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IDENTIFYING THE MECHANICAL PROPERTIES AND SURFACE MORPHOLOGY OF ARTOCARPUS ELASTICUS FIBER BIOCOMPOSITES DUE TO THE EFFECT OF ALKALI TREATMENT FOR AUTOMOTIVE APPLICATIONS

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Lantung bark (Artocarpus elasticus), a natural fiber abundant in Bengkulu and other Indonesian regions, was studied as reinforcement in polyester-based biocomposites. The increasing demand for environmentally friendly materials has driven the development of natural fiber-based biocomposites as alternatives to synthetic materials. The main problem addressed is the weak interfacial bonding between untreated Lantung fibers and polymer matrices, reducing composite mechanical performance. To overcome this, fibers were treated with Sodium Hydroxide (NaOH) solutions at 2%, 4%, and 6% concentrations for 2 hours to improve surface morphology and chemical reactivity. After drying, treated fibers were fabricated into biocomposites using the hand lay-up pressing method. Testing included morphological observation via 3D microscopy and mechanical evaluation through tensile and bending tests based on ASTM standards. Results showed that 2% NaOH treatment provided the best biocomposite's mechanical properties, with a Modulus of Rupture (MOR) of 82.41 MPa and a Modulus of Elasticity (MOE) of 4.71 GPa. These improvements are explained by effective removal of surface impurities without significant fiber damage, enhancing fiber-matrix adhesion. The distinctive feature of this study is identifying an optimal alkali concentration that maintains fiber integrity while significantly improving mechanical performance. The developed Lantung biocomposites have potential applications as eco-friendly interior or non-structural automotive components requiring moderate tensile strength and high flexural performance

Keywords: Artocarpus elasticus, biocomposites, hand lay-up, mechanical properties, morphology, sodium hydroxide

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1. Introduction

Increased environmental concerns have accelerated the development of sustainable alternatives to petroleum-based materials. Natural fiber-reinforced biocomposites have emerged as promising candidates due to their biodegradability, cost-effectiveness, and wide availability. These materials offer eco-friendly solutions to replace conventional synthetic reinforcements such as plastics and glass fibers in various engineering applications [1]. Among natural fibers, Lantung bark (Artocarpus elasticus) shows promise as a composite reinforcement material. It remains underutilized in Indonesia, despite its high cellulose content and favorable morphological characteristics [2].

The main challenge in using Lantung bark as a reinforcing material is poor adhesion with polyester resin. This is due to the presence of lignin and hemicellulose on the fiber surface, which reduces chemical reactivity. High lignin content makes the fiber surface less active, hindering resin-fiber interaction during composite formation [3–5]. Alkali treatment using sodium hydroxide (NaOH) is a common method for improving the surface properties of natural fibers. This process removes lignin, hemicellulose, and contaminants, enhancing surface smoothness and chemical reactivity [6, 7]. As a result, the bond strength between natural fibers and the polymer matrix increases significantly.

Research on the optimization of Lantung bark fiber processing for biocomposite reinforcement is highly relevant. This research addresses adhesion limitations and promotes sustainable, high-performance biocomposites for engineering applications.

2. Literature review and problem statement

A comprehensive review of the development and processing of natural fiber-based composites is presented by [8], which emphasizes that alkali treatment-specifically sodium hydroxide (NaOH) soaking-plays an important role in improving fiber matrix adhesion and mechanical strength. The paper highlights improvements in sisal and abaca composites through mechanical testing and SEM analysis, elucidating interfacial bonding mechanisms and the effects of fiber content and matrix compatibility. However, it predominantly focuses on well-studied fibers, overlooking less-explored ones such as Lantung bark. Moreover, it lacks a detailed evaluation of optimal alkali treatment parameters (e.g., concentration, duration) and their impact on fiber degradation or preservation. This gap limits understanding of treatment optimization across diverse fibers and hinders the direct application of findings to underutilized fibers with distinct chemical and morphological features. Thus, critical assessment of treatment conditions and extension to novel fibers remain necessary to fully harness alkali treatment benefits.

Further investigations confirmed that NaOH treatment effectively removes hemicellulose, lignin, and surface impurities from natural fibers, leading to improved surface roughness, enhanced wettability, and increased chemical reactivity. However, each study presents specific nuances that warrant critically examined. In paper [9], hemp fibers were analyzed, demonstrating that NaOH treatment alters the fiber-matrix interface by reducing hemicellulose and lignin content, which correlates with improved composite strength. Nevertheless, the study also indicates that excessive removal of these components can compromise fiber integrity, suggesting the need for optimized treatment parameters tailored to each fiber type. The paper [10] provides a comprehensive overview of fiber processing and alkaline treatments, emphasizing that while NaOH generally enhances fiber surface properties across various natural fibers, variations in treatment concentration and duration produce inconsistent effects on mechanical performance. The authors emphasize the lack of standardized protocols and the importance of balancing impurity removal with fiber preservation to avoid degradation. In study [11], eco-friendly natural rubber–jute composites were investigated, where NaOH treatment improved fiber surface characteristics and composite compatibility. However, as this research primarily focused on jute fibers, the transferability of its conclusions to other fibers, especially those with different chemical compositions such as Lantung bark, remains uncertain.

This process improves interfacial bonding with the polymer matrix and results in higher tensile strength and flexural modulus. For example, 5% NaOH treatment has been reported to increase the tensile strength and thermal stability of various fiber-reinforced composites [12], while hybrid composites such as hemp-flax showed increased flexural strength and reduced water absorption after alkali treatment [13]. In another study, an optimal concentration range of 3–7% NaOH resulted in the most balanced mechanical and thermal performance in enset fiber composites, with 5% NaOH producing the most favorable results. However, these studies primarily focus on specific fiber types and do not fully address the variability in responses among diverse natural fibers with distinct chemical and morphological characteristics. Moreover, long-term effects of treatment duration and concentration on fiber degradation and composite durability remain insufficiently investigated, particularly for less-studied fibers such as Lantung bark.

Despite these advancements, studies consistently acknowledge that improper NaOH concentration or extended treatment durations can damage fiber morphology, compromise mechanical integrity, and reduce overall composite performance. Therefore, the careful optimization of treatment parameters aimed at balancing cleaning efficacy and fiber preservation is critical, yet remains an underexplored area that warrants further investigation.

However, the majority of these investigations focus primarily on widely available and commercially utilized fibers such as hemp, flax, ramie, and sisal. A critical gap remains in research involving underutilized natural fibers such as Lantung bark (Artocarpus elasticus), which possesses a unique chemical composition and microstructural characteristics. Lantung bark differs from conventional fibers in terms of cellulose content, lignin concentration, and surface morphology, which may significantly influence alkali treatment effectiveness and composite performance [14].

This research void is further complicated by several factors: limited regional availability of Lantung bark, variability in its fiber properties, and the high cost of conducting comprehensive parameter optimization and advanced morphological characterization. The majority of existing studies either exclude such fibers or apply generalized treatment protocols without considering fiber-specific responses to chemical modification.

To address these challenges, a promising strategy is to conduct systematic laboratory experiments that vary NaOH concentration and treatment duration, while comprehensively evaluating resulting mechanical and morphological properties. This approach has proven effective in studies on commercial natural fibers [9, 10, 12, 15], but has not yet been specifically applied to Lantung bark fiber.

Therefore, it is appropriate and timely to pursue a dedicated experimental study focused on optimizing alkali treatment parameters for Artocarpus elasticus fibers. Such a study could yield high-performance, eco-friendly biocomposites capable of replacing synthetic materials in automotive and structural engineering applications. In addition to advancing material science, this would also promote the sustainable use of regional, underutilized natural resources.

3. The aim and objectives of the study

The aim of this study is to identifying the mechanical properties of Lantung bark fiber (Artocarpus elasticus) treated with alkali at varying concentrations of NaOH to produce biocomposites with optimal mechanical properties and environmental friendliness suitable for automotive applications.

To achieve this aim, the following objectives were accomplished:

– to analyze the effect of varying NaOH concentrations on the mechanical strength of LB;

– to analyze changes in the morphological structure of Lantung fibers and LB after alkali treatment with NaOH.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of this study is the mechanical properties of Lantung bark fiber (Artocarpus elasticus) treated with alkali at different concentrations of sodium hydroxide (NaOH).

The main hypothesis of this study states that treatment with NaOH at an optimal concentration can improve the surface characteristics of Lantung bark fibers, which in turn produces optimal mechanical properties in the biocomposite.

Assumptions and Simplifications:

– the Lantung bark fiber used in this study is assumed to represent the characteristic properties of the species throughout the region;

– a soaking time of 2 hours at room temperature is assumed to be sufficient to produce significant surface modification of the fiber without causing excessive damage at all concentrations of NaOH tested;

– the manual printing method (hand lay-up pressing) is assumed to provide uniform resin impregnation and consistent sample thickness;

– environmental conditions during the drying and curing process are assumed to be stable and controlled.

4. 2. Materials

The materials used in this study were:

– Lantung bark fiber (*Artocarpus elasticus*);

– Sodium hydroxide (NaOH) solutions with concentrations of 2%, 4%, and 6% (w/v);

– unsaturated polyester resin (Yucalac 157) and catalyst.

The laboratory equipment employed included an oven, a 3D microscope (Keyence VHX-6000), and a Shimadzu AGS-10kNXD mechanical testing machine.

4. 3. Experimental procedures

4. 3. 1. Fiber treatment

The cleaned Lantung bark fibers were soaked separately in NaOH solutions with concentrations of 2%, 4%, and 6% (w/v) for 2 hours at room temperature [16]. This chemical treatment aims to remove surface impurities such as lignin and hemicellulose and improve fiber-matrix bonding characteristics. After processing, the fibers were washed with running water until a neutral pH was achieved, then dried in an oven at 60°C for 24 hours to remove residual moisture [17].

4. 3. 2. Composite fabrication

Biocomposite specimens were prepared using a manual layering and pressing method. Lantung bark fibers treated with alkali were layered in three layers and impregnated with a mixture of unsaturated polyester resin (Yucalac 157) and catalyst. The composite stack was pressed using a special mold to ensure uniform thickness and resin distribution. After drying for 24 hours at room temperature, the specimens were cut to standard dimensions specified in ASTM D3039 for mechanical testing [18, 19].

4. 3. 3. Mechanical testing

Tensile and flexural (bending) tests were conducted using a Shimadzu AGS-10kNXD universal testing machine in accordance with ASTM D3039 [17]. Tensile testing was conducted within a force range of 1–6 MPa, and flexural testing within a range of 0–1.4 N. Measurements included tensile strength, tensile modulus, flexural strength, and flexural modulus [20].

4. 3. 4. Morphological analysis

Surface morphology of untreated and NaOH-treated Lantung bark fibers was qualitatively evaluated with a Keyence VHX-6000 3D digital microscope. Observations focused on the removal of lignin and hemicellulose, surface roughness enhancement, and fiber texture changes induced by chemical treatment. Morphological results were cross-validated with secondary data and relevant scientific literature [21].

4. 4. Research flowchart

The experimental workflow encompassing sample preparation, treatment, fabrication, characterization, and analysis is summarized in Fig. 1.

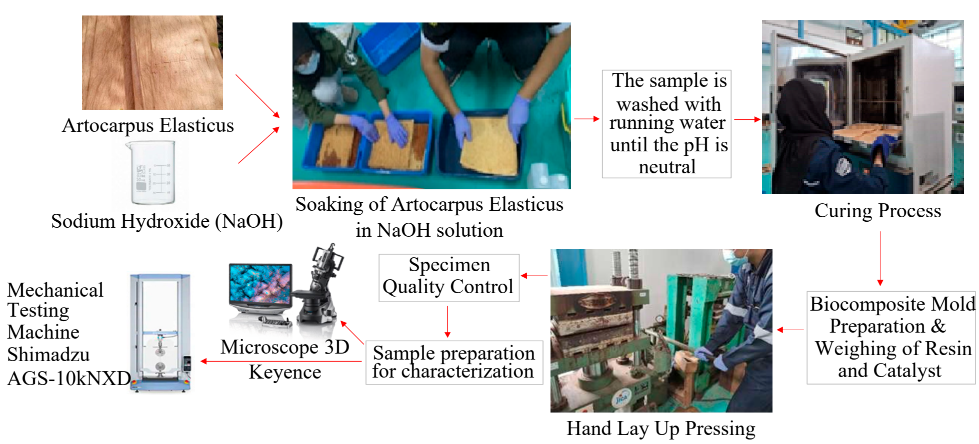


Fig. 1. Research flowchart

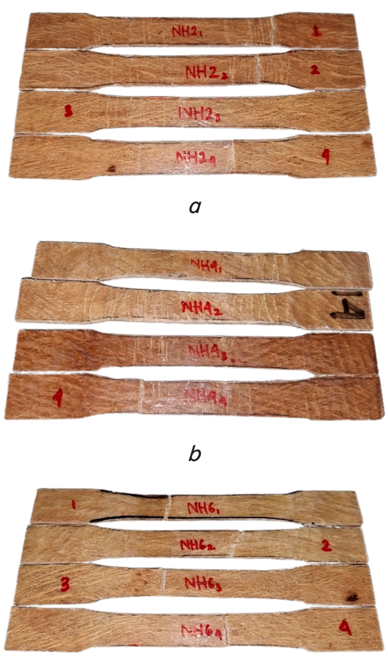
This experimental framework enables a comprehensive assessment of how different NaOH concentrations influence the mechanical strength and surface morphology of *LB*. The systematic approach adopted in this study establishes a clear relationship between chemical treatment parameters and composite performance, providing robust scientific evidence to support the utilization of Lantung bark as a promising reinforcement material in eco-friendly engineering and automotive applications.

5. Research result: mechanical and morphological performance of Lantung bark biocomposites

5. 1. Mechanical properties test results

5. 1. 1. Biocomposite tensile properties

Tensile testing was performed to determine the maximum tensile strength and tensile modulus of elasticity of *LB*. Fig. 2 shows the tensile test specimens for each NaOH soaking concentration. Analysis of the tensile modulus of elasticity was conducted within the force range of 1–6 MPa. The test results indicate that treatment with 2% NaOH yielded the highest tensile strength value of 27.22 MPa and a tensile modulus of 2.41 GPa. At a concentration of 4%, the tensile strength and tensile modulus decreased to 21.35 MPa and 2.08 GPa, respectively. Meanwhile, at a concentration of 6%, further reductions were observed, with the tensile strength dropping to 17.91 MPa and the tensile modulus to 1.85 GPa [22]. Table 1 presents the tensile test results of *LB*.



a

b

c

Fig. 2. Tensile test samples of *LB* with NaOH: *a* – 2%; *b* – 4%; *c* – 6%

Table 1 confirms that 2% NaOH treatment achieves the most optimal tensile properties, as indicated by the highest averages and lowest deviations, reflecting more uniform and reliable composite behavior.

Table 1

LB tensile test results

Samples	Replications	Tensile strength (MPa)	Average	Tensile modulus (GPa)	Average
NaOH 2%	1	27.12	27.23 ± 1.55	2.45	2.41 ± 0.13
	2	28.77		2.39	
	3	27.88		2.55	
	4	25.13		2.23	
NaOH 4%	1	11.24	16.75 ± 5.18	1.41	1.78 ± 0.53
	2	13.48		1.24	
	3	21.76		2.19	
	4	20.53		2.28	
NaOH 6%	1	20.89	22.12 ± 2.79	1.39	1.53 ± 0.12
	2	25.01		1.51	
	3	18.83		1.51	
	4	23.73		1.69	

The graphical representation of tensile strength and modulus trends across different NaOH concentrations is shown in Fig. 3, clearly illustrating the superior performance achieved at 2% NaOH. This Fig. 3 effectively complements the numerical data in Table 1 and clearly highlights the gradual reduction in properties at higher alkali concentrations, emphasizing the critical importance of optimizing chemical treatment to preserve fiber integrity and maximize mechanical performance.

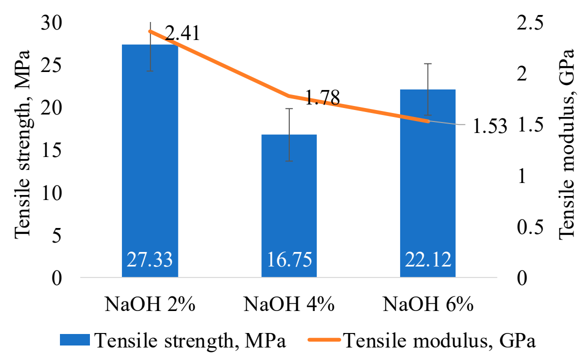


Fig. 3. *LB* tensile properties

Fig. 3 graphically displays tensile strength and modulus trends across NaOH concentrations, clearly emphasizing the peak performance at 2%. These visual supports numerical data and helps identify degradation effects at higher alkali levels.

5. 1. 2. Biocomposite bending properties

The bending modulus was analyzed in the force range of 0–1.4 N, Fig. 4 shows the bending test samples of *LB* at various NaOH concentrations. The bending test results of the biocomposite treated with 2% NaOH showed the best performance, with a bending strength of 82.41 MPa and a bending modulus of 4.71 GPa. At a concentration of 4%, the bending strength and modulus were 65.17 MPa and 3.40 GPa, respectively, while at a concentration of 6%, there was a significant decrease to a bending strength of 52.03 MPa and a bending modulus of 2.37 GPa [23]. Table 2 presents the bending test results of *LB*.

Table 2 indicates that 2% NaOH treatment offers the most consistent and highest bending strength and modulus, emphasizing its superior performance under flexural loads compared to higher concentrations.

a *b* *c*

Fig. 4. Bending test samples of *LB* with NaOH: *a* – 2%; *b* – 4%; *c* – 6%

Table 2

Bending test results of *LB*

Samples	Replications	Bending strength (MPa)	Average	Bending modulus (GPa)	Average
NaOH 2%	1	113.31	82.41 ± 29.88	6.70	4.71 ± 1.79
	2	60.97		5.51	
	3	102.37		4.05	
	4	53.00		2.57	
NaOH 4%	1	26.18	50.74 ± 26.95	1.62	3.40 ± 2.51
	2	29.83		0.91	
	3	80.73		5.99	
	4	66.21		5.08	
NaOH 6%	1	56.11	52.03 ± 15.70	2.71	2.37 ± 0.85
	2	61.11		2.25	
	3	62.08		3.26	
	4	28.80		1.26	

The graphical representation of these trends is provided in Fig. 5, which clearly depicts the decline in mechanical properties as the NaOH concentration increases beyond the optimal level. This Fig. 5 reinforces the numerical findings presented in Table 2 and highlights the necessity of precisely controlling alkali treatment parameters to maintain fiber integrity and ensure maximum flexural performance without inducing fiber degradation.

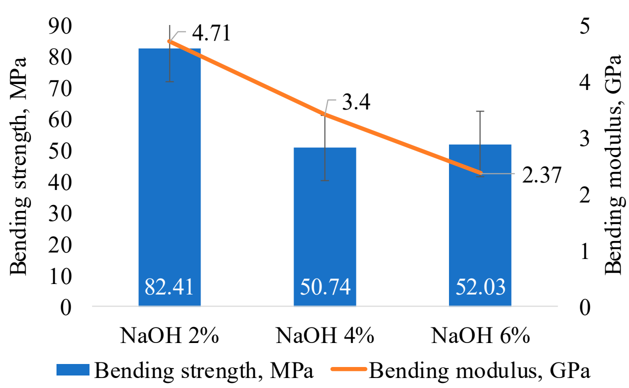


Fig. 5. *LB* bending properties

Fig. 5 visually illustrates the downward trend in bending properties at higher NaOH concentrations, reinforcing the importance of optimized chemical treatment to achieve maximum flexural performance.

5. 2. Morphological observation results (3D microscope)

Observation of the *LB* surface revealed significant morphological changes, as shown in Fig. 6. Based on 3D microscope observations, NaOH treatment at concentrations of 2% and 4% was able to clean the Lantung bark surface of impurities, lignin, and hemicellulose, resulting in a rougher and more active surface. Photos of the *LB* surface at 100x and 200x magnification can be seen in Fig. 7 and Fig. 8, respectively. At a concentration of 4%, the *LB* appeared cleaner and more uniform; however, at a concentration of 6%, signs of degradation began to emerge, such as fragmented fibers and fine cracks on the *LB* surface due to excessive dissolution [21].

The surface morphology changes observed at different NaOH concentrations are summarized in Fig. 7, 8. Fig. 7, 8 clearly shows that treatments with 2% and 4% NaOH effectively remove surface impurities and non-cellulosic components, resulting in cleaner and more reactive fiber surfaces that promote stronger resin bonding. In contrast, the 6% NaOH treatment leads to significant surface degradation, including excessive etching and fiber fragmentation, which may weaken the overall composite structure and compromise mechanical integrity.

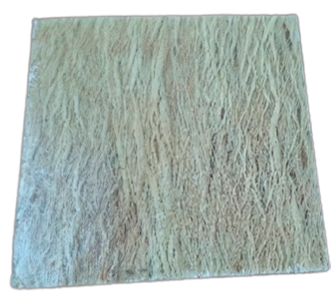


Fig. 6. Sample of LB for morphological observation

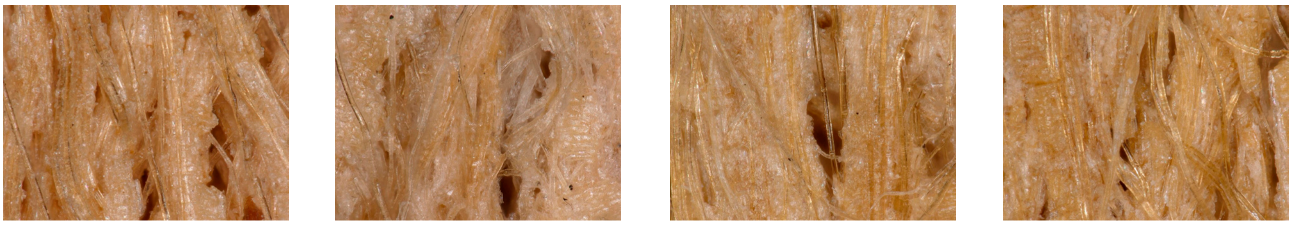
Fig. 7, 8 demonstrate that 2% and 4% treatments successfully remove surface impurities, promoting better resin bonding, while 6% treatment shows excessive surface damage that can compromise mechanical integrity.

The finer surface features of the *LB* samples treated at various NaOH concentrations are further detailed in Fig. 9, 10. Fig. 9, 10 emphasizes the presence of micro-cracks and fragmented fiber structures in samples treated with 6% NaOH, confirming severe morphological degradation at higher alkali levels. Meanwhile, the smoother and more uniform textures observed at 2% and 4% NaOH treatments correlate with the superior mechanical performance noted in tensile and bending tests.

Fig. 10 highlights fine surface details, emphasizing micro-cracks and fiber fragmentation at 6% NaOH, further confirming morphological degradation at higher concentrations. The improved texture at 2% and 4% explains the superior mechanical test outcomes.

a *b* *c* *d*

Fig. 7. Results of LB observation with a 3D microscope at 100x magnification:
a – untreated; *b* – NaOH 2%; *c* – NaOH 4%; *d* – NaOH 6%



a *b* *c* *d*

Fig. 8. Results of LB observation with a 3D microscope at 200x magnification:
a – untreated; *b* – NaOH 2%; *c* – NaOH 4%; *d* – NaOH 6%

a *b* *c*

Fig. 9. Results of LB observation with a 3D microscope at 100x magnification: *a* – NaOH 2%; *b* – NaOH 4%; *c* – NaOH 6%

a *b* *c*

Fig. 10. Results of LB observation with a 3D microscope at 200x magnification: *a* – NaOH 2%; *b* – NaOH 4%; *c* – NaOH 6%

6. Discussion of the results of property mechanical performance and morphological characteristics of Lantung bark biocomposites determination

The plotted data shown in Fig. 3, 5 further emphasize the excellent flexural performance and competitive tensile modulus of *LB* composites treated with 2% NaOH, which indicate strong resistance to bending loads and adequate tensile capabilities. Although the tensile strength of *LB* composites (27.23 MPa) is slightly below the upper limit of ABS, their superior flexural strength (82.41 MPa) and higher flexural modulus (4.71 GPa) suggest significant advantages for applications that require high rigidity and impact resistance, especially in interior automotive components such as dashboards, door trims, and other structural panels.

These findings demonstrate that the use of *LB* treated with 2% NaOH not only supports efforts to reduce dependence on synthetic materials but also contributes to the development of environmentally friendly, sustainable solutions in the automotive sector. Therefore, it can be concluded that *LB* represent a promising and viable alternative material for future automotive applications.

The characterization results indicate that alkali treatment with NaOH at a concentration of 2% is the optimal condition for improving the mechanical properties of *LB*. At this concentration, lignin and hemicellulose, which hinder fiber adhesion within the *LB* to the polyester resin matrix, are successfully removed without damaging the fiber structure, allowing effective stress transfer between the fiber and the matrix. At a concentration of 4%, the *LB* surface does become cleaner, but slight degradation begins to occur, resulting in a decrease in mechanical properties. Meanwhile, at a concentration of 6%, excessive dissolution causes damage to the *LB* fiber structure, leading to a significant reduction in the mechanical strength of the biocomposite [21].

According to [24], when compared to synthetic materials such as ABS plastic, *LB* treated with 2% NaOH exhibits competitive mechanical strength and has potential as an environmentally friendly alternative material, especially for automotive applications. These findings are also consistent with previous research stating that alkali treatment of natural fibers can increase tensile and bending strength when performed at optimal concentrations [20].

These results are further supported by the research of [25] which demonstrated that alkali treatment of kenaf fibers with optimal parameters (6% NaOH, 30°C, 8 hours, fiber: solution ratio 1:15) increased the tensile strength of the composite to 58.16 MPa [25].

Tensile testing was performed to determine the tensile strength and tensile modulus of *LB* treated with NaOH at concentrations of 2%, 4%, and 6%. Based on the test results, *LB* treated with 2% NaOH exhibited the highest tensile strength value of 27.23 MPa, with the highest tensile modulus of 2.41 GPa. The standard deviation for tensile strength was 1.55 MPa, while the standard deviation for tensile modulus for this treatment was 0.13 GPa.

With the 4% NaOH treatment, there was a significant decrease in tensile strength to 16.75 MPa, with an average tensile modulus of 1.78 GPa. The standard deviations for tensile strength and tensile modulus were 5.18 MPa and 0.53 GPa, respectively, indicating that the 4% NaOH treatment caused considerable fiber degradation, which affected the mechanical properties of *LB*, as shown in Fig. 3.

With the 6% NaOH treatment, there was a slight increase in tensile strength compared to the 4% treatment, reaching 22.12 MPa, but this value was still lower than that of the 2% NaOH treatment. The tensile modulus for this treatment was 1.53 GPa, with standard deviations for tensile strength and tensile modulus of 2.79 MPa and 0.12 GPa, respectively. The decrease in tensile strength and tensile modulus for the 4% and 6% NaOH treatments compared to the 2% treatment indicates that higher alkali concentrations cause excessive fiber structure degradation, resulting in weakened fiber load-bearing capacity and reduced modulus of elasticity and tensile strength. Therefore, it can be concluded that the 2% NaOH treatment is the optimal condition for improving the tensile properties of *LB*, as shown in Fig. 3.

Bending tests were conducted to evaluate the *LB* resistance to flexural loads by measuring bending strength and bending modulus, as shown in Fig. 5. Based on the test results, *LB* treated with 2% NaOH exhibited the highest bending strength of 82.41 MPa, with an average bending modulus of 4.71 GPa. The standard deviations for bending strength and bending modulus under this treatment were 29.88 MPa and 1.79 GPa, respectively, indicating that 2% NaOH treatment significantly improved the flexural resistance of the biocomposite compared to other NaOH treatments.

For *LB* treated with 4% NaOH, bending strength decreased to 50.74 MPa, while the bending modulus dropped to 3.40 GPa. The standard deviations for bending strength and bending modulus were 26.95 MPa and 2.51 GPa, respectively, suggesting that 4% NaOH treatment reduced the flexural resistance of *LB*, likely due to fiber degradation and reduced adhesion between the fibers and the resin matrix.

With 6% NaOH treatment, there was a slight increase in bending strength compared to the 4% treatment, reaching 52.03 MPa, but this value was still much lower than that of the 2% NaOH treatment. The bending modulus for this treatment was 2.37 GPa, and the standard deviations for bending strength and bending modulus of *LB* treated with 6% NaOH were 15.70 MPa and 0.85 GPa, respectively. This decrease indicates that higher NaOH concentrations make the fibers more brittle due to excessive chemical degradation. Therefore, 2% NaOH treatment is also the optimal condition for improving the bending properties of *LB*, as illustrated in Fig. 5.

Previous studies have examined the effect of NaOH treatment on the mechanical properties of natural fiber-based composites. It has been demonstrated that banana fiber biocomposites treated with 1% NaOH achieved the best tensile modulus of 625 MPa and the highest tensile strength of 36.42 MPa. However, at a 5% NaOH concentration, mechanical properties declined due to fiber degradation. This study supports the current research, in which excessively high NaOH concentrations reduce the mechanical properties of biocomposites as a result of excessive fiber degradation [22]. In a comparison of natural fiber-based composites, found that composites made from rice straw exhibited a tensile strength of 7.9 MPa and a flexural strength of 139.6 MPa [26].

The results of this research indicate that natural fibers subjected to chemical treatment have superior mechanical properties compared to untreated fibers. This aligns with the findings for *LB*, where NaOH treatment improved mechanical properties up to a certain optimal level before degradation set in. For comparison, the specifications of synthetic ABS high impact plastic show that this material has a tensile strength in the range of 20–40 MPa, a tensile modulus of 1–2.5 GPa, flexural strength of 37–76 MPa, and flexural modulus of 1.235–2.588 GPa [24]. Based on the findings of this study, *LB* treated with 2% NaOH demonstrates significant potential as an alternative to ABS plastic, particularly due to its more environmentally friendly characteristics.

Test data reveal that this composite has a competitive tensile modulus of 2.41 GPa compared to ABS, as well as superior performance in bending strength (82.41 MPa) and bending modulus (4.71 GPa). Although its tensile strength of 27.23 MPa still requires improvement to match the ABS level, its advantages in terms of sustainability and bending resistance make this composite a promising candidate for replacing synthetic materials [22–24].

The results of 3D microscope observation indicate that NaOH treatment helps clean Lantung bark of impurities and non-cellulosic components, with 4% NaOH yielding the best results in terms of improving fiber uniformity and cleanliness. In untreated fibers, the surface remains rough with significant amounts of impurities. Treatment with 2% NaOH begins to clean the fibers, but some lignin residues remain. Treatment with 4% NaOH results in cleaner and more uniform fibers, while 6% NaOH removes nearly all impurities but causes damage to the fiber structure.

In *LB* treated with 2% NaOH, fiber distribution is less uniform, whereas 4% NaOH results in a more homogeneous distribution and better bonding with the polyester resin matrix. Conversely, 6% NaOH causes some fiber damage, which can weaken the biocomposite structure. Overall, treatment with 4% NaOH is the optimal condition for enhancing fiber cleanliness, homogeneity within the resin matrix, and good adhesion without damaging the fiber structure, making it the best treatment for *LB* fabrication.

The results obtained in this study confirm that the 2% NaOH treatment condition is optimal for enhancing both mechanical and morphological properties of Lantung bark (*Artocarpus elasticus*) biocomposites. As illustrated in Fig. 3, 5, as well as supported by data in Tables 1, 2, the tensile strength and modulus, along with bending strength and modulus, reached their peak at this treatment level. The improved mechanical properties can be explained by the effective removal of hemicellulose and lignin at moderate alkali concentration, which increases the surface roughness and chemical reactivity of the fibers, thereby promoting better adhesion with the polyester resin matrix [8, 9].

In contrast, treatments with 4% and 6% NaOH led to a progressive reduction in mechanical performance due to fiber degradation and excessive surface etching, which was confirmed by morphological observations in Fig. 7–10. These findings are consistent with previous studies reporting that while alkali treatment can enhance fiber-matrix bonding, excessively high concentrations result in structural damage and loss of mechanical integrity [10–12]. The balance between fiber cleaning and fiber preservation is therefore critical. The effectiveness of the 2% NaOH treatment also parallels results found in other natural fibers, such as in hybrid hemp-flax composites, where optimal alkali treatment significantly improved flexural and tensile performance without compromising fiber morphology [13].

Compared to synthetic materials such as ABS, which typically exhibits tensile strength of 20–40 MPa, tensile modulus of 1–2.5 GPa, flexural strength of 37–76 MPa, and flexural modulus of 1.235–2.588 GPa, the biocomposites treated with 2% NaOH demonstrated comparable tensile properties (27.23 MPa) and superior flexural performance (82.41 MPa bending strength and 4.71 GPa bending modulus) [24]. This supports the feasibility of using these biocomposites in automotive interior components requiring high rigidity and impact resistance, such as door trims and dashboard panels.

The main peculiarity of this study lies in the identification of an optimal NaOH concentration that effectively enhances fiber properties while preserving structural integrity, a point that has not been fully explored for *Artocarpus elasticus* fibers. Previous works have optimized NaOH treatments for other fibers, but application to Lantung bark is novel and addresses the gap concerning its unique chemical composition and underutilized potential [8–15].

Nevertheless, certain limitations are inherent in this research. The study focuses on laboratory-scale experiments, which may not fully capture variations in large-scale or industrial fabrication processes. Additionally, environmental factors such as humidity and fiber origin variability were not extensively examined, which could influence reproducibility and performance consistency in practical applications. Future research should consider these aspects and integrate comprehensive long-term durability and aging studies under real automotive service conditions.

As for disadvantages, while the study successfully optimizes treatment for tensile and flexural properties, it does not yet explore other critical aspects such as impact strength, thermal behavior under fluctuating temperatures, and detailed chemical analysis of fiber-matrix interfacial bonding. Addressing these points would strengthen the case for practical adoption. Future work could also investigate hybridization with other natural fibers or the addition of nano-fillers to further improve mechanical performance and broaden application possibilities.

Potential developments of this research include scaling up production processes, assessing lifecycle environmental impacts, and exploring hybrid designs that incorporate Lantung bark with other natural or synthetic reinforcements. Challenges that might arise include methodological difficulties in maintaining uniform treatment in mass production, controlling resin impregnation homogeneity, and ensuring consistent quality of raw Lantung fibers sourced from different regions.

7. Conclusions

1. Soaking treatment Lantung bark in 2% NaOH proved to be the most effective treatment for improving the mechanical properties of the biocomposite. In tensile tests, composites treated with 2% NaOH achieved an average Modulus of Rupture (MOR) of 27.23 MPa and a Modulus of Elasticity (MOE) of 2.41 GPa. Increasing the NaOH concentration to 4% and 6% resulted in a reduction of both MOR and MOE. Similarly, in bending tests, composites treated with 2% NaOH exhibited the highest results, with an MOR of 82.41 MPa and an MOE of 4.71 GPa, while higher NaOH concentrations led to decreased MOR and MOE.

2. The results observations using 3D microscopy showed that NaOH treatment successfully removed impurities and non-cellulosic components from the fibers, thereby enhancing fiber-matrix adhesion. However, at a 6% NaOH concentration, excessive alkali treatment caused fiber structure damage, which could reduce the effectiveness of the fibers as reinforcing agents in the biocomposite.

Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship-related, or other factors that could affect the study and its results presented in this article.

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Data availability

Data are available in the manuscript as electronic supplementary material.

Use of artificial intelligence

The study methods section describes how the authors used artificial intelligence technology to give their own validated data, within reasonable bounds.

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