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The Effect of Processing Route Parameters on Tensile Properties of *Pandanus Tectorius* Fibers

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Abstract. The effect of temperature and time duration of degumming process on tensile properties of *Pandanus Tectorius* fibers has just been studied. While degumming temperature and soaking time for alkali treatment were kept constant at 80 °C and 2 hours, respectively, degumming time was varied at 1, 2, 3 and 4 hours, and sodium hydroxide solution content was varied at 2.5 and 5 wt%. A bundle of fiber was placed in an O-shape cardboard holder for being tensile tested until fracture occurred. Cross sectional areas and fracture modes of representative fibers were captured under optical microscope. Whilst the cross section image areas were then measured by means of an open source software, the imageJ, the fracture images were closely evaluated to determine their respective fracture modes. The result showed that tensile strength, tensile failure strain and elastic modulus increase with the increase of degumming time up to 3 hours, then decrease for 4 hours degumming time. The highest values were found being 614.5 MPa, 0.11 mm/mm and 1.07 GPa, respectively.

1. Introduction

Natural fibers have partially substituted synthetic fibers as reinforcement for composite materials, due mainly to their local availability, biodegradability, low price [1] and lightweight [2]. In order to effectively substitute synthetic fibers, natural fibers should possess comparable mechanical properties with those of synthetic fibers. Mechanical properties of materials, including natural fibers, depend on their respective precursors, and processing routes [3]. The disadvantages of natural fibers are being inhomogeneous fiber diameters as well as their properties being depending on a number of factors [4] including the places where they are grown, as well as age and season when they are harvested. In addition, the mechanical properties of their resulted composite materials depend also on the fiber-matrix interfacial properties. The mechanical properties of natural fiber-matrix interfaces can be improved by pre-embedded treatment, i.e. physical, chemical or biological treatment [1].

There are some parameters being controllable in natural fiber extraction process, as well as in pre-embedded fiber treatment, and a number of researches on fibers surface modification have been reported. Gandini and Belgacem [5] reported the result of cellulose fiber modification using imidazolidinone derivative.

Dated back in 1999, Valadez-Gonzalez and his colleagues [6] reported the improvement of henequen fiber-matrix interfacial bond strength due to fiber surface treatment. They pointed out that the improvement was caused by improvement of fiber-matrix mechanical interlocking due to

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improvement of surface roughness, and increase of the quantity of cellulose micro-fibril exposed to the surface of the fibers. Ravi et al [7] reported that surface modification can increase fiber-matrix interfacial shear strength (IFSS) due to hydrophobicity leading to increase of composite performance being produced. Owolabi and Megat-Yusoff [8] reported that the highest cellulose content (73%) of *pandanus* fibers was obtained at 10 wt% sodium hydroxide content and 2 hour soaking time for alkaline treatment, but the mechanical properties were not reported. Although Maulida [9] reported that tensile strength of *pandanus* fiber/polypropylene composite was found being higher than that of abaca fiber/polypropylene composite at the same fiber volume fraction of 0.7, it was not reported whether the fiber underwent pre embedded treatment or not.

The purpose of this work is to determine the effect of degumming time during fiber extraction and sodium hydroxide content during pre-embedded treatment on tensile strength, failure strain and modulus of *Pandanus Tectorius* fibers.

2. Experimental method.

2.1. Fiber preparation

Pandanus leaves were obtained from Parangtritis coastal area, a local district of Yogyakarta. The leaves being taken were those that were mature enough, the third and fourth lowest rows. The leaves were cut into ~200 mm long (figure 1(a)), washed in a flowing water in order to clean from any sand and dust particles, let them getting withered, pressed, and boiled at 80 ºC for either 1, 2, 3 or 4 hours. Next, the boiled leaves were then let to cool, pressed again and the bundles of fibers were taken out one by one from the leaves. Last, the fibers were washed and slowly dried to avoid any possible surface damage due to imbalanced water content between the inner and outer parts of the fibers. The resulted fibers have been depicted in figure 1(b).

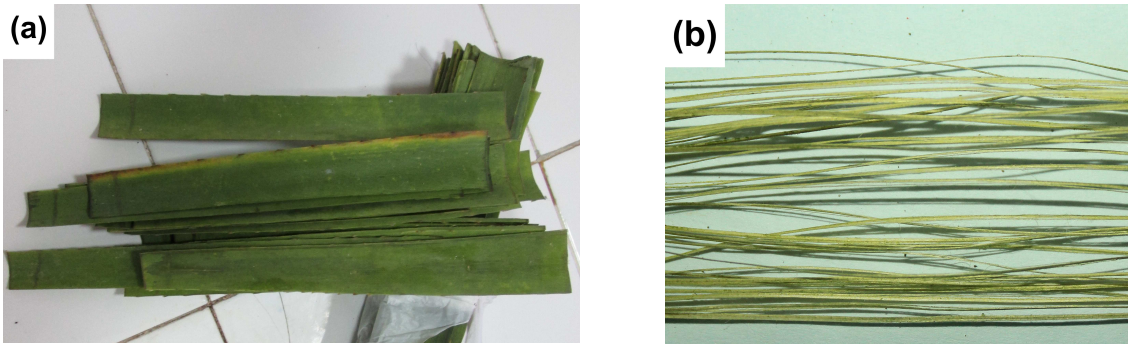

Figure 1. (a) *Pandanus Tectorius* leaves, (b) Bundles of fibers.

Prior to being affixed into cardboard holders, the fibers underwent alkaline treatment by soaking them in alkaline solution containing either 2.5 or 5.0 wt% of sodium hydroxide for two hours. Following this, the fibers were washed in flowing water and neutralized by being soaked in plain water for 8×6 hours, where every 6 hours the fibers were washed in flowing water and the soaking water was replaced. After the final washed, the fibers were slowly dried for three days.

2.2. Specimen preparation

The specimens for fiber bundle tension test were prepared by modification of tensile specimens used by Fidelis et al [10], as presented in figure 2. Epoxy was used to glue the fiber onto a symmetrical fold cardboard holder, such that the fiber was laid between the two sheets of the cardboard. The connecting parts of the holder would be cut after a specimen affixed in the UTM such that the fiber would be load-free before the test began.

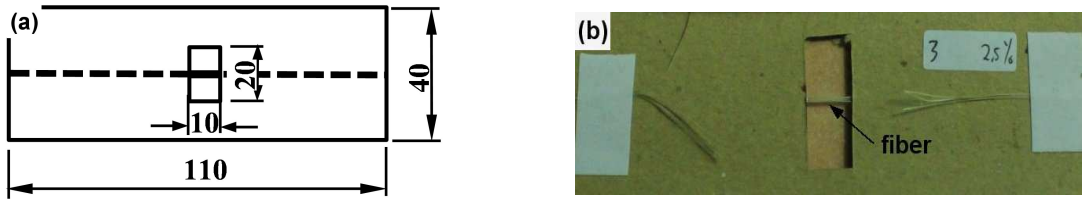

Figure 2. Specimen: (a) Geometry, (b) Ready for being tested.

2.3. Mechanical testing

Tensile testing was carried out at Material Testing Laboratory of Universitas Sebelas Maret, Surakarta, using a COM SERVO UTM having maximum load of 50 kgf. The output of the test was load-displacement plots of each specimen. Tensile strength, failure strain and modulus were calculated using the following equations (1) to (3), respectively.

$$\sigma = \frac{F}{A} \text{ (MPa)} \tag{1}$$

$$\varepsilon = \frac{D}{l_o} \text{ (mm/mm)} \tag{2}$$

$$E = \frac{\Delta F \cdot l_o}{\Delta D \cdot A} \text{ (MPa)} \tag{3}$$

where F, A, D and l_o are the maximum load [N], initial cross sectional area (mm^2), displacement at failure [mm], and initial length of the fiber [mm], respectively. It should be noted that ΔF and ΔD were taken between two points on the elastic region of F-D plot obtained from the tensile test. In addition, prior to being used for calculation, each F-D plot have been toe-corrected for any nonlinear initial part of the F-D plot.

2.4. Image capturing

Whilst surface morphology of the fibers was evaluated by closely observed SEM images of some sample fibers, the cross sectional areas of the fibers were measured by means of measuring their respective cross sectional photo micrographs using an open source software, the imageJ.

3. Result and discussion

3.1. Fiber surface morphology

Figure 3 shows SEM images of untreated and treated fibers. Figure 3(a) shows two untreated fibers. The one in the front was heavily coated with Ag-Pd (dark color arrows) until the surface morphology cannot be identified. The one in the back shows its original surface morphology (white arrows). In comparison with the later fiber, the alkaline treated fiber shown in figure 3(b) shows cleaner surface morphology showing more cellulose microfibril exposed to the surface (dark color arrows). In addition, more opaque holes due to washing out of any contaminant, part of lignin and pectin as well as fat from the surface [11], can be observed.

An increase of the amount of cellulose exposed to the fiber surface will increase hydrophobicity leading to increase of fiber-matrix interfacial bonding [12]. Opaque holes on the surface of fiber will increase mechanical locking and increase the quality of load transfer from matrix to fibers, and vice versa.

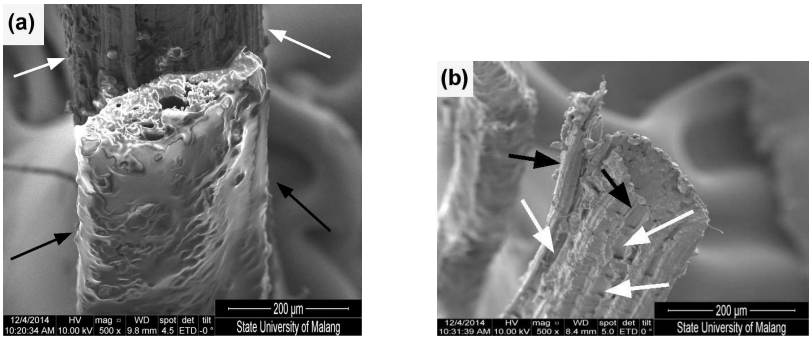

Figure 3. Fiber surface morphology: (a) untreated, (b) alkaline treated

3.2. Load-displacement (F-D) response

Figure 4 shows a representative load-displacement plot a single fiber bundle test. Initial part of the plot shows nonlinearity, then considerably linear up to maximum load, and followed by load drop until failure occurred.

All plots obtained from the single fiber bundle test exhibited nonlinear part at their initial loading. These may be caused by imperfect straightness of fiber bundle lay-up. Initial cross-head displacement was used to extend the gage length until the fiber become straight. At the next stage, the increase of cross-head displacement accompanied by the increase of the magnitude of the load was used to stretch the fiber and produced considerably linear F-D plot until approaching maximum load. Toe correction was carried out prior to being used to calculate tensile properties.

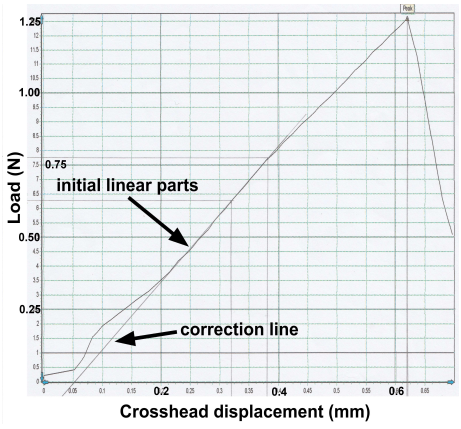

Figure 4. Load-displacement relation showing considerably linear relation up to failure

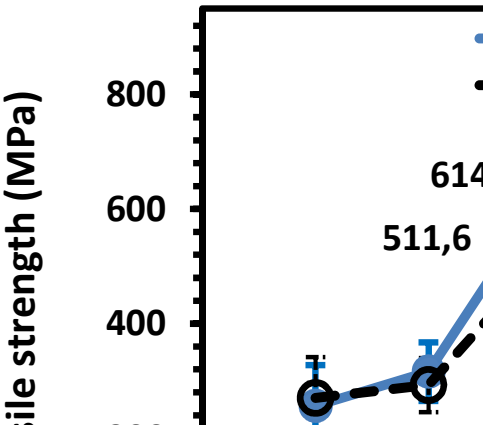

Figure 5. Effect of soaking time on tensile strength

3.3. Tensile strength

The effect of soaking time on tensile strength of the resulted fibers has been presented in figure 5. Tensile strength was calculated using equation (1). Whilst the magnitude of load F was obtained from tensile test, the cross sectional area of the sample fiber bundle was obtained from measuring its micrograph by means of open source software, the imageJ. At least 5 specimens were tested for each case, and the results presented here are their average values.

Unlike date palm fiber/polyurethane system that optimum IFSS was obtained at 5 wt% of sodium hydroxide content of the soaking water and one hours soaking time [11], the figure shows that 5 wt% sodium hydroxide content resulted in slightly lower tensile strength of the fibers in comparison with that of 2.5 wt% sodium hydroxide content. For further increase of soaking time to 4 hours, the tensile strength significantly decreases. Fiber damage due to higher sodium hydroxide content [11, 13] and

longer soaking time may be responsible for the decrease of tensile strength of *padanus* fiber/epoxy system similar to those reported for date palm fiber/polyurethane system.

The highest tensile strength was obtained at 3 hour soaking times for both 2.5 wt% and 5.0 wt% sodium hydroxide content. The magnitudes of tensile strength are 511.6 MPa and 614.5 MPa for 2.5 wt% and 5.0 wt% of alkaline content, respectively. These results are comparable with those previously reported for bamboo fiber, 500-575 MPa [14], and jute fiber, 393-800 MPa [15], but still lower than that of abaca fiber, 717 MPa [16].

3.4. Tensile failure strain

Tensile strain was calculated using equation (2). Figure 6 shows the effect of soaking time on tensile failure strain. Unlike tensile strength, 2.5 wt% sodium hydroxide content of soaking water resulted in slightly lower tensile failure strain. The highest tensile failure strain was obtained at 3 hour soaking time the same pattern as that for tensile strength, for both 2.5 and 5.0 wt% alkaline content of the soaking water. The magnitudes of tensile failure strain was found being 0.08 mm/mm and 0,11 mm/mm for 2.5 and 5.0 wt% of sodium hydroxide content of the soaking water, respectively. These values are comparable with that previously reported for raw date palm fiber [17].

It is also noticed according to figure 6 that at higher (5.0 wt% compared to 2.5 wt%) sodium hydroxide content, the irregularity, represented by their large standard deviations, of the magnitude of strain to failure is more obvious. The decrease of structural integrity of fiber bundle due to lignin over washing on the fiber surface at higher alkaline concentration of the soaking water [11] may be responsible for such increase.

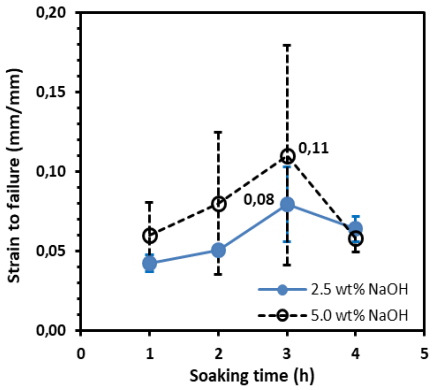

Fig. 6. Effect of soaking time on tensile failure strain

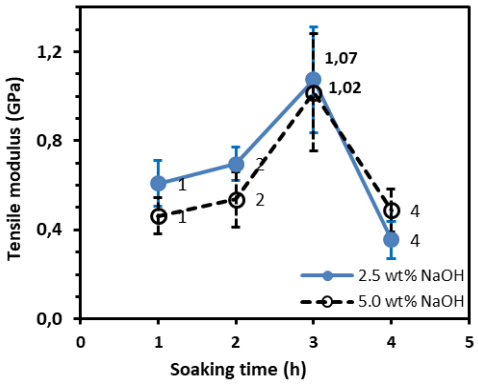

Fig. 7. Effect of soaking time on tensile mudulus

3.5. Tensile modulus

Tensile modulus was calculated using equation (3), and the two points were taken at the initial straight line of each F-D plot. The effect of sodium hydroxide content on tensile modulus of *pandanus* fibers has been depicted in figure 7. It shows similar pattern with those of tensile strength and tensile failure strain where optimum values were obtained at 3 hour soaking time both for 2.5 wt% and 5.0 wt% sodium hydroxide content. Tensile modulus of the fiber increases with the increase of soaking time up to 3 hour, then decrease when the soaking time further increased to 4 hours.

Just like tensile strength, tensile modulus of fibers treated with 2.5 wt% of sodium hydroxide content was found being higher in comparison with that being treated with 5.0 wt% of sodium hydroxide. This is consistent with the pattern of tensile and strain to failure, when both the tensile strength and strain-to-failure increase tensile modulus also found being increase, and vice versa. The highest tensile modulus was found being 1.07 GPa at 3 hour soaking time and 2.5 wt% sodium hydroxide content. Although the modulus has increased with the increase of soaking time up to 3 hours, this value is still lower than that of coir fiber being reported by Thakur et al [18].

4. Conclusion

The effect of soaking time and sodium hydroxide content at degumming temperature of 80 °C on tensile properties of *Pandanus Tectorius* fiber has been investigated. It was found that the optimum soaking time being 3 hours. Whilst the highest tensile strength was obtained at 2.5 wt% NaOH content, the highest modulus was obtained at 5 wt% NaOH content of the solution. The highest tensile strength, strain to failure and modulus were 614.5 MPa, 0.11 mm/mm and 1.07 GPa, respectively. Further increase of soaking time resulted in decrease of tensile strength, strain to failure and modulus of the *pandanus* fibers that may be due to over washing of lignin and fat existed on fiber surface functioning as microfibril binder leading to poorer fiber structural integrity. Further research may be conducted at different temperature and higher sodium hydroxide content.

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