Characterization of Calcium Hydroxide-treated Zalacca Fibers for Improving Properties as Reinforcement for Composites

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Abstract. Chemical treatment is done to enhance characteristics of plant fibers and its interfacial compatibility with polymer matrix. Calcium hydroxide is an environmental-friendly alternative. This research aims to explore the influence of calcium hydroxide treatment on chemical, physical, thermal, morphological, and mechanical characteristics of zalacca fibers as reinforcements for composites. The time of treatment were varied for 24, 48, and 72 h. Fiber content analysis, XRD, FTIR, TGA-DTA, SEM, density, and single fiber tensile testing were performed. The percentage of cellulose was decreased meanwhile hemicellulose and lignin were increased. There was a decrease in crystallinity and crystallinity index after Ca(OH)\textsubscript{2} treatment. The treatment induced some chemical groups correlated to the slight increase of lignin and hemicellulose percentage. There was an improvement of thermal stability of the fiber up to 200°C. The observation using SEM revealed that there were cleaning and roughing effect on fiber surface. There was no significant change in fiber density due to the treatment. However, the tensile strength and elastic modulus were improved after Ca(OH)\textsubscript{2} treatment but the decline happened in a longer time of treatment. Accordingly, Ca(OH)\textsubscript{2} treatment up to 24 h is appropriate in enhancing the properties of zalacca fibers as composite reinforcements.

Keywords: zalacca fibers, Ca(OH)\textsubscript{2} treatment, crystallinity, surface morphology, thermal stability

1. Introduction
Demands for materials having high-specific-stiffness and strength are increased as a result of conventional energy and material reserve insufficiency. Composites, consisted of at least two components such as matrix and reinforcements, are promisingly alternative materials. Green composites consisting natural matrix and/or reinforcement [1] are encouraged by the environmental issue. Plant fibers have the largest kind of natural fibers. Nevertheless, they have main disadvantage, that is poor adhesivity with ordinary polymer matrices [2]. There are essential factors in obtaining the optimally mechanical characteristics of composites, such as mechanical properties and compatibility of fibers and matrix [3], volume fraction, length, orientation, and thermal stability of fibers [4].
One of the native Indonesian plants is zalacca (Zalacca edulis), which farmed for its delicious fruits. To maintain the quality and quantity of harvest, several of its old midribs are cut. Usually they are disposed of as wastes and have not been utilized as goods with higher added-value. Raharjo and co-workers [5] extract fibers from the midribs and their content of cellulose, hemicellulose, and lignin 42.54, 34.35, and 28.01 %, respectively. Compared to wheat straw [6], coir [7], alfa grass [8], and sugarcane bagasse [9], zalacca fibers content of cellulose is comparable. Therefore, zalacca fibers have potency to be utilized as raw materials for textile and reinforcements of composites.

As lignocellulose, the compatibility of hydrophilic zalacca fibers with hydrophobic polymer matrix are low. Fiber hydrophilicity is affected mainly by hemicellulose, meanwhile, lignin has hydrophobic nature [10]. The poor compatibility between polymer matrices and fibers requires fiber surface modification. Therefore, treatment eliminating hemicellulose but maintaining the lignin content is needed. Lignin is important in fibrils (elementary fibers) binding become technical fibers and is essential for stiffening the fibers [11].

Chemical treatment is commonly performed due to its practicability. The method used widely is alkaline treatment [12]. However, there are two disadvantages of the sodium hydroxide treatment. First, high care must be attended when handling and discarding the toxic liquid. Second, NaOH treatment eliminates lignin. Calcium hydroxide treatment has a lower amount of delignification compared to alkali’s [13]. Moreover, crystallinity index can be increased using Ca(OH)2 by the elimination of amorphous substance, such as hemicellulose and lignin [14]. In accordance with the study of Chang and co-workers [15] on the comparison in sugarcane bagasse pre-treatment, Ca(OH)2 is cheaper than NaOH. Hence, it is a chemical treatment alternative being safe for environment and human. Nevertheless, the limited solubility in water is its disadvantage. Hence, to obtain the same effect of treatment with NaOH, longer immersion time is required. However, investigation for the effect of Ca(OH)2 treatment on zalacca fiber chemical, physical, thermal, morphological and mechanical characteristics has not been performed yet.

In relation with zalacca fibers as composite reinforcement, this research is to study the correlation of Ca(OH)2 treatment to fiber content, morphological, thermal stability, chemical and physical properties, in addition to mechanical characteristics of zalacca midrib fibers.

2. Materials and Methods

2.1. Materials

The zalacca midribs were supplied from plantations in Sleman, Yogyakarta Province of Indonesia. They were cut from the plants attaining 3-years age, as indicated in figure 1 (a). They were then immersed for 2 weeks in distilled water, in which the separation of midribs bark and fibers occur, figure 1 (b). The fibers obtained, figure 1 (c), were washed using distilled water and rinsed, then dried in open air for 48 h followed by in a ventilated oven at 105°C for 2 h. Finally, the fibers were cut to ±40 mm length and then were put in a container with silica gel. The calcium Ca(OH)2 used was analytical being purchased from Merck.

2.2. Calcium hydroxide treatment

Solubility of Ca(OH)2 in water is 0.15 % in room temperature [16]. The fibers of 5 g were soaked in 100 ml of Ca(OH)2 with soaking time of 24, 48, and 72 h and were rinsed using distilled water. They were then dried using a ventilated oven at 80°C for 24 h.

2.3. Composition testing of fibers

Kurchner-and-Hoffer, and Klaslon methods were used to measure the content of cellulose and lignin [17] meanwhile NFT 12-008 standard was used to measure the content of hemicellulose. The untreated and Ca(OH)2-treated fibers were powdered, then were extracted and hydrolyzed by dichloromethane (CH2Cl2) and 7% sulfuric acid (H2SO4) solution, respectively. The unsolved part was separated and quantified as lignin. The sample extracted using CH2Cl2 and added by the mixture of 95
% nitric acid (HNO$_3$) solution and ethanol resulted in cellulose as the unsolved part. The sample heated in hydrobromic acid (HBr) solution was transformed to be furfural and extracted by distillation resulted in hemicellulose and finally weighed by spectrophotometry. The weighed lignin, cellulose, and hemicellulose were then measured as their percentage of the fiber content.

2.4. X-ray diffraction
Crystallinity degree of zalacca fibers was analyzed using a Philips PW 1800 X-ray diffractometer with CuK$_\alpha$ radiation. The voltage and current used were 30 kV and 17.5 mA, respectively. The step scan, step size, and reading range were 2.5 s, 0.075°, and 10-60°, respectively. The samples of powdered untreated and Ca(OH)$_2$ treated fibers were put into the equipment.

Crystallinity index (CI) and crystallinity (%Cr) were used to express the degree of fiber crystallinity, and were measured using equation (1) and (2), in which $I_{101}$ and $I_{002}$ are the maximum peak intensities corresponding to amorphous and crystalline part, respectively.

\[
CI = \left(1 - \frac{I_{101}}{I_{002}}\right) \times 100
\]

\[
%Cr = \left(\frac{I_{002}}{I_{101}+I_{002}}\right) \times 100
\]

$I_{002}$ was correlated with the plane having Miller indices (0 0 2) in the sample, taken in a range of $2\theta=22-23^\circ$ [18] meanwhile $I_{101}$ was corresponded with (1 0 1) at approximately $2\theta=18^\circ$.

2.5. Fourier transform infrared spectroscopy
FTIR analysis was carried out to examine the change of functional groups on fiber surface due to Ca(OH)$_2$ treatment. A Shimadzu IR Prestige-21 FTIR Spectrometer was equipment used. Five percent of powdered fibers and 95 % KBr were mixed and passed through a disk. The spectrum of untreated and treated fibers was recorded by 32 scans at 4 cm$^{-1}$ resolution in a range of 400-4000 cm$^{-1}$.

![Figure 1](image). (a) A zalacca midrib after cutting; (b) a midrib after retting; and (c) zalacca midrib fibers
2.6. Thermogravimetric-differential thermal analysis
Changes in fiber mass and heat flow along with temperature increase were observed using TGA-DTA. It was carried out using Linseis STA PT 1600 TG-DT analyzer equipped by purging gas of nitrogen. Powdered sample of ±20 mg was placed in a pan made of platina. It was heated and simultaneously weighed from room temperature up to 600°C with 10°C/min heating rate.

2.7. Scanning electron microscopy
SEM was used in observing surface morphology of zalacca fiber before and after Ca(OH)₂ treatment. It was performed using a SEM equipment JEOL JSM 5800. Gold-coated samples were inserted into the apparatus after laid on a silver-coated holder.

2.8. Density of fiber
Density of zalacca fiber was determined according to ASTM D276 standard, using Archimedes principle. Before weighed, the untreated and Ca(OH)₂-treated fibers were put into a desiccator for 24 h after dried using a ventilated oven at 100 ± 2°C for 4 h. They were then rolled up and bonded. An Ohaus PA224 analytical balance having 0.1 mg accuracy and 220 g capacity was used to weigh 5 samples of each variation of treatment. They were then immersed in pure methanol having \( \rho = 0.791 \) g/cm³ in a measuring cylinder to determine the fibers volume.

2.9. Diameter of fibers
An Olympus SZX2-TR30 optical microscope equipped by CellSens® software having 10⁻² µm accuracy was used in measuring the diameter of single fiber at room temperature. The measurement was performed 4 times in separate locations of the fiber then the results were averaged. Eighty fibers were selected randomly and twenty fibers were grouped into 4 categories: untreated and Ca(OH)₂-treated for 24, 48, and 72 h.

2.10. Tensile testing of single fiber
Mechanical properties of untreated and Ca(OH)₂-treated fibers were determined by single fiber tensile testing, in accordance with ASTM C1557-03 standard. A JTM UTS210 universal testing machine was used with its cross-head speed being set on 50 mm/min and 50 kg-load cell. Randomly zalacca fibers were selected and cut as tensile testing specimens. Twenty specimens, as shown in figure 2, were tested for each variation, with 20 mm gage-length. Tensile strength of fiber was calculated by dividing the maximum applied load by cross-sectional area of a fiber, as indicated in equation (3). Fiber strain was a ratio of elongation and initial length of a fiber. By assuming the cross-section area of a fiber was a circle, it was calculated using equation (4).

\[
\sigma_u = \frac{F_{\text{max}}}{A} \quad (3)
\]

\[
A = \frac{\pi d^2}{4} \quad (4)
\]

Figure 2. Specimen of single fiber tensile testing
in which $\sigma_u$, $F_{\text{max}}$, $A$, and $d$ are tensile strength, maximum load, cross-section area and average diameter of fiber, respectively. Modulus of elasticity was determined in the linear portion of stress-strain curve.

3. Results and Discussion

3.1. Composition testing

The cellulose, hemicellulose, and lignin content of zalacca fiber before and after Ca(OH)$_2$ treatment is indicated in table 1 as their percentage. The composition of cellulose, hemicellulose, and lignin in untreated fibers are 42.54, 34.35, and 28.01 %, respectively. Cellulose has the highest elastic modulus and strength of all components of lignocellulosic fiber [19]. Zalacca fiber content of cellulose is higher than that of alfalfa grass, wheat straw, and coir, but lower than that of cotton, flax, jute, and hemp fibers.

The cellulose content was decreased a bit by Ca(OH)$_2$ treatment for 24, 48, and 72 h become 40.37, 39.84, and 36.86 %, respectively, meanwhile hemicellulose and lignin are relatively constant. Also, the cellulose tends to decrease due to longer treatment. However, its content of Ca(OH)$_2$ treated fibers is still comparable with those of coir and alfalfa grass. It corresponds to the study on the composition and structures of hemp fibers after the treatment using Ca(OH)$_2$ by Le Troedec and co-workers [20].

Table 1. Composition of zalacca fibers before and after Ca(OH)$_2$ treatment for zalacca and several plant fibers

| Fibers       | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Reference |
|--------------|---------------|-------------------|------------|-----------|
| Untreated ZF | 42.54         | 34.35             | 28.01      |           |
| Ca(OH)$_2$   |               |                   |            |           |
| for 24h      | 40.37         | 37.46             | 23.26      |           |
| for 48h      | 39.84         | 36.83             | 25.71      |           |
| for 72h      | 36.86         | 35.16             | 28.94      |           |
| Cotton       | 85-90         | 1-3               | 0.7-1.6    | [21]      |
| Flax         | 85            | 9                 | 4          | [21]      |
| Hemp         | 58.7          | 14.2              | 6          | [22]      |
| Jute         | 58-63         | 20-24             | 12-15      | [23]      |
| Coir fibres  | 32-43         | 0.15-0.25         | 40-45      | [24]      |
| Alfa grass   | 33-38         | -                 | 17-19      | [8]       |
| Wheat straw  | 38.8          | 39.5              | 17.1       | [6]       |

3.2. X-ray diffraction

XRD analysis of untreated and Ca(OH)$_2$-treated zalacca fibers results the diffractograms, as indicated in figure 3, which focusing in 15-30° range of 2θ. Meanwhile, the degree of crystallinity of zalacca fibers are shown in table 2, calculated based on equation (1) and (2).
Based on figure 3, the spectrums of untreated and Ca(OH)$_2$-treated zalacca fibers have same patterns. The untreated fibers spectrum has 3 peaks at $2\theta = 16.35^\circ$ (broad), 21.99$^\circ$ (sharp), and 34.59$^\circ$ (broad) which are corresponding to crystallographic plane reflection of (1 0 -1), (0 0 2), and (0 4 0), respectively. The broad peak at $2\theta = 16.35^\circ$ is correlated with the amorphous fractions of fibers, meanwhile the sharp one at 21.99$^\circ$ is due to crystalline cellulose. Figure 3 indicates that Ca(OH)$_2$ treatment reduces the sharpness of peak at $2\theta = 21.99^\circ$ and also 16.35$^\circ$.

From table 2, the value of CI and %Cr of zalacca fiber are 69.81 and 76.81, respectively. Its values are higher than those of mendong, rice straw, wheat straw, jute, sanseviera and sisal fiber. They are lower than those of hemp and relatively comparable with those of cotton fiber. CI and %Cr have trend to decline after the treatment meanwhile the duration of treatment does not give the significant effect. This is correlated with the reduction of cellulose percentage after Ca(OH)$_2$ treatment which decrease the crystalline component of fiber, as shown in table 1.

**Table 2.** Cristallinity index and cristallinity of untreated and Ca(OH)$_2$-treated zalacca fibers and other fibers

| Fibers                     | Crystallinity Index (CI) | Crystallinity (%Cr) | Reference |
|----------------------------|--------------------------|---------------------|-----------|
| Untreated ZF               | 69.81                    | 76.81               |           |
| Ca(OH)$_2$ treated ZF for  |                          |                     |           |
| 24h                        | 62.81                    | 72.89               |           |
| 48h                        | 63.52                    | 73.27               |           |
| 72h                        | 62.96                    | 72.97               |           |
| Mendong                    | 58.6                     | 70.7                | [25]      |
| Hemp                       | 80                       | 87.87               | [20]      |
| Sisal                      | 55                       | 70.9                | [20]      |
| Rice straw                 | 57                       | 62.8                | [26]      |
| Wheat straw                | 45.57                    | 48                  | [27]      |
| Sanseviera                 | 60                       | -                   | [17]      |

![Figure 3. X-ray diffractogram of untreated and Ca(OH)$_2$-treated zalacca fibers](image-url)
Cotton 68 78.7 [21]
Jute 65.8 68.89 [28]

3.3. Fourier transform infrared spectroscopy
Zalacca fibers spectra resulted by FTIR are indicated in figure 4. In general, these spectra have the same pattern of lignocellulosic fibers like date palm [29], Sansevieria cylindrica [17], banana [26, 27], and mendong grass fibers [25].

Figure 4 shows that there are the similar pattern of bands between the spectra of untreated and Ca(OH)\(_2\)-treated zalacca fibers. At around 3000-3800 cm\(^{-1}\), the broadband is attributed to hydrogen bonds consisting C-H and O-H stretching from cellulose, lignin and hemicellulose alcohol compounds. This C-H bond often met in aromatic groups and alkane are correlated by broadband at 2850-3000 and 690-900 cm\(^{-1}\), respectively. Meanwhile, the overtone of aromatic C-H bond is found near 1750 cm\(^{-1}\). The aromatic groups characterize the content of lignin. The O-H bond of alcohol groups is related to the 3200-3600 cm\(^{-1}\) broadband. Ca(OH)\(_2\) treatment, like that of NaOH [32], decreases the peak intensity. This signifies that the treatment reduces the lignin content, but the reduction is not proportional with the duration of chemical treatment. The longer Ca(OH)\(_2\) treatment (48 and 72 h) does not effectively eliminate the lignin content so that the increase of lignin percentage happens.

The broadband between 3200-3650 cm\(^{-1}\) are correlated to the O-H stretch of alcohol for cellulose and hemicellulose. There is almost no difference between the spectra of untreated and Ca(OH)\(_2\)-treated fibers and suited to the cellulose and hemicellulose contents before and after the treatment, table 1. There are small peaks between 2500-3000 cm\(^{-1}\) having relation with O-H stretch bonds of carboxylic acid for hemicellulose. The peaks formed from Ca(OH)\(_2\) treated fibers are larger than those of untreated one. It indicates that there is an increase of hemicellulose percentage in the fibers caused by Ca(OH)\(_2\) treatment. Meanwhile, bonds of C=O stretch of aldehyde for hemicellulose are indicated by the peaks at 1720-1740 cm\(^{-1}\). For untreated zalacca fibers there is small peak but there is a big peak for Ca(OH)\(_2\) treated fibers. It also indicates the increasing percentage of hemicellulose after Ca(OH)\(_2\) treatment.

The bonds of C-O stretch of amide for cellulose and hemicellulose are obtained in peaks between 1650-1690 cm\(^{-1}\). There is a decrease of peaks degree which shows that Ca(OH)\(_2\) treatment partly eliminates cellulose and hemicellulose. The bonds of C-O of phenol for lignin are detected in peaks between 1200 and 1300 cm\(^{-1}\). The treatment for 72 h makes the peaks seem clearer which indicate the increase of lignin portion.
3.4. Thermogravimetric and differential thermal analysis

From the TGA curve, as indicated in figure 5 (a), there are three regions of the mass change of the fibers. This is appropriate to the research of Hossain and co-workers [33], in which the deterioration of natural fibers commonly happens in three stage: (1) evaporation of water content in the fibers, (2) decomposition of hemicellulose and cellulose, and (3) decomposition of non-cellulose content, include lignin. In general, cellulose and lignin are decomposed in 220-350°C and 200-500°C temperature range, respectively.

The TGA curve shows that the mass reduction of the Ca(OH)$_2$-treated fibers is smaller than that of untreated ones between room temperature until 200°C range (stage 1). The decline is caused by the lower content of hydrophilic hemicellulose, and proved by the lesser negative DTA curve, as shown in figure 5 (b). It reveals the reduction of endothermic reaction caused by the evaporation of water content of the fibers. In general, all tested fibers are relatively stable until 200°C without degradation or decomposition.

The DTA curve which are right shifted indicates significant increase of thermal stability until 350°C due to the treatment. In stage 2 with temperature range of 200-350°C, the decomposition of hemicellulose and lignin cannot be precisely determined due to overlap decomposition temperature and gradual degradation process of lignin. Also, it is shown that all of the tested fibers begin to fast degrade from 230 until 350°C. Above 350°C, Ca(OH)$_2$-treated fibers tend to degrade faster compared to untreated ones. This is due to higher lignin content in treated fibers, as indicated in table 1. For temperature above 500°C, the TGA and DTA curve are the same for untreated and Ca(OH)$_2$ treated fibers. This indicates that all fibers components, such as hemicellulose, lignin, and cellulose are decomposed completely then remained as ash.
3.5. Scanning electron microscopy

Morphological analysis using SEM, as indicated in figures 6 (a) and (b), shows that calcium hydroxide treatment causes the fiber surface clean. This is due to the role of Ca(OH)$_2$ as impurity capturer [34]. Moreover, the submersion of zalacca fibers in Ca(OH)$_2$ solution make the fiber surface rougher so that its contour seem clear. The high surface roughness can improve the fiber and matrix interfacial bonding. Nevertheless, compared to NaOH treatment [5] causing higher fiber roughness promoted by significant decrement of the hemicellulose and lignin content, the elimination of unwanted fiber component like hemicellulose by Ca(OH)$_2$ treatment is less effective, as revealed in Table 1.

![SEM micrograph of zalacca fiber](image)

Figure 6. SEM micrograph of zalacca fiber: (a) untreated; and Ca(OH)$_2$-treated for: (b) 24 h; (c) 48 h; and (d) 72 h

Longer immersion in Ca(OH)$_2$ makes the fiber surface cleaner, as revealed in figures 6 (c) and (d), but there is only a little morphological change on it. This is caused by the elimination of a bit lignin and hemicellulose content due to the treatment.
3.6. Density of fiber
The change of zalacca fiber density caused by Ca(OH)$_2$ treatment is shown in figure 7. The average density of the Ca(OH)$_2$-treated fibers for 24, 48, and 72 h increases from 600.9 kg/m$^3$ becomes 634.8, 633.4, and 633.8 kg/m$^3$, respectively. Longer duration of treatment does not significantly raise the density, which is attributed to the even elimination of hemicellulose, lignin, and cellulose, as indicated in table 1.

![Figure 7. Density of untreated and Ca(OH)$_2$-treated single fiber](image)

3.7. Diameter of single fiber
Figure 8 (a) shows the diameter of untreated and Ca(OH)$_2$-treated fibers. The statistical analysis using Analysis of Variance (ANOVA) indicates that Ca(OH)$_2$ treatment does not cause the significant difference in fiber diameter.

3.8. Tensile testing of single fiber
The tensile strength, elastic modulus, and fracture strain of zalacca fibers are indicated in figures 8 (b), (c), and (d), respectively. Average tensile strength of untreated zalacca fibers reaches 185.68 MPa meanwhile their elastic modulus is 5.05 GPa. They are comparable with those of coir fibers and higher than those of wheat straw and sugarcane bagasse, as shown in table 3. It is correlated to cellulose content of the fibers (table 1).

Treatment up to 24 h raises the average tensile strength of the fibers, figure 8 (b). This is due to CaO formed after water evaporation in Ca(OH)$_2$ treatment having properties as a binder [34]. CaO binds elementary fibers, meso fibrils, and micro fibrils together become technical fibers so that they are stronger. The fracture surface observation of tensile testing specimen by SEM, figure 9 (a), indicates that the fracture surface of untreated fiber seems crumbly. For longer treatment time, although there is binding of elementary fibers, however, elimination of cellulose by Ca(OH)$_2$, as indicated in table 1, decreases fiber strength in longer soaking time. The SEM examination of Ca(OH)$_2$-treated fiber for 48 and 72 h, figures 9 (c) and (d), show mangled surface of fracture due to the lack of load-barrier components of the fiber. Meanwhile, Ca(OH)$_2$-treated fiber for 24 h, figure 9 (b), reveals intact fracture surface due to CaO binder. Elimination of cellulose for longer treatment is also proved by the reduction of crystallinity and crystallinity index, as indicated in table 2.
### Table 3. Mechanical properties of ZF and several fibers

| Fibers      | Diameter (μm) | Tensile strength (GPa) | Elastic modulus (MPa) | Reference |
|-------------|---------------|------------------------|-----------------------|-----------|
| Untreated ZF| 145 ± 16      | 185.68 ± 29.99         | 5.05 ± 0.84           |           |
| Ca(OH)2 for |               |                        |                       |           |
| 24h         | 151 ± 16      | 350.43 ± 60.80         | 9.25 ± 1.68           |           |
| 48h         | 147 ± 6       | 315.46 ± 31.17         | 8.54 ± 1.22           |           |
| 72h         | 135 ± 8       | 267.41 ± 61.83         | 9.71 ± 1.59           |           |
| Cotton      | 12-38         | 287-597                | 5.5-12.6              | [35]      |
| Flax        | 40-600        | 345-1035               | 27.6                  | [21]      |
| Jute        | 26.0          | 1316                   | 91.9                  | [8]       |
| Sisal       | 50-200        | 530-630                | 9.4-22                | [36]      |
| Coir fibres | 100-460       | 131-220                | 4.6                   | [24]      |
| Wheat straw | 76 ± 3        | 146.5 ± 53             | 7.9 ± 2               | [6]       |
| Sugarcane bagasse | 20   | 89.9                  | 4.5                   | [8]       |
Figure 8. (a) Diameter; (b) tensile strength; (c) elastic modulus; and (d) strain at fracture of untreated and Ca(OH)$_2$-treated single fiber
Based on TG-DT analysis, figure 5, the strength of untreated and Ca(OH)$_2$-treated fibers are relatively stable until the temperature of 200°C, when the fibers start to degrade. Cellulose and lignin begin to decompose above 200°C. Compared to that of Ca(OH)$_2$, zalacca fiber treated by NaOH has higher tensile strength. It is due to hemicellulose and lignin partial elimination which decreases the average fiber diameter [5], from 151.92 μm (untreated fiber) to 112.10 and 108.74 μm (1% and 5% NaOH-treated fiber, respectively). It induces the increase of stress due to the decrease of cross-sectional area as denominator meanwhile there is hardly reduction of cellulose as load supporter.

The influence of calcium hydroxide on elastic modulus of the fibers is indicated in figure 8 (c) where the fibers become stiffer. This is due to the CaO binding to the elementary fibers. Because Ca(OH)$_2$ relatively does not eliminate lignin, longer treatment relatively does not decrease fiber stiffness. The elastic modulus obtained for calcium hydroxide treatment is not as high as that of NaOH. It is because NaOH treatment leaves cellulose behind as load supporter meanwhile the left cellulose in Ca(OH)$_2$ treatment is lower.

Strain at fracture of the fibers, figure 8 (d) tends to descend for longer treatment time due to the remainder of lignin which causes the higher rigidity and brittleness. The case is nearly the same for NaOH treatment but it is particularly caused by the cellulose content.

4. Conclusion
Zalacca midrib fibers have physical, chemical, thermal and mechanical properties possessing potency for utilizing as reinforcement of composites. Calcium hydroxide treatment slightly reduces the content of cellulose. Ca(OH)$_2$ causes cleaning effect and roughening on the fiber surface. It increases the thermal stability of zalacca fibers up to 200°C but makes the fibers degrade faster after 350°C. After Ca(OH)$_2$ treatment some chemical groups emerge which indicate the raise of lignin content. There are decrease in crystallinity index and crystallinity which do not directly correlate with the mechanical properties. By Ca(OH)$_2$ treatment there are improvement in mechanical properties includes elastic modulus and tensile strength but they was decreased after treatment with longer duration. The raise of modulus of elasticity and tensile strength is not caused by increase of cellulose percentage but the binding of elementary fibers by CaO. In general, calcium hydroxide treatment up to 24 h is proper in improving the properties of zalacca fibers as reinforcements for composites.

Acknowledgments
The authors concede the financial aid from the Indonesian Ministry of Education and Culture for this research.
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