

Mechanical Strength and Physical of Bamboo/Nettle Fiber Reinforced Epoxy Hybrid Composites

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Bamboo grows abundantly in Indonesia. Bamboo is a source of fiber with a fairly strong strength. Nettles, which grow widely in Indonesia, are wild plants whose use is still minimal because they are considered to have no economic value. Nettle is available in nature a little but has a very strong fiber. This study combined hybrid natural fibers, namely bamboo and nettle fibers, to take advantage of their advantages and cover their weaknesses. Bamboo/nettle fibers are treated by soaking them in 5% NaOH solution for 2 hours, and after that, the fibers are cut into 10 mm pieces. The fibers are arranged randomly inside the mold, and the production method uses hand lay-up. A fiber volume fraction of 30% is used in the production of hybrid composites, with a total ratio of bamboo/nettle fiber of 100:0 (A), 75:25 (B), 50:50 (C), 25:75 (D), and 0:100 (E). As a comparison, 0% fibers (A0), epoxy without fiber reinforcement, was made. Composite testing was carried out in the mechanical properties research, namely tensile and flexure tests. In physical testing, namely water absorption and fuel resistance. TGA testing to determine weight loss when burned. SEM examination to view the Composite's microstructure. According to the test results, specimen (B) has the maximum tensile stress of 30.50 MPa, whereas specimen (A0) has the lowest tensile stress of 22.58 MPa. The highest elongation at break tensile occurred in specimen (B) of 1.67 %, and the lowest tensile strain in specimen (A0) of 0.96 %. The highest tensile modulus of elasticity was found in specimen (E) of 1.43 GPa, while the lowest tensile modulus was found in the specimen (C) of 1.20 GPa. The highest flexural stress was found in the specimen (B) at 46.26 MPa, while the lowest flexural stress

was found in the specimen (A0) at 37.85 MPa. The highest flexural strain value is found in the specimen (A0) at 5.17%, and the lowest flexural strain is in the specimen (A) at 2.98%. The highest flexural modulus is found in specimen (B) of 2.19 GPa, and the lowest is found in the specimen (A0) of 0.95 GPa. Specimen (A) had the highest water absorption test results (5.31%), while specimen (E) had the lowest results (3.7%). TGA results show the lowest weight loss value at a temperature of 950°C, namely 90.66% in the specimen (A). Based on the fuel test results, sample (E) had the maximum combustion rate (ROB) at 10.63 mm/s, whereas sample (A) had the lowest ROB at 6.89 mm/s. The results of mechanical and physical testing of hybrid composites with a 30% fiber volume fraction the most optimal value is 75% bamboo plus 25% nettle.

Keywords: Composites, Epoxy, Bamboo, Nettle, materials.

1. Introduction

Technological developments have had a major impact on the materials manufacturing industry. Composite materials are made to replace metal. The study of composite materials was developed to find various types of composite materials that are mechanically, physically, and morphologically useful for various applications.

The Composite are a combination of matrix and fiber. Fiber and matrix have different functions; the fiber acts as a framework that determines the strength of Composite, and matrix functions to bind the fibers so that they do not reposition. Natural fibers such as bamboo and nettle have many benefits for non-abrasive materials because of their qualities, low energy usage in the production process, high specific mechanical properties, and biodegradability [1, 2].

Bamboo is a giant grass that grows quickly compared to woody plants. Several studies have shown that bamboo is the best source of fiber by peeling it into fibers. One of the benefits of using bamboo fiber is as a composite reinforcement. Bamboo is abundant in Indonesia. Bamboo fiber has relatively high tensile strength. This makes bamboo have its appeal because it can be an alternative substitute for metal in material tensile loading applications. A study comparing the mechanical behavior of fully continuous unidirectional bamboo fiber and epoxy resin composites and demonstrating the feasibility of exploiting the effects of different unidirectional fiber patterns for discontinuous studies. It has been shown that the tensile stiffness is strongly influenced by the discontinuities of bamboo fibers[3]. Throughout the soaking period with water, the bamboo-PVC (polyvinyl chloride) composite with a particle load of 25% showed the lowest percentage increase in water absorption. Because bamboo particles are a natural filler with a high water absorption capacity, the water absorption of the bamboo-PVC Composite with particle loading is 50% higher [4]. The highest adhesive strength between short fibers and bamboo powder was found in bamboo powder composites, which were created at a pressure and temperature of 200 °C using bamboo fiber bundles as a reinforcement. This Composite can be a substitute for PVC and plastic, especially in terms of density, tensile strength, and bending [5]. Natural bamboo

fibers also have properties comparable to conventional fibers, as evidenced by the excellent mechanical properties of fiber tensile strength and tensile modulus. The natural plant fiber most widely available in Southeast Asia, which has high stiffness properties, can substitute glass fiber [6].

The wild plant nettle (*Urtica dioica* L.) is widely distributed across Asia and Europe. The use of nettle stinging plants in Indonesia is still low because they have no economic value, have an itchy effect if touched by human skin, and are considered parasites for other plants. The technical specifications for nettle fiber (*Urtica dioica* L.) as a composite reinforcing material are Modulus Young $87 (\pm 28)$ GPa, single fiber tensile strength $1594 (\pm 640)$ MPa, fracture strain $2.11 (\pm 0.81)\%$ and average diameter $19.9 (\pm 4.4)$ μm [7]. In some conditions, strong fiber tensile strength cannot be obtained depending on the retting process and environmental conditions where it grows [8, 9, 10].

Because of their exceptional mechanical, thermal, and electrical qualities, modified epoxy resins are frequently employed in the manufacturing of natural fiber reinforced composites and other industrial products. This article describes epoxy structure, synthesis, modified epoxy resins, bioepoxy resins, and their applications[11]. The epoxy matrix as hybrid composites with glass/ramie fiber reinforcement has been researched, and composites were hybridized at two weight percentages (20% and 30%), obtained tensile strength, flexural strength, and impact strength exhibited better mechanical properties than the individual samples [12]. Research on nettle fiber reinforced epoxy, fiber treatment with silane and NaOH. The results show that the highest bending strength is 49.325 MPa, the bending elongation is 0.0284 mm/mm, and the elastic modulus is 3.195 GPa [13]. Generally, thermosetting resin is used in the manufacturing industry to manufacture composite materials. A thermoset is a resin that experiences irreversible cross-linking in its forming structure, resulting in hardening so that it cannot be melted and reshaped. Epoxy belongs to a group of polymers used as a matrix for adhesives, coatings, and composite materials and is widely used in many applications, such as cars, aircraft, and ships [14, 15, 16].

This research designed a hybrid composite material with an epoxy matrix and natural bamboo and nettle fibers regarding fiber fabrication, fiber composition, fiber treatment, and the hybrid composite manufacturing process. This research aims to obtain comparative data on the number of fibers on changes in composite materials' mechanical and physical properties. Next, tensile, flexural, water absorption and burn tests were carried out.

2. METHOD

Materials

The nettle plant's bark produces fibers with high tensile strength and fineness [17]. In this research, nettle fiber was harvested from the Denbantas area and processed directly by researchers to make fiber [18]. Bamboo fiber was obtained from Liahren (Beijing) Tech Co Limited – China. The material obtained is already in fiber form.



Fig. 1 a). Bamboo fiber



b). Nettle fiber

The resin used is Epoxy Sikadur 52-id, purchased at Sesetan Bali, Indonesia [19]. Epoxy is a type of polymer included in the thermosetting resin group. Thermosets are liquid polymers that can turn into solids through cross-linking and chemical formation of three-dimensional polymer chains. The mechanical properties depend on the molecular units forming a dense network and the length of the crosslinks. Thermosets are sensitive to temperature, isotropic, do not melt, cannot be recycled, have tightly bound atoms, and cannot undergo chain transitions. The polymer fabrication process can be carried out at room temperature (30 °C), taking into account the chemicals used as modifiers for cross-linking polymerization to achieve optimal material properties.

Sample preparation

The leaves of the nettle harvested were cleaned, and the main stem was taken. The stems are cut and removed ± 10 cm at the end and ± 5 cm at the base. The stems were exposed to the sun for three days to dry. For four days, the stem fiber was submerged in water. Manual and careful fiber retting was done next. The aim is to produce high mechanical properties of fibers by removing non-cellulosic components. The fiber treatment was soaked in 5% NaOH solution for 2 hours. Bamboo/nettle fibers were cut 10 mm and arranged randomly. A fiber volume fraction of 30% is used in the production of hybrid composites, with a total ratio of bamboo/nettle fiber of 100:0 (A), 75:25 (B), 50:50 (C), 25:75 (D), and 0:100 (E). As a comparison, 0% (A0) epoxy without fiber reinforcement was made.

NaOH was purchased from PT. Brataco Ltd (Indonesia). After NaOH treatment of the bamboo/nettle fiber, the fiber is washed using distilled water (pH=7) until clean. After cleaning with water, they were dried with a fan for 24 hours. Chemical treatments such as soaking the fibers in NaOH solution are widely used to study natural fiber composites. When natural fibers are soaked in a NaOH solution, the amount of lignin, or wax, on their surface is reduced. The mechanical characteristics of the Composite can be enhanced by a thinner layer of wax.

Composite Manufacturing Methods

The composite manufacturing process uses open mold molding. The hand lay-up method is one of the open mold molding methods. Starting from pouring the resin into the mold, then *Nanotechnology Perceptions* Vol. 20 No.2 (2024)

adding reinforcing material and smoothing it using a roller. Bamboo/nettle fiber with certain fractions that have been treated are arranged randomly in the mold. This process can be repeated until it reaches a certain thickness and is carried out at room temperature in direct contact with open air. A fiber volume fraction (Vf) of 30% is used to determine the Composite's mechanical characteristics, namely the fiber and matrix ratio.



Fig. 2. Example of a tensile testing specimen



Fig. 3. Examples of flexure testing specimens

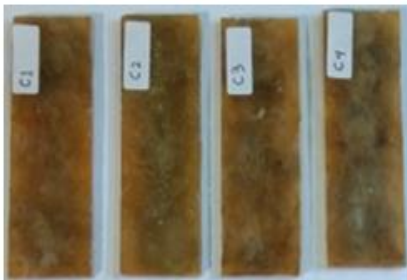


Fig. 4. Example of a water absorption test specimen



Fig. 5. Examples of burnt test specimens

This research method began with fiber extraction, making composites using the hand lay-up technique under a pressure of 25 kgf. Specimen dimensions for tensile tests in line with ASTM D3039 and flexural test specimen dimensions ASTM D790-03.

Tensile and Flexural Testing

The RTG-1250 tensilon testing machine was used for testing tensile test specimens, which aimed to measure tensile stress, strain, and modulus of elasticity of composite materials. The tensile test specimen measured 250 mm in length, 25 mm in width, and 3 mm in thickness. This test continuously monitored the increasing load and length throughout the test. Tensile testing produces maximum tensile strength values.

The tensile stress that occurs was calculated by the equation:

$$\sigma = \frac{P}{A_0} \quad (1)$$

The tensile strain that occurs was calculated by the equation:

$$\varepsilon = \frac{\Delta L}{L_0} \times 100\% \quad (2)$$

The tensile modulus of elasticity that occurs was calculated by the equation:

$$E = \frac{\Delta \sigma}{\Delta \varepsilon} \quad (3)$$

Where σ is the tensile stress, P is the force, and A_0 is the area of the tensile field. Where ε is the tensile strain, ΔL is the increase in length, and L_0 is the initial length. E is the tensile modulus of elasticity, $\Delta \sigma$, and $\Delta \varepsilon$ is the change in tensile stress and strain in the elastic region.

The flexural test is a test intended to determine flexural strength in testing using the three-point bending method. The tested specimens undergo tensile stress at the bottom and compressive stress at the top. Testing of the specimen is done up until a failure or fracture occurs. The flexural test specimen has the following measurements: it is 127 mm long, 12.7 mm wide, 3 mm thick, and has a 48 mm support distance.

The bending stress equation is

$$\sigma_l = \frac{3 P L}{2 b d^2} \quad (4)$$

The bending strain equation is

$$\varepsilon_l = \frac{6 \delta d}{L^2} \quad (5)$$

The equation for the bending modulus of elasticity is

$$E_l = \frac{L^3 m}{4 b d^3} \quad (6)$$

Where σ_l is the bending stress, P is force, L stands for the support's length, b for the specimen's width, and d for the specimen's thickness. Furthermore, δ represents the deflection value and ε_l the bending strain. where m is the tangent line gradient and E_l is the bending modulus of elasticity.



Fig. 6 a). Tensile Testing Process



b). Flexural Testing Process

Water absorption test and flammability test

Test for water absorption in compliance with ASTM D570-98 guidelines. Weighing the specimen yields the dry mass and moist mass. The samples were submerged in water at a depth of less than 3 cm horizontally from the surface of room-temperature distilled water. Soaking process was carried out for eight days by weighing the mass of the specimen and changing the distilled water every 24 hours. The water absorption test used four specimens for each composition.



Fig. 7 a). Water absorption testing process



b). Burn testing process

The hybrid Composite was checked by horizontal burning test according to ASTM D635. Specimens are marked at lengths of 25 and 75 mm. One end of the specimen was exposed to a flame after it was constricted 5 mm horizontally. Constant flame with a flame height of 20 mm does not shoot out. The flame angle is 45 degrees, and the distance from the tip of the specimen to the flame is 6 mm. The value of the flame ignition time is calculated from the flame spreading across the specimen starting at 25 mm in length and ending at 100 mm. Then, the time is recorded. Four composite specimens were tested, and the burning rate of the Composite was calculated.

3. RESULT AND DISCUSSION

Tensile and Flexural Test Results

Tensile and flexure test data are the results of testing epoxy hybrid composites reinforced with bamboo/nettle fibers at the Metallurgical Mechanical Engineering Laboratory at Udayana University. Tests were carried out using Tensilon RTG 1250 mechanical test equipment. Six specimens for each treatment were used in the tensile and flexural tests, and the mean score was computed.

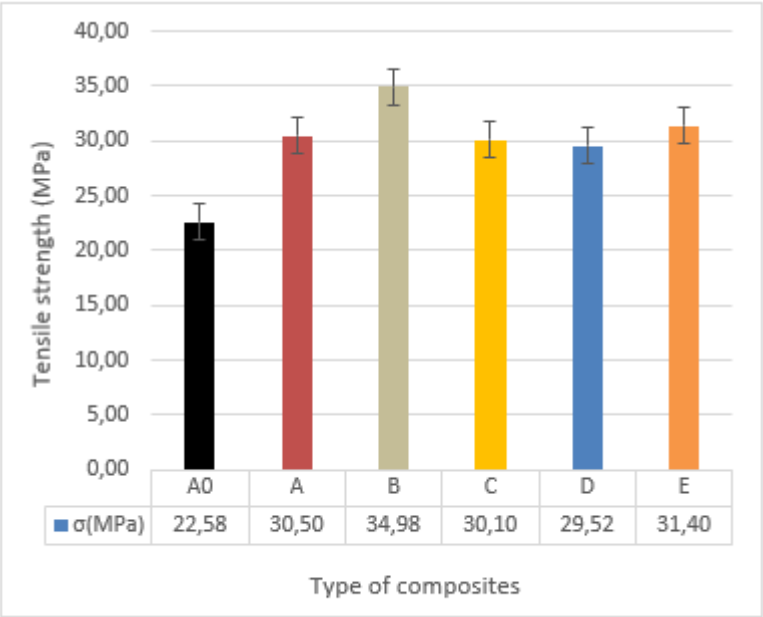


Fig. 8. Tensile strength of epoxy and hybrid composites

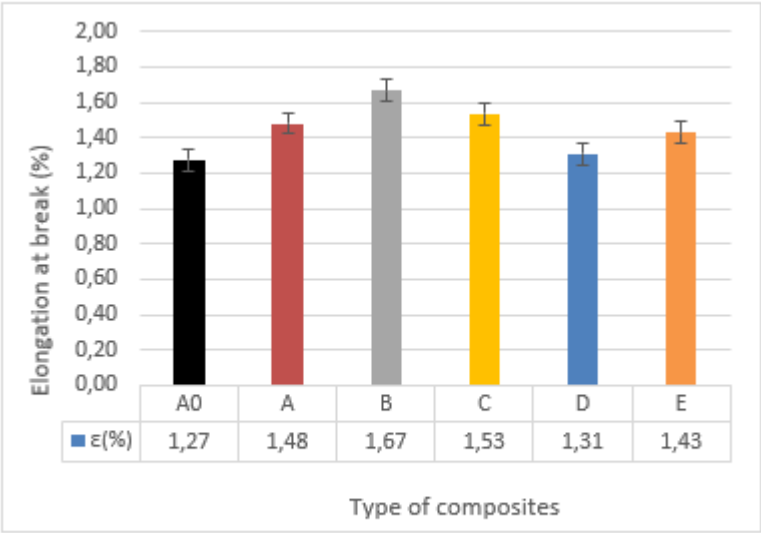


Fig. 9. Elongation at break tensile of epoxy and hybrid composites

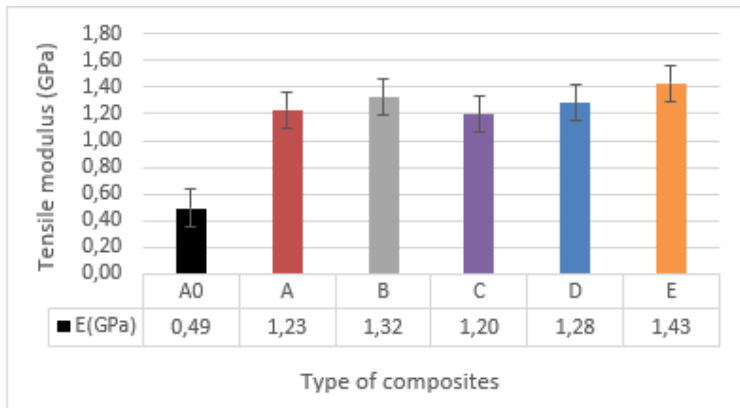


Fig. 10. Tensile modulus of epoxy and hybrid composites

Fig. 8 states that all nettle fiber-reinforced composites have higher tensile strength than epoxy. The hybrid Composite (B) has the highest tensile stress, with an average of 34.98 MPa. Hybrid Composite (D) has the lowest tensile stress, with an average value of 29.52 MPa. Meanwhile, fiberless epoxy (A0) has a tensile stress of only 22.58 MPa. The tensile strength value is influenced by adding bamboo or nettle fibers in the Composite to strengthen the bond between the resin and the fibers. As the percentage of bamboo fibers in the epoxy hybrid composite specimen grew, the Composite's tensile strength increased as well.

Based on Fig. 9, hybrid Composite (B) has the highest elongation at a break value of 1.67%, while hybrid Composite (D) has the lowest tensile strain value of 1.31%. As a comparison, epoxy without fiber (A0) has a very low value of 1.27%. According to the collected data, the ratio of the amount of bamboo fibers in the composite correlated with an increase in tensile strain between hybrid composites.

Fig. 10 obtained the highest tensile modulus of elasticity value for hybrid composites (E) of 1.43 GPa. Hybrid Composite (C) has the lowest modulus of elasticity value of 1.20 GPa. Meanwhile, fiberless epoxy (A0) has the lowest elastic modulus value of 0.49 GPa.

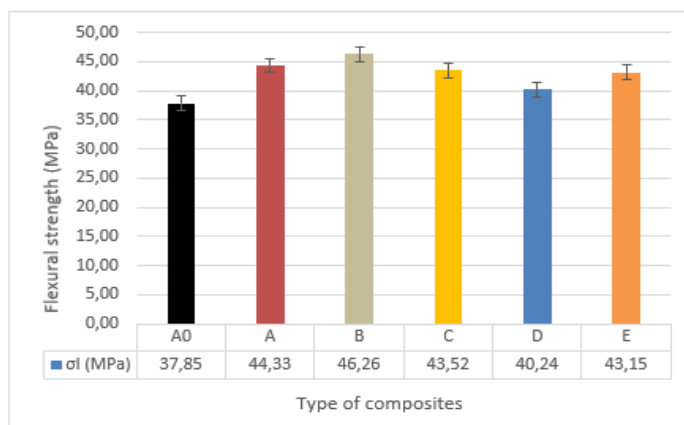


Fig. 11. Flexural strength of epoxy and hybrid composites

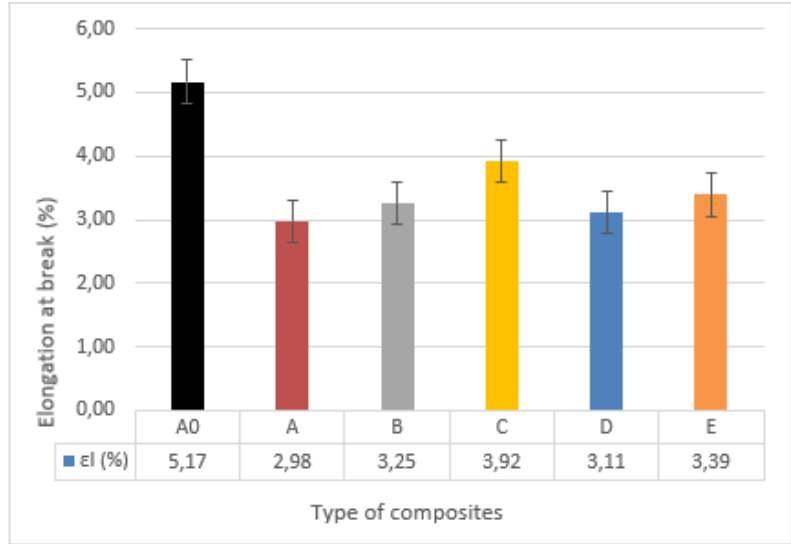


Fig. 12. Elongation at break flexural of epoxy and hybrid composites

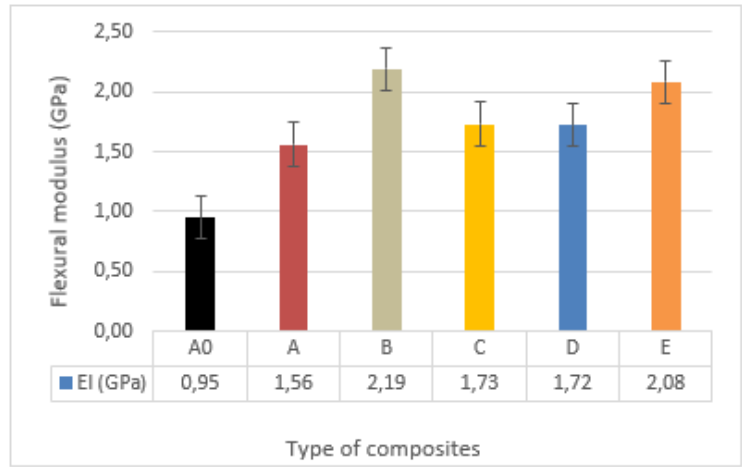


Fig. 13. Flexural modulus of epoxy and hybrid composites

According to Fig. 11, the addition of fibers to hybrid composites results in an improvement in their flexural strength. The largest bending stress value was obtained in the bamboo/nettle fiber ratio composite of 75:25 (B), namely 46.53 MPa. The hybrid Composite (D) has the lowest bending stress value, 40.24 MPa. The epoxy bending stress value (A0) is 37.85 MPa, the lowest value in this study. This is influenced by the presence of fibers in the Composite so that the load that occurs is given to the matrix and the fibers properly. The more fibers, the higher the bending stress. It is evident that when the proportion of bamboo fibers in the Composite rises, bending stress increases.

Hybrid composites with a 50:50 (C) bamboo/nettle fiber ratio showed the greatest elongation, with a break value of 9.92%, according to Fig. 12. At 2.98%, (A) is the hybrid Composite with the lowest elongation at break value. The maximum elongation at break

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value, or 5.17%, is observed for epoxy (A0). Based on the data obtained, the elongation at break value between specimens did not experience a significant decrease because the fiber volume fraction in each variation was the same at 30%.

Based on Fig. 13, Epoxy specimens (A0) have the lowest bending elastic modulus value, namely 0.95 GPa. Hybrid Composite (B) with the largest flexural modulus of elasticity value, namely 2.19 GPa. Hybrid Composite (D) has the smallest bending modulus of elasticity value, 1.72 GPa. There was no significant decrease in the elastic modulus in specimens (C) and (D). As the ratio of bamboo fibers in the hybrid Composite grows, so does the flexural elastic modulus value.

Water Absorption Test Results

Water absorption influences the stability of composite materials [20, 21]. Water absorption in composite materials is influenced by a number of parameters, including voids, fiber loading, matrix viscosity, ambient conditions, etc., according to research by Jawaid et al. [22]. A water absorption study must be carried out to ascertain the proper application of the material in order to assess physical and dimensional changes and enhance the stability of composite materials.

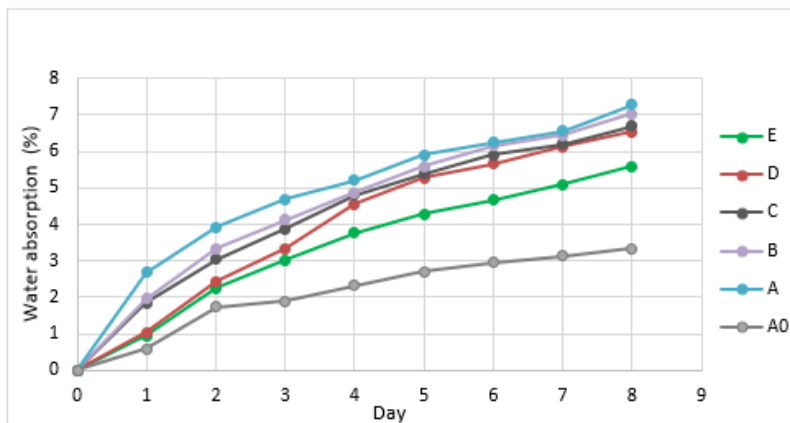


Fig. 14. Graph water absorption of epoxy and hybrid composites

Figure 14 displays the results of a water absorption test that illustrate the variation in the test material's mass percentage of water absorption with respect to soaking duration. Epoxy (A0) has a water absorption of at least 2.33% because it is hydrophobic. Composites reinforced with natural fibers have high water-absorbing properties because natural fibers are hydrophilic. Likewise, when the matrix bonds with the fibers, cavities allow water to seep into the small gaps of the hybrid Composite. The hybrid Composite with a bamboo fiber/nettle ratio of 100:0 (A) had the highest average water absorption of 5.31%, and the bamboo fiber/nettle hybrid composite 0:100 (E) had the lowest average water absorption of 3.70%.

Burn Test Results

Water adsorption was the cause of weight loss in the combustion test below 200 °C. Over

500°C, the condensation of silanol groups results in weight loss. As a result, organic components (fibers and epoxy) degrade at temperatures between 200 and 500°C [23]. In this research, the TGA results obtained in Fig. 15 of the hybrid composites, the specimens tested were composites with bamboo and nettle fibers 100:0(A), 75:25(B), 50:50(C), and 25:75(D).

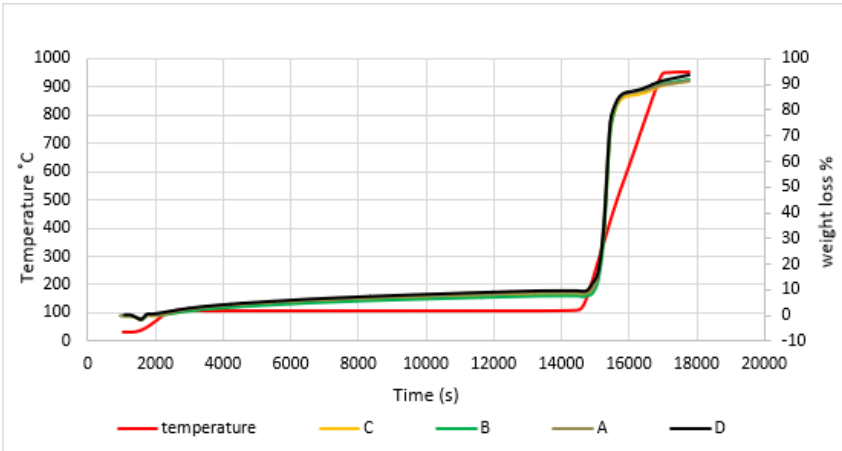


Fig. 15. Graph of TGA results of bamboo fiber/nettle hybrid composite

The sample experiences a decrease in mass proportional to the increase in temperature. Specimen (A) at a temperature of 950°C experienced a weight loss of 90.66% with a lower volatile value of 82.18% and the highest fixed carbon value of 6.52%. Specimen (B) at a temperature of 950°C experienced a weight loss of 90.88%, with a volatile value of 84.22% and a fixed carbon value of 5.95%. Specimen (C) at a temperature of 950°C experienced a weight loss of 91.43% with a volatile value of 83.02% and a fixed carbon value of 5.58%. Specimen (D) at a temperature of 950°C experienced a weight loss of 92.61% with the highest volatile value of 84.54% and the lowest fixed carbon value of 4.41%. The comparison of the number of bamboo/nettle fibers provides a difference in the Composite's resistance to temperature. Hybrid Composite (B) bamboo/nettle (75:25) produces good temperature resistance.

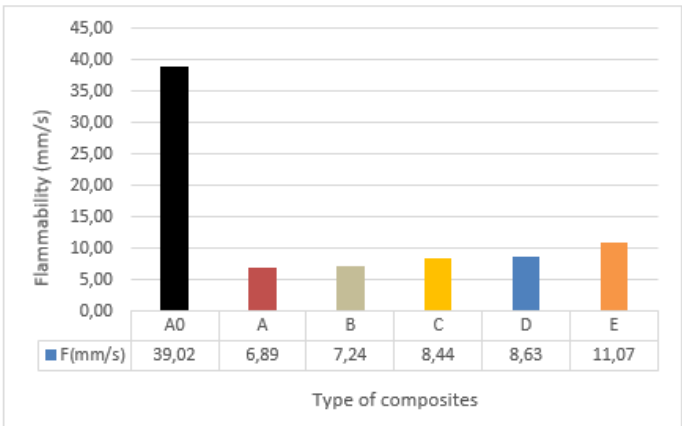


Fig. 16. Composite burning rate

A low burning rate indicates that flame propagation takes a long time in hybrid composites. Burn resistance test results in Fig. 16 show that for epoxy resin, the shortest burning time value was obtained, namely 29.21 seconds, and the highest burning speed value was 39.02 mm/s. The resulting fiber-reinforced Composite has greater burn resistance than epoxy resin. For the bamboo/nettle fiber reinforced Composite (A)100:0, the highest ignition time value was 108.7 seconds, and the combustion speed was 6.89 mm/s. The bamboo/nettle fiber composite (E) 0:100 has the lowest ignition time value of 37.89 seconds, and the burn speed is 11.07 mm/s. The research results show that the more bamboo fiber in the hybrid Composite, the lower the burning speed value. Natural fiber composites are the most appropriate because of their long ignition time, long time to reach before flashover, and low smoke emissions.

SEM morphology

The hybrid composite tensile test findings' fracture surface defines microstructural observation analysis (SEM). The fibers of nettle and bamboo are dispersed equally and randomly throughout the matrix, as seen in Fig. 17. In Fig. 18, fracture surfaces of the bamboo/nettle hybrid composite reveal the void content between the fibers and the matrix and are not well mixed. Fig. 19 shows that bamboo and nettle fibers have good consolidation in the resin matrix and provide a hybrid interlock mechanism for composite materials. Siakeng et al. [25] conducted a study on natural fiber-reinforced hybrid composites, fibers treated with alkali have shown an alkalizing effect on the fiber. According to SEM research, the majority of the surface is characterized with microcracks and void contents due to unstable matrix defects and fiber bonds. Agro-waste fiber, on the other hand, is described by Elbadry's [26] SEM analysis as occurring when alkali chemicals create fiber-pulling structures and grooves that weaken the interfacial fiber matrix.

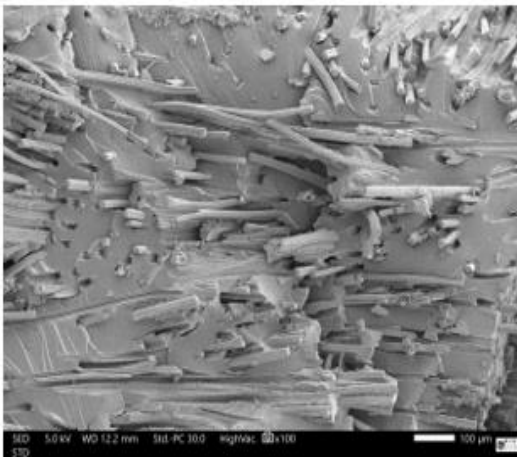


Fig. 17. Hybrid Composite 100x

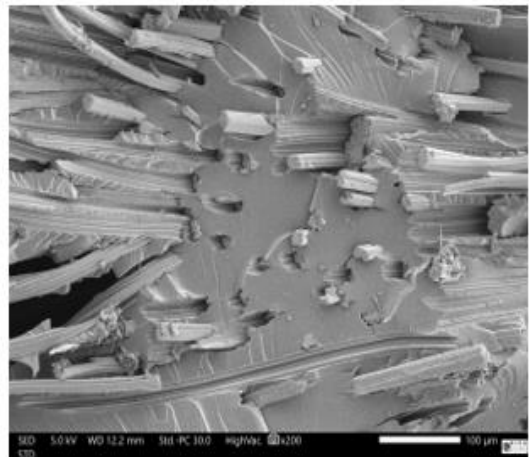


Fig. 18. Hybrid Composite 200x

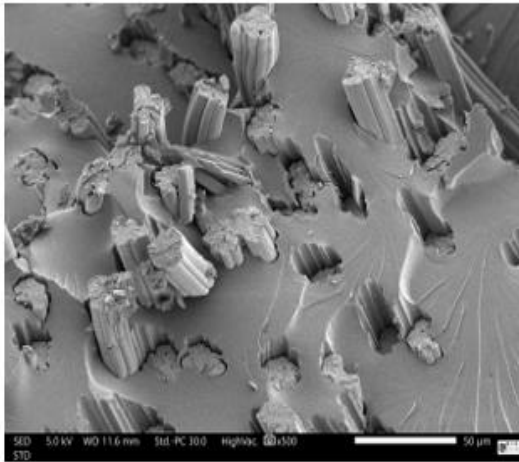


Fig. 19. Hybrid Composite

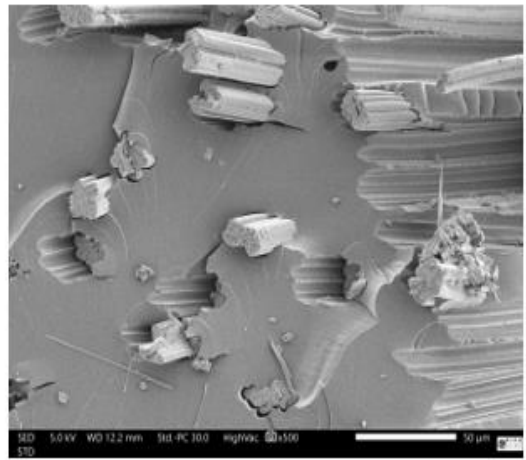


Fig. 20. Hybrid Composite 500x

4. CONCLUSION

This study investigated and explored the potential of bamboo/nettle fibers as a reinforced composite hybrid. The mechanical and physical properties were improved by using stiffer bamboo fibers for reinforcement in the hybrid Composite. Additionally, compared to non-hybridized bamboo fiber composites, the experimental results of bamboo/nettle hybrid composites demonstrated enhanced characteristics. That contrast in properties of bamboo and nettle hybrid composites can be summarized as follows:

- Composite (B) has the highest tensile stress with an average of 34.98 MPa
- Tensile strain shows that the hybrid Composite (B) has the highest tensile strain value of 1.67%,
- The hybrid Composite (E) has a maximum tensile elastic modulus of 1.43 GPa
- The largest bending stress value was obtained in the bamboo/nettle fiber ratio composite of 75:25 (B), namely 46.53 MPa.
- The hybrid Composite with the maximum elongation at break value, 9.92%, has a 50:50 (C) bamboo/nettle fiber ratio.
- Hybrid Composite (B) with the largest flexural modulus of elasticity value, namely 2.19 GPa.
- The bamboo fiber/nettle hybrid composite 0:100 (E) has the lowest average water absorption, 3.70%.
- Specimen (B) at a temperature of 950°C experienced a weight loss of 90.88%, with a volatile value of 84.22% and a fixed carbon value of 5.95%.

The burning speed of the 0:100 bamboo/nettle reinforced composite (B) is 10.63 mm/s. According to mechanical and physical tests, the best combination for hybrid composites with

a 30% fiber volume fraction is 75% bamboo and 25% nettle.

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