THE EFFECT OF SILANE REINFORCEMENT ON THE MECHANICAL PROPERTIES AND MORPHOLOGY OF ARTOCARPUS *ELASTICUS BIOCOMPOSITES* FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Lantung bark (*Artocarpus elasticus*) biocomposite is a natural fiber-based material exhibiting potential as an eco-friendly alternative due to its competitive mechanical properties. This research evaluates the mechanical properties and morphology of polyester resin-based composites reinforced with lantung bark, specifically utilizing silane modification to enhance matrix compatibility. The biocomposites were fabricated using the hand lay-up method with varying silane concentrations of 2%, 4%, and 6%, followed by characterization through tensile tests, bending tests, and 3D imaging analysis. The results indicated that the sample with 2% silane concentration (N6S2) achieved the highest tensile strength (31.20 MPa) and bending strength (74.08 MPa). Meanwhile, the highest Modulus of Elasticity (MOE) for both tensile (2.54 GPa) and bending (3915.59 GPa) was observed in the sample with 4% silane concentration. However, increasing the silane concentration to 6% resulted in a decrease in mechanical strength, attributed to plasticization or adhesion interference as confirmed by morphological analysis. Overall, the research demonstrates that a 2% silane concentration yields the optimal performance, making this biocomposite suitable for lightweight structural applications, such as automotive interior parts.

The object of research: the biocomposites made from Artocarpus elasticus (lantung bark) fibers reinforced with silane-treated polyester resin, targeted for automotive interior applications.

Investigated problem: the core problem is the lack of data on how silane matrix treatment influences mechanical properties and morphology of Artocarpus elasticus (lantung bark) biocomposites, limiting their optimization for automotive interiors.

The main scientific results: silane treatment at 2% concentration optimizes *Artocarpus elasticus* (lantung bark) biocomposites, achieving peak mechanical performance exceeding SNI standards (tensile > 4 MPa, bending >35 MPa).

The area of practical use of the research results: lantung bark (Artocarpus elasticus) biocomposites with 2% silane treatment serve as lightweight, sustainable alternatives for automotive interiors, meeting/exceeding SNI standards (tensile >4 MPa, bending >35 MPa).

Innovative technological product: the optimized silane-reinforced Artocarpus elasticus (lantung bark) biocomposite using 2% silane in polyester resin (post-NaOH fiber treatment).

Scope of the innovative technological product: encompasses non-structural automotive interiors using optimized Artocarpus elasticus (lantung bark) biocomposites with 2% silane-treated polyester resin.

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1. Introduction

1. 1. The object of research

The object of research in this study is the enhancement of *Artocarpus elasticus* (lantung bark) biocomposites through silane treatment of the polyester matrix to improve interfacial adhesion for automotive applications.

1. 2. Problem description

With advancements in material technology, the use of renewable and environmentally friendly materials has become increasingly common. One of the most rapid advancements is the utilization of natural fibers as reinforcement in composites. The material industry is now shifting towards biocomposites, which are natural fiber-based materials that are lightweight, environmentally friendly, and possess competitive mechanical qualities compared to synthetic materials [1].

Biocomposites offer the advantages of being renewable and biodegradable, leading to their growing use in manufacturing and material engineering. Lantung bark (*Artocarpus elasticus*) is a highly promising natural fiber for use as a reinforcing material in composites. This tree, from which lantung bark is derived, is widely found in various regions of Indonesia, such as Sumatra, Papua, Kalimantan, and Palu [2]. Lantung bark has a fibrous structure with parallel interweaving. Currently, the utilization of lantung bark is limited to craft materials such as ropes, bags, and souvenirs [2].

The mechanical properties of composites with natural fibers, including lantung barks, are significantly influenced by the quality of the materials themselves and the interaction between the reinforcement and the matrix. This fibrous structure allows the fibers to be used as reinforcement in polymer-based composites. Fiber adhesion to the matrix is crucial for the mechanical function of lantung bark biocomposites, as it is for other natural fibers. Poor adhesion can lead to a loss of flexural and tensile strength, necessitating special treatments to improve adhesion between the fibers and the matrix [3].

1. 3. Suggested solution to the problem

To enhance the mechanical characteristics of biocomposites, two primary techniques exist: modifying the polymer matrix and chemically treating the fibers. Immersion in alkaline solutions, such as NaOH, is a common chemical treatment for natural fibers. Previous research indicates that alkaline treatment of fibers can improve adhesion between the fibers and the matrix by removing lignin and hemicellulose. For example, in a study on corn husk fibers, immersion in 5% NaOH for two hours enhanced the mechanical capabilities of the fibers by strengthening the interface between the fibers and the matrix [3]. Therefore, to observe the best impact on lantung bark-based biocomposites, a 6% NaOH concentration was used in this research.

Improving the quality of biocomposites also involves modifying the matrix in addition to chemical treatment of the fibers. Applying silane treatment to the polymer matrix is one of the widely developed techniques. This treatment aims to enhance compatibility between the fibers and the matrix by creating stronger chemical cross-links. According to research on the application of this compound, silane can improve matrix adherence to fibers, which will enhance the mechanical and physical quality of composite materials [4].

The use of catalysts in biocomposite manufacturing is also crucial to ensure proper polymerization reactions. Methyl Ethyl Ketone Peroxide (MEPOXE) is one of the most commonly used catalysts in epoxy systems because it accelerates the curing reaction between epoxy resin and hardener. With the appropriate addition of MEPOXE, the hardening time can be well controlled [4].

With the increasing demand for strong, lightweight, and environmentally friendly materials, the production of lantung bark-based biocomposites with appropriate chemical treatment becomes highly important. Therefore, the objective of this research is to determine how silane treatment of the matrix affects the mechanical and physical strength of biocomposites. Additionally, it investigates how immersing lantung bark in 6% NaOH affects the physical strength of biocomposites. This research also examines the role of the MEPOXE catalyst in improving the efficiency of the polymerization reaction and the quality of the resulting biocomposites. This research is expected to contribute to the development of more innovative natural fiber-based composite materials that can be utilized in various fields, such as construction and vehicles (e.g., in car interiors).

The problem statement in this research is the lack of information regarding changes in the mechanical properties and morphology of lantung bark (*Artocarpus elasticus*) biocomposites influenced by silane chemical treatment, as well as weight reduction and efficiency improvement of lantung bark-based biocomposites with silane compared to currently used car interior materials.

The limitations of this research include: lantung bark (*Artocarpus Elasticus*) as the reinforcing natural fiber originates from Bengkulu province; the composite material used is in sheet form; the fiber orientation used is cross-ply with 3 layers of fibers; chemical treatment of lantung bark fibers is limited to immersion in a 6% NaOH solution at room temperature for 2 hours and drying using an oven at 60°C for 3 days; polymer matrix modification is performed only with silane treatment at concentrations of 2%, 4%, and 6%; testing uses polyester resin 157 and MEPOXE catalyst; the specimen fabrication technique used is hand lay-up; and the tests conducted are mechanical properties (bending and tensile tests using ASTM D3039 standard) and morphology (using 3D imaging).

The objectives of this research are: to analyze the impact of silane treatment on the mechanical properties of lantung bark as determined by tensile and bending tests; to analyze the impact of silane treatment on the morphological characteristics of lantung bark biocomposites as observed from 3D imaging analysis; and to analyze lantung bark as a biocomposite material that can be utilized for car interior applications.

2. Materials and methods

This research employed a laboratory experimental approach to analyze the effect of varying silane treatment concentrations on the enhancement of mechanical properties and morphology of lantung bark (*Artocarpus elasticus*) fiber-based biocomposites. The applied silane concentrations were 2%, 4%, and 6% by weight of the resin, aiming to improve the interfacial compatibility between the fibers and the polyester resin matrix (Yucalac 157) [4].

The initial phase of the research involved preparing laboratory equipment, such as an oven for drying, a Universal Testing Machine (UTM) for tensile and bending tests, a 3D optical microscope for morphological analysis, and specimen cutting tools. All equipment and materials were calibrated and ensured to be in proper working condition before the commencement of research.

The initial process was chemical treatment on lantung bark using a 6% sodium hydroxide (NaOH) solution for two hours. This alkaline treatment serves to remove lignin, hemicellulose, and impurities from the lantung bark surface, thereby improving adhesion between the fibers and the matrix [5, 6]. After the alkalization and drying processes, the lantung bark were spread with polyester resin, which was treated by silane at varied concentration as a coupling agent. The primary function of silane is to form chemical bonds between the hydroxyl groups on the fibers and the matrix, thereby increasing the tensile and bending strength of the biocomposites [4]. The composition of the resin and fiber mixture was set at 75% polyester resin and 25% lantung bark [7]. The mixing process was carried out mechanically to achieve homogeneity before molding.

Fabrication was performed using the hand lay-up method accompanied by pressing. The lantung bark were arranged in three cross-ply layers to enhance multi-directional load distribution [8]. After the resin was formulated and the lantung bark were immersed, the material was placed into a mold and pressed at 3 MPa for 30 minutes. This stage is crucial for minimizing porosity, increasing density, and achieving uniform resin distribution, thereby yielding biocomposites of good quality.

Specimens were prepared according to mechanical testing standards: tensile strength samples measured 1.8 × 16.2 × 0.3 mm, bending strength samples 1.5 × 10.5 × 0.3 mm, and samples for morphological analysis measured 5 × 5 × 0.3 cm. Mechanical tests were conducted using tensile and bending tests with a Shimadzu AGS-10kNXD according to ASTM D3039 standard. The data obtained included tensile strength, tensile modulus, bending strength, and bending modulus. Biocomposites' morphological analysis was performed using a Keyence VHX-6000 3D microscope. Tensile tests were conducted to obtain maximum tensile stress and Modulus of Elasticity (MOE) data, while bending tests were performed to determine Modulus of Rupture (MOR) and bending modulus of elasticity. Analysis of the fracture surface morphology served to study fiber distribution, fiber-matrix cohesion, and potential defects such as voids or delamination. All primary data were compared with secondary data and literature references to assess the effectiveness of silane treatment in improving biocomposite performance [4]. Samples were coded as follows: N6S2 used 2% silane concentration; N6S4 used 4% silane concentration; and N6S6 used 6% silane concentration. **Fig. 1** illustrates the research flowchart.

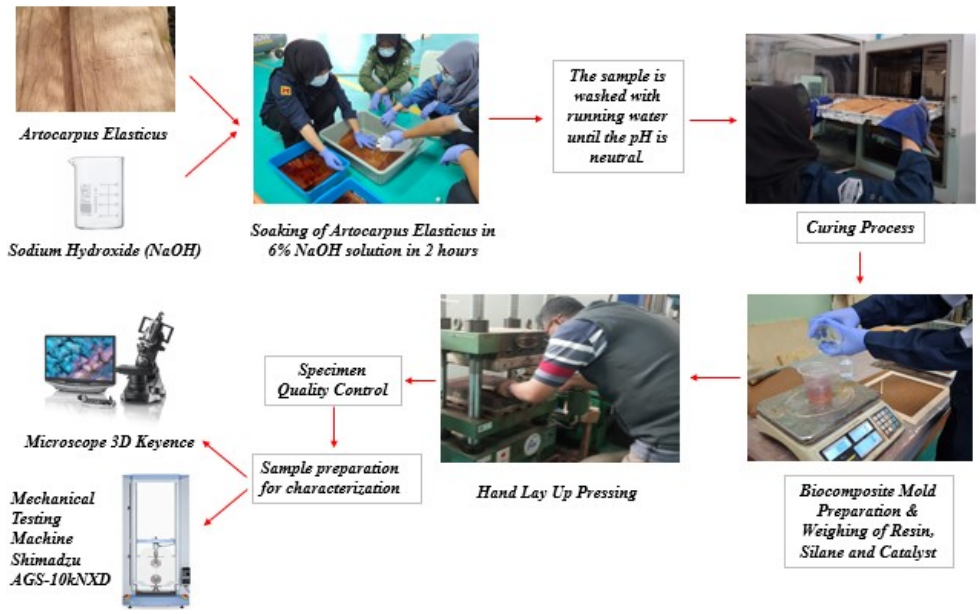


Fig. 1. Research flowchart

3. Results

Tensile and bending tests were conducted using a SHIMADZU Universal Testing Machine to measure the material's ability to withstand tensile and flexural forces before deformation or fracture. The data obtained from these tests were then processed and analyzed to assess the material's mechanical characteristics.

3. 1. Tensile characteristics of biocomposites

The tensile test results showed variations in various parameters, including Modulus of Elasticity (MOE) and Tensile Strength. **Table 1** presents the results of the tensile test on polyester-NaOH modified lantung bark biocomposite, while **Table 2** presents the tensile strength of silane-treated polyester-lantung bark biocomposites. The sample tensile test pieces are shown in **Fig. 2**.

Table 1

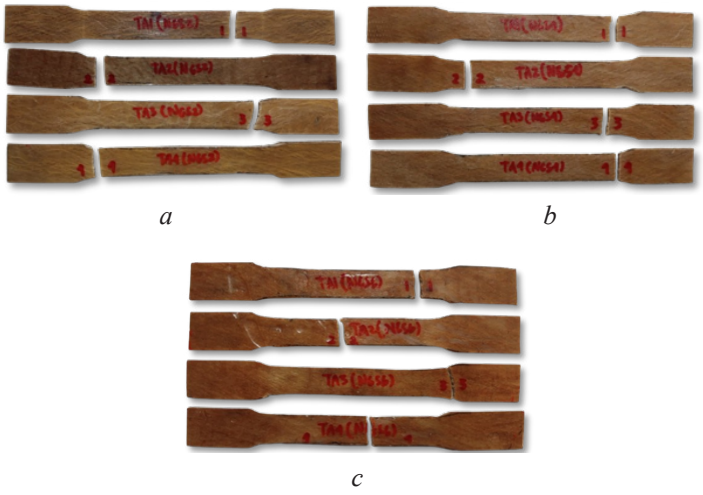
Polyester-NaOH-treated lantung bark biocomposites tensile test results

Samples	Replications	Tensile strength (MPa)	Average	Tensile modulus (GPa)	Average
Silane 2%	1	29.68	31.20 ± 3.53	2.94	2.23 ± 0.77
	2	27.61		2.84	
	3	35.88		1.66	
	4	31.62		1.48	
Silane 4%	1	25.22	24.37 ± 1.66	2.46	2.54 ± 0.21
	2	24.17		2.73	
	3	22.13		2.29	
	4	25.94		2.69	
Silane 6%	1	22.37	23.11 ± 1.34	1.52	1.48 ± 0.18
	2	21.76		1.28	
	3	24.81		1.71	
	4	23.49		1.43	

Table 2

Silane-treated polyester-lantung bark biocomposites Tensile test results

No	Samples	Matrix ratio: fiber (%)	Silane (%)	Tensile modulus (GPa)	Tensile strength (MPa)
1.	N6S2	75:25	2	2.23 ± 0.77	31.20 ± 3.53
2.	N6S4	75:25	4	2.54 ± 0.21	24.37 ± 1.66
3.	N6S6	75:25	6	1.48 ± 0.18	23.11 ± 1.34



a *b* *c*

Fig. 2. Tensile test samples of lantung bark-polyester treated with silane at concentrations of: *a* – 2%; *b* – 4%; *c* – 6% biocomposites

From the tensile test results, sample N6S2 showed the highest tensile strength of 31.20 MPa. Sample N6S4 has a tensile strength of 24.37 MPa, while N6S6 has the lowest tensile strength of 23.11 MPa. This indicates that an increase in silane concentration does not always positively impact biocomposite tensile strength. The highest modulus of elasticity (MOE) was obtained from N6S4 (2.54 GPa), followed by N6S2 (2.23 GPa), and the lowest from N6S6 (1.48 GPa). The MOE value for N6S4 was more consistent compared to N6S2, as indicated by the smaller standard deviation for N6S4 (0.21) compared to N6S2 (0.77). Sample N6S6 had the smallest standard deviation (0.18) but the lowest MOE value. The tensile strength test results showed values of 31.20 MPa (N6S2); 24.37 MPa (N6S4); 23.11 MPa (N6S6), all of which are well above the minimum standard of 4 MPa for high-density fiberboard tensile strength (SNI 01–4449–2006) [8].

3. 2. Bending characteristics of biocomposites

Bending tests yielded bending strength and bending modulus data. **Table 3** and **Table 4** present the complete results of the bending test. The sample bending test pieces are shown in **Fig. 3**

Table 3

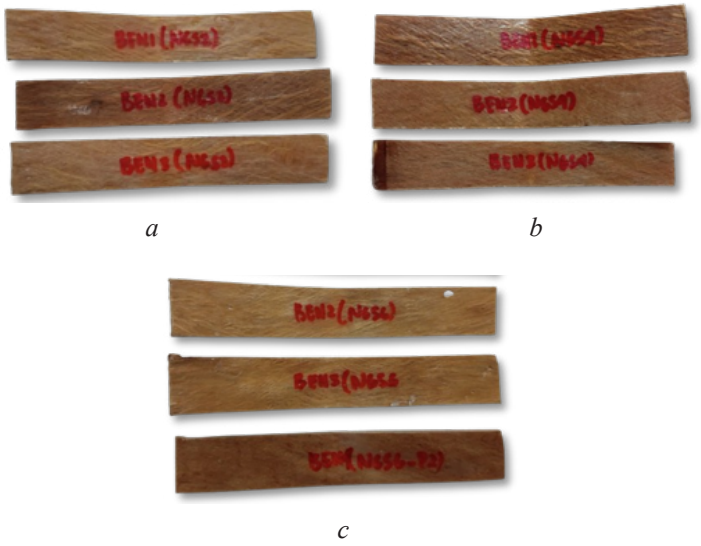
Polyester-NaOH treated lantung bark biocomposites bending test results

Samples	Replications	Bending strength (MPa)	Average	Bending modulus (GPa)	Average
Silane 2%	1	47.50	74.08 ± 34.32	2558.69	3068.82 ± 747.48
	2	104.29		3290.88	
	3	41.39		2398.87	
	4	103.15		4026.84	
Silane 4%	1	73.86	59.74 ± 12.15	3619.72	3915.59 ± 477.84
	2	65.89		3604.26	
	3	49.80		3821.59	
	4	49.40		4616.79	
Silane 6%	1	65.72	59.36 ± 9.31	374.75	1431.07 ± 1050.99
	2	58.72		2359.46	
	3	66.55		680.22	
	4	46.43		2309.85	

Table 4

Bending test results of silane-treated polyester-lantung bark biocomposites

No	Samples	Matrix ratio: fiber (%)	Silane (%)	Bending strength (MPa)	Bending modulus (GPa)
1	N6S2	75:25	2	74.08 ± 34.32	3068.82 ± 747.48
2	N6S4	75:25	4	59.74 ± 12.15	3915.59 ± 477.84
3	N6S6	75:25	6	59.36 ± 9.31	1431.07 ± 1050.99



a *b*

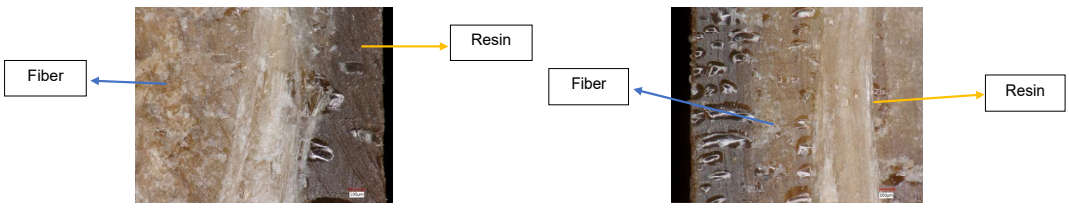
c

Fig. 3. Bending test samples of lantung bark- polyester treated with silane at concentrations of: *a* – 2%; *b* – 4%; *c* – 6% biocomposites

Results of the bending test show that sample N6S2 had the highest Bending strength at 74.08 MPa, while N6S6 had the lowest bending strength at 59.36 MPa. The highest bending modulus was found in N6S4 (3915.59 GPa), followed by N6S2 (3068.82 GPa), and the lowest in N6S6 (1431.07 GPa). The bending test results showed values of 74.08 MPa (N6S2); 59.74 MPa (N6S4); 59.36 MPa (N6S6), all of which are higher than the minimum limit of 35 MPa for the highest type (TI 35) in SNI 01–4449–2006 standard [8].

3. 3. Biocomposite morphology

Biocomposite morphological analysis using a 3D microscope (200x magnification) was conducted to observe the structure of lantung bark biocomposites. The microscopes analysis showed the interaction between lantung bark fibers and polyester resin within the composite structure. **Fig. 4**–**6** indicate that the lantung bark fibers have a rougher and non-uniform surface, while the polyester resin appears smoother and fills the spaces around the lantung bark fibers. In sample N6S4, despite some imperfections at the interface (uneven polyester resin distribution and the presence of voids or gaps), the material still exhibited better mechanical resistance compared to other samples, which is consistent with the highest bending modulus value obtained. Conversely, in sample N6S6, microscope analysis clearly showed uneven polyester resin distribution, with significant voids and gaps at the lantung bark fiber-polyester resin interface. This condition indicates that the polyester resin did not fully penetrate the lantung bark fibers, leading to weaker adhesion. This poor adhesion can cause structural failure or delamination when the material is subjected to load, which is consistent with the observed decrease in mechanical properties in sample N6S6. The rougher lantung bark fiber surface, not fully covered by polyester resin in N6S6, also indicates a poor impregnation process, which can lead to imperfect load distribution when the material is subjected to external forces.



a *b*

Fig. 4. N6S2 Biocomposite surface morphology by 3D microscope analysis: *a* – horizontal-vertical-horizontal fiber direction; *b* – vertical-horizontal-vertical fiber direction

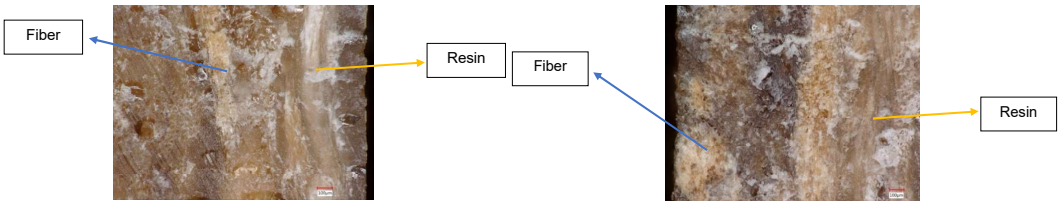


Fig. 5. N6S4 Biocomposite surface morphology by 3D microscope analysis: *a* – horizontal-vertical-horizontal fiber direction; *b* – vertical-horizontal-vertical fiber direction

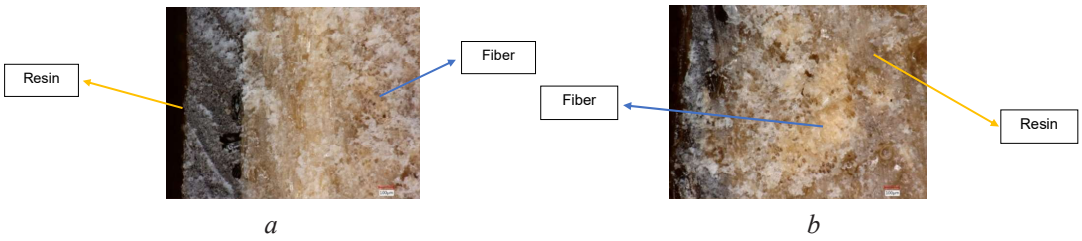


Fig. 6. N6S6 Biocomposite morphology by 3D microscope analysis: *a* – horizontal-vertical-horizontal fiber direction; *b* – vertical-horizontal-vertical fiber direction

4. Discussion

This research comprehensively evaluated the effect of silane treatment on the mechanical properties and morphology of lantung bark biocomposites. The obtained results provide important insights into the potential of this material as an environmentally friendly alternative for lightweight structural applications, particularly in automotive interiors.

4. 1. Effect of silane concentration on mechanical properties

From the tensile and bending test results, it is clear that the addition of silane to the polyester resin significantly impacts the improvement of the mechanical properties of lantung bark biocomposites. Sample N6S2 showed the highest tensile strength (31.20 MPa) and the highest bending strength (74.08 MPa). This indicates that at optimal silane concentrations, this coupling agent successfully improved adhesion between lantung bark fibers and the polyester resin, allowing for more efficient load transfer and enhancing the structural integrity of the biocomposite [9, 10].

However, the results also indicate that a continuous increase in silane concentration does not always lead to an improvement in mechanical properties. In sample N6S6, there was a decrease in tensile strength (23.11 MPa) and bending strength (59.36 MPa) compared to biocomposites with polyester treated by 2% and 4% silane concentrations. This phenomenon can be explained by several factors. First, excessively high silane concentrations can cause plasticization, where silane acts as a plasticizer, reducing resin stiffness and interfacial bonding. Second, excess silane can lead to agglomeration of silane particles or the formation of an overly thick interfacial layer between the fibers and the resin. Such an excessively thick layer can disrupt optimal adhesion and create weak points in the composite structure, thereby reducing the material's ability to withstand loads [4, 11].

Modulus of Elasticity (MOE) also showed an interesting trend. Sample N6S4 had the highest MOE in both tensile (2.54 GPa) and bending (3915.59 GPa) tests. This indicates that at a 4% silane concentration, the material achieved optimal stiffness. Although N6S4 did not have the highest tensile strength or bending strength, its high MOE value demonstrates the material's ability to resist elastic deformation well. The decrease in MOE in N6S6 (1.48 GPa for tensile and 1431.07 GPa for bending modulus) further strengthens the hypothesis of plasticization or adhesion interference at excessive silane concentrations.

Comparison with SNI standards for high-density fiberboard shows that the lantung bark biocomposites produced in this research meet and even exceed the minimum standards. The tensile strength of all samples was well above 4 MPa, and the bending strength of all samples was higher than 35 MPa [8]. This confirms the potential of this material for applications requiring adequate

mechanical strength, such as car interior components. Thus, it can be concluded that 2% silane treatment on the polyester resin is the optimal condition for improving the tensile and bending properties of lantung bark biocomposites, as shown in **Fig. 7**, **8**.

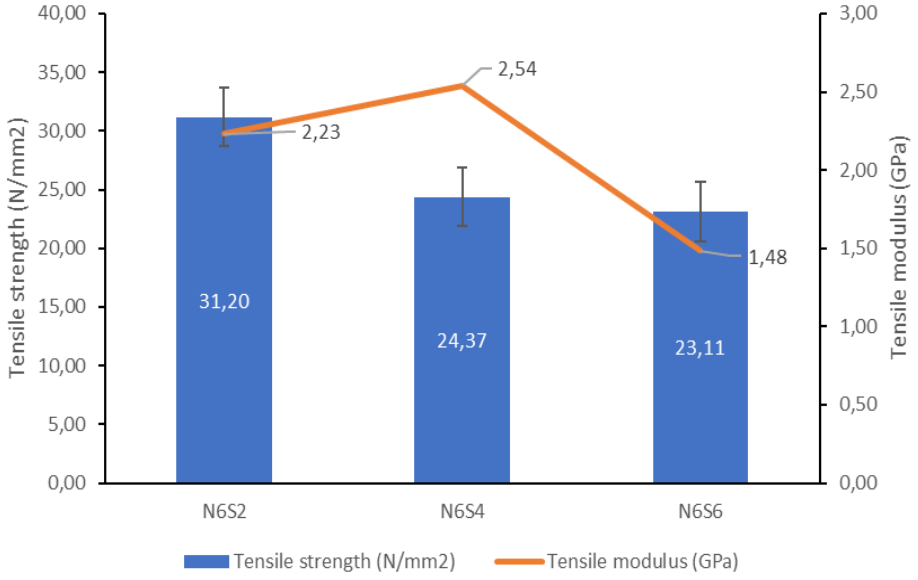


Fig. 7. Tensile characteristics of lantung bark biocomposites

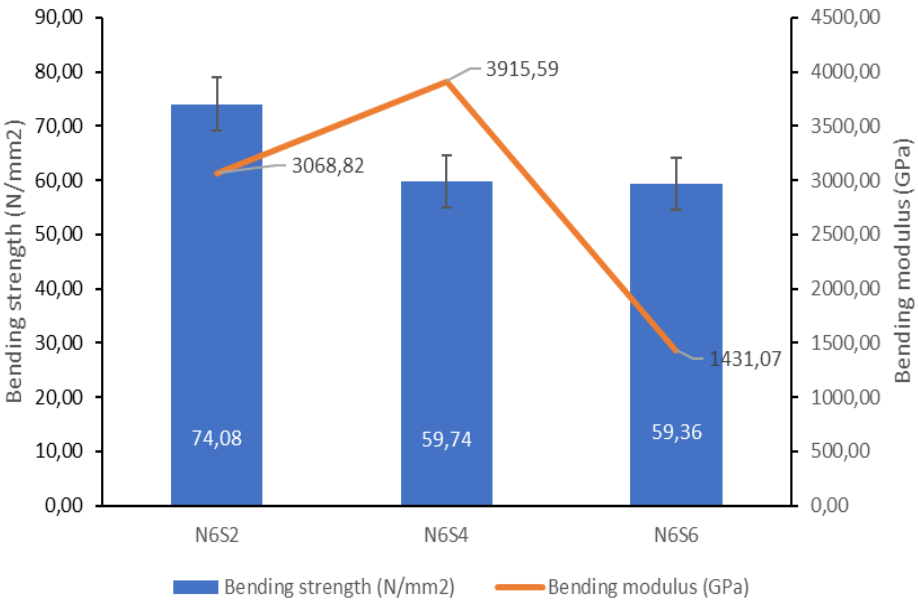


Fig. 8. Bending characteristics of lantung bark biocomposites

4. 2. Morphological analysis and its correlation with mechanical properties

The biocomposite surface morphology analysis was provided by a 3D microscope show the interaction between lantung bark fibers and polyester resin, which is very important for understanding the macroscopic characteristics of materials. In samples N6S2 and N6S4, despite some imperfections in polyester resin distribution, overall, the biocopoistes exhibit relatively good impregnation. However, in sample N6S6, surface morphology analysis clearly shows uneven polyester resin distribution, with significant voids and gaps at the lantung bark fiber-polyester resin interface. This condition indicates that the polyester resin did not fully penetrate the lantung bark fibers, resulting in weaker adhesion. This poor adhesion can lead to structural failure or delamination when the material is subjected to load, consistent with the observed decrease in mechanical

properties in the N6S6 sample. The rougher lantung bark fiber surface and incomplete polyester resin coverage on N6S6 also indicate poor impregnation, which can result in uneven load distribution when the material is subjected to external forces [6].

The correlation between the surface morphology analysis and mechanical properties is very clear. The N6S4 sample, despite showing some morphological imperfections, has the highest bending modulus. This may be due to the optimal combination of silane reinforcement effects at that concentration, which can compensate for some micro-imperfections. Conversely, N6S6, with the worst surface morphology (many voids and cracks) exhibited the lowest mechanical properties, confirming that lantung bark fiber-polyester resin interface integrity is a crucial factor in determining the overall performance of the biocomposites.

4. 3. Implications and potential applications

This research shows that 2% silane-modified polyester resin – lantung bark biocomposites have promising mechanical performance. This material has great potential for use in lightweight structural applications, particularly in automotive interiors, where strength and weight requirements are key considerations. The use of this biocomposite also aligns with global trends toward more environmentally friendly and sustainable materials, reducing reliance on synthetic materials and their negative environmental impacts [1, 12].

However, challenges related to the consistency of natural fiber, such as lantung bark supply and quality variations, still need to be addressed for industrial-scale applications. Further research is needed to optimize the fabrication process, including silane mixing methods and hand lay-up techniques, to ensure more homogeneous distribution and reduce internal defects. Additionally, long-term testing of environmental resistance and material stability is also important for practical applications.

The limitations of this research are identified based on the findings of this research, several limitations for the research are:

1. Raw material origin: the lantung bark (*Artocarpus elasticus*) used as the reinforcing natural fiber was sourced exclusively from Bengkulu province. Consequently, the results may vary for fibers obtained from different geographical locations due to environmental factors affecting fiber properties.

2. Composite configuration: the biocomposite specimens were fabricated solely in sheet form with a fixed cross-ply orientation consisting of three layers of fibers. Other geometries, fiber orientations, or stacking sequences were not investigated in this research.

3. Chemical treatment parameters: the chemical modification of the fibers was limited to immersion in a 6% NaOH solution at room temperature for 2 hours, followed by oven drying at 60°C. Furthermore, the matrix modification was restricted to silane treatment at specific concentrations of 2%, 4%, and 6%, without exploring a broader range or other types of coupling agents.

4. Manufacturing process: the fabrication technique employed was the manual hand lay-up method using Polyester Resin 157 and MEPOXE catalyst. This method relies heavily on operator skill and may result in less consistency in resin distribution compared to automated techniques like vacuum infusion.

5. Scope of characterization: the testing was limited to mechanical properties (tensile and bending strength according to ASTM D3039) and morphological analysis using 3D imaging. Other important properties such as thermal stability, impact strength, water absorption, and long-term durability were not covered in this research.

6. Conclusion

This research successfully evaluated the effect of silane treatment on enhancing the mechanical properties and morphology of lantung bark biocomposites. Based on the test results and analysis, several conclusions can be drawn: silane in the polyester resin significantly improves the mechanical properties of lantung bark biocomposites. A 2% silane concentration (N6S2) showed the highest tensile strength (31.20 MPa) and the highest bending strength (74.08 MPa); surface morphological analysis confirmed that uneven polyester resin distribution and the presence of voids and gaps at the lantung bark fiber-polyester resin interface, especially in sample N6S6, directly correlated with a decrease in mechanical properties. The integrity of the lantung bark fiber-polyester

resin interface is crucial for the overall performance of biocomposites; Biocomposites of lantung bark bonded with polyester resin treated by 2% silane concentration showed promising mechanical performance, meeting and even exceeding the minimum SNI standards for high-density fiberboard. This material has great potential as an environmentally friendly alternative for lightweight structural applications, such as automotive interior components, aligning with the need for strong, lightweight, and sustainable materials.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

ChatGPT-4o (OpenAI) used in the "Introduction" and "Discussion" sections. The tool was used for paraphrasing and checking English grammar to improve readability. The authors manually verified all generated text to ensure scientific accuracy and original meaning were preserved. The AI tool only assisted in language refinement and had no influence on the data, results, or conclusions of this research.

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Authors' contributions

Sulaksana Permana: Conceptualization, Methodology, Writing - original draft, Supervision; **Affap Fitri Ani**: Investigation, Data curation, Formal analysis; **Tri Mulyanto**: Validation, Writing – review & editing; **Supriyono**: Validation, Resources; **Muhammad A'Zom Ar-Rabaqi**: Investigation, Visualization; **Firda Aulya Syamani**: Methodology, Resources; **Ismadi**: Validation, Formal analysis; **Deni Purnomo**: Data curation, Software; **Abdul Azis Abdillah**: Writing – review & editing, Visualization; **Asep Mohamad Noor**: Project administration, Funding acquisition.

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