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RESEARCH ARTICLE

Effect of fibre orientation on the tensile and bending strength of salacca fibre composites reinforced with Anadara granosa powder

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Abstract – The use of natural fibres as composite reinforcement materials continues to be developed to reduce dependence on less environmentally friendly synthetic materials. However, studies on the effect of fibre orientation in hybrid composites based on Salacca zalacca fibre and Anadara granosa shell powder are still limited. This study aims to analyse the effect of fibre orientation on the mechanical properties of epoxy-matrix composites. The composites were fabricated using the hand lay-up method with a volume fraction of 40% epoxy, 50% fibre, and 10% shell powder. The fibres were treated with 10% KOH alkali for 4 hours. The fibre orientations used were 0°/0°/0°, 0°/+45°/0°, and 0°/+90°/0°. Tensile and flexural tests were conducted to evaluate the composite mechanical properties. The results showed that the 0°/0°/0° orientation produced the highest tensile and flexural strengths, at 33.19 MPa and 135.5 MPa, respectively. The 0°/+45°/0° and 0°/+90°/0° orientations showed a decrease in strength due to non-uniform stress distribution. This study concluded that the hybrid composite based on snake fruit stem fibre and Anadara granosa shell powder has the potential as an environmentally friendly alternative material for automotive applications. Natural fibre-reinforced composites have attracted increasing attention as sustainable alternatives to synthetic composite materials. However, studies investigating the effect of fibre orientation in hybrid composites based on Salacca zalacca fibre and Anadara granosa shell powder remain limited. This study aims to evaluate the influence of fibre orientation on the tensile and flexural properties of epoxy-based hybrid composites. The composites were fabricated using the hand lay-up method with a composition of 40% epoxy resin, 50% Salacca fibre, and 10% Anadara granosa shell powder. Prior to fabrication, the fibres were treated with a 10% KOH alkaline solution for 4 hours to improve interfacial bonding. Three fibre orientations were investigated: 0°/0°/0°, 0°/+45°/0°, and 0°/90°/0°. Tensile and flexural tests were conducted to characterize the mechanical performance of the composites. The results indicated that the 0°/0°/0° orientation exhibited the highest tensile and flexural strengths of 33.19 MPa and 135.5 MPa, respectively. In contrast, the 0°/+45°/0° and 0°/90°/0° orientations showed reduced mechanical performance due to inefficient load transfer and non-uniform stress distribution. These findings demonstrate that fiber orientation significantly affects the mechanical properties of hybrid composites and highlight the potential of Salacca fibre and Anadara granosa shell powder as sustainable reinforcement materials for lightweight automotive applications.

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1. Introduction

The development of materials science, particularly in the field of polymers, continues to advance in line with human efforts to improve quality of life through the utilisation of materials and waste-treatment technology. Various types of polymer materials, both synthetic and natural, are increasingly applied in many sectors of life [1]-[2]. One material that has recently gained considerable attention is natural fibre, which has long been utilised in various human activities. The application of natural fibres in composite materials for the automotive industry aims to produce environmentally friendly, lightweight, and strong materials while also utilising abundant natural resources to overcome the limitations of synthetic composites. This is in accordance with Sustainable Development Goal number 12, which emphasises efficient resource utilisation and waste reduction. Natural fibre-reinforced polymer composites have the potential to replace conventional materials such as metal and wood due to their environmental benefits, lower density, and more affordable cost [3]-[4]. As technology advances, many researchers are working to develop composite materials that are more efficient, environmentally friendly, and derived from abundant, renewable raw materials. One of the composite materials that is increasingly being researched is natural fibre-based composites [5]-[6]. These composite materials have key advantages, namely their recyclability and renewable nature, which distinguish them from synthetic composites. Composites are combinations of two or more different materials, in which the matrix and reinforcement serve to withstand the main load [7-8]. One widely studied alternative reinforcement material is natural fibre, which is considered more environmentally friendly than fibreglass due to its biodegradability [9]. In composite applications, natural fibres can also be combined with fillers, such as Anadara granosa powder, to improve the material's mechanical properties [10]-[11]. Among natural fibres, Salak frond fibre has considerable potential because it is abundant and often considered agricultural waste. Salak, also known as Salacca zalacca, is a plant native to Indonesia that thrives in tropical regions. In this study, salak fronds were obtained from Banjarnegara. Besides Indonesia, salak plants are also widely distributed in Southeast Asian countries such as Malaysia, the Philippines, Brunei, and Thailand [12]. Salak plants grow in clusters and can reach up to 7 meters tall, though they are generally around 4.5 meters in Indonesia. The plant has separate male and female flowers and is

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covered with spines hidden beneath dense fronds and leaves. Its leaves are sword-shaped, ranging from 2.5 to 7 meters in length. Salak fronds contain several important chemical constituents, including cellulose, hemicellulose, lignin, and silica, which contribute to their potential as reinforcement materials in composite applications. Salacca zalacca fibres are known for their lightweight characteristics and good mechanical strength, making them suitable for composite reinforcement [13].

In addition to salak frond fibres, clam shell waste also has significant potential as a filler material in composite manufacturing. In Indonesia, blood clams (Anadara granosa) are commonly found in coastal areas, although the utilisation of their shells remains limited, primarily for handicraft products. In this study, blood clam shells were obtained from an online store. Blood clam shells are oval-shaped, white in colour, and possess a hard outer structure. They generally measure about 5–6 cm in length and 4–5 cm in width and naturally bury themselves in mud or sand regardless of tidal conditions. Blood clams belong to the Arcidae family and are recognised for their ability to produce haemoglobin. They are widely cultivated for consumption and distributed to restaurants. Blood clam production in the Indo-Pacific region increased significantly in 2010, reaching 34.482 tons, with an average annual growth rate of 5.18% between 2000 and 2010. Clam shells contain high amounts of calcium oxide (CaO) and magnesium oxide (MgO), which can enhance the strength and stiffness of composite materials [14]- [15]. The combination of salak frond fibres and Anadara granosa powder in polymer composites offers promising potential for engineering applications, particularly in the automotive sector. Due to their lightweight, low-cost, and environmentally friendly characteristics, natural fibre composites are considered suitable alternatives to conventional materials for manufacturing motorcycle components such as front fenders [16]–[17]. Furthermore, the mechanical performance of composites can be influenced by several factors, including fibre orientation. Therefore, this study aims to investigate the effects of salak frond fibre orientation and the addition of Anadara granosa powder on the tensile and bending strengths of epoxy-based composites. The results of this study are expected to provide an alternative material for lightweight, environmentally friendly applications in motorcycle front fenders.

2. Materials and Methods

This research methodology consists of three main stages. The first stage is the initial preparation phase, which includes providing raw materials and all supporting components for the composite manufacturing process. This stage involves material preparation, fibre alkalization treatment, and determination of fibre orientation. The next stage is the composite fabrication process, which produces test specimens. Mechanical testing is then conducted to evaluate the characteristics and strength of the resulting composite. A more detailed explanation of each stage is presented in the following sections.

2.1 Salacca Zalacca Frond Fibre

Salacca fibre (Salacca zalacca) used in this study was obtained from salak fronds collected in Banjarnegara, Central Java, Indonesia. The fibres were manually extracted from the fronds, cleaned to remove impurities, and dried for 2 × 24 h at room temperature prior to fabrication. The fibres were 250 mm long and classified as long natural fibres. Salacca fibre was selected as the reinforcement material because it contains high cellulose content and exhibits good mechanical properties, such as tensile strength and Young’s modulus, which are suitable for polymer composite applications. The morphology of the Salacca fibre is shown in Figure 1, while its chemical, physical, and mechanical properties based on previous studies are presented in Tables 1 and 2.

Table 1**.** Chemical properties of Salacca fibre vascular bundle [18]

Chemical content of FVB	Species of salacca	
	S. sumatrana (% wt)	S. zalacca (% wt)
Cellulose	44.60	41.75
Hemicellulose	31.36	36.39
Klason lignin	33.00	27.90
Solubility in Hot water	5.5	2.96
Solubility Ethanol-toluene	25.00	18.54
Solubility Ash content	0.89	1.28

Figure 1. Salacca zalacca fiber

Table 2. Physical and mechanical properties of Salacca fibre [18]

Physical and mechanical properties of fibro-vascular bundles	Species of salacca	
	S. sumatrana	S. zalacca
Diameter (mm)	0.047±0.14	0.036±0.01
Density (g/m²)	0.46±0.15	0.35±0.11
Tensile strenght (MPa)	212.75 ±97.78	193.51±47.39
Young's modulus (GPa)	3.03±0.91	2.25±0.60
Specific tensile strength (MPa)	495.69±236.86	602.30±215.85
Specific young' modulus (GPa)	7.09±2.5	6.93±2.36

2.2 Anadara Granosa Powder

Anadara granosa clam shells used in this study were obtained from local seafood waste sources in Central Java, Indonesia. The shells were thoroughly cleaned to remove dirt and organic residues, dried in sunlight, and then crushed into powder. The powdered shells were used as filler material during composite fabrication. Anadara granosa shell powder was selected for its high calcium oxide content, which can improve the mechanical properties of composite materials. The morphology of the clam shells is shown in Figure 2, while the chemical composition of the shell powder based on previous studies is presented in Table 3.

Figure 2. Anadara granosa clam shell

Table 3. Clam shell composition [19]

Chemical components	Compositions (%)
CaO	66.70
SiO_2	7.88
Fe_2O_3	0.03
MgO	22.28
AI_2O_3	1.25

Figure 3. Epoxy resin

2.3 Epoxy Matrix

The epoxy resin used in this study was obtained from the Indrasari store in Semarang, Indonesia. Epoxy resin is a popular material used in various applications, including composite manufacturing. This type of resin is usually obtained from online stores such as Nusa Kimia, with an epoxy-to-hardener ratio of 2:1, as shown in Figure 3. Epoxy resin is very important in industry because of its excellent characteristics such as chemical resistance and strong mechanical properties [20]. This matrix is a polymer that exhibits outstanding mechanical properties, including high tensile strength, high stiffness, and corrosion resistance. The epoxy matrix also binds and protects the reinforcing fibres in the composite structure. This is very important for maintaining the strength and reliability of the helmet material and for protecting the reinforcing fibres from damage [21] - [22].

Table 4. Mechanical properties of epoxy resin with hardener [23]

Properties	Values
Density of epoxy at 20^0C (g/cm^3)	1.175
Density of hardener at 20^0C (g/cm^3)	1.01
Tensile Strength (MPa)	39
Elongations (%)	15
Young modulus E (MPa)	2900
Bending strength (MPa)	69
Bending modulus (MPa)	3440
Impact resistance (kJ/m^2)	10

2.4 Alkalization Treatment

The alkalization method using KOH (obtained from the Indrasari chemical store in Semarang, Indonesia) is shown in Figure 4. The powdered KOH used was first dissolved in distilled water. The initial stage of the process began with preparing the extracted Salacca zalacca fibre. A 10% KOH solution was then prepared by dissolving 100 grams of KOH in 1,000 ml of distilled water. Once the solution was ready, the Salacca zalacca fibre was soaked for 4 hours in the alkali solution to ensure complete immersion. After soaking, the fibre was rinsed with clean water to remove any remaining alkali solution. The fibre was then dried in the sun at room temperature for 24 hours until completely dry. The dryness of the fibre was determined visually by changes in colour and texture, and by the absence of moisture. The alkalization treatment caused physical changes in the fibre, characterised by a colour change from light brown to dark brown as seen in Figure 5. Furthermore, previous research has shown that a 4-hour alkalization process effectively removes hemicellulose and lignin, thereby improving fibre performance [24] – [26].

Figure 4. Alkalization KOH

(a) (b)

Figure 5. Salacca zalacca fibre (a) before alkalinization; (b) after alkalinization

2.5 Orientation of Composite Fibre Direction

Fibre orientation is an important parameter in the manufacture of composite materials because it greatly affects the resulting mechanical properties. The arrangement of the fibre direction determines the composite's ability to withstand and distribute the loads acting on the material. In this study, as seen in Figure 6, variations in fibre orientation were used, namely (0°/0°/0°), (0°/45°/0°), and (0°/90°/0°), to determine the effect of the fibre arrangement direction on the tensile strength and bending strength of the composite. The 0° fibre orientation is arranged parallel to the loading direction to maximise stress transfer along the fibre, while the 45° and 90° orientations are used to improve stress distribution and mechanical characteristics in different directions. With these variations in orientation, it is expected that a fibre configuration can be obtained that produces the best mechanical performance in the composite material.

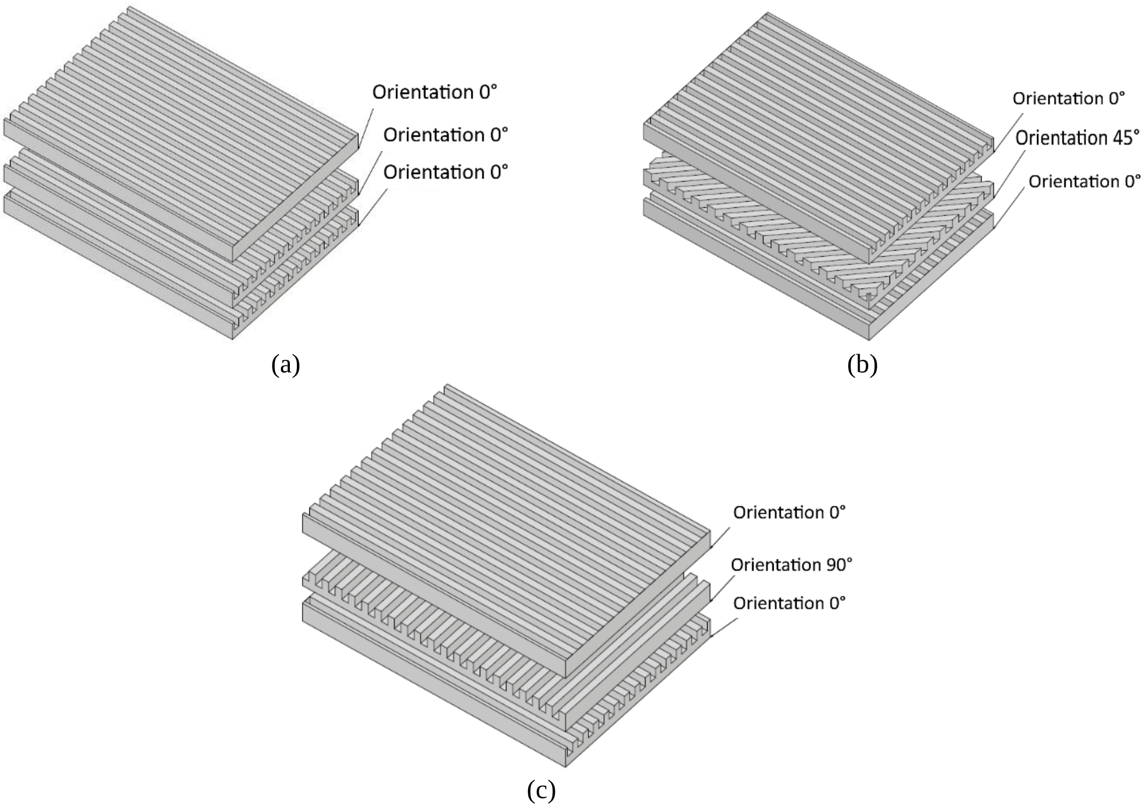


Figure 6. Orientation fibre (a) (0°/0°/0°); (b) (0°/45°/0°); (c) (0°/90°/0°)

2.6 Sample Fabrication

The composite manufacturing process begins with cleaning and processing Salacca zalacca fibre, which is then soaked in a 10% KOH alkali solution to remove lignin and improve the fibre's surface quality. Meanwhile, Anadara granosa shells are crushed and sieved to a 200-mesh size. The material composition consists of 50% fibre, 40% resin matrix, and 10% shell powder. The mixing process begins by mixing the resin and shell powder according to the specified volume fractions, then stirring using a mixer at 250 rpm for 3 minutes until homogeneous. Afterwards, the hardener is added to the mixture and stirred again using the mixer for 2 minutes until evenly mixed. The composite is then fabricated using the hand lay-up method with a specific lamina arrangement. This study aims to evaluate the mechanical properties of natural fibre composites and analyse the effect of fibre orientation on material performance. The fibre orientation variations used include sample A (0°/0°/0°), sample B (0°/+45°/0°), and sample C (0°/+90°/0°), with a matrix-to-reinforcement ratio of 40% : 60%. Mechanical property testing was carried out using tensile tests in accordance with ASTM D638 and flexural tests to determine the composite's overall strength characteristics. Figure 7 presents the stages of the research carried out, from material preparation and fibre treatment to composite manufacturing.

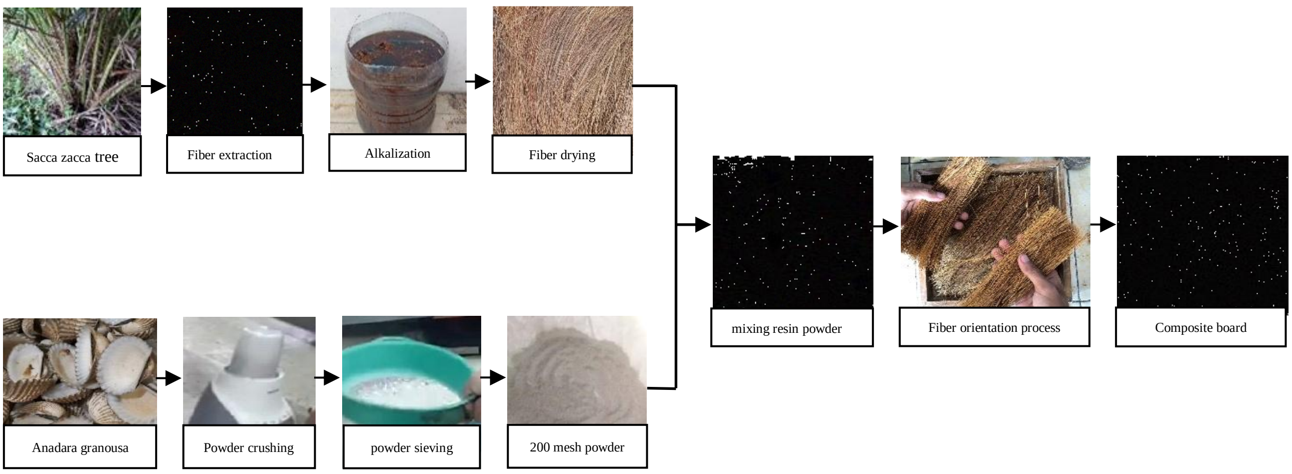


Figure 7. Composite manufacturing process

2.7 Composite Preparation

The equipment used in this study included rollers, digital scales, a grinding machine with grinding stones, composite moulds, scissors, wire brushes, measuring cylinders, callipers, a hacksaw, and a universal testing machine. The materials used were snake fruit (Salacca zalacca) fibre, Anadara granousa shells, KOH solution, epoxy resin, and plasticine. The research process began with combing the Salacca zalacca fibres. Next, the fibres were treated with a KOH solution for 4 hours. Afterwards, the fibres were neutralised by rinsing with distilled water and then dried at room temperature for 24 hours. They were then cut into 250 mm lengths and classified as long fibres. The shells, on the other hand, were first washed, then crushed, and sieved to obtain a 200-mesh powder. The next step was to calculate the fibre mass fraction and the matrix requirements. The fibres were then arranged according to the predetermined orientation angles, and then the mass fraction composition between the fibre and matrix was adjusted according to the planned variations.

Table 5. Fibre and matrix mass requirements

Variants	Tensile testing	Bending testing
Epoxy + fiber salacca zalacca tree	4	4
Epoxy + powder anadara granosa	4	4
Epoxy + powder anadara granosa + fiber orientation salacca zalacca tree 0°/0°/0°	4	4
Epoxy + powder anadara granosa + fiber orientation salacca zalacca tree 0°/+45°/0°	4	4
Epoxy + powder anadara granosa + fiber orientation salacca zalacca tree 0°/+90°/0°	4	4
Front motorcycle fender	4	4

2.8 Tensile Test

ASTM D638 tensile testing is conducted to determine the mechanical properties of the material, particularly its tensile strength and resistance, especially strength and resistance to tensile strength. This test uses a universal testing machine, Geotech Testing Machine Inc. Model UN-7001-LC30, TC180200162 Series, 2018, as shown in Figure 8. The procedure involved clamping the specimen in the testing machine and gradually increasing the load until the specified load was reached, causing the test object to fail. The tensile force on the test item increases its length, thereby decreasing its thickness. The data obtained during testing can be computed using the following equation.

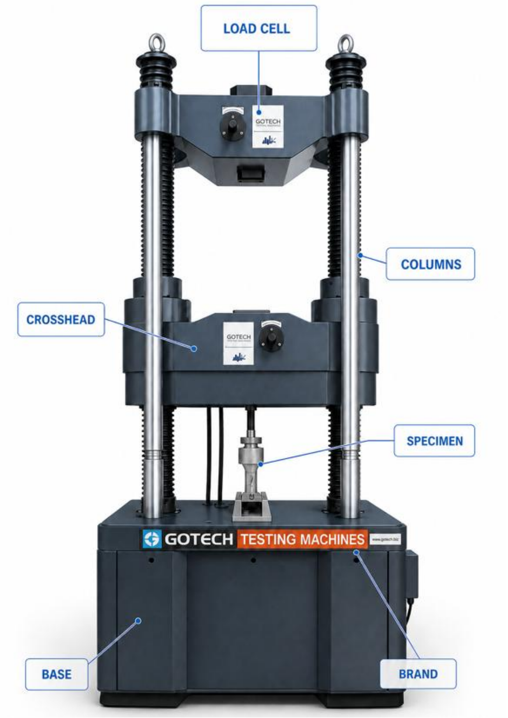


Figure 8. Universal testing machine

This test provides insight into the behaviour of the material. The parameters of tensile strength and modulus of elasticity of the material can be determined through Equation 1 as follows:

$$\sigma = \frac{P}{A} \tag{1}$$

$$\varepsilon = \frac{\Delta L}{L_0} \tag{2}$$

$$Y = \frac{\sigma}{\varepsilon} \tag{3}$$

where in Equation (1) the tensile strength of a material is expressed as σ with units of MPa, P =tensile force (N), A = cross-sectional area (N/mm^2), in Eq. (2) tensile strain is expressed as ε, L_0 = length of the initial specimen (cm), and ΔL= length increase (cm), in Eq. (3). Express the modulus of elasticity Y with units (N / m^2), ε = Engineering strain, and σ = Engineering stress or stress (MPa). The use of specimen dimensions facilitates calibration and test equipment settings in accordance with the appropriate specimen dimensions for tensile testing per ASTM D-638, as shown in Figure 9.

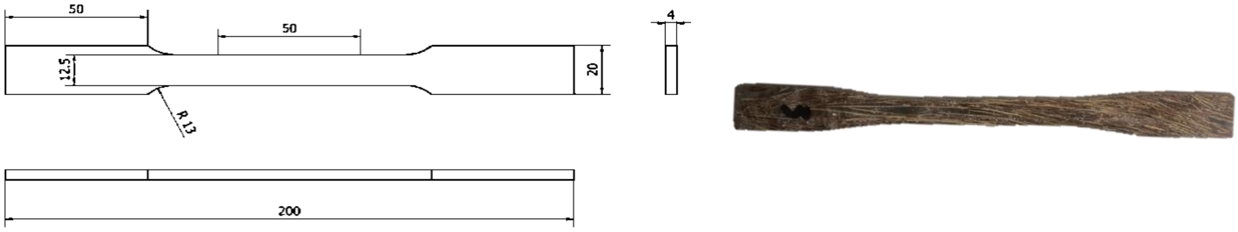


Figure 9. ASTM D-638 tensile testing material dimensions

2.9 Bending Test

The bending test ASTM D-790, commonly called flexibility testing, is a test performed to determine the behaviour of the material under load at a point [27]. This test uses a universal testing machine, Geotech Testing Machine Inc. model UN-7001-LC30, TC180200162 Series, 2018. Further bending test procedures are illustrated in Figure 10.

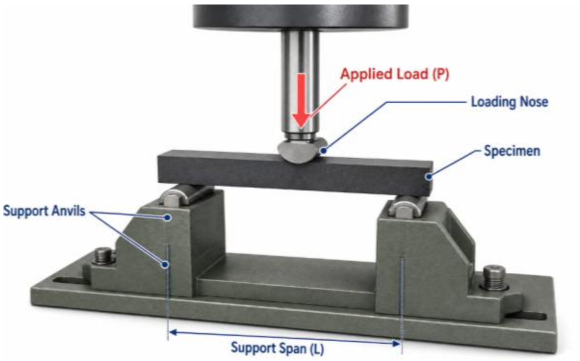


Figure 10. Bending testing process

Three-point bending is a method of testing that uses two pedestals and one press; it is specified in ASTM D-790 and is commonly called flexure testing. The initial parameters of a material specimen are recorded by the test machine, including specimen thickness, cross-sectional length, and other relevant parameters. In the middle of the specimen, a pressure point is marked, and loading is then applied at that point. The universal testing machine arm moves vertically downward until it touches the specimen. Loading on the specimen is achieved by controlling the test machine to the peak load the specimen can bear until the specimen breaks. The results of the tests carried out on each specimen are recorded by the system on the universal testing machine. The same is done for the composite material specimens A, B, and C, which are curved to observe changes in the material. The bending test produces bending strength values that can be calculated using Equation (4).

$$\sigma = \frac{3FL}{2bd^2}. \quad E = \frac{FL^3}{4bd^3\delta} \tag{4}$$

In the bending test *F* is the maximum load of the test object: *L*, *b*, and *d* are the length, width, and height of the span, respectively. δ denotes the energy absorbed at the point of loading. The specimen dimensions used to facilitate calibration and test equipment settings, in accordance with the appropriate specimen dimensions shown in the bending test per ASTM D-790, are shown in Figure 11.

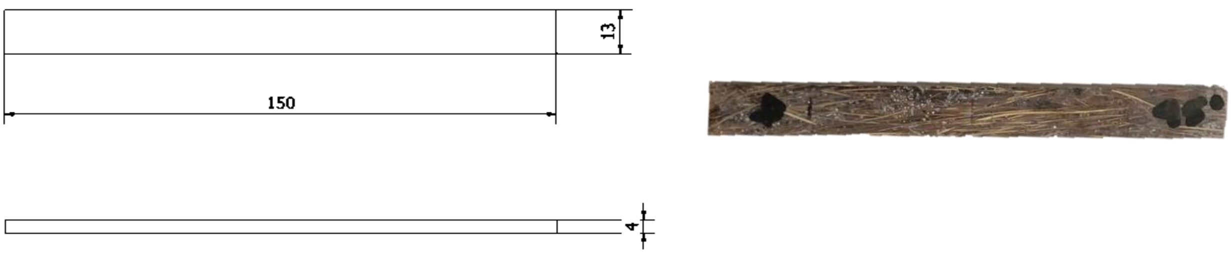
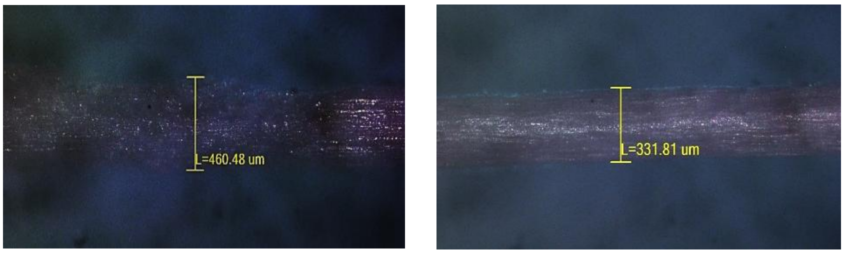


Figure 11. ASTM D-790 standard bending test material dimensions

3. Results and Discussion

3.1 Fibre Surface Morphology

The microphotographic results in Figure 12 showed that the alkalization treatment had a significant effect on fibre diameter. The fibre diameter before the alkalization treatment was 460.48 µm, whereas after the treatment it decreased to 331.81 µm. The decrease in fibre diameter reached 27.94%, indicating that the alkalization process effectively removed some of the hemicellulose, lignin, wax, and other impurities attached to the fibre surface [28]. The reduction in the impurity layer makes the fibre surface cleaner and rougher, potentially increasing the interfacial bond between the fibre and the matrix in the composite material.



(a) (b)

Figure 12. Fibre microphoto 50x magnification (a) before alkalization; (b) after alkalization

3.2 Tensile Strength

The tensile test results are presented in Figure 13. On the tensile testing graph, it can be seen that each tensile test group has a different value from the control variable for the product in use, namely the front motorcycle fender. The highest tensile strength was observed in the 0°/0°/0° fibre orientation, with an average value of 33.19 MPa. Next was the specimen group 0°/45°/0°, with an average value of 25.81 MPa. The third-highest value was obtained by the specimen group 0°/90°/0°, with an average of 20.99 MPa, in the 4th position among random fibre specimen kempok, with an average of 17.56 MPa. and the last, with the lowest tensile strength among the powder specimen group, with an average value of 15.31 MPa.

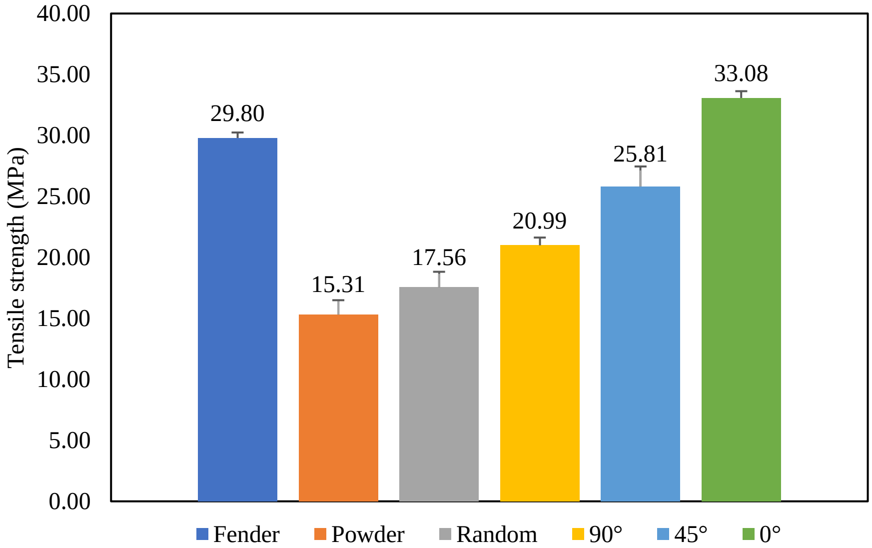


Figure 13. Tensile strength comparison diagram

In composites, fibres are the main load-bearing component. When aligned at 0°, they can effectively withstand tensile loads, since they are oriented in the same direction as the applied force. This alignment maximizes the contribution of the fibres to the overall tensile strength of the composite material [29]–[31]. Existing fibre orientation affects the modulus of elasticity, as shown in Figure 14, with the modulus maximised at 0° and decreasing significantly as the angle increases, becoming nearly constant beyond 45°. The 0° longitudinally oriented fibres show superior performance in terms of the highest strength and rigidity compared to other orientations. The findings of this study show that fibre orientation deviations from the loading direction reduce fibre contributions to the composite's tensile strength and stiffness, resulting in lower elastic modulus values. Finite element analysis supports these findings, demonstrating that fibre orientation parallel to the loading direction provides optimal stiffness and load-bearing capacity [32] - [33].

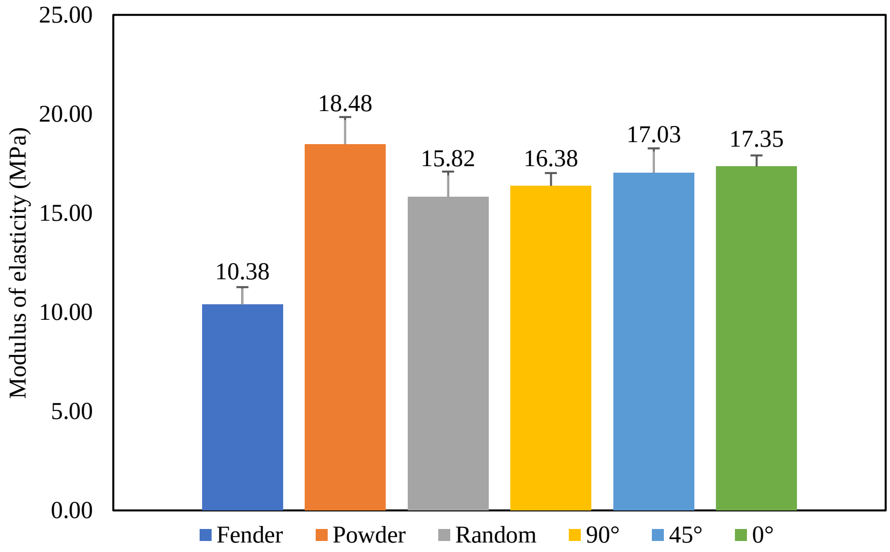


Figure 14. Comparison diagram of elastic modulus

The study results revealed that in the tensile test of fibre composites reinforced with virgin Anadara granosa leaf sheaths and powder, fibre tugging and cavities were observed, as illustrated in Figure 15. Composite fibre pull-out is a failure observed in the manufacture of composites, especially in fibre-reinforced materials. This occurs due to the detachment of the fibre interface bond from the matrix and pull-out against a given load; this often occurs in composites that use fibre direction [34]. A void or cavity is a condition in which the composite is not filled with matrix or fibre, leaving a cavity inside. Voids in the composite manufacturing method using hand lay-up are a common manufacturing defect. Conditions during the manufacturing process of composites are among the factors that cause voids or cavities and can decrease the composite's performance. The presence of cavities can be formed when pouring the matrix into the mold or due to uneven shrinkage [35] - [36].

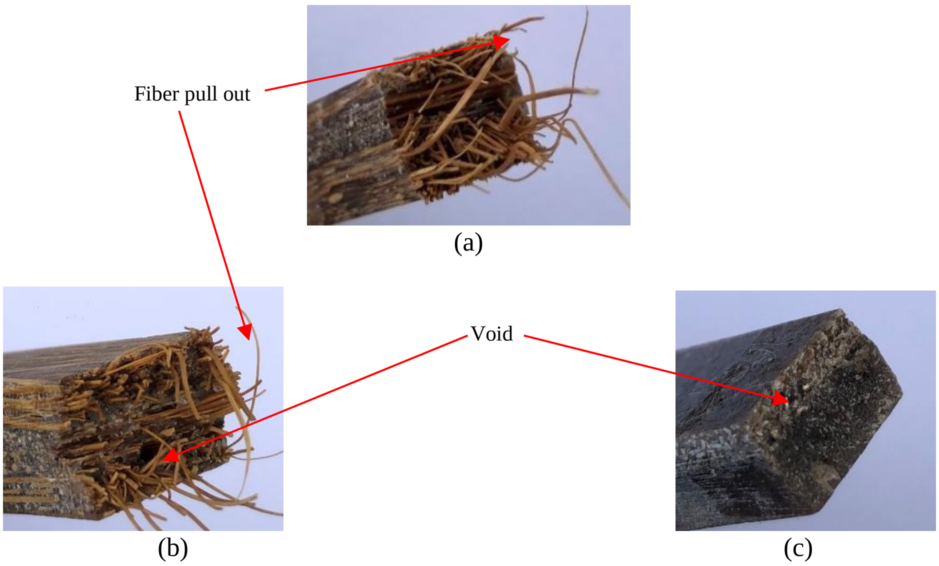


Figure 15. (a) Fibre pull-out phenomenon, (b) Void phenomenon, and (c) Void phenomenon

3.3 Bending Testing

Based on the bending test results shown in Figure 16, each test group exhibited different values from the control specimen, a motorcycle front fender. The highest bending strength in the composite group was observed in the 0°/0°/0° orientation, with an average value of 135.5 MPa. Next followed the specimen group 0°/45°/0° with an average value of 108.9 MPa, the specimen group 0°/ 90°/0° with an average of 84.46 MPa, the random fibre specimen group with an average value of 79.7 MPa, and the last with the lowest tensile strength, the powder specimen group with an average value of 47.6 MPa. The bending strength test results showed that the 0° orientation produced the highest bending stiffness, while the composite without fibre showed the lowest. This is due to the directional feeding of the fibres used. Fibre orientation 0° is placed in the direction of the load received [37]. This allows the bending force to be evenly distributed throughout the material, thereby reducing stress at a given point. Thus, the material can withstand the load better before failure [38]-[39].

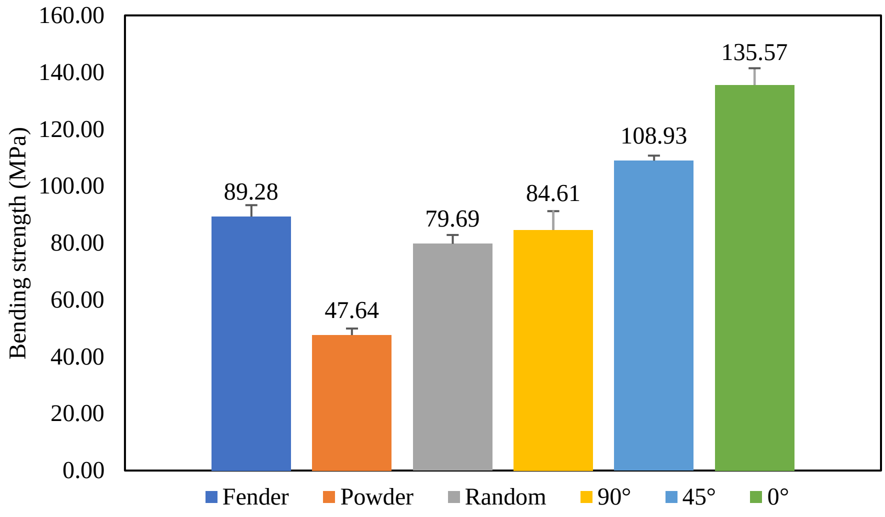


Figure 16. Bending strength comparison diagram

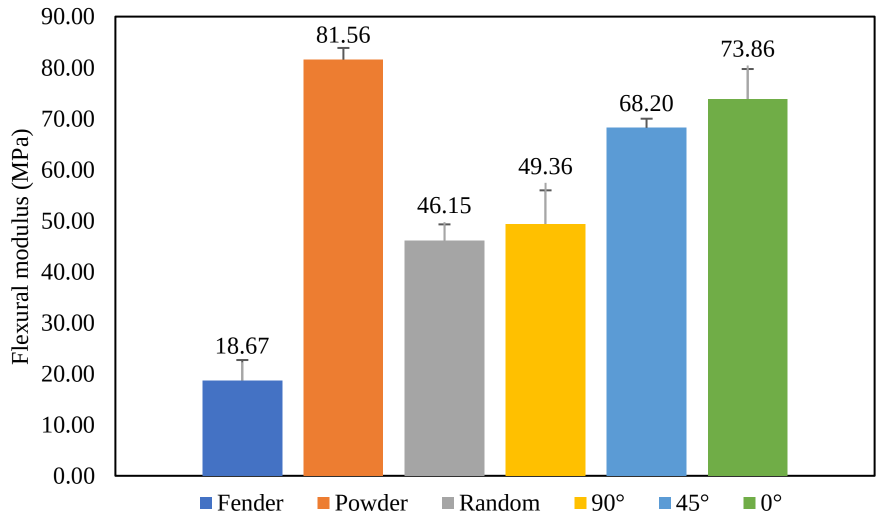
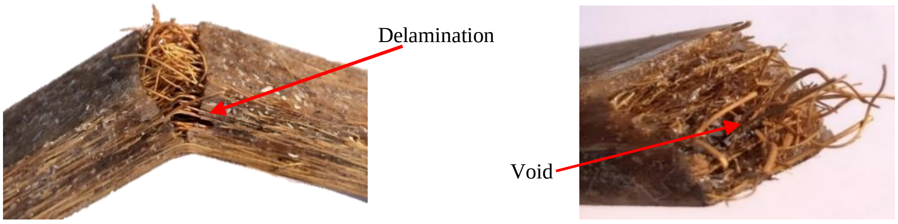


Figure 17. Flexural modulus comparison diagram

The elastic modulus findings of the flexural test in Figure 17 shows a larger tendency compared to previous tests due to many reasons linked to the properties of the material and the test method itself. In bending tests, materials often exhibit elastic behaviour over a wider range of applied loads before failure. This is especially true for powders that have been shaped into blocks, because they can better maintain structural integrity under bending loads. The ability to distribute the force evenly helps achieve higher modulus values [40]. Materials made of powders have greater particle-to-particle contact, which can increase rigidity. Using powders results in a higher modulus of elasticity because the material behaves more like a solid than a loose powder during testing [41]. The study [42] discusses the effect of the ratio of blood clam shells to natural fibres on bending strength, with the largest composite value at a volume fraction of 0:30 (39.57 MPa) and the lowest at a volume fraction of 20:10 (23.63 MPa). From these results, it can be concluded that coconut fibre without Anadara granosa powder exhibits the highest bending strength. The addition of Anadara granosa powder can increase bending strength at lower volume fractions; conversely, using less fibre volume decreases bending strength because the composite bond structure becomes smaller, reducing the amount of composite reinforcing material and weakening the composite strength. If the composite contains a lot of shells, flexural strength is weakened because the load received only rests on the shells of the blood shells. This is in line with research by Sedang, in which the composite with shellfish powder shows a high modulus, and that higher modulus is associated with weaker flexural strength.

The results of the test specimen bending composite hybrid fibre midrib bark and blood Anadara granosa powder, with epoxy resin as the matrix, are shown in Figure 18. There is a phenomenon of delamination and voids. Delamination in composites is a condition in which the constituent layers of the composite rupture, forming cracks between layers along the fibre direction within the composite thickness. Delamination can be caused by the rotation of the fibre under adjacent stress [45]-[46]. In the bending test there is a phenomenon of voids or bubbles trapped or empty voids trapped in the specimen shown in Figure 18 is one of the common defects in the manufacture of specimens with the hand layup method, the phenomenon of voids trapped in the composite has an impact on the mechanical properties of the material, the existence of voids can reduce the cross-sectional area, tensile strength, and bending resistance of the specimen, because if a composite has voids or air cavities are not evenly distributed resulting in cracking or failure of the material [47].



(a) (b)

Figure 18. (a) Delamination phenomenon, (b) Void phenomenon

4 Conclusions

Tensile test results showed that the tensile strength of the composite with various fibre orientations varied, with the highest value in the 0°/0°/0° orientation group, reaching 33.19 MPa. The orientation group 0°/45°/0° had a value of 25.81 MPa, followed by 0°/90°/0° at 20.99 MPa. The random fibre group had an average value of 17.56 MPa, while the blood Anadara granosa powder group recorded the lowest value, at 15.31 MPa. Previous studies have also shown that 0° fibre orientation generally provides higher tensile strength, as the fibre aligns with the applied load, improving force distribution efficiency and reducing failures in fibre-matrix bonding. In contrast, fibre orientations of 45° and 90° exhibit lower tensile strength because they are less effective in transferring stress. This result is consistent with findings from various studies showing that a 0° fibre orientation yields higher tensile strength and elastic modulus than other orientations. Bending test results showed that the composite group with fibre orientation 0°/0°/0° had the highest bending strength of 135.5 MPa, followed by the group with orientation 0°/45°/0° at 108.9 MPa, and 0°/90°/0° at 84.46 MPa. Meanwhile, the group with random fibre and powder had lower strength, 79.7 MPa and 47.6 MPa, respectively. These results show that 0° fibre orientation provides more effective load distribution due to continuous fibres, whereas 45° and 90° fibre orientations tend to fail faster due to shorter fibres and their orientation perpendicular to the load. Other studies also support this finding, showing that a fibre orientation of 0° generally results in higher bending strength compared to other orientations

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Declaration of Competing Interests

The authors declare no conflicts of interest.

CRediT Authorship Contribution Statement

Priyadi Bambang Widjanarko: Writing-draft; Conceptualization; Investigation; Resources; Supervision
Heri Yudiono: Methodology; Validation; Analysis; Supervision; Writing-revise & review

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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