Analytical Sciences, 22, 143-150.

[5] Li, Z., Chen, C., Mi, R., Gan, W., Dai, J., Jiao, M., Xie, H., Yao, Y., Xiao, S., and Hu, L. (2020).A Strong, Tough, and Scalable Structural Material from Fast-Growing Bamboo, Advanced Materials, 32, 1-8.

[6] Chattopadhyay, S. N., Pan, N. C., Roy, A. N., and Samanta, K. K. (2020).Pretreatment of Jute and Banana Fibre—Its Effect on Blended Yarn and Fabric, Journal of Natural Fibers, 17, 75-83.

[7] Tahir, A. A. M., Hani, A., Rashid, A., Nasir, S. H., Ahmad, M., Amirah, A., and Anuwar, N. (2022).Thermal

Resistance and Bursting Strength Analysis of Multilayer Needle-Punched Bamboo / Polyester Nonwoven Batt, The Journal of The Textile Institute, 0, 1-12.
[8] Rathour, R., Kumar, H., Prasad, K., Anerao, P., Kumar, M., Kapley, A., Pandey, A., Kumar Awasthi, M., and Singh, L. (2022).Multifunctional Applications of Bamboo Crop beyond Environmental Management: An Indian Prospective, Bioengineered, 13, 8893-8914.
[9] Farina, N., Fadzil, M., and Saji, N. (2021).Study of The Use of Bamboo as a Construction Material for Accommodation in The Tourism Industry, Progress in Engineering Application and Technology, 2, 328-333.
[10] Siam, N. A., Uyup, M. K. A., Husain, H., Mohmod, A. L., and Awalludin, M. F. (2019).Anatomical, Physical, and Mechanical Properties of Thirteen Malaysian Bamboo Species, BioResources, 14, 3925-3943.
[11] Osman, S., Ahmad, M., Zakaria, M. N., Zakaria, A. M., Ibrahim, Z., Abu, F., Bahari, S. A., and Wan Jaafar, W. N. R. (2022).Bamboo as Future Bio-Industrial Material: Physical Behaviour and Bending Strength of Malaysia's Beting Bamboo (Gigantochloa Levis), IOP Conference Series: Earth and Environmental Science, 951, 012001.
[12] Jais, F. N. M., Roslan, M. N., Nasir, S. H., Baharuddin, N., and Uyup, M. K. A. (2020).Tensile Properties of Untreated Bambusa Vulgaris, Gigantochloa Levis Gigantochloa Scortechinii, Gigantochloa Wrayi, and Schizostachyum Zollingeri Bamboo Fibers, International Journal of Advanced Trends in Computer Science and Engineering, 9, 314-319.
[13] Mokeramin, M., Roslan, M. N., Rashid, A. H. A., Nasir, S. H., and Halip, J. A. (2020).Chemical Effect on the Mechanical Properties of Bamboo Fiber for Textile: A Review, International Journal of Advanced Trends in Computer Science and Engineering, 9, 353-359.
[14] Salih, A. A., Zulkifli, R., and Azhari, C. H. (2020).Tensile Properties and Microstructure of Alkali Treatment, Fibers, 8, 1-10.
[15] Rocky, B. P., and Thompson, A. J. (2020).Production and Modification of Natural Bamboo Fibers from Four Bamboo Species, and Their Prospects in Textile Manufacturing, Fibers and Polymers, 21, 2740-2752.
[16] Sreenivasa Murthy, H. V. (2018).*Introduction to Textile Fibres*, Woodhead Publishing India Limited.
[17] Aaditaa, A., and Jahan, S. (2018).Extraction and Processing of Bast Fibres from Ficus Glomerata- A New Source for Non- Conventional Fibres, Journal of Applied and Natural Science, 10, 661-666.
[18] Hu, M., Wang, C., Lu, C., Intan, N., Anuar, S., Yousfani, H. S., Jing, M., Chen, Z., and Zakaria, S. (2019).Investigation on the Classified Extraction of the Bamboo Fiber and Its Properties Investigation on the Classified Extraction of the Bamboo Fiber And, Journal of Natural Fibers, 0, 1-11.
[19] Samaei, S. E., Mahabadi, H. A., Mousavi, S. M., Khavanin, A., Faridan, M., and Taban, E. (2022).The Influence of Alkaline Treatment on Acoustical, Morphological, Tensile and Thermal Properties of Kenaf Natural Fibers, Journal of Industrial Textiles, 51, 8601S-8625S.
[20] Rizal, M. Z. M., and Hamdan, A. (2021).Investigation of Single Fibre Tensile Properties of the Pineapple Leaf (PALF), Journal of Physics: Conference Series, 2129.
[21] Jalil, M. A., Moniruzzaman, M., Parvez, M. S., Siddika, A., Gafur, M. A., Repon, M. R., and Hossain, M. T. (2021).A Novel Approach for Pineapple Leaf Fiber Processing as an Ultimate Fiber Using Existing Machines, Heliyon, 7, e07861.
[22] Retnam, S. J. and E. R. J. D. (2017).A Review on Extraction of Bamboo Fibres and Its Properties, International Journal of Advanced Chemical Science and Applications (IJACSA), 5, 6.
[23] Rocky, B. P., and Thompson, A. J. (2018).Production of Natural Bamboo Fibers-1: Experimental Approaches to Different Processes and Analyses, The Journal of The Textile Institute, 109, 1381-1391.
[24] S.Behera, N. Prasad, S. K. (2018).Study of Mechanical Properties of Bamboo Fibers before and after Alkali Treatment, International Journal of Applied Engineering Research, 13, 5251-5255.
[25] Shinde, A., Veer, S., Shinde, T., Sagale, P., and Kamble, D. P. (2018).A Review on Extraction of Bamboo Fibers and Banana Fibers, International Journal of Recent Trends in Engineering and Research, 4, 7-12.
[26] Mittal, K. L., and Bahners, T. (2017).*Textile Finishing: Recent Developments and Future Trends*.
[27] Kaur, V., Chattopadhyay, D., Kaur, S., and Kaur, M. (2019).Fibrous Raw Material of Bamboo Origin with Improved Fibrillation and Spinnability, The Journal of The Textile Institute, 110, 832-837.
[28] Vardhini, K. J. V., Murugan, R., Selvi, C. T., and Surjit, R. (2016).Optimisation of Alkali Treatment of Banana Fibres on Lignin Removal, Indian Journal of Fibre & Textile Research (IJFTR), 41, 156-160.
[29] Debnath, S. (2017).*Sustainable Production and Application of Natural Fibre-Based Nonwoven*, Elsevier Ltd.
[30] Wang, G., and Chen, F. (2017).Development of Bamboo Fiber-Based Composites, Advanced High Strength Natural Fibre Composites in Construction, 235-255.
[31] Geng, Q., Zhou, C., Nie, K., Lv, W., Ben, H., Han, G., and Jiang, W. (2021).Relationship between Fiber Fineness and Diameter of Three Bast Fibers, Journal of Natural Fibers, 00, 1-8.
[32] Grishanov, S. (2011).*Structure and Properties of Textile Materials*, Woodhead Publishing Limited.
[33] Wang, W., Zhang, F., Xiao, Z., Geng, L., and Wu, J. (2019).Fiber Diameter Measuring Method of Textile Materials Based on Phase Information, Journal of Physics: Conference Series, 1187.
[34] Yanagisawa, M., Keynia, S., Belteton, S., Turner, J. A., and Szymanski, D. (2022).A Conserved Cellular

Mechanism for Cotton Fibre Diameter and Length Control, in silico Plants, 4, 1-21.
[35] V, K., DP, C., S, K., and K, K. (2018).Study on the Performance of Bamboo Fibre Modified with Different Concentrations of Sodium Hydroxide and Chlorine Containing Agents, Journal of Textile Science & Engineering, 08.
[36] Ridzuan, M. J. M., Majid, M. S. A., Afendi, M., Azduwin, K., Kanafiah, S. N. A., and Dan-mallam, Y. (2015).The Effects of the Alkaline Treatment's Soaking Exposure on the Tensile Strength of Napier Fibre, Procedia Manufacturing, 2, 353-358.
[37] Hashim, M. Y., Roslan, M. N., Mahzan Mohd Zin, S., and Ariffin, S. (2014).Impact of Alkali Treatment Conditions on Kenaf Fiber Polyester Composite Tensile Strength, Applied Mechanics and Materials, 660, 285-289.
[38] Tamanna, T. A., Belal, S. A., Shibly, M. A. H., and Khan, A. N. (2021).Characterization of a New Natural Fiber Extracted from Corypha Taliera Fruit, Scientific Reports, 11, 1-13.
[39] Jin, Q., Zhang, W., and Yao, W. (2018).Bamboo Conditions for Processing Bamboo Fiber with Combing Method, IOP Conference Series: Materials Science and Engineering, 381.
[40] Chin, S. C., Tee, K. F., Tong, F. S., Ong, H. R., and Gimbun, J. (2020).Thermal and Mechanical Properties of Bamboo Fiber Reinforced Composites, Materials Today Communications, 100876.
[41] Sugiman, S., Setyawan, P. D., and Anshari, B. (2019).Effects of Alkali Treatment of Bamboo Fibre under Various Conditions on the Tensile and Flexural Properties of Bamboo Fibre/Polystyrene-Modified Unsaturated Polyester Composites, Journal of Engineering Science and Technology, 14, 27-47.
[42] Chen, H. (2014).*Biotechnology of Lignocellulose: Theory and Practice*.
[43] Othman, M. H., Chuan Huat, N., Amin, A. M., Hashim, M. Y., Yunus, M. R. M., and Marwah, O. M. F. (2017).The Effect of Alkali Treatment under Various Conditions on Physical Properties of Kenaf Fiber, Journal of Physics: Conference Series, 914, 012030.
[44] Chen, H., Yu, Y., Zhong, T., Wu, Y., Li, Y., Wu, Z., and Fei, B. (2017).Effect of Alkali Treatment on Microstructure and Mechanical Properties of Individual Bamboo Fibers, Cellulose, 24, 333-347.
[45] Bhuyan, S., and Gogoi, N. (2020).Natural Fibers: Innovative Sustainable and Eco-Friendly, International Journal of Current Microbiology and Applied Sciences, 9, 1004-1011.
[46] Hulle, A., Kadole, P., and Katkar, P. (2015).Agave Americana Leaf Fibers, Fibers, 3, 64-75.
[47] Sakthivel, J. C., Sivaraman, S. S., Sathish, J., and Venkatesh, D. (2021).Extraction and Characterization of Fibre from Musa Plant Bract, Indian Journal of Fibre and Textile Research, 46, 191-194.
[48] Ibrahim, M. I., Hassan, M. Z., Dolah, R., Yusoff, M. Z. M., and Salit, M. S. (2018).Tensile Behaviour for Mercerization of Single Kenaf Fiber, Malaysian Journal of Fundamental and Applied Sciences, 14, 437-439.
[49] Salih, A. A., Zulkifli, R., and Azhari, C. H. (2020).Tensile Properties of Single Cellulosic Bamboo Fiber (Gigantochloa Scortechinii) Using Response Surface Methodology, Journal of Natural Fibers, 00, 1-10.
[50] Zhang, W., Wang, C., Gu, S., Yu, H., Cheng, H., and Wang, G. (2021).Physical-Mechanical Properties of Bamboo Fiber Composites Using Filament Winding, Polymers, 13.
[51] Islam, M. N., Khatton, A., Sarker, J., Sikder, H. A., and Chowdhury, A. M. S. (2022).Modification of Jute Fibre by Etherification Method for Diverse Textile Uses, Saudi Journal of Engineering and Technology, 7, 107-111.
[52] Yang, X., Wang, K., Tian, G., Liu, X., and Yang, S. (2018).Evaluation of Chemical Treatments to Tensile Properties of Cellulosic Bamboo Fibers, European Journal of Wood and Wood Products, 76, 1303-1310.
[53] Yang, X., Shang, L., Liu, X., Yang, S., and Tian, G. (2017).Changes in Bamboo Fiber Subjected to Different Chemical Treatments and Freeze-Drying as Measured by Nanoindentation, Journal of Wood Science, 63, 24-30.
[54] Chen, C., Li, H., Dauletbek, A., Shen, F., Hui, D., Gaff, M., Lorenzo, R., Corbi, I., Corbi, O., and Ashraf, M. (2022).Properties and Applications of Bamboo Fiber—A Current-State-of-the Art, Journal of Renewable Materials, 10, 605-624.