Effect of limestone mass concentration on tensile strength and surface morphology of coconut fiber

Sutrisno\(^1\), Rudy Soenoko\(^2\), Yudy Surya Irawan\(^2\), Teguh Dwi Widodo\(^2\)

\(^1\) Department of Mechanical Engineering, Merdeka University, Jl. Serayu 79 Taman, Madiun, Indonesia; Email: sutrisno@unmer.madiun.ac.id
\(^2\) Department of Mechanical Engineering, Brawijaya University, Jl. M. T. Haryono 169, Malang, Indonesia

Abstract. The material processing technology was developed to answer the increasing material needs. The material developed is a composite material based on natural fibers. Among many natural fibers and maximum utilization is coconut fiber. This study aims to determine the effect of limestone as a medium for coconut fiber immersion on the tensile strength of a single fiber and the surface morphology of the fiber. Coconut fiber that has been cleaned is soaked in a solution of lime water for 8 hours with a variation of lime content: 0\%, 2.5\%, 5\%, 7.5\%, and 10\%. Coconut fiber that has been processed is tested by testing a single fiber and SEM. The results obtained from testing a single fiber with 5\% limestone content for 8 hours total tensile strength of 236.27 MPa. The tensile strength without treatment, 5\% limestone, 7.5\% limestone, and 10\% limestone are 172.15 MPa, 204.37 MPa, 199.73 MPa and 180.32 MPa. The surface morphology of the fibers with limestone treatment becomes rougher.

Keywords: coconut fiber, limestone, tensile strength, scanning electron microscopy

1. Introduction

The development of technical materials today leads to the discovery and exploitation of natural materials or cellulose-based biomaterials that have beneficial aspects both in terms of technology, economy and environment [1]. Industrial countries, for example, are Japan which has utilized natural fiber-reinforced composite materials as components of car interior panels. Besides, car manufacturer Daimler-Bens has also utilized abaca fiber as a reinforcement of composite materials for the dashboard. The technology shift is based on the nature of the composite reinforced natural fibers that are more environmentally friendly [2]. This composite also has a strength ratio with a high density so that the resulting component is lighter. The industrialists use these composites as superior products according to their features. Compared to synthetic fibers, natural fibers have several advantages which include the ability to decompose by decomposing bacteria, lightweight, renewable, high mechanical properties and large numbers [3].

Research that has led to the development of composite materials has been widely carried out, especially those related to natural fiber reinforcement composites made from the polymer matrix. This research was conducted in line with the progress of exploitation of the use of natural materials in everyday life. The basic advantages possessed by natural fibers are abundant quantities, low density, low prices, can be renewed or recycled, easily obtained, have good acoustic properties, and friendly to the environment [4]. Natural fibers have several disadvantages, including non-uniform strength, high...
hydrophilic properties (like water). Some natural fibers that are used as reinforcement include: pineapple fiber, kenaf fiber, sisal fiber, bamboo fiber, and coconut fiber. To obtain good mechanical properties in natural fibers treatment needs to be done. The treatment that is often used by researchers is a liquid containing alkali / NaOH [5]. Among these fibers, coconut fiber has the largest amount in Indonesia. This is due to the fact that Indonesia has the most coconut trees in the world [6]. Coconut fiber has not been used optimally and mostly used as local crafts that do not have economic value. To make coconut fiber into a good commodity, it is necessary to try to use fiber as a composite material. The use of coconut fiber as a composite material has been widely used in the interiors of the automotive industry where previously the fibers were treated with a chemical treatment to obtain strong and durable fibers [7]. Fiber processing to improve mechanical properties has been carried out, among others, by alkali treatment [8]. The use of alkali/NaOH has a bad impact on the environment. Then it is necessary to try fiber treatment using natural ingredients. Natural material used to process natural fibers to have good mechanical properties. The natural ingredients used have alkaline/basic properties. Natural ingredients that have properties such as NaOH are limestone. Where the availability of lime in Indonesia is still abundant [9]. The purpose of this study was to determine the effect of immersion coconut fiber with a certain mass content on the tensile strength with a single fiber tensile test. Fiber treatment is done by soaking coconut fiber in a solution of limestone with a certain mass.

2. Methods and Materials
Coconut coir fibers obtained from Wonogiri, Central Java, Indonesia. Fiber is taken from 12-month-old coconuts on trees that are 10-years old. Limestone obtained from the Ponorogo area, East Java, Indonesia (Table 1).

| No | Code | Description (% wt) | Length of immersion (hours) |
|----|------|---------------------|-----------------------------|
| 1  | 0    | 0                   | 0                           |
| 2  | 1    | 2.5                 | 8                           |
| 3  | 2    | 5.0                 | 8                           |
| 4  | 3    | 7.5                 | 8                           |
| 5  | 4    | 10                  | 8                           |

Figure 1. (a) Coconut fiber which has been cleaned from meat. (b) Limestone

Coconut fiber which has been separated from the meat/washed with water until clean and then dried at room temperature. Coconut coir fiber is cured with a solution of limestone water with a percentage of limestone content: 0%, 2.5%, 5%, 7.5%, and 10% with an immersion time of 8 hours. Form a single fiber testing specimen in accordance with ASTM D-3379 as shown in the Figure 2.
3. Results and Discussion

From the results of the single tensile test, it can be seen that the greatest tensile stress is found in the treatment or immersion of 5% limestone solution that is 236.27 MPa with a strain of 0.76%, and the Modulus of Elasticity of 0.17 GPa (Figure 3). The smallest tensile stress is found in the immersion of 10% limestone solution, which is 172.15 MPa, with a strain of 0.83% and modulus of elasticity of 0.12 GPa. Figure 4 shows that the best tensile strength is found in the immersion of the fiber with a concentration of 5% limestone. The increase in tensile strength in the treatment of limestone 5% with an immersion time of 8 hours is due to the loss of some components and other impurities in fibers such as lignin, pectin, wax and others. The tensile strength of fibers with 5% limestone mass immersion media treatment due to the treatment of fiber causes increased crystallinity [10]. While the decrease in fiber strength in the 10% limestone immersion treatment with an immersion time of 8 hours may be caused due to damage or reduction of some reinforcing elements such as holocellulose, alpha-cellulose, hemicellulose and cellulose which have degraded. The decrease in tensile strength of the fiber along with the increasing concentration of NaOH is also suspected by the breaking of bonds between cellulose fiber molecules. And at the micro scale there is an excessive process of opening the fiber which causes the breakdown of a single fiber into microfibrils due to the dissolution of lignin as a binder. The treatment of coconut coir fiber immersion at high concentrations with a long soaking time can cause fiber to degrade, resulting in a decrease in fiber strength [11].

![Figure 2. Model of a single fiber tensile test specimen](image)

![Figure 3. Single fiber test specimen](image)

![Figure 4. Graph of single fiber test results](image)
Figure 5a shows the cross-section of coconut fiber without treatment, where there is still a lot of fiber impurities. This can be seen from the photoelectron scanning machine (SEM). Lots of dirt attached to the dirt is thought to contain lignin that has not been separated from the fiber. Figure 5b shows a cleaner fiber surface, compared to an untreated fiber surface. This shows that the limestone water solution can remove impurities from the fiber. Calcium-containing limestone that has reacted with water can clean lignin in coconut fiber. Figure 5c shows a large fiber surface, a solution of limestone water with a mass concentration of 5% capable of removing lignin and other impurities. This can be seen in a cross-section that looks neat and orderly grooved. Figure 5d shows the damaged fiber surface. The limestone mass is higher, it produce fiber degradation and it causes the solution to become harder. This results in cellulose in the fiber being degraded. Where the cellulose element is the main element as a buffer strength in natural fibers [12].

Figure 6 shows the fiber content without treatment and Figure 7 shows the content of coconut fiber with an immersion treatment of 5% mass of limestone. The picture was produced from the FESEM test, SEM-EDS test at the Central Laboratory of Biological Sciences, Universitas Brawijaya. The results show that the content that really distinguishes between Figures 6 and 7 is the Calcium (Ca) content. This can be clearly seen in Table 2, and Table 3, wherein Table 2 the atomic Ca is 0.05% while Table 3 is where the fiber is soaked with 5% limestone, the atomic Ca is 0.59% (Eriksson, 2016).
From Table 2 and Table 3, it can be found out the main element that makes the fiber stronger; the difference is the strongest, the calcium content. Womb calcium which produces hydroxyl group elements in a solution of limestone water. The hydroxyl group of solution that binds to the hydroxyl group of fibers, making the surface of the fiber rougher, cleaner and grooved [13].

Table 2. Fiber content without treatment

| Element | Line Type | Weight % | Weight % Sigma | Atomic % |
|---------|-----------|-----------|----------------|----------|
| C       | K series  | 56.29     | 0.33           | 64.19    |
| O       | K series  | 40.51     | 0.33           | 34.68    |
| Si      | K series  | 0.68      | 0.02           | 0.33     |
| Ti      | K series  | 1.68      | 0.05           | 0.48     |
| Cl      | K series  | 0.14      | 0.02           | 0.06     |
| K       | K series  | 0.21      | 0.02           | 0.07     |
| Ca      | K series  | 0.13      | 0.02           | 0.05     |
| Na      | K series  | 0.15      | 0.03           | 0.09     |
| Fe      | K series  | 0.20      | 0.04           | 0.05     |
| Total   |           | 100.00    | 100.00         |          |
Table 3. Content of 5% immersion fiber limestone

| Element | Line Type | Weight % | Weight % Sigma | Atomic % |
|---------|-----------|----------|----------------|----------|
| C       | K series  | 54.59    | 0.41           | 62.74    |
| O       | K series  | 41.72    | 0.41           | 36.00    |
| Ca      | K series  | 1.73     | 0.05           | 0.59     |
| Ti      | K series  | 1.45     | 0.05           | 0.42     |
| Si      | K series  | 0.11     | 0.02           | 0.05     |
| Cl      | K series  | 0.12     | 0.02           | 0.05     |
| S       | K series  | 0.09     | 0.02           | 0.04     |
| K       | K series  | 0.08     | 0.02           | 0.03     |
| Na      | K series  | 0.13     | 0.03           | 0.08     |
| **Total** |          | **100.00** |               | **100.00** |

The reaction between limestone and water, from which the reaction will form calcium and hydroxyl, where the hydroxyl group (OH) will bind to lignin contained in coconut fiber. This is what causes the surface of the fiber to be more rough, grooved and cleaner. Lime water content of more than 7.5% also results in damage to the surface of the fiber (cellulose is degraded). Figure 7 shows the bond between a hydroxyl group of limestone solution and a hydroxyl group on a coconut fiber. The hydroxyl group which is a balanced amount of solution and fiber causes the surface of the fiber to become rough, clean and the cellulose element is not result [11].

4. Conclusion
Based on the results of the study, it can be concluded that the solution of limestone water can be used to increase the tensile strength of coconut fiber. Limestone water solution can replace chemicals (NaOH) currently used as natural fiber treatment media. The concentration of 5% limestone mass makes maximum strength of coconut coir fiber at its maximum point, whereas in the mass concentration of more than 7.5% causes reduced strength of coconut coir fiber.

5. References
1. Ezzatahmadi, N., Ayoko, G. A., Millar, G. J., Speight, R., Yan, C., Li, J., ... Xi, Y. (2017). Clay-supported nanoscale zero-valent iron composite materials for the remediation of contaminated aqueous solutions: A review. Chemical Engineering Journal, 312, 336–350. https://doi.org/10.1016/j.cej.2016.11.154
2. Tekieli, M., De Santis, S., de Felice, G., Kwiecień, A., & Roscini, F. (2017). Application of Digital Image Correlation to composite reinforcements testing. Composite Structures, 160, 670–688. https://doi.org/10.1016/j.compstruct.2016.10.096
3. Suyanto, H. (2016). Review Serat Alam : Komposisi, Struktur, Dan Sifat Mekanis. October, (October), 14.
4. Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. Progress in Polymer Science (Oxford), 24(2), 221–274. https://doi.org/10.1016/S0079-6700(98)00018-5
5. Matheus, J., Irawan, Y. S., & Soenoko, R. (2013). Pengaruh Perlakuan Silane Dan NaOH Pada Permukaan Serat Kontinyu Limbah Epulur Sagu (Metroxylon Sp) Terhadap Daya Serap Air Dan Kekuatan Bending. 4(2), 212–219.
6. Anonim. (2017). Indonesia, Negara Produsen Kelapa Terbesar di Dunia. 2016. Retrieved from databoks.katadata.co.id/datapublish/2017/01/06/indonesia-negara-produsen-kelapa-terbesar-di-dunia
7. Sood, M., & Dwivedi, G. (2017). Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review. Egyptian Journal of Petroleum. https://doi.org/10.1016/j.ejpe.2017.11.005
8. Nopparut, A., & Amornsakchai, T. (2016). Influence of pineapple leaf fiber and it's surface treatment on molecular orientation in, and mechanical properties of, injection molded nylon
composites. Polymer Testing, 52, 141–149. https://doi.org/10.1016/j.polymertesting.2016.04.012
9. Bendjillali, K., Goual, M. S., Chemrouk, M., & Damene, Z. (2011). Study of the reinforcement of limestone mortars by polypropylene fibers waste. Physics Procedia, 21, 42–46. https://doi.org/10.1016/j.phpro.2011.10.007
10. Eriksson, M. (2016). Characterization of kiln feed limestone by dynamic heating rate thermogravimetry. International Journal of Mineral Processing, 147, 31–42. https://doi.org/10.1016/j.minpro.2016.01.001
11. Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. Journal of Applied Polymer Science, 84(12), 2222–2234. https://doi.org/10.1002/app.10460
12. Siad, H., Alyousif, A., Keskin, O. K., Keskin, S. B., Lachemi, M., Sahmaran, M., & Hossain, K. M. A. (2015). Influence of limestone powder on mechanical, physical and self-healing behavior of Engineered Cementitious Composites. Construction and Building Materials, 99, 1–10. https://doi.org/10.1016/j.conbuildmat.2015.09.007
13. Torkaman, J., Ashori, A., & Sadr Momtazi, A. (2014). Using wood fiber waste, rice husk ash, and limestone powder waste as cement replacement materials for lightweight concrete blocks. Construction and Building Materials, 50, 432–436. https://doi.org/10.1016/j.conbuildmat.2013.09.044