Journal of Integrated and Advanced Engineering (JIAE)
Vol. 2, No. 2, September 2022: 89-96
http://asasijournal.id/index.php/jiae
http://doi.org/10.51662/jiae.v2i2.43

Effect of Alkaline 5% NaOH treatment with variations of immersion time on tensile strength and flexural strength of Betung bamboo internode

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Abstract
Betung bamboo has a bigger stem diameter, thicker walls, and shorter internodes than other species of bamboo, making it ideal for building materials such as bridges and interior furnishings that may also be turned into works of art. Alkaline NaOH treatment was introduced to Betung bamboo to increase its mechanical properties. The alkaline treatment used a solution consisting of 5 %NaOH. Specimens with alkaline treatment were immersed into 5%NaOH solution for one hour, two hours, and three hours, followed by two hours of drying in a furnace at 60 °C. Tensile tests (ASTM D638) and flexural tests (ASTM D790) were carried out using servo hydraulics MTS Landmark 100 kN under static loading. The tensile strength, modulus of rupture (MOR) and modulus of elasticity (MOE) were analyzed from the results tests. The average maximum tensile strength of the Betung bamboo internode immersed for two hours into 5%NaOH solution is about 195.95 MPa, whereas the average values of MOR and MOE are about 207.35 MPa and 4.56 GPa, respectively. The faults and surface conditions in the Betung bamboo internode were observed using fractographic and morphological observations.

Keywords:
Alkaline NaOH treatment;
Betung bamboo;
Modulus of elasticity;
Modulus of rupture;

Article History:
Received: April12, 2022
Revised: July 5, 2022
Accepted: August 22, 2022
Published: September 16, 2022

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INTRODUCTION

Bamboo plants are included in the Poaceae family, a family of grasses with a relatively rapid growth rate with a span of 3-4 years to become an adult [1]. The content of lignocellulose (Hemicellulose, Cellulose and Lignin) in bamboo can be used as a composite. The condition happed because bamboo is made up of cellulose fibers embedded in a lignin matrix. Therefore, it is a naturally occurring composite material [2]. In addition, bamboo is also commonly used for building construction and also various furniture. Bamboo is a practical wood alternative because it is stronger than hardwood and has a greater strength-to-weight ratio than aluminum, regular wood, and steel composites [3]. Munawarah et al. [4] reported that 157 bamboo are growing in Indonesia that have good potential to be developed, one of which is Betung bamboo.

Betung bamboo (Dendrocalamus asper) is a bamboo plant with larger stem diameter, thicker walls, and shorter internodes than other types of bamboo. Betung bamboo is hard and suitable for building materials because of its large fibers and long internodes. Betung bamboo has an internode length of up to 60 cm with a diameter of around 14 cm and a wall thickness of 2 cm [5]. On each internode grows branches that are much smaller than the reed itself. Betung bamboo is used for several things, on the bamboo shoots as food and on the trunk as a construction material that can replace wood because of its large size and thick walls and can also be used as handicrafts [6, 7, 8].

Betung bamboo is a natural material with the disadvantage of lack of resistance to water and low tensile strength. Due to these weaknesses and to optimize the application of Betung bamboo, chemical treatment is carried out in the form of alkaline treatment. According to Gozan et al. [9], alkali treatment is the most widely used method, which aims to remove the lignin and oil content covering the fibre's outer surface. The effect that arises from the alkalization treatment is the change in hydrogen bonds in the fiber network structure, which causes the fiber surface to become rough. On the other hand, alkaline NaOH treatment removes hemicellulose and lignin. In addition, it also increase the cellulose content in Betung bamboo internodes fibers. In addition, it also improves mechanical properties, especially the tensile strength and stiffness of the fibers found in natural material fibers [10][11].

In the research conducted by Zariatin et al. [12], Enhanced Apus bamboo using an alkaline NaOH concentration of 5% with variations in immersion time for 60 minutes, 90 minutes and 120 minutes at a temperature of 70 °C. The results obtained from the tensile test showed that after being given alkaline treatment the tensile strength of Apus bamboo fibers increased compared to those not treated. It was stated that the alkaline treatment of NaOH proved effective in improving natural fibres' mechanical properties. The highest increase results were obtained at 90 minutes of immersion, and at 120 minutes of immersion, it was found a decrease in the value of the tensile strength was. From these results, the immersion time also affects the effectiveness of the alkaline treatment, where too long soaking time can result in a decrease in the tensile strength of the fiber, because the cellulose content in the fiber has been damaged so that the tensile strength of the fiber is weak.

METHOD

Materials And Specimen Preparation

The material used in this study is Betung bamboo which was chosen at the internode area of bamboo. Tensile specimens (ASTM D638) and flexural specimens (ASTM D790) were manufactured using conventional turning, and the surface of the specimen was grinded using sandpaper with a number of 1000 grades. The shape and dimension of the tensile specimen and flexural specimen are displayed in Figure 1 and Figure 2, respectively.

Alkaline NaOH Treatment

Specimens were subjected to an alkalization process. Alkalization process using NaOH solution with a concentration of 5%. Specimens were immersed into a container containing 5% NaOH solution, with a predetermined immersion time variation of one hour, two hours, and three hours. After the immersion process has reached the specified time, the specimen is then rinsed with distilled water to remove the alkaline NaOH content that is still attached to the specimen. Then drained and dried in a furnace at a temperature of 60 °C for two hours.

Testing

Test specimens that have been prepared accordingly will be distinguished based on no treatment (WT) and treatment with variations in immersion time. The tests carried out were tensile and flexural tests to determine the mechanical properties of the specimens after being treated with alkaline NaOH using the MTS Landmark 100Kn machine. In the tensile test, the Betung bamboo specimen will be pulled at a constant speed of 3.5 mm/min until it fails. At the same time, the flexural test of the Betung bamboo specimen will be given a load at a rate of 2.5 mm/min until the specimen fails. Specimen of Betung Bamboo Internode using a tensile test and a flexural test can be seen in Figure 3.

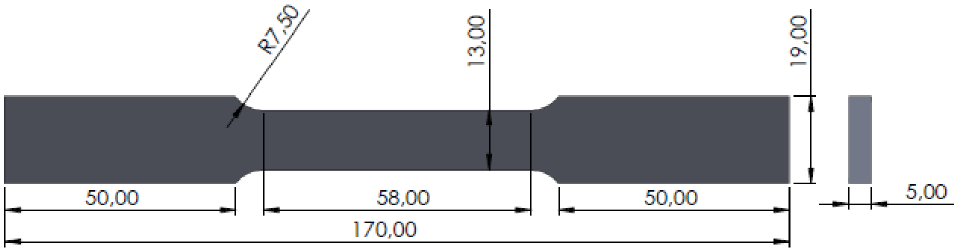

Figure 1. Tensile Test Specimen (unit in mm)

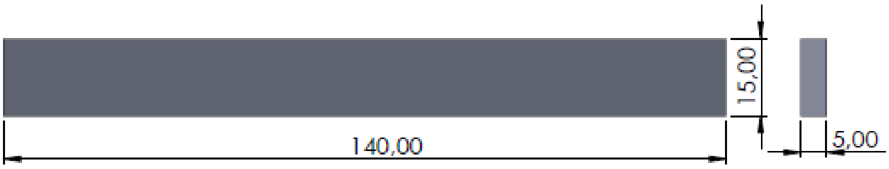

Figure 2. Flexural Test Specimen (unit in mm)

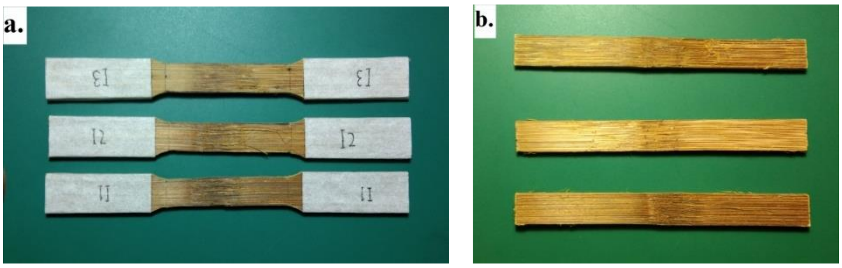

Figure 3. Specimen of Betung Bamboo Internode (a) Tensile Test and (b) Flexural Test

Observations of the shape of cracks and flexural test results were taken using a digital Dynolite microscope, with observation points in the gage length area and the area experiencing maximum deflection. Fractography and morphology were applied and explained using scanning electron microscopy (SEM), the specimens used were the results of tensile tests taken at the gage length that failed.

RESULTS AND DISCUSSION

Tensile Test Result

Figure 4 shows the engineering stress-strain curves of Betung bamboo internodes with various immersion times into 5% NaOH solution. Betung bamboo internode with 5% NaOH treatment experienced an increase in tensile strength compared to Betung bamboo without treatment (WT). According to Maulana et al. [13], the increase in tensile strength was caused by the alkaline NaOH immersion process which affected the hemicellulose and lignin content on the surface of Betung bamboo internode fibers to decrease. The condition happened because hemicellulose and lignin were easily dissolved in an alkaline solution, while cellulose was not easily dissolved and increased the cellulose content. Therefore, alkaline treatment of NaOH itself will increase the cellulose content on the fiber surface so that it can increase the strength of the fiber from Betung bamboo [14][15].

In this study, using a concentration of 5% NaOH solution effectively improved the mechanical properties of Betung bamboo internode. According to Yang et al. [16], the concentration of the solution affects the alkali treatment. The greater the concentration, the more it affects the lignocellulosic content of the material. However, a solution concentration that is too large can cause damage to the lignocellulosic content contained so that it can reduce the mechanical properties of the material [10][17].

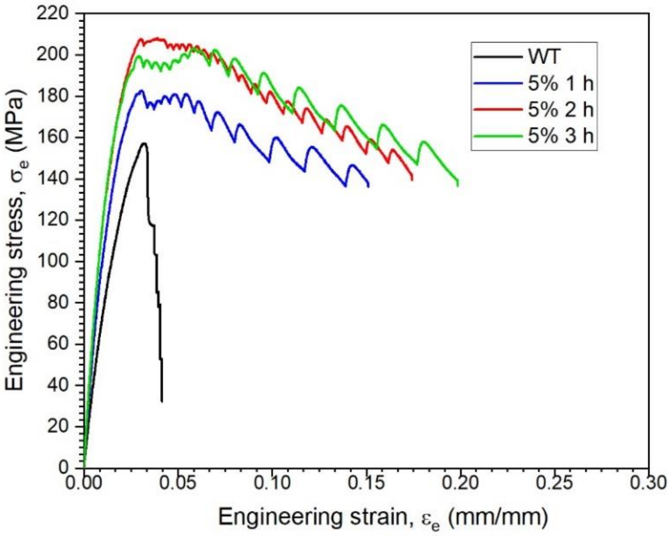

Figure 4. Bamboo Betung Internode Tensile Test Results

Cracks start from the parenchyma tissue that is between the fiber bonds. This is caused by the strength of the weak parenchyma tissue. According to Huang et al. [18], parenchyma tissue is a weaker tissue than fiber. In addition, parenchyma tissue will always be the starting point for failure. As stress increases, slip occurs between the fiber bundles and the parenchyma cells followed by cracks in other areas of weak intercellular strength. For example, the area between the bamboo fibers and the parenchyma cells leads to pulling the bamboo fibers from the parenchyma cells. Figure 5 shows the cracks and breakage of Betung Bamboo Fibers from a tensile test result.

Flexural Test Results

The curve of the test results shows in Figure 6. the maximum load value, Betung bamboo internode, was treated with 5% NaOH alkali with an immersion time of two hours. The alkaline NaOH immersion procedure increased the maximum load by decreasing the hemicellulose and lignin content on the surface of the Betung bamboo fiber and increasing the cellulose content on the fiber surface to raise the Betung bamboo fiber strength, as stated in this literature [13] [19].

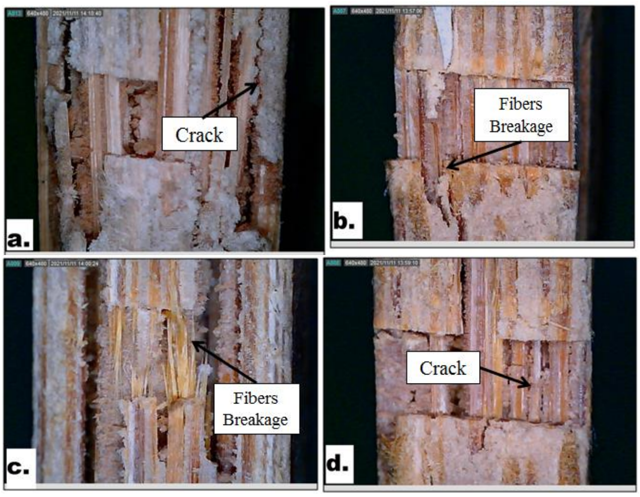

Figure 5. Cracks and Breakage of Betung Bamboo Fibers from Tensile Test Results (a) Without Treatment and with Alkaline 5% NaOH Treatment for Immersion Time of (b) one hour, (c) two hours, (d) three hours

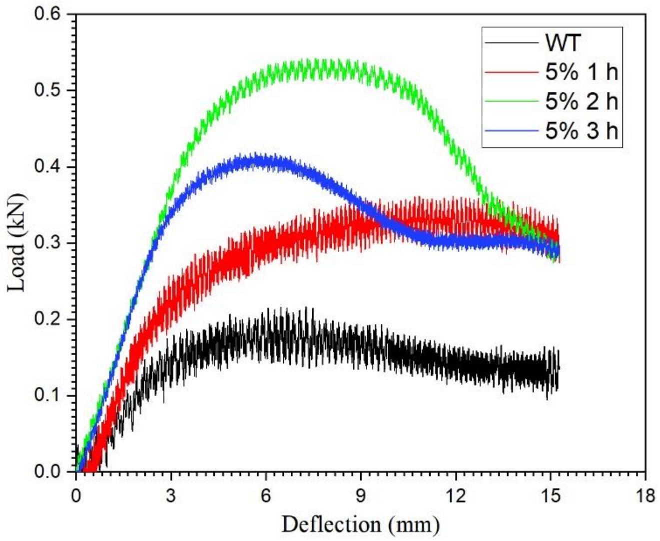

Figure 6. The plot of Load-Deflection Curve of Betung Bamboo Internode Without Treatment and With Alkaline NaOH Treatment

A 5% NaOH treatment with two hours of immersion had the most optimal tensile strength value, while three hours of immersion experienced a decrease in the maximum tensile strength value. According to Zariatin et al. [12], this can be caused by immersion that is too long can reduce the tensile strength of Betung bamboo because the cellulose on the surface of the fiber is damaged or dissolved along with hemicellulose and lignin to make the tensile strength of the fiber low. It can also be interpreted that increasing discontinuous immersion time increases the tensile strength.

Deflection occurs when the surface of the Betung bamboo internodes is subjected to a load that causes the breakage of fibers of the Betung bamboo internode and cracks at the other side of the Betung bamboo internode with the fiber breaking. Fiber density can determine bamboo's mechanical and physical qualities, according to Zakikhani et al. [20], who evaluated the morphological, mechanical, and physical aspects of four species of bamboo. Maulana et al. [21] reported that material density influenced the mechanical and physical parameters of Betung bamboo internodes specimens. The low fiber density affects the occurrence of cracks when tested on the surface of the Betung bamboo internode due to the weak fiber strength. With the lack of cracks in the flexural test results, it can be concluded that the Betung bamboo internode has good fiber density and strength. Figure 7 depicted a macro observation from photos of the fibers breakage for Betung Bamboo Internode with alkaline 5% NaOH treatments.

SEM Observation

Figure 8a shows the smooth surface of the Betung bamboo internode specimen. This is because no alkali treatment is given to the specimen. So, the surface of the specimen is still covered with lignocellulose, indicating that Betung bamboo is one of the natural fibers. Figure 8b shows rougher and cleaner surfaces due to the removal lignin and hemicellulose substances during the NaOH alkalizing treatment. As stated in literature [22][23] that the delignification process caused the roughness and cleanliness on the surface of natural fibers by immersing them in an alkaline NaOH solution. This is consistent with NaOH alkalization, which reduces lignin and hemicellulose levels in the material while increasing cellulose content, resulting in increased mechanical strength [24]. According to Rineksa et al. [25], the effect of the alkaline treatment of NaOH on the surface of the Betung bamboo internodes is to make the surface of the Betung bamboo internodes was rougher.

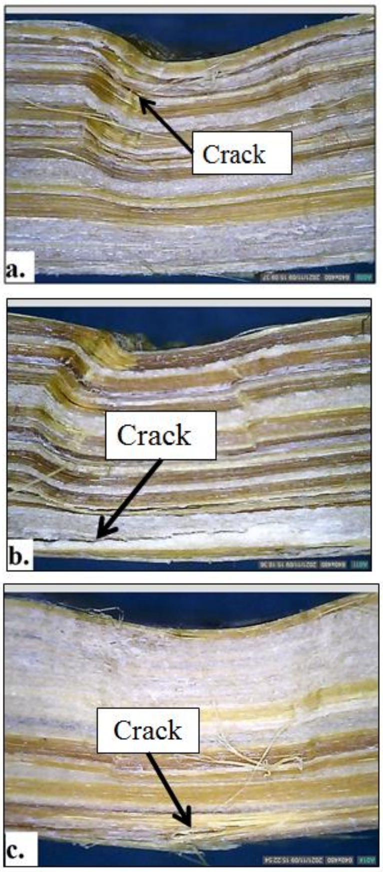

Figure 7. Macro Observation from Photos of the fibers breakage for Betung Bamboo Internode with alkaline 5% NaOH treatments for (a) one hour, (b) two hours, (c) three hours

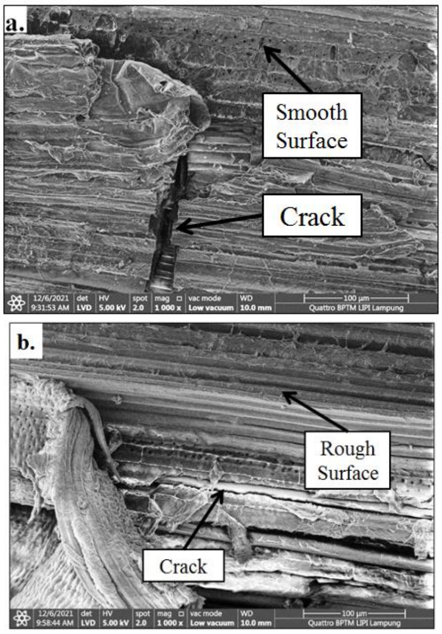

Figure 8. SEM Fractography and Morphology of Betung Bambu Internode (a) Without Treatment and (b) With alkaline 5% NaOH Treatment for two hours

CONCLUSION

Alkaline 5% NaOH treatment with variations of immersion time affected the tensile and flexural strength of the Betung bamboo internode. The tensile strength and flexural strength of the bamboo Betung internode with alkaline 5% NaOH treatment increases. The mechanical properties (tensile strength, MOR and MOE) of Betung bamboo internode with alkaline 5% NaOH treatment for two hours is higher than those of the mechanical properties of Betung bamboo internode with alkaline 5% NaOH treatments for one hour and three hours immersion time. The average values of tensile strength, MOR and MOE for the Betung bamboo internode with alkaline 5% NaOH treatment are about 195.95 MPa, about 207.35 MPa and about 4.56GPa, respectively. Therefore, too fast immersion is ineffective in increasing the tested specimens' mechanical strength. On the other hand, an immersion that is too long can cause damage to the cellulose content, which can strengthen the fiber to be dissolved along with hemicellulose and lignin. It can also be interpreted that increasing discontinuous immersion time increases the tensile strength.

ACKNOWLEDGMENT

This work was a part of the basic research of a competitive national grant under contract No. 3972/UN26.21/PN/2021.

REFERENCES

[1] S. Sugiman, I. K. Candra, P. D. Setyawan and B.Anshari, “Effect of alkali treatment on the flexural strength of bamboo fibers reinforced styrofoam-modified polyester resin,” *AIP Conference Proceedings*, vol. 1983, no. 1, ID: 050005, 2018, doi: 10.1063/1.5046278.

[2] O. Y. Ogunsanwo, A. O. Adenaiya and C. A. Adedeji., “Effect of adhesive quantity on selected physico-mechanical properties of bamboo glulam,” *Maderas: Ciencia y Tecnología*, vol. 21, no. 1, pp. 113-122, 2019, doi:10.4067/S0718-221X2019005000111.

[3] I. Kenneth Omaliko and U. O. Uzodimma, “Evaluation of the compressive strength of bamboo culms under node and evaluation of the compressive strength of bamboo culms under node and internode conditions,” *Saudi Journal of Civil Engineering (SJCE)*, vol. 5, no. 8, pp. 251-258, 2021, doi:10.36348/sjce.2021.v05i08.001.

[4] A. Munawarah et al., “Inventarisasi bambu di daerah aliran sungai semoya Lombok Barat,” *BioWallacea Jurnal Ilmiah Ilmu Biologi*, vol. 5, no. 2, pp. 80-91, 2019, doi: 10.29303/biowal.v5i2.144.

[5] S. H. Park et al., “Anatomical and physical properties of Indonesian bamboos carbonized at different temperatures,” *Journal of the Korean Wood Science and Technology*, vol. 46, no. 6, pp. 656-669, 2018, doi: 10.5658/WOOD.2018.46.6.656.

[6] W. Zhang, et al., “A novel surface treatment for bamboo flour and its effect on the dimensional stability and mechanical properties of high density polyethylene/bamboo flour composites,” *Construction and Building Materials*, vol. 186, pp. 1220-1227, 2018, doi: 10.1016/j.conbuildmat.2018.08.003.

[7] M. J. Ghoushji et al., “Energy absorption capability of axially compressed woven natural ramie/green epoxy square composite tubes,” *Journal of Reinforced Plastics and Composites*, vol. 36, no. 14, 2017, pp. 1028-1037, 2017, doi: 10.1177/0731684417700482.

[8] A. Fatrawana et al., “Changes in chemical components of steam-treated betung bamboo strands and their effects on the physical and mechanical properties of bamboo-oriented strand boards,” *European Journal of Wood and Wood Products*, vol. 77, no. 5, pp. 731-739, 2019, doi: 10.1007/s00107-019-01426-7.

[9] M. Gozan, N. Chrisayu Natasha, and P. Srinophakun, “Lignin decomposition of Oil Palm Frond by Pleurotus ostreatus with a variation of corn and rice-husk media,” *Journal of Integrated and Advanced Engineering (JIAE)*, vol. 2, no. 1, pp. 55-62, 2022, doi: 10.51662/jiae.v2i1.40

[10] S. Behera et al., “Study of mechanical properties of bamboo fibers before and after alkali treatment,” *International Journal of Applied Engineering Research*, vol. 13, no. 7, pp. 5251-5255, 2018

[11] A. Oushabi et al., “The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): study of the interface of DPFePolyurethane composite,” *South African Journal of Chemical Engineering*, vol. 23, pp. 116-123, 2017, doi: 10.1016/j.sajce.2017.04.005.

[12] D. L. Zariatin Dede, M. A. Ravizqi and A. S. Siregar, "Analisis pengaruh waktu perebusan serat bambu apus (Gigantochloa Apus) pada larutan NaOH terhadap beban tarik," *Prosiding Seminar Rekayasa Teknologi (SemResTek)*, 2020, Jakarta, Indonesia, pp. 51-57
[13] M. I. Maulana et al., "Effect of alkali-washing at different concentration on the chemical compositions of the steam treated," *Journal of The Korean Wood Science and Technology*, vol. 49, no. 1, pp. 14-22, 2021, doi: 10.5658/WOOD.2021.49.1.14
[14] A. A. Salih et al., "Tensile properties and microstructure of single-cellulosic bamboo fiber strips after alkali treatment," Fibers, vol. 8, no. 5, pp. 1-10, 2020, doi: 10.3390/fib8050026.
[15] S. Sugiman et al., "Effects of alkali treatment of bamboo fibre under various conditions on the tensile and flexural properties of bamboo fibre/polystyrene-modified unsaturated polyester composites," J. Eng. Sci. Technol., vol. 14, no. 1, pp. 27-47, 2019.
[16] I. Yang, et al., "Relationship between lignin content and the durability of wood pellets fabricated using larix kaempferi C. sawdust," *Journal of The Korean Wood Science and Technology*, vol. 47, no. 1, pp. 110-123, 2019, doi: 10.5658/WOOD.2019.47.1.110.
[17] F. Wang, et al., "Changes in the morphological–mechanical properties and thermal stability of bamboo fibers during the processing of alkaline treatment," *Polymer Composites*, vol. 39, no. S3, pp. E1421-E1428, 2018, doi: 10.1002/pc.24332.
[18] X. Huang, et al., "Analysis of bambusa rigida bamboo culms between internodes and nodes: Anatomical characteristics and physical-mechanical properties," *Forest Products Journal*, vol. 68, no. 2, pp. 157-162, 2018, doi: 10.13073/FPJ-D-17-00035.
[19] Y. Jung, et al., "Optimization of alkali pretreatment from steam exploded barley husk to enhance glucose fraction using response surface methodology," *Journal of The Korean Wood Science and Technology*, vol. 45, no. 2, pp. 182-194, 2017, doi: 10.5658/WOOD.2017.45.2.182.
[20] P. Zakikhani et al., "Morphological, mechanical, and physical properties of four bamboo species," *BioResources*, vol. 12, no. 2, pp. 2479-2495, 2017.
[21] S. Maulana et al., "Effects of steam treatment on physical and mechanical properties of bamboo oriented strand board," *Journal of The Korean Wood Science and Technology*, vol. 45, no. 6, pp. 0-2, 2017, https://doi.org/10.5658/WOOD.2017.45.6.872.
[22] M. Y. Hashim et al., "The effect of alkali treatment under various conditions on physical properties of kenaf fiber," *Journal of Physics: Conference Series*, vol. 914, no. 1, 2017, doi: 10.1088/1742-6596/914/1/012030.
[23] Y. Liu et al., "Development and characterization of alkali treated abaca fiber reinforced friction composites," *Composite Interfaces*, vol. 26, no. 1, pp. 67-82, 2019, doi: 10.1080/09276440.2018.1472456.
[24] H. Chen et al., "Effect of alkali treatment on microstructure and mechanical properties of individual bamboo fibers Effect of alkali treatment on microstructure and mechanical properties of individual bamboo fibers," *Cellulose*, vol. 24, no. 1, pp. 333-347, 2017, doi: 10.1007/s10570-016-1116-6.
[25] G. Rineksa, Y. Whulanza, and M. Gozan, "Preliminary Study of Potential Bioimplant from Glycerol Plasticized Starch-Microcrystalline Cellulose Composite," *Journal of Integrated and Advanced Engineering (JIAE)*, vol. 1, no. 1, pp. 29-36, 2021, doi: 10.51662/jiae.v1i1.10