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THE EFFECT OF VOLUME FRACTION VARIATION ON THE MECHANICAL PROPERTIES OF EPOXY-BASED SUGARCANE FIBER COMPOSITES

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Abstract. The use of natural fibers as reinforcement in composite materials offers an environmentally friendly alternative to synthetic fibers. Among them, sugarcane fiber (bagasse), an agro-industrial byproduct rich in cellulose, hemicellulose, and lignin, holds considerable potential but remains underutilized. This study aims to evaluate the effect of varying sugarcane fiber volume fractions (50%, 60%, and 70%) on the mechanical properties of epoxy resin-based composites. The composites were fabricated using the hand lay-up method, followed by mechanical testing including tensile tests (ASTM D3039) and bending tests (ASTM D790). The results showed that the highest tensile strength of 26.43 MPa was achieved by the E70 sample, while the E50 sample exhibited the highest bending strength at 142.53 MPa. Fractographic analysis revealed that structural defects such as voids, fiber pull-out, and debonding significantly influenced the mechanical performance of the composites. While fiber volume fraction has a notable impact on tensile and bending strengths, the relationship is not strictly linear due to variations in fiber-resin distribution and interfacial bonding quality. These findings suggest that sugarcane fiber-based epoxy composites, particularly with a 50% volume fraction, have strong potential for application in lightweight structural components, furniture panels, or automotive interior parts. Future research may focus on improving interfacial bonding through chemical treatments or hybridization with other natural fibers to further enhance performance

Keywords:Bending Composite, Epoxy, Sugarcane, Fiber

1. INTRODUCTION

The advancement of material technology in recent decades has increasingly driven the search for materials that not only exhibit high mechanical performance but are also environmentally friendly and sustainable. One promising innovation is the development of natural fiber-reinforced composites, which are considered an ideal alternative to synthetic fibers that are difficult to decompose and potentially harmful to the environment. Previous studies by Liu et al. [1] and Ismail et al. [2],[3] demonstrated that sugarcane fiber composites with epoxy matrices exhibit promising mechanical properties, but optimal fiber content and distribution remain a challenge. Moreover, research on the influence of high-volume fractions (above 50%) is still limited, particularly regarding their behavior under combined tensile and bending loads. This study aims to fill this gap by systematically evaluating the effect of 50%, 60%, and 70% fiber volume fractions on the mechanical response of the composites. The use of natural fibers in composites not only reduces reliance on synthetic materials but also promotes the utilization of organic waste from the agricultural and industrial sectors [4], [5].

Among the various types of natural fibers, sugarcane bagasse, an agro-industrial byproduct of sugarcane processing, holds significant potential yet remains underutilized. This fiber contains cellulose, hemicellulose, and lignin, which are the primary constituents responsible for its inherent strength [6],[7]. Sugarcane fiber is lightweight, biodegradable, abundantly available, and cost-effective, making it a promising candidate as a reinforcement material in environmentally friendly composites.

In composite structures, the fiber acts as the reinforcement that contributes to mechanical strength, while the resin matrix binds the fibers together and distributes the applied loads. In this study, epoxy resin was selected as the matrix due to its excellent adhesion, high mechanical strength, and resistance to environmental and chemical degradation. The combination of sugarcane fiber and epoxy resin is expected to yield composite materials with competitive mechanical properties [8],[9].

However, one of the main challenges in fabricating natural fiber composites lies in determining the optimal fiber volume fraction. A fiber ratio that is too low may result in insufficient mechanical strength, whereas an excessively high fiber content can lead to structural defects such as voids, debonding, and fiber pull-out due to inadequate resin impregnation[10]. These defects can significantly compromise the quality and durability of the composite under tensile and bending loads.

To address these challenges, this study investigates the effects of varying sugarcane fiber volume fractions (50%, 60%, and 70%) on the mechanical properties of epoxy-based composites. The research focuses on evaluating tensile and bending strength and includes macroscopic analyses of fracture surfaces to better understand the failure mechanisms involved.

2. METHODS

This study was conducted to fabricate a composite material using natural fibers derived from sugarcane bagasse, with fiber volume fractions of 50%, 60%, and 70%. The process began with fiber preparation, where dry sugarcane fibers were combed using a wire brush to remove any residual cork or surface impurities. The fibers were then thoroughly washed and sun-dried until completely dry.

Subsequently, the fibers underwent an alkali treatment by soaking them in a 5% sodium hydroxide (NaOH) solution for 2 hours [11]. This surface modification process aims to remove components such as hemicellulose, lignin, and pectin, which are less effective in promoting interfacial bonding. Reducing these components increases the cellulose content, thereby enhancing fiber stiffness and strength, while also improving surface roughness to facilitate better wetting and adhesion with the resin. After soaking, the fibers were rinsed with water until a neutral pH was achieved.

The composite fabrication employed the hand lay-up method, which is suitable for producing simple components with smooth mold surfaces [12]. The mold was first coated with wax, and a layer of waxed Teflon paper was placed at the base. A mixture of epoxy resin and hardener was then poured slowly into the mold to fill it halfway. Sugarcane fibers were placed onto the resin layer, followed by another layer of resin to fully encapsulate the fibers. The top was covered with another sheet of waxed Teflon paper, and pressure was applied to the mold to eliminate air entrapment and ensure proper impregnation of the fibers.

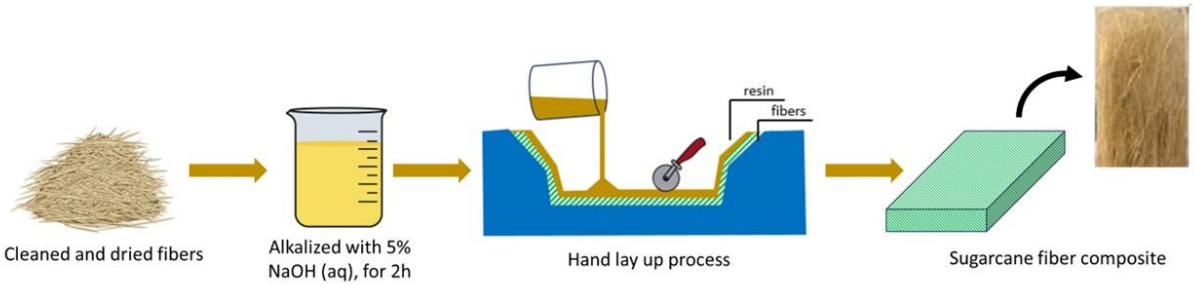

Figure 1. Research procedure for producing sugarcane fiber composites using the hand lay-up method.

Tensile and bending tests were conducted following ASTM D3039 and ASTM D790 standards, respectively [13]. The tensile test was performed to determine key mechanical properties of the composite, including tensile strength, elongation, and modulus of elasticity. The test specimens measured 175 mm × 25 mm × 3 mm and were tested using a Universal Testing Machine (UTM) at a crosshead speed of 2 mm/min (0.05 in/min). The testing was carried out in the Materials Engineering Laboratory at the Sumatra Institute of Technology (ITERA).

The results included the calculated values of maximum tensile strength (σ), strain (ε), and modulus of elasticity (E). In addition, a bending test is also carried out to measure the strength of the material due to loading and elasticity of the sample. The bending test was carried out using a Universal Testing Machine (Zwick/Roell Z250, capacity 250 kN), this test uses a specimen measuring 127 mm x 12.7 mm x 3.5 mm, equipped with a three-point bending fixture and operated at a crosshead speed of 1.4 mm/min, in accordance with ASTM D790.

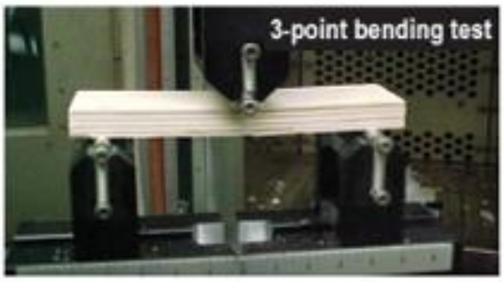

Figure 2. Three-Point Bending

To find the bending stress (σb), bending strain (εb), and bending modulus of elasticity (Eb), use the following equations:

$$\sigma b = \frac{3FL}{2db^2} \quad (1)$$

$$Eb = \frac{L^3 m}{4bd^3} \quad (2)$$

$$Eb = \frac{L^3 m}{4bd^3} \quad (3)$$

Description:
F = load applied at the midpoint (N)
L = span length (distance between two supports) (mm)
b = specimen width (mm)
d = specimen thickness (mm)
D = deflection (displacement) at the midpoint of the specimen (mm)
m = slope of the load-deflection curve in the linear section (N/mm)

3. RESULTS AND DISCUSSION

3.1 Composite Tensile Test Results

The strain versus stress graph of sugarcane fiber composites with fiber volume fractions of 50%, 60%, and 70% is shown in Figure 3.

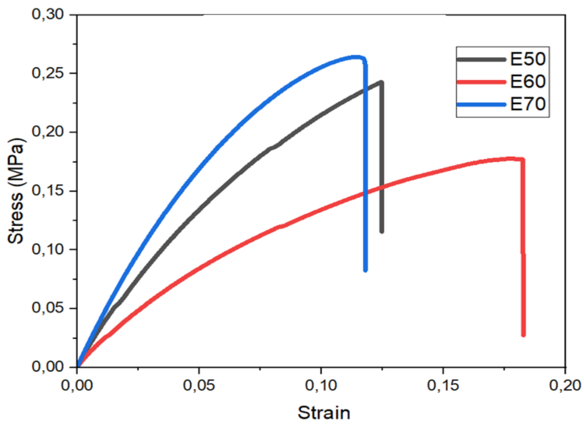

Figure 3. Stress–strain curves of sugarcane fiber-reinforced composites with varying fiber volume fractions.

Based on the graph above, the highest tensile stress is observed in sample E70 (with a 70% fiber volume fraction), reaching 26.43 MPa. This result is attributed to the higher fiber content in sample E70, which allows the applied load to be more evenly distributed. Since fibers generally possess higher tensile strength than the epoxy resin matrix, the increased fiber content enhances the overall tensile strength of the composite. As a result, sample E70 exhibits greater tensile strength compared to the samples with 60% and 50% fiber content.

However, an increase in fiber volume fraction does not always lead to a linear improvement in tensile strength. The effectiveness of load transfer is also influenced by the fabrication process and the uniformity of fiber–resin distribution. In the E60 sample (60% fiber volume), an imbalance in fiber and resin distribution likely created structural weak points, which served as initiation sites for failure under tensile loading. This is supported by both macroscopic analyses of the fracture surface, which revealed significant voids and fiber pull-outs. These defects, such as voids and debonding, reduce the interfacial bonding and compactness of the composite, preventing effective stress transfer from the matrix to the fibers. Consequently, the E60 sample exhibited the lowest tensile strength value of 17.79 MPa. The tensile test results for each sample are summarized in Table 1 below.

Table 1. Mechanical Properties Of Sugarcane Fiber Composite Samples From Tensile Testing.

Sample	UTS (Ultimate Tensile Strength) (MPa)	Yield Strength (MPa)	Young's Modulus (MPa)	Strain
E50	24.30 ± 1.91	23.5± 6.3	2.609 ± 68.51	0.12 ± 0.04
E60	17.79 ± 2.34	17.5 ± 2.68	1.844 ± 24.03	0.18 ± 0.05
E70	26.43 ± 0.75	22.5 ± 1.59	2.375 ± 84.55	0.17 ± 0.03

Based on the tensile test results, the highest Young's modulus was recorded in sample E50 at 2.609 ± 68.51 MPa, followed by sample E70 at 2.375 ± 84.55 MPa, and the lowest in sample E60 at 1.844 ± 24.03 MPa. Theoretically, an increase in fiber volume fraction should correlate positively with an increase in elastic modulus, since natural fibers possess greater stiffness than the resin matrix[14]. However, the experimental findings revealed discrepancies from this expectation, primarily due to the presence of different types and levels of defects in each sample.

Sample E50, with a 50% fiber volume fraction, exhibited a relatively uniform distribution of fiber and resin. Although minor defects such as voids and matrix-rich zones were present, they occurred in minimal amounts. This favorable distribution allowed for effective elastic load transfer from the matrix to the fiber, resulting in the highest elastic modulus among the samples.

In contrast, sample E60 exhibited the highest concentration of defects, including voids, fiber pull-out, and debonding, indicating poor interfacial bonding between the fiber and matrix. These imperfections hindered uniform stress transfer, leading to a significant reduction in the composite's stiffness. In sample E70, although the fiber content was higher, defects such as voids and crack deflection were also observed. These defects were primarily caused by suboptimal fiber arrangement and insufficient resin coverage, which impeded the fiber's ability to effectively resist elastic deformation.

This behavior aligns with the chemical characteristics of the epoxy resin used. Epoxy is a thermosetting polymer formed through the polymerization of epoxide groups (−C−O−C−), which are highly reactive and capable of forming strong covalent bonds with the hydroxyl groups found in natural fibers such as cellulose[15][16]. These chemical bonds enhance interfacial adhesion and reinforce the interaction between the matrix and the fiber. When the resin is properly distributed, epoxy functions optimally as a binder, improving the mechanical integrity of the composite[17].

3.2 Fracture Pattern Analysis of Composite Tensile Test Results

Fracture pattern analysis of the tensile-tested composites was carried out to examine how variations in fiber volume fraction influence fracture mechanisms. Figure 4 illustrates the fracture patterns observed in samples with fiber volume fractions of 50%, 60%, and 70%.

In Figure 4, the composite sample with a 50% fiber volume fraction (E50) exhibits a fracture located at the center of the specimen, classified as an LGM (Lateral Gage Middle) fracture. A midsection fracture indicates that the applied was evenly distributed and that failure occurred at the region with the highest stress concentration.

In contrast, the E60 and E70 samples show fractures occurring near the top of the specimens, classified as LGT (Lateral Gage Top) fractures. This pattern suggests irregularities in fiber and resin distribution or the presence of localized defects, such as voids or debonding, near the top region. At higher fiber volume fractions, the resin may not sufficiently wet and bond with all fiber surfaces, leading to poor interfacial adhesion. As a result, stress distribution becomes uneven, and the specimen is more prone to early failure.

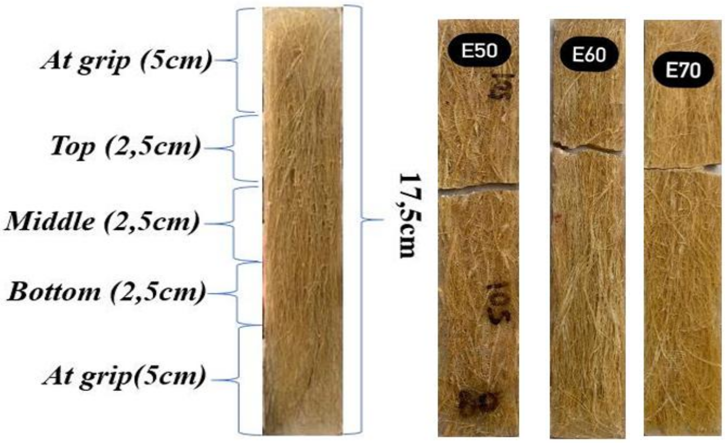

Figure 4. Fracture patterns of tensile test specimens with varying fiber volume fractions (E50, E60, E70).

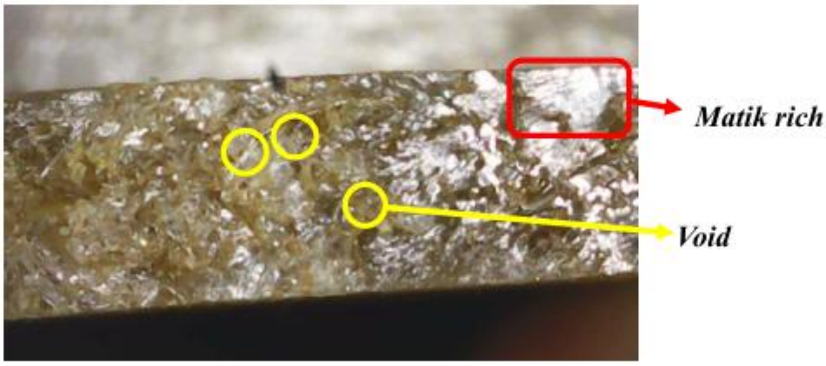

Figure 5. Macroscopic image of tensile fracture surface in sample E50.

Figure 5 shows the fracture surface of the E50 composite sample. The image reveals a failure mode characterized by matrix-rich regions, where the composite is dominated by resin with little to no presence of reinforcing fibers. This condition typically results from uneven fiber distribution during the fabrication process, leading to zones composed primarily of the matrix without adequate fiber reinforcement. In addition, void defects were also observed, which are attributed to air entrapment within the resin during molding. These trapped air pockets form cavities as the resin cures. However, the voids in this sample appear to be minimal and randomly distributed, thus having a negligible effect on the overall structural integrity and mechanical performance of the composite.

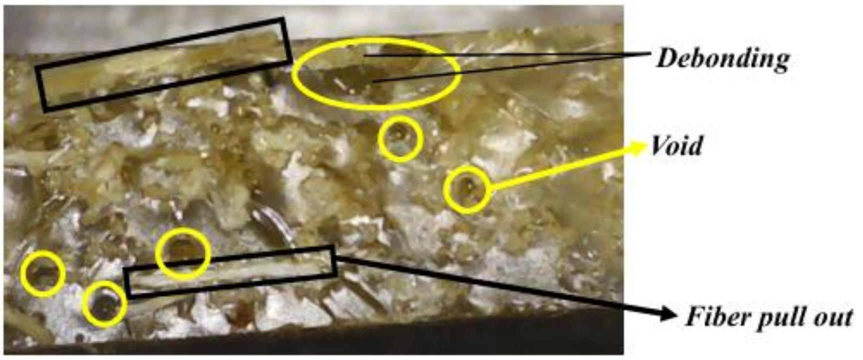

Figure 6. Macroscopic image of tensile fracture surface in sample E60.

Figure 6 displays the fracture surface of the E60 composite sample. The image reveals a LGT (Lateral Gap Top) fracture pattern, where the failure occurs near the upper section of the specimen. This indicates an uneven distribution of fiber and resin within the composite, resulting in non-uniform load transfer during tensile testing.

Compared to the E50 and E70 samples, the E60 sample exhibits a higher concentration of void defects, which are likely caused by trapped air during the fabrication process. Additionally, the fracture surface shows evidence of fiber pull-out, where fibers are detached from the resin matrix. This phenomenon is indicative of debonding at the fiber–matrix interface, reflecting poor adhesion and contributing to the reduced mechanical performance of the sample.

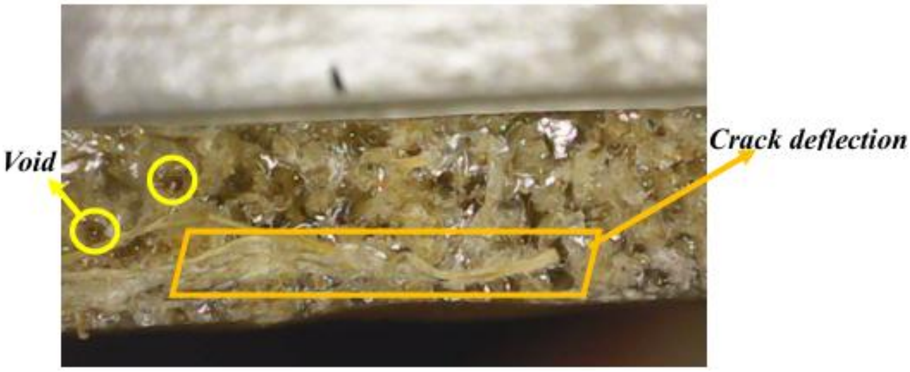

Figure 7. Macroscopic image of tensile fracture surface in sample E70.

Figure 7 shows that the failure type observed is also LGT (Lateral Gage Top), where the fracture initiates at the upper region of the specimen. In this sample, a crack deflection defect is evident, which is caused by the misaligned or tilted orientation of the fibers. When subjected to loading, the crack propagates along the path of the inclined fibers rather than perpendicular to the applied stress. This condition is likely the result of improper fiber alignment during the molding process, indicating a fabrication error that affects the structural integrity of the composite.

3.3 Composite Bending Test Results

The force–deformation curves resulting from the bending test of sugarcane fiber composites with varying fiber volume fractions (50%, 60%, and 70%) are shown in Figure 8.

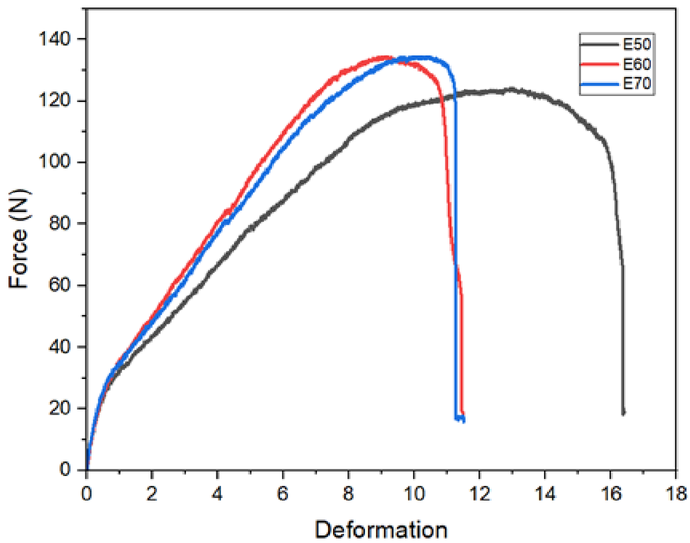

Figure 8. Force deformation graph of sugarcane fiber composite samples under bending test.

Table 2. Mechanical Properties Of Sugarcane Fiber Composites From Bending Tests

Sample	Max Force (N)	Bending Strength (MPa)	strain (mm)	Modulus of Elasticity (MPa)
E50	134.45	142.53 ± 8.73	9.73	1.57 ± 0.41
E60	133.75	119.15 ± 13.83	11.73	1.09 ± 0.08
E70	109.79	89.53 ± 10.38	11.70	2.10 ± 0.70

Based on Figure 8 (force deformation graph) and Table 2, which present the results of the bending test on sugarcane fiber-reinforced epoxy composites with fiber volume fractions of 50%, 60%, and 70%, the highest force and bending strength values were recorded in the E50 sample, at 134.45 N and 142.53 MPa, respectively. The E50 sample demonstrates an optimal ratio between fiber and resin, where the resin adequately coats the fibers, ensuring strong interfacial adhesion and effective mechanical interlocking. This optimal bonding allows the composite to withstand higher bending loads before failure occurs.

In contrast, the lowest force and bending strength values 109.79 N and 89.53 MPa were observed in the E70 sample. The high fiber content in this sample resulted in insufficient resin to fully impregnate all fibers, leading to poor fiber–matrix bonding. Additionally, the uneven resin distribution contributed to the formation of voids and inconsistent load transfer during testing. Despite having the highest elastic modulus (2.10 MPa), which indicates greater stiffness, the E70 sample exhibited low resistance to deformation and failed more quickly under bending loads.

4. CONCLUSION

Based on the mechanical testing results, variations in sugarcane fiber volume fraction significantly affect the tensile and flexural properties of the epoxy-based composites. The sample with a 70% fiber volume fraction (E70) achieved the highest tensile strength of 26.43 MPa, while the sample with a 50% fiber volume fraction (E50) exhibited the highest flexural strength of 142.53 MPa. However, increasing the fiber content does not always lead to a proportional improvement in all mechanical properties. For applications requiring a balance between tensile and flexural strength, a 50% fiber volume fraction is recommended as the optimal composition. At this level, the fiber and resin distribution is more uniform, resulting in better interfacial bonding and minimal defects such as voids and delamination. Therefore, the 50% fiber volume fraction offers well-balanced mechanical performance and can serve as a practical guideline for material selection in future lightweight structural composite applications

5. REFERENCES

[1] K.-L. Liu, K. Hsieh, S. Lai, and J. Han, “Properties of sugarcane fiber/polyurethane-crosslinked epoxy composites under different interfacial treatments,” Polym. Compos., vol. 41, no. 3, pp. 511–519, 2020, doi: 10.1002/pc.25710.

[2] I. Ismail, Q. Aini, Zulfalina, Z. Jalil, and S. H. S. Md Fadzullah, “Mechanical and physical properties of the rice straw particleboard with various compositions of the epoxy resin matrix,” J. Phys. Conf. Ser., vol. 1120, no. 1, pp. 1–7, 2018, doi: 10.1088/1742-6596/1120/1/012014.

[3] I. Ismail et al., “Properties enhancement of nano coconut shell filled in packaging plastic waste bionanocomposite,” Polymers, vol. 14, no. 4, p. 772, 2022, doi: 10.3390/polym14040772.

[4] S. Huo, M. Fuqua, and C. Ulven, “Natural fiber reinforced composites,” Polym. Rev., vol. 52, no. 3, pp. 259–320, 2012, doi: 10.1080/15583724.2012.705409.

[5] H. Fink, A. Bledzki, M. Sain, and O. Faruk, “Progress report on natural fiber reinforced composites,” Macromol. Mater. Eng., vol. 299, no. 1, pp. 9–26, 2014, doi: 10.1002/mame.201300008.

[6] S. Mazumder and N. Zhang, “Cellulose–hemicellulose–lignin interaction in the secondary cell wall of coconut endocarp,” Biomimetics, vol. 8, no. 2, p. 188, 2023, doi: 10.3390/biomimetics8020188.

[7] B. Prasetya, A. A. Prakoso, A. Rianjanu, W. S. Sipahutar, and A. Fitri, “Mechanical properties of sugarcane bagasse fiber composites: Epoxy vs polyester resin matrices,” J. Perancangan, Manufaktur, Material, dan Energi (PERMADI), vol. 7, no. 1, pp. 95–104, 2025.

[8] A. Fitri, F. F. Mubina, B. Prasetya, M. Y. Siregar, Q. Ainia, and W. S. Sipahutar, “Effect of coconut and sugarcane fiber volume fraction variations on the tensile properties of epoxy matrix composites,” J. Perancangan, Manufaktur, Material, dan Energi (PERMADI), vol. 7, no. 1, pp. 105–113, 2025.

[9] M. Y. Siregar, F. F. Mubina, W. S. Sipahutar, A. Fitri, and M. G. I. Khan, “Tensile strength of epoxy hybrid composites reinforced with coconut and sugarcane fibers,” J. Perancangan, Manufaktur, Material, dan Energi (PERMADI), vol. 7, no. 2, pp. 155–162, 2025.

[10] P. Banakar, J. Katiyar, R. Sailaja, P. Sampathkumaran, and H. Jagadeesh, “Influence of varying matrix/fiber concentration on mechanical properties of bi-directional carbon fiber reinforced polymer composite,” J. Reinf. Plast. Compos., 2024, doi: 10.1177/07316844241263188.

[11] T. Zhong et al., “Effect of alkali treatment on microstructure and mechanical properties of individual bamboo fibers,” Cellulose, vol. 24, pp. 333–347, 2016, doi: 10.1007/s10570-016-1116-6.

[12] Y. Gawali, S. Tambe, P. S. Kanade, C. Mate, and S. Nimse, “Fabrication of fiber reinforced composite material like bamboo flex, glass fiber and epoxy resin,” Int. J. Sci. Technol., vol. 16, no. 2, 2025, doi: 10.71097/ijsat.v16.i2.3146.

[13] T. Batu and H. G. Lemu, “Investigation of mechanical properties of false banana/glass fiber reinforced hybrid composite materials,” Results Mater., vol. 8, p. 100152, 2020, doi: 10.1016/j.rinma.2020.100152.

[14] M. Arifuzzaman, M. S. Hossain, M. S. Islam, and M. S. Anwar, “Effect of fiber orientation and volume fraction on Young’s modulus for unidirectional carbon fiber reinforced composites: A numerical investigation,” Malaysian J. Compos. Sci. Manuf., vol. 13, no. 1, pp. 45–54, 2024, doi: 10.37934/mjcsm.13.1.4554.

[15] K. Tanaka, A. Shundo, and S. Yamamoto, "Network formation and physical properties of epoxy resins for future practical applications," JACS Au, vol. 2, pp. 1522–1542, 2022, doi: 10.1021/jacsau.2c00120.

[16] S. Jodeh et al., "Viscosity of epoxy resins based on aromatic diamines, glucose, bisphenolic and bio-based derivatives: A comprehensive review," J. Polym. Res., vol. 29, no. 1, pp. 1–29, 2022, doi: 10.1007/s10965-022-03040-3.

[17] M. A. S. Anam, P. Manik, and G. Rindo, "Analisis pengaruh material abrasif pada blasting dengan variasi metode coating terhadap prediksi laju korosi dan daya rekat adhesi," J. Tek. Perkapalan, vol. 12, no. 2, pp. 65–72, Jun. 2024.