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Mechanical Performance of Alkali-Treated Rattan Strips with Epoxy Coating for Sustainable Composite Applications

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Abstract. The use of natural materials like rattan in eco-friendly composites is gaining attention in materials engineering. However, its hydrophilic nature and interaction with other materials can affect mechanical strength. This study investigates how variations in rattan size and alkali treatment influence the tensile properties of single rattan strips through an epoxy dipping process. Rattan was prepared with varying lengths (5–15 cm), widths (3–8 mm), and a consistent thickness (0.5 mm). Alkali treatment used 5% and 10% NaOH concentrations for 1 and 24 hours. Tensile testing showed that a 5 cm × 8 mm strip achieved the highest tensile strength (49.95

MPa), Young's modulus (3562.77 MPa), and low strain (5.4%), while the 15 cm × 3 mm strip had the lowest strength (9.48 MPa) and modulus (475.69 MPa) with higher strain (10.32%). A 5% NaOH treatment for 24 hours improved adhesion and performance, while 10% caused degradation.

Keywords: natural fiber composites, sustainable materials, green materials, bio-composites, surface treatment, green engineering, rattan strips.

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1. Introduction

Rattan is one of Southeast Asia's most abundant natural resources, found in countries such as Indonesia and Malaysia. This natural material has been widely utilized in the handicraft industry, furniture making, and light building [1] [2] [3]. However, the utilization of rattan as a structural composite material is still relatively limited so far. One of the main challenges is that the mechanical strength of rattan has not been optimized, particularly in terms of its tensile properties, which significantly contribute to its use in engineering applications. In fact, with proper processing, rattan can become an environmentally friendly alternative to replace synthetic materials or hardwood, which is now increasingly limited [4].

Parts of rattan that can be utilized in the composite industry include bast and core types, where the tensile strength that both materials can produce is around 41.97-121.5 MPa and 43.5-85.6 MPa [5]. In 2020, Yang et al. evaluated the mechanical properties of rattan with different lengths and diameters of 2420/1.76 cm, 1779/2.31 cm, 1314/1.44 cm, and 1629/1.27 cm. The difference in dimensions contributed to tensile strength of 41.99-57.21 MPa, tensile modulus of 1897.01-2514.2 MPa, compressive strength of 25.07-27.75 MPa, and impact toughness of 22.56-53.81 J/cm² [6]. This suggests that the dimension of the rattan plays a crucial role in supporting the performance of the composite.

Various studies have provided investigation results that show rattan is a natural material composed of several constituent components, including cellulose, hemicellulose, lignin, and other impurities. This can inhibit the creation of a strong bond between rattan and resin. Chemical treatments such as alkali (NaOH) are present to manipulate the surface structure of rattan to become rougher, improve the bonding power of the interface, and improve mechanical properties [7] [8]. Applying 1-10% NaOH with a variation of 0.5-48 hours can affect the fiber and matrix interface. This impacts the characterization of composites, as well as their physical, mechanical, thermal, and tribological properties [9].

On the other hand, the polymer dipping process plays a significant role in coating and supporting the rattan structure [10]. However, there is a lack of studies evaluating the combination of alkali treatment and resin dipping on rattan single strips. Moreover, the difference in rattan dimensions significantly contributes to the final mechanical properties. From a broader perspective, exploring rattan as a composite material not only addresses material properties but also aligns with the goals of sustainable engineering. As a fast-growing, biodegradable, and renewable resource, rattan offers substantial life cycle benefits, including a low carbon footprint and reduced energy consumption compared to synthetic fibers [11] [12] [13].

Its local abundance minimizes transportation emissions, and its ability to sequester carbon adds value to climate change mitigation efforts [14] [15] [16]. Despite these advantages, the scientific community still lacks a comprehensive understanding of how to enhance rattan's mechanical performance for high-strength applications. Therefore, this study aims to analyze the effect of rattan size, alkali treatment, and epoxy resin dipping on the tensile properties of rattan. This study aims to enhance the understanding of rattan utilization in an environmentally friendly and sustainable composite industry.

2. Methods

2.1. Materials

The resin used in this research is epoxy, as shown in Table 1. The natural fiber chosen as reinforcement is a roll-shaped rattan purchased from a local market in Indonesia.

Table 1 Specifications of Epoxy Resin and Hardener Mixture.

EpoxAmite™ 100 Resin with (A):	**103 SLOW Hardener (B)**
Mix Ratio By Volume	3A : 1B
Specific Gravity - Mixed; g./c.c. (ASTM D1475)	1.10
Spec. Volume - Mixed; cu. in./lb. (ASTM D792)	25.2
Color - Mixed	Clear Yellow

2.2. Alkali Treatment

Samples used in alkali treatment are from rattan with a selected size that produces the maximum tensile strength. Alkali treatment was carried out by immersing the rattan into 5% and 10% sodium hydroxide (NaOH) solution for 1 hour and 24 hours at room temperature [17] [18]. After that, the rattan was cleaned using distilled water to achieve a pH of 7 and then dried in a vacuum oven at 105 °C for 24 hours [19] [20] [21] [22]. The final step is to store the rattan in a plastic box to prevent direct contact with humid air.

2.3. Sample Preparation

In this study, the rattan was cut with a cutting tool to obtain the size shown in Table 2. After that, the rattan was cleaned using distilled water at room temperature to remove dirt and natural oils and then dried in a vacuum oven at 105 °C for 24 hours to remove the remaining water content. The dried rattan was stored in a closed plastic box to avoid contamination in a humid environment. The manufacture of test samples was carried out in two stages. In the first stage, each sample passed the dipping process in a plastic box containing a mixture of epoxy resin and hardener with a ratio of 3 1. The dipping process utilizes clamping tools to ensure that the entire surface of the rattan is evenly coated. After that, the rattan was dried using direct sunlight for 24 hours. For the second stage, test samples were prepared by obtaining the rattan size that produced the best tensile strength in the first stage and then applying alkali treatment according to the mechanism described in Section 2.2. Afterward, the samples underwent an epoxy dipping process and drying to be prepared as test samples.

Table 2 Dimension of Rattan Sample.

Sample Name	**Length (cm)**	**Width (mm)**	**Thickness (mm)**	**Sample Code**
R1	5	3	0.5 ± 0.011	$R1_A$
	5	6	0.5 ± 0.011	$R1_B$
	5	8	0.5 ± 0.011	$R1_C$
R2	10	3	0.5 ± 0.011	$R2_A$
	10	6	0.5 ± 0.011	$R2_B$
	10	8	0.5 ± 0.011	$R2_C$
R3	15	3	0.5 ± 0.011	$R3_A$
	15	4	0.5 ± 0.011	$R3_B$
	15	8	0.5 ± 0.011	$R3_C$

2.4. Testing of Specimen

Tensile tests were conducted to analyze the tensile strength, Young's modulus, and tensile strain of the rattan specimens using a Universal Testing Machine (Instron 3367, USA) based on ASTM D3822-01 standard. Five test samples were prepared for each size of a single rattan strip. The samples were glued to mounting tabs made of 200 gsm A4 paper using super glue and allowed to dry for 2 hours at room temperature. The mounting tab was designed with a protective sleeve to prevent the clamping pressure from the machine from damaging the single rattan strip. After drying, both sides of the mounting tab were placed on either side of the UTM gripper. Then, the center of the tab was carefully removed, allowing the specimen to hang freely between the grips. The tensile test was conducted at a withdrawal speed of 2 mm/min with a load of 30 kN until the specimen failed.

3. Results and Discussion

3.1. Mechanical Properties

Figure 1 shows the tensile test results of rattan single-strip specimens subjected to the epoxy resin dipping process. The results showed significant variations in tensile strength, Young's modulus, and tensile strain values based on sample size and code. Sample R1C achieved the highest tensile strength value at 49.95 MPa, followed by R1B at 42.47 MPa. Conversely, the lowest value was found in R3A at 9.48 MPa. For Young's modulus value, R1C also showed the highest stiffness of 3562.77 MPa, while the lowest value was recorded in R3A at 475.69 MPa. Sample R1A recorded the highest value of 11% in tensile strain, indicating higher deformation capability before breaking, while the lowest strain occurred in R3B with a value of 1.46%.

The finding in this study was that as the width of the specimen increased (from A to B and C). Generally, the tensile strength and Young's modulus increased significantly, indicating that the cross-sectional dimension contributes greatly to the load-carrying capacity [6]. Samples with larger widths (B and C) appear stiffer and stronger, as seen in R1C and R1B. However, increasing the width also decreases the strain, indicating that the specimens become stronger but less flexible. This demonstrates the rigid nature of the material, where a low deformation capability accompanies a high modulus. In addition, the variation in specimen length (R1 = 5 cm, R2 = 10 cm, and R3 = 15 cm) also contributed to the tensile strength. In general, the tensile strength and modulus values tend to decrease as the specimen length increases, which can be seen in samples A, B, and C, respectively, from R1 to R3. This is due to the possibility of increased defects and inhomogeneous distribution of epoxy during the dipping process in the rattan structure in longer specimens [23]. Therefore, cross-sectional size and length play an essential role in determining the tensile strength of single rattan strips.

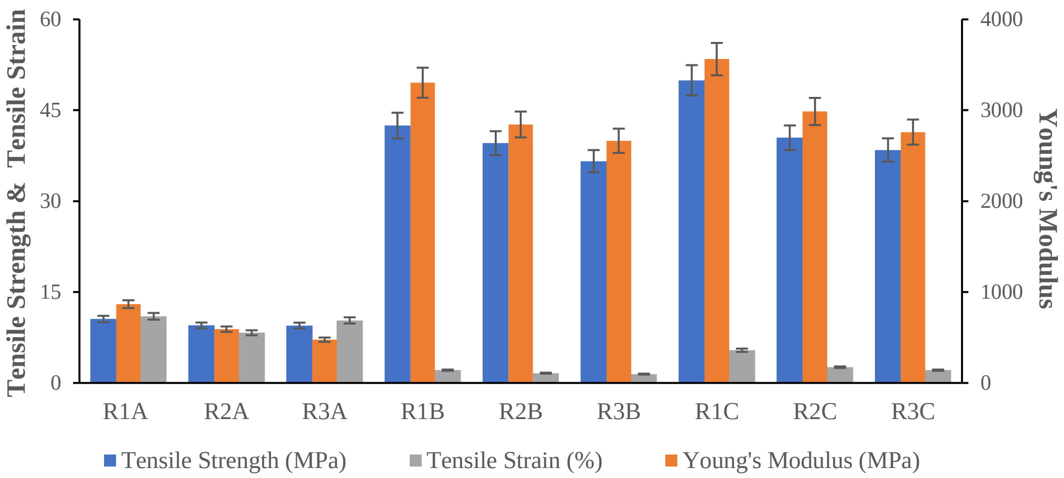

Figure 1. Effect of rattan size variation on mechanical properties of rattan single strips with epoxy dipping process.

Figure 2 presents the effect of NaOH concentration and soaking time on the tensile strength, Young's modulus, and tensile strain of rattan single strips undergoing the epoxy resin dipping process. The samples used were taken from the rattan that produced the greatest tensile strength (Figure 1), with a length of 50 mm, a width of 8 mm, and a thickness of 0.5 mm. The results showed that the best treatment was achieved by samples immersed in a 5% NaOH solution for 24 hours, with a tensile strength of 15.54 MPa and Young's modulus of 793.23 MPa, although the strain decreased to 13.44%. In contrast, treatment with 10% NaOH for 24 hours resulted in a decrease in tensile strength and modulus to 9.71 MPa and 232.45 MPa but with a relatively high tensile strain of 21.79%. Meanwhile, the untreated sample exhibited a tensile strength of 12.58 MPa, Young's modulus of 275.72 MPa, and a strain of 21.58%. The findings in this study indicate that NaOH concentration and soaking duration significantly affect the tensile strength of rattan single strips. The substantial increase in tensile strength and elastic modulus at 5% treatment for 24 hours indicates that this treatment effectively removes non-cellulosic components such as lignin and hemicellulose. In addition, the manipulation of the surface structure of the rattan strengthened the interaction between the rattan and epoxy, thus supporting the strength of the rattan [24]. However, the same increase in soaking time at a higher NaOH concentration (10%) decreased the strength and stiffness of the material. This is likely due to the degradation of the rattan structure resulting from excessive alkalization, which weakens the rattan's integrity and accelerates the failure process [24].

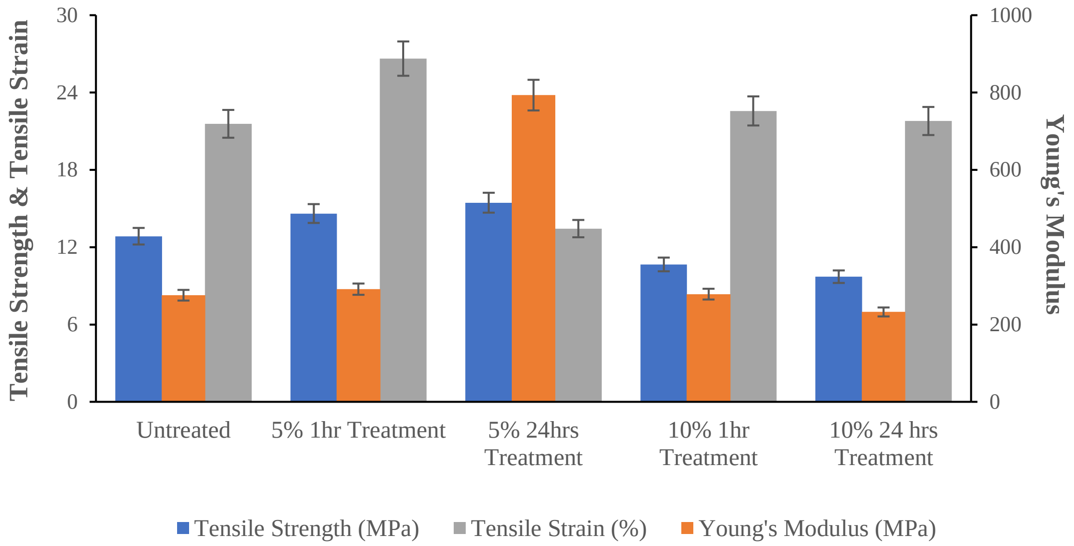

Figure 2. Effect of variation in concentration and duration of NaOH immersion in rattan on the mechanical properties of rattan single strips with the epoxy dipping process.

3.2. Morphology Fracture

Figure 3 shows the fracture pattern of the single strips of rattan for the variation of the dimensions of the rattan. Based on microscope observation of specimens R1A, R2A, and R3A, the fracture pattern formed is dominated by fiber breakage near the grip, with the phenomenon of weak interfacial bond between rattan and epoxy. This contributed negatively to the low tensile strength of 10.55 MPa, 9.5 MPa, and 9.48 MPa, respectively. In addition, it is evident that the fracture is irregular and shows many detached fine fibers. This indicates failure due to excessive strain and weak surface cohesion [25].

In contrast, samples R1B, R2B, and R3B, as well as R1C, R2C, and R3C, exhibited matrix failure phenomena, including epoxy surface cracks, delamination, and indications of stress concentration in the grip area. This finding proves a better bonding of the rattan and epoxy, although the epoxy shows voids, which are the starting point of failure [26]. These specimens produced significantly higher tensile strengths, ranging from 36.6 MPa to 49.95 MPa, thanks to the increased dimensions of the rattan and possibly a more homogeneous stress distribution. The difference in fault patterns between samples A and B/C emphasizes the importance of interfacial bonding strength and epoxy distribution in determining the material's mechanical performance [27].

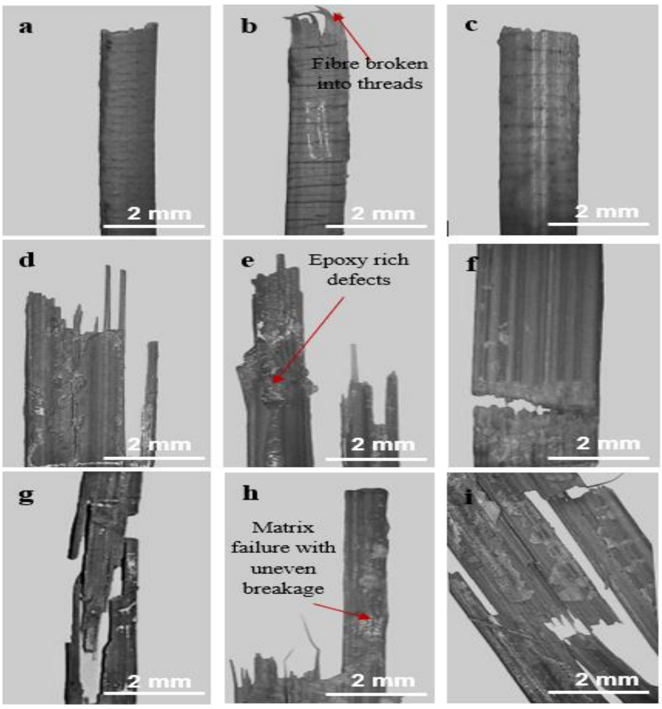

Figure 3. Fracture patterns of specimens of R1A (a), R2A (b), R3A (c), R1B (d), R2B (e), R3B (f), R1C (g), R2C (h), and R3C (i).

Figure 4 shows the fracture patterns of the five types of specimens with different alkali treatments. This demonstrates how variations in NaOH concentration and treatment duration affect the tensile strength of rattan using the epoxy dipping process. The untreated specimens and the 5% treatment for 1 hour both exhibited fiber pullout symptoms, indicating that the interlocking of rattan and epoxy remains very weak [28]. This is aligned with the low tensile strength produced, which amounted to 16.98 MPa and 18.06 MPa, respectively. However, the specimens treated with 5% for 24 hours showed a brighter, cleaner fiber surface and much better interface contact. This proved an increase in tensile strength of 24.57 MPa. This finding demonstrates that applying alkali with moderate concentration and sufficient time can effectively remove lignin, hemicellulose, and other impurities on the surface while creating a rough surface that strengthens the mechanical interlock [29].

On the other hand, at 10% concentration, for both 1 hour (12.68 MPa) and 24 hours (11.67 MPa), there was a significant decrease in tensile strength as indicated by the appearance of blackened and damaged fibers due to surface degradation. This shows that although chemical treatment is necessary, the concentration and soaking time must be appropriate [25] [30]. Moreover, higher concentrations can destroy the internal structure of the rattan and degrade its mechanical properties. The findings in this study indicate that a 5% NaOH concentration and an immersion time of 24 hours are the optimal conditions for increasing the tensile strength of rattan single strips using the epoxy dipping process.

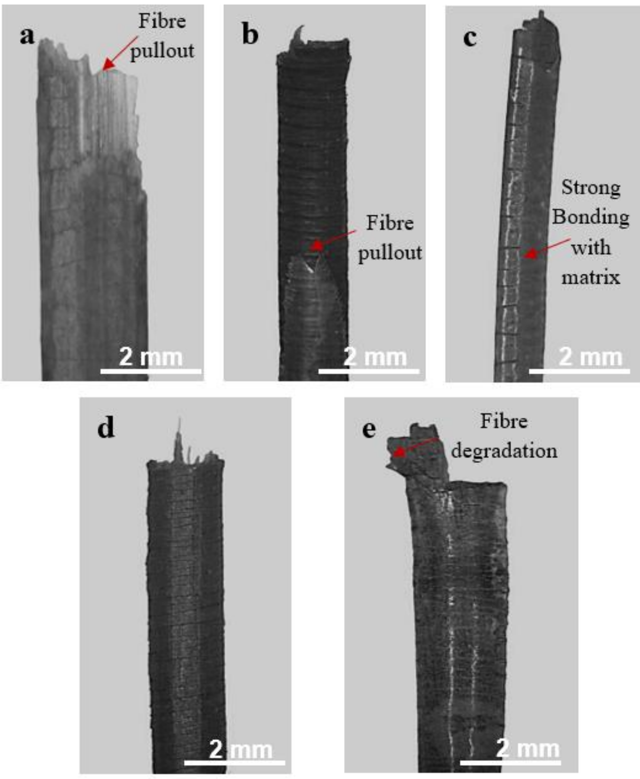

Figure 4. Fracture patterns for untreated specimens (a), 5% and 1-hour treatment (b), 5% and 24-hour treatment (c), 10% and 1-hour treatment (d), and 10% and 24-hour treatment (e).

4. Conclusion

This study analyzed the effect of different rattan sizes and alkali treatment on the tensile strength of rattan single strips with an epoxy dipping process. The tensile test results showed that rattan with a length of 5 cm and a width of 8 mm produced a higher tensile strength Young's modulus of 49.95 MPa and 3562.77 MPa and a relatively low tensile strain of 5.4%. In contrast, the 15 cm long and 3 mm wide rattan showed a low tensile strength of 9.48 MPa and Young's modulus of 475.69 MPa, with a high tensile strain of 10.32%, reflecting large deformation but low strength. The larger size offers improved load distribution and enhanced durability, albeit at the risk of delamination in the grip area. The 5% alkali treatment for 24 hours proved to effectively improve the interlocking of rattan and epoxy, resulting in a tensile strength of 24.57 MPa, Young's modulus of 1024.91 MPa, and tensile strain of 7.2%, which is more balanced between rigidity and flexibility. However, 10% degradation occurred due to fiber degradation, as Young's modulus dropped to 654.44 MPa and the strain was only 5.67%. The findings of this study indicate that the strip dimensions, as well as the concentration and duration of alkali treatment, significantly influence the mechanical performance. The main contribution of this study is to provide a comprehensive understanding of the association between the physical size, chemical treatment, and mechanical behavior of rattan single strips. These insights can serve as a reference for designing lightweight, eco-friendly composite components in the construction, furniture, and interior industries. However, this study is limited to tensile properties and does not cover other mechanical or thermal characteristics. Further investigations on molding pressure, resin spread, fiber alignment, and environmental exposure are recommended to support industrial-scale applications and to strengthen the case for rattan as a sustainable engineering material.

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References
[1] K. Krisdianto, J. Jasni, and T. Tutiana, "Anatomical properties of nine indigenous rattan species of Jambi, Indonesia," *Indones. J. For. Res.*, vol. 5, no. 2, pp. 147–161, 2018.
[2] R. Wahab, N. Mokhtar, R. S. Mohd Ghani, and M. S. Sulaiman, "An Overview of Rattan Industry Status and Its Economic Aspect in Setting Up Rattan-Based Industry in Malaysia," *e-BANGI J.*, vol. 16, no. 3, 2019.
[3] Afentina, P. McShane, and W. Wright, "Ethnobotany, rattan agroforestry, and conservation of ecosystem services in Central Kalimantan, Indonesia," *Agrofor. Syst.*, vol. 94, no. 2, pp. 639–650, 2020.
[4] S. K. Sahoo *et al.*, "Fabrication and characterization of acrylic acid treated rattan fiber reinforced polyethylene terephthalate composites for packaging industries," *J. Nat. Fibers*, vol. 19, no. 13, pp. 5768–5781, 2022.
[5] Y. Gu and J. Zhang, "Tensile properties of natural and synthetic rattan strips used as furniture woven materials," *Forests*, vol. 11, no. 12, p. 1299, 2020.
[6] S. Yang, E. Xiang, L. Shang, X. Liu, G. Tian, and J. Ma, "Comparison of physical and mechanical properties of four rattan species grown in China," *J. Wood Sci.*, vol. 66, no. 1, p. 3, 2020.
[7] S. K. Sahoo, J. R. Mohanty, S. Nayak, and B. Behera, "Chemical treatment on rattan fibers: durability, mechanical, thermal, and morphological properties," *J. Nat. Fibers*, vol. 18, no. 11, pp. 1762–1771, 2021.
[8] D. Bachtiar *et al.*, "Effect of alkaline treatment on the thermal and mechanical properties of sugar palm fibre reinforced thermoplastic polyurethane composites," *Sci. Rep.*, vol. 15, no. 1, pp. 1–14, 2025, doi: 10.1038/s41598-025-99227-x.
[9] M. H. Hamidon, M. T. H. Sultan, A. H. Ariffin, and A. U. M. Shah, "Effects of fibre treatment on mechanical properties of kenaf fibre reinforced composites: a review," *J. Mater. Res. Technol.*, vol. 8, no. 3, pp. 3327–3337, 2019.
[10] D.-H. Jeong, L. Xing, M. K. H. Lee, N. Vani, and A. Sauret, "Deposition and alignment of fiber suspensions by dip coating," *J. Colloid Interface Sci.*, vol. 650, pp. 407–415, 2023.
[11] G. Açıkbaş, "Interfacial and physico-mechanical properties of walnut shell fiber reinforced polyester matrix composites," *Mater. Test.*, vol. 60, no. 5, 2018, doi: https://doi.org/10.3139/120.111176.
[12] T. Cionita, R. Dewi, N. Sylvia, J. P. Siregar, and D. Fajar, "Effect of plasticizer and carboxyl methyl cellulose (CMC) on degradable plastics from rice straw and palm fiber," vol. 12, no. March, pp. 478–494, 2025, doi: 10.3934/environsci.2025022.
[13] M. S. Sulaiman *et al.*, "An economic study for rattan industry from raw materials to an enhancement of products development," *Math. Stat. Eng. Appl.*, vol. 71, no. 3, pp. 1819–1839, 2022.
[14] L. O. Cortat, N. C. Zanini, R. F. S. Barbosa, A. G. de Souza, D. S. Rosa, and D. R. Mulinari, "A sustainable perspective for macadamia nutshell residues revalorization by green composites development," *J. Polym. Environ.*, vol. 29, pp. 3210–3226, 2021, doi: 10.1007/s10924-021-02080-y.
[15] C. R. Álvarez-Chávez, D. L. Sánchez-Acosta, J. C. Encinas-Encinas, J. Esquer, P. Quintana-Owen, and T. J. Madera-Santana, "Characterization of extruded poly (lactic acid)/pecan nutshell biocomposites," *Int. J. Polym. Sci.*, pp. 1–12, 2017, doi: 10.1155/2017/3264098.
[16] Z. W. Ng *et al.*, "Process design and life cycle assessment of furfural and glucose co-production

derived from palm oil empty fruit bunches," *Environ. Dev. Sustain.*, vol. 25, no. 12, pp. 13937–13958, 2023, doi: 10.1007/s10668-022-02633-8.
[17] A. I. Imran *et al.*, "Advancements in sustainable material development: A Comprehensive review of coir fiber and its composites," *Mech. Eng. Soc. Ind.*, vol. 4, no. 3, pp. 415–454, 2024, doi: 10.31603/mesi.12556.
[18] A. L. Cahyani, V. Linda, D. Guntama, M. N. Dewi, and L. Hakim, "Effect of Chitosan Variation in Starch and Cellulose Based Biofoam," *Adv. Sustain. Sci. Eng. Technol.*, vol. 5, no. 3, pp. 1–9, 2023, doi: 10.26877/asset.v5i3.17126.
[19] O. V Potadar and G. S. Kadam, "Preparation and testing of composites using waste groundnut shells and coir fibres," in *Procedia Manufacturing*, Elsevier, 2018, pp. 91–96. doi: https://doi.org/10.1016/j.promfg.2018.02.013.
[20] G. B. Nyior, S. A. Aye, and S. E. Tile, "Study of mechanical properties of raffia palm fibre/groundnut shell reinforced epoxy hybrid composites," *J. Miner. Mater. Charact. Eng.*, vol. 6, no. 2, pp. 179–192, 2018, doi: 10.4236/jmmce.2018.62013.
[21] A. E. Uzoma, C. F. Nwaeche, M. Al-Amin, O. S. Muniru, O. Olatunji, and S. O. Nzeh, "Development of interior and exterior automotive plastics parts using kenaf fiber reinforced polymer composite," *Eng*, vol. 4, no. 2, pp. 1698–1710, 2023.
[22] T. Setyayunita, R. Widyorini, S. N. Marsoem, and D. Irawati, "Effect of different conditions of sodium chloride treatment on the characteristics of kenaf fiber-epoxy composite board," *J. Korean Wood Sci. Technol.*, vol. 50, no. 2, pp. 93–103, 2022, doi: https://doi.org/10.5658/WOOD.2022.50.2.93.
[23] A. B. Rashid, A. M. Rayhan, S. I. Shaily, and S. M. M. Islam, "An experimental study of physical, mechanical, and thermal properties of Rattan fiber reinforced hybrid epoxy resin laminated composite," *Results in Engineering*. Elsevier, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2590123024003074
[24] S. Sahu, S. Nayak, S. B. Sahu, and M. K. Roul, "Influence of various surface treatments on mechanical, thermal, morphological, and water absorption properties of rattan (Calamus beccarii) fiber," *J. Nat. Fibers*, vol. 20, no. 1, p. 2125924, 2023.
[25] H. Wang, H. Memon, E. A. M. Hassan, M. S. Miah, and M. A. Ali, "Effect of jute fiber modification on mechanical properties of jute fiber composite," *Materials (Basel).*, 2019, [Online]. Available: https://www.mdpi.com/1996-1944/12/8/1226
[26] J. Naveen, M. Jawaid, P. Amuthakkannan, and ..., "Mechanical and physical properties of sisal and hybrid sisal fiber-reinforced polymer composites," ... *Compos. hybrid ...*, 2019, [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780081022924000217
[27] M. Bosquetti, A. L. da Silva, E. C. Azevedo, and ..., "Analysis of the mechanical strength of polymeric composites reinforced with sisal fibers," ... *Nat. Fibers*, 2019, doi: 10.1080/15440478.2019.1612310.
[28] S. Nayak, P. K. Rout, and P. K. Jena, "Investigation of mechanical, thermal and morphological properties of rattan fiber-reinforced polymer composites to produce lightweight material for automotive industries," *Therm. Adv.*, vol. 2, p. 100014, 2025.
[29] B. Koohestani, A. K. Darban, P. Mokhtari, E. Yilmaz, and E. Darezereshki, "Comparison of different natural fiber treatments: a literature review," *Int. J. Environ. Sci. Technol.*, vol. 16, pp. 629–642, 2019.
[30] A. Atiqah, M. Jawaid, M. R. Ishak, and ..., "Effect of alkali and silane treatments on mechanical and interfacial bonding strength of sugar palm fibers with thermoplastic polyurethane," *J. Nat. fibers*, 2018, doi: 10.1080/15440478.2017.1325427.