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Experimental study on the tensile and compressive properties of local bamboo fiber polyester composites with varying fiber species and resin ratios

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Abstract

In response to the growing demand for eco-friendly materials, natural fibers have gained increasing attention as renewable alternatives for automotive and structural materials. Despite extensive research, the mechanical performance of locally sourced bamboo species from Langsa, Aceh, including *Gigantochloa apus* (apus), *Bambusa vulgaris* (yellow), and *Bambusa blumeana* (thorn) remains largely unexplored. This study investigates the tensile and compressive properties of composites reinforced with these three bamboo species. The composites were fabricated using the hand lay-up method using BTQN 157 polyester resin and varying resin-to-fiber ratios of 60:40, 70:30, and 80:20. Mechanical tests were conducted in accordance with ASTM standards to evaluate the influence of bamboo species and fiber composition. Three specimens were tested for each composition, and the results were averaged to ensure data reliability. The results show that both bamboo type and resin fiber ratio significantly affect mechanical performance. The thorn bamboo composite at a 60:40 resin-to-fiber ratio exhibited the highest tensile strength of 81.94 MPa and compressive strength of 9.11 MPa. A 29.67% increase in tensile strength was achieved when varying the resin-to-fiber ratio from 80:20 to 60:40 for yellow bamboo, while a 28.93% improvement was observed across different species. Similarly, a 44.40% rise in compressive strength occurred for apus bamboo composites when the ratio changed from 80:20 to 60:40, and a 54.68% enhancement was recorded across species. These findings confirm that Langsa's local bamboo, particularly *B. blumeana* at a 60:40 ratio, offers strong, lightweight, and sustainable reinforcement potential for next-generation composite materials.

Keywords:

Bamboo, polyester resin, fiber-reinforced composite, hand lay-up, tensile strength, compressive strength.

1 Introduction

Bamboo has emerged as one of the most sustainable reinforcement sources due to its rapid growth, renewability, and superior mechanical strength-to-weight ratio. Structurally, its fibrous composition, comprising cellulose, hemicellulose, and lignin, provides a balance of stiffness, flexibility, and durability, making bamboo fibers a viable alternative to synthetic reinforcements such as glass or carbon fibers. Recent reviews [1, 2] have underlined bamboo's excellent tensile strength, modulus, and adhesion potential with thermosetting matrices such as epoxy and polyester resins, alongside its biodegradability and low environmental footprint.

The mechanical behavior of bamboo fiber composites is controlled by several key factors, such as fiber species, aspect ratio,

surface treatment, and resin fiber ratio. Chemical modification using alkaline solutions has been widely reported to enhance interfacial bonding and load transfer. For instance, Huang et al. [3] demonstrated that alkali treatment significantly improved stress distribution at the fiber–matrix interface, reducing failure due to debonding. Similarly, Lokesh et al. [4] and Abdullah et al. [5] reported that fiber volume fraction and controlled resin infiltration govern the resulting tensile and compressive responses of natural fiber composites.

Variations among bamboo species also result in substantial differences in fiber strength and structural performance. Harmono's study [6] found that vascular bundle density and wall thickness strongly correlate with tensile performance and stiffness, highlighting the importance of regional bamboo characterization. Complementary studies such as [7, 8] have reinforced that optimized fiber alignment and density yield superior tensile efficiency. Moreover, Benthony et al. [9] showed that surface conditioning prior to fabrication could enhance interfacial adhesion, while Fu et al. [10] demonstrated bamboo's adaptability as reinforcement in both polymeric and cementitious matrices.

Beyond laboratory characterization, bamboo composites have been increasingly applied in automotive and structural applications due to their high specific strength and low density. Natural fiber reinforced composites have already replaced synthetic materials in interior and non-structural automotive components such as door panels, dashboards, and seat backrests [11, 12]. Their advantages: light weight, energy absorption capacity, and biodegradability, make them suitable for replacing petroleum-based plastics in interior panels and insulation layers. Evaluating these mechanical properties is therefore essential to assess the material's feasibility for such end-use applications, particularly where load-bearing and deformation resistance determines long-term reliability [13–15].

Despite extensive international research on bamboo fiber composites, the author's literature review indicates that only limited studies have examined the mechanical response of locally available bamboo species from Langsa, Aceh, Indonesia, specifically *Gigantochloa apus* (apus), *Bambusa vulgaris* (yellow), and *Bambusa blumeana* (thorn). Although previous works [1–10] have highlighted bamboo's potential as a high-performance reinforcement material, the mechanical performance of these three local species and the effects of varying resin–fiber ratios remain largely unexplored.

Therefore, this study focuses on evaluating the tensile and compressive behavior of composites reinforced with Langsa bamboo fibers combined with polyester resin at ratios of 60:40, 70:30, and 80:20. This investigation bridges experimental characterization with prior findings, while addressing the absence of localized data for Indonesian bamboo composites. The present study contributes by establishing structure–property correlations for three Indonesian bamboo species, thus providing fundamental insights for developing eco-efficient, load-bearing composites suitable for structural and automotive applications.

2 Research Methods

2.1 Materials

The raw materials consisted of three bamboo species (apus, yellow and thorn) as reinforcement, and polyester resin (BTQN 157) with Methyl Ethyl Ketone Peroxide (MEKP) as catalyst. A 5% sodium hydroxide (NaOH) solution was employed for fiber surface treatment.

These bamboo species were selected because they are locally available in Langsa, Aceh, and represent abundant natural resources that are often underutilized. Their evaluation as reinforcement fibers aims to explore their potential as sustainable, renewable materials while simultaneously addressing the lack of prior research on their mechanical performance. Similar approaches of utilizing locally available bamboo species have been emphasized in previous works on bamboo composites [10].

2.2 Natural fibers

The bamboo culms were sourced locally from Langsa, Aceh, Indonesia. Each culm was cut into 25 cm segments before being mechanically processed into fibers. The fibers were air-dried under sunlight until a stable weight was achieved to reduce initial moisture content. After mechanical extraction, the fibers were manually cut into lengths of approximately 20–30 mm to ensure uniform distribution within the mold. Fiber orientation was primarily random but tended toward semi-aligned layers along the casting direction due to the hand lay-up process.

As illustrated in Fig. 1, bamboo anatomy consists of culm, rhizomes, roots, shoots, branches, and leaves, with its morphology generally divided into underground (rhizome–root) and aboveground (culm–branch–leaf) systems [1,2,13]. In this study, the culm was utilized because it is the cylindrical stem composed of nodes and internodes that matures in 3–4 years, becoming stronger and more rigid. Its high specific gravity, stiffness, and tensile properties make bamboo fibers competitive with other natural fibers such as kenaf, jute, and sisal, and even comparable in stiffness to E-glass fiber [1, 2]. These characteristics position bamboo as a sustainable and efficient reinforcement material in polymer composite applications.

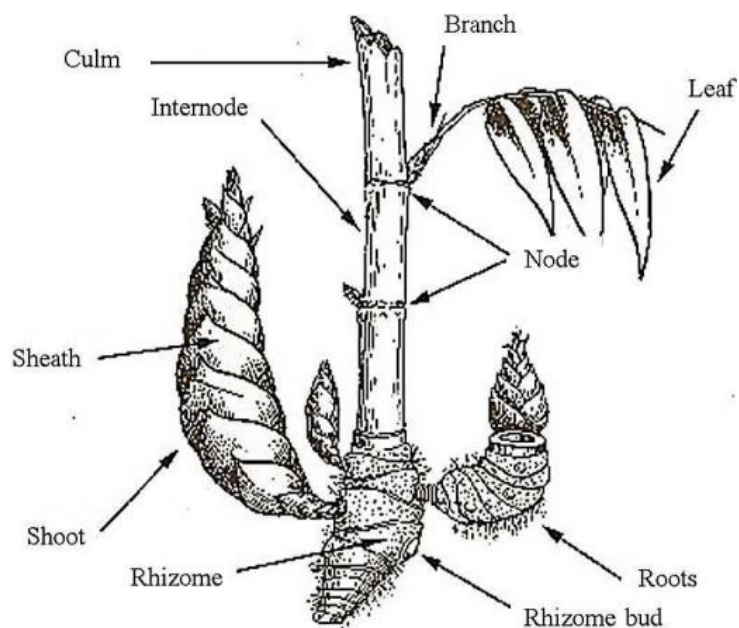


Fig. 1. Bamboo's anatomy [1, 2, 13].

To improve interfacial bonding with the resin, the fibers underwent alkali treatment. They were immersed in 5% NaOH solution for 2 h to remove lignin, hemicellulose, and surface impurities. Following treatment, the fibers were thoroughly rinsed with distilled water until neutral pH and dried again under sunlight. Alkali treatment is widely reported to enhance surface roughness and promote fiber–matrix adhesion in natural fiber composites [3].

2.3 Resin and hardener

Polyester resin BTQN 157 was used as the polymer matrix, providing good adhesion and mechanical strength. MEKP catalyst was added according to the supplier specifications to accelerate the curing process. The resin-to-hardener ratio was maintained

consistently for all specimens to ensure comparable curing conditions.

Polyester resin BTQN 157 was selected as the matrix material due to its favorable mechanical properties. As shown in Table 1, the resin possesses a density of 1.215 g/cm³, an elastic modulus of 0.03 GPa, and a tensile strength of 55 MPa. These values are consistent with those reported in polymer composite studies where polyester resins are preferred due to their low cost and adequate mechanical performance [9]. Its relatively low density also supports the development of lightweight composites, which is advantageous for renewable structural material applications.

Table 1. Material properties of polyester resin BTQN 157

Property	Value
Density	1.215 g/cm ³
Elastic modulus	0.03 GPa
Tensile strength	55 MPa

2.4 Fabrication of composite specimens

The composites were fabricated using the hand lay-up method. Resin and catalyst were first mixed thoroughly, after which treated bamboo fibers were incorporated at three weight ratios: 40% fiber: 60% resin, 30% fiber: 70% resin, and 20% fiber: 80% resin.

For ease of identification during testing and discussion, a coding system was applied to all specimen fractions (Table 2). Each code consisted of two parts: (1) the numerical ratio (60:40, 70:30, or 80:20), which indicates the fiber-to-resin mass fraction, and (2) a letter denoting the bamboo species (A = apus, Y = yellow, and T = thorn). For instance, specimen code 60:40A refers to a composite containing 40% apus bamboo fiber and 60% resin, while 70:30D refers to a composite with 30% thorn bamboo fiber and 70% resin. This systematic coding follows practices recommended in composite testing literature to ensure consistency and clarity in experimental design [10].

Table 2. Coding system for varied composite specimens

Code	Composition	
6040A	BTQN 157 (60%)	<i>G. apus</i> (40%)
7030A	BTQN 157 (70%)	<i>G. apus</i> (30%)
8020A	BTQN 157 (80%)	<i>G. apus</i> (20%)
6040Y	BTQN 157 (60%)	<i>B. vulgaris</i> (40%)
7030Y	BTQN 157 (70%)	<i>B. vulgaris</i> (30%)
8020Y	BTQN 157 (80%)	<i>B. vulgaris</i> (20%)
6040T	BTQN 157 (60%)	<i>B. blumeana</i> (40%)
7030T	BTQN 157 (70%)	<i>B. blumeana</i> (30%)
8020T	BTQN 157 (80%)	<i>B. blumeana</i> (20%)

The mixtures were poured into steel molds prepared according to ASTM D638 for tensile testing and ASTM D1021 for compressive testing (Fig. 2). The specimens were cured at room temperature for 24 h, followed by post-curing under sunlight assisted with a heat gun. After curing, the composites were removed from the molds and cut to the required dimensions using a grinder and fine saw. To support clarity of the process, an illustrative schematic of the fabrication procedure is provided in Fig. 3.

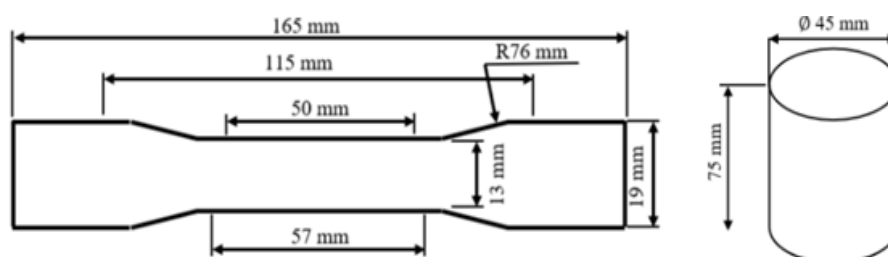


Fig. 2. Dimensions of the tensile (thickness = 3.2 mm, left) and compressive (right) composite test specimens according to ASTM D638 and ASTM D1021, respectively.

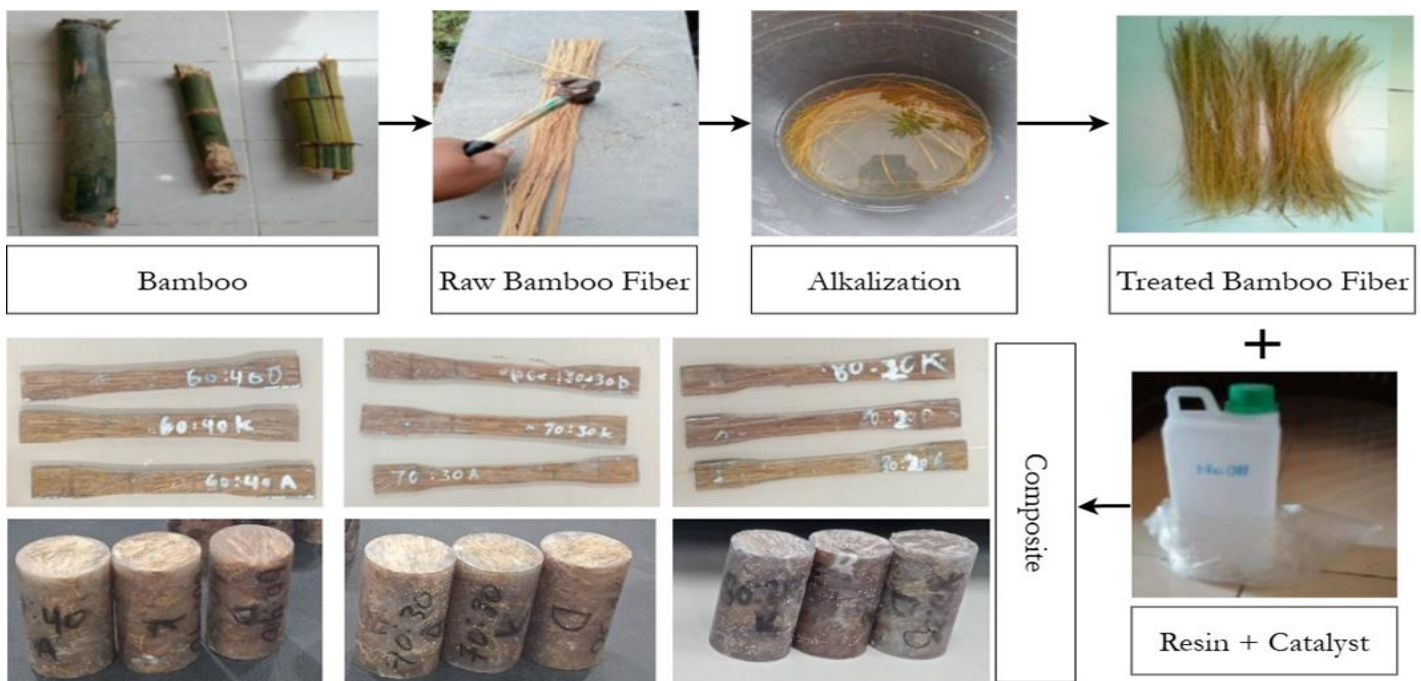


Fig. 3. Schematic representation of the fabrication of bamboo fiber composite.

To ensure accurate preparation of specimens, the fiber and resin were combined according to predetermined mass fractions (Table 3). The calculated mass of fiber and resin was determined based on mold volume and material densities, enabling consistent fabrication for tensile testing:

Table 3. Mass fraction composition of tensile and compressive test specimens, respectively

Code	Fiber mass (g)	Resin mass (g)
6040A	17.43 / 251.98	26.15 / 377.97
7030A	12.81 / 185.12	29.9 / 431.95
8020A	8.36 / 120.93	33.47 / 483.74
6040Y	17.43 / 251.98	26.15 / 377.97
7030Y	12.81 / 185.12	29.9 / 431.95
8020Y	8.36 / 120.93	33.47 / 483.74
6040T	17.43 / 251.98	26.15 / 377.97
7030T	12.81 / 185.12	29.9 / 431.95
8020T	8.36 / 120.93	33.47 / 483.74

The mold volume was first determined using Eq. (1).

$$V = P \times L \times T \quad (1)$$

Where V is the mold volume, P is the mold length, L is the width, and T is the thickness. The composite density was then calculated from the weighted average of fiber and resin densities Eq. (2) - Eq. (5).

$$\rho = (\% \text{ resin} \times \rho_{\text{resin}}) + (\% \text{ fiber} \times \rho_{\text{fiber}}) \quad (2)$$

The total mass of the composite specimen was obtained by Eq. (3).

$$m_{\text{total}} = V \times \rho \quad (3)$$

The resin mass fraction was determined by Eq. (4).

$$m_{\text{resin}} = (\% \text{ resin}) \times m_{\text{total}} \quad (4)$$

The fiber mass fraction was determined by Eq. (5).

$$m_{\text{fiber}} = (\% \text{ fiber}) \times m_{\text{total}} \quad (5)$$

2.5 Mechanical testing

2.5.1 Tensile and compressive test

Tensile properties of the bamboo fiber-polyester composites were evaluated according to ASTM D638 standards using a

Universal Testing Machine (MTS Model E43, USA). Dog-bone-shaped specimens were fabricated with dimensions of 165 mm × 19 mm × 3.2 mm, prepared in accordance with the mold geometry. Fig. 2 shows the dimensions of the tensile according to ASTM D638. The specimens were subjected to a constant crosshead speed of 10 mm/min until fracture occurred.

The compressive properties of the bamboo fiber-polyester composites were evaluated in accordance with ASTM D1021 using a Tensilon testing machine (Fig. 2). Cylindrical specimens with a diameter of 45 mm and a height of 75 mm were fabricated from each fiber-resin composition and tested under axial loading. The crosshead speed was maintained at a constant rate until a visible fracture or collapse of the specimen occurred.

During testing, load (N) and extension (mm) were recorded continuously, and the resulting data were used to construct stress-strain curves. From these curves, key mechanical parameters were determined, including tensile strength (σ), elongation at break (ϵ), and Young's modulus (E). Each test was repeated for three specimens per composition to ensure accuracy and reproducibility, and the average values were reported for analysis.

All specimens were tested at ambient laboratory temperature, 26°C. Before testing, samples were conditioned at room temperature for at least 24 h to minimize the influence of residual curing stresses.

The tests were conducted until specimen failure to characterize both tensile and compressive behavior. During tensile testing, the procedure was terminated immediately upon specimen fracture, which typically exhibited brittle failure modes characteristic of fiber-resin composites. In compressive testing, loading continued until visible crushing, cracking, or structural collapse occurred along the axial direction. The dominant failure modes under compression included brittle crushing and localized buckling, both commonly observed in short-fiber polymer composites. These fracture characteristics confirm the behavior expected from natural fiber-reinforced composites tested in accordance with ASTM D638 and ASTM D1021 standards.

2.5.2 Data analysis

All tests were performed in triplicate for each bamboo species and composition. The mean values were computed, and comparative analysis was conducted to determine the influence of fiber species and resin-fiber ratio on tensile behavior. Graphical plots (stress-strain and load-displacement curves) were used to interpret the experimental results and highlight performance differences among the composite groups. Statistical analysis was

performed to verify data consistency among replicates. For each composition, three samples were tested, and the mean, standard deviation, and Coefficient of Variation (CV) were calculated to assess the reliability of the results. The CV values were found to be within 5–8%, indicating acceptable repeatability of the experimental data in accordance with ASTM recommendations. [1–10].

3 Results and discussion

3.1 Tensile Test

The tensile behavior of the bamboo fiber-polyester composites was evaluated for the three bamboo species, apus (*Gigantochloa apus*), yellow (*Bambusa vulgaris*), and thorn (*Bambusa blumeana*), at resin-to-fiber ratios of 60:40, 70:30, and 80:20.

The results in Table 4 show a consistent trend in which the 60:40 composition produced the highest tensile strength for all species. Thorn bamboo achieved the maximum value of 81.94 MPa, followed by yellow bamboo with 75.34 MPa and apus bamboo with 71.49 MPa.

Table 4. Tensile strength of composites at different fiber ratios

Code	Tensile strength (MPa)	Composition improvement	Fiber type improvement
6040A	71.49	60.72	14.62
7030A	62.1	25.40	29.13
8020A	55.45	0	16.84
6040Y	75.34	44.97	8.76
7030Y	64.22	38.60	0
8020Y	58.1	0	0
6040T	81.94	95.79	0
7030T	70.15	60.93	6.95
8020T	71.49	0	24.18

Composition improvement (%) refers to strength gain relative to 80:20 composition; fiber type improvement (%) compares performance among species at identical ratios.

An increase in fiber fraction clearly improved tensile performance. In apus bamboo composites (Fig. 4), tensile strength rose by 60.72% when the fiber content increased from 20 to 40%.

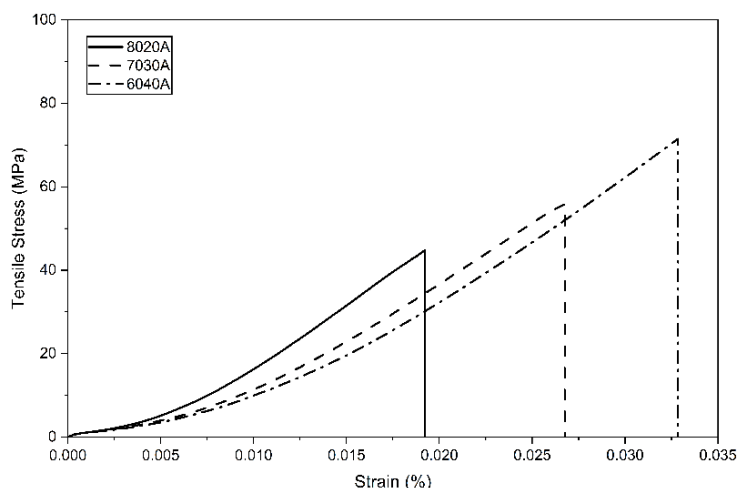


Fig. 4. Tensile stress-strain curves of apus bamboo composites.

A similar pattern occurred in yellow and thorn bamboo composites (Fig. 5 – Fig. 6), which showed improvements of 44.97 % and 95.79 %, respectively. These findings indicate that higher fiber loading enhances stress transfer between the fiber and the matrix, as also observed in [7].

Among all compositions, thorn bamboo (Fig. 6) consistently demonstrated superior strength. Its dense vascular bundles, thicker fiber walls, and higher culm density (approximately 0.88 g cm^{-3}) provide better stiffness and reduce crack propagation, as also observed in [6]. This microstructural advantage contributes to more

efficient load transfer, explaining the nearly 96% improvement compared with lower fiber fractions.

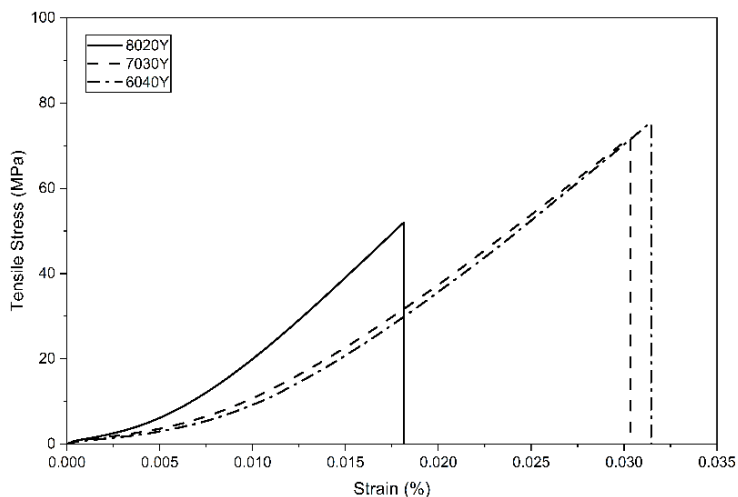


Fig. 5. Tensile stress-strain curves of yellow bamboo composites.

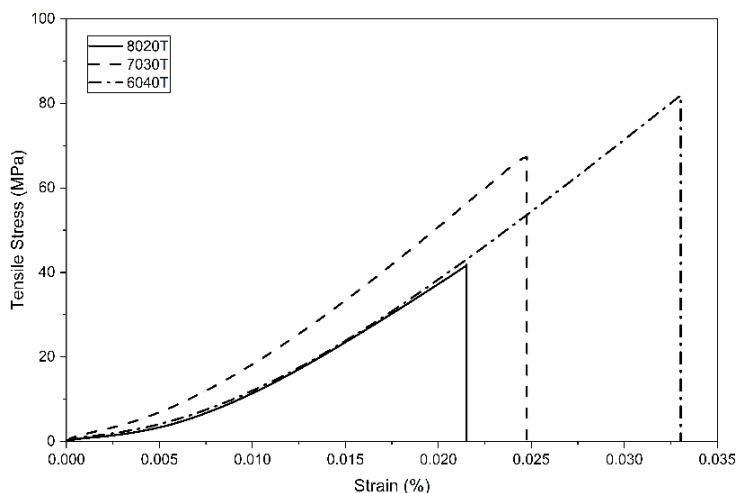


Fig. 6. Tensile stress-strain curves of thorn bamboo composites.

Fig. 7 presents the correlation between the bamboo fiber-to-polyester weight ratios (60:40, 70:30, and 80:20) and the corresponding mechanical properties, namely tensile strength (MPa, left Y-axis) and elastic modulus (GPa, right Y-axis). The analysis includes three local bamboo species: *Gigantochloa apus* (A), *Bambusa vulgaris* (Y), and *Bambusa blumeana* (T).

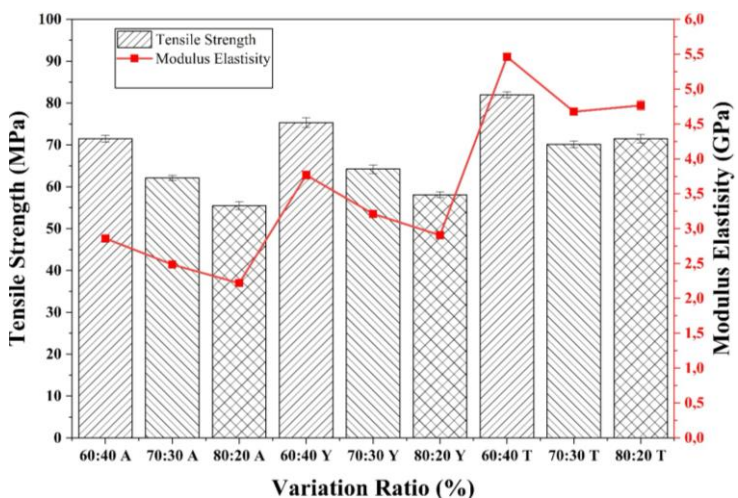


Fig. 7. Effect of composition ratio on tensile strength and elastic modulus.

A clear upward trend can be observed as the fiber proportion increases, where the 60:40 *B. blumeana* composite shows the greatest tensile strength of about 82 MPa and the highest elastic modulus near 5.6 GPa. This enhancement reflects the more

efficient stress transfer and improved bonding between the treated bamboo fibers and the polyester matrix, suggesting that the 60:40 configuration provides an optimal balance between load-bearing capacity and stiffness [9].

Differences among the bamboo species are evident in their mechanical responses. The *Bambusa blumeana*-reinforced composite demonstrates superior performance compared with *B. vulgaris* and *G. apus* at all fiber fractions, which can be attributed to its compact vascular bundle distribution, thicker cell walls, and greater culm density 0.88 g/cm³. These characteristics enhance internal cohesion, allowing stress to be more uniformly distributed throughout the matrix and delaying crack propagation under load [9]. Meanwhile, the 80:20 composition shows a noticeable decline in tensile and elastic properties, likely due to an excessive resin phase that restricts effective fiber engagement and introduces voids. The mechanical improvement observed at the 60:40 ratio aligns with the classical rule of mixtures, indicating that higher fiber incorporation increases stiffness up to a limit where fiber wetting and resin saturation begin to deteriorate [9].

The significant rise in tensile strength, approximately 96% for the 60:40 *Bambusa blumeana* composite, correlates strongly with earlier findings in natural fiber composite research. Lokesh et al. [4] documented that elevating the fiber loading to around 40% enhances tensile efficiency through improved interfacial stress transmission and matrix anchoring. Likewise, Abdullah et al. [5] reported similar tendencies, noting a 30–50% increase in tensile performance in bamboo-based epoxy composites when fiber content was increased. The consistent trend between the current investigation and these prior studies reinforces that the 60:40 composition produces the most favorable combination of tensile strength and modulus for bamboo–polyester composites [9]. Consequently, this ratio can be identified as the most effective reinforcement configuration for achieving superior stiffness and durability in sustainable, lightweight structural and automotive components.

A direct comparison of tensile strength across all fiber ratios highlights the significance of fiber volume fraction. Increasing the fiber fraction from 20 to 40% led to substantial improvements in strength, ranging from 45 to 96% depending on the species. This behavior follows the rule of mixtures, where the load-bearing contribution of the fiber increases with volume fraction until voids or poor impregnation appear.

At the same fiber ratio (Fig. 8), differences among species were also clear. Thorn bamboo outperformed yellow and apus bamboo by 14–29%, confirming the influence of fiber morphology [11]. Microstructural investigations from [8] show that thorn bamboo has more compact fiber bundles with low porosity, which limits microcracking and enhances stress distribution. In contrast, apus bamboo, with larger lumen diameters and lower fiber density, exhibited earlier onset of fracture.

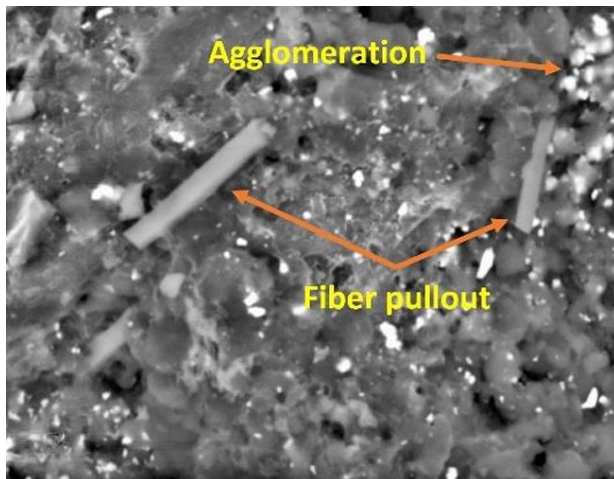


Fig. 8. Illustration of typical tensile failure and fiber rupture in natural fiber–reinforced composites [11].

Fracture surface observations further supported these findings. At the 60:40 ratio, failure was primarily governed by fiber rupture and cohesive separation within the matrix, indicating strong interfacial bonding between the fiber and resin. This agrees with the cohesive fracture behavior reported [3], where improved interfacial adhesion promoted fiber breakage instead of matrix delamination, confirming the effectiveness of alkali treatment.

3.2 Compressive test

The compressive strength results are summarized in Table 5. The 60:40 composites again displayed the highest strength for all bamboo types. Thorn bamboo achieved 9.11 MPa, followed by apus at 7.48 MPa and yellow at 7.20 MPa. These values are comparable to those reported in [5] and [9], confirming the reliability of the trend.

Table 5. Compressive strength of composites at different fiber ratios

Code	Compressive strength (MPa)	Composition improvement	Fiber type improvement
6040A	7.48	44.68	21.79
7030A	5.45	5.42	54.68
8020A	5.17	0.00	43.33
6040Y	7.2	29.26	26.53
7030Y	6.58	18.13	28.12
8020Y	5.57	0.00	33.03
6040T	9.11	22.94	0.00
7030T	8.43	13.77	0.00
8020T	7.41	0.00	0.00

Composition improvement (%) refers to strength gain relative to 80:20 compositions; fiber type improvement (%) compares performance among species at identical ratios.

When the fiber fraction was increased from 20 to 40%, compressive strength improved by 44.68% in apus (Fig. 9), 29.26% in yellow (Fig. 10), and 22.94% in thorn bamboo (Fig. 11). This increase reflects the greater confinement provided by the fibers, which support the resin and delay buckling. The enhanced mechanical interlocking and frictional resistance between treated fiber surfaces and the matrix contribute to the observed strength gain.

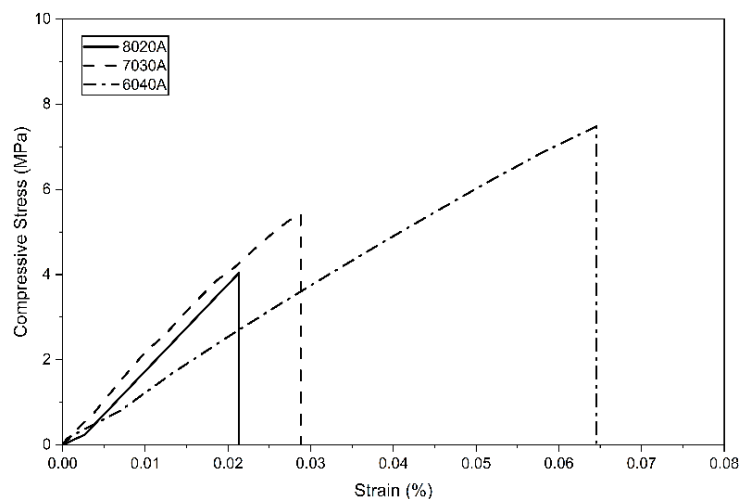


Fig. 9. Compressive stress-strain curves of apus bamboo composites.

Thorn bamboo composites (Fig. 11) exhibited the highest resistance to crushing and localized deformation. A similar interfacial load-transfer mechanism under compression was observed in [4], where enhanced fiber–matrix adhesion increased stiffness and delayed the onset of crushing. The compact fiber bundles and thicker secondary walls of *Bambusa blumeana* restricted lateral expansion during axial loading, improving

compressive strength [6]. In contrast, apus and yellow bamboo composites showed early matrix cracking, resulting in lower load-bearing capacity.

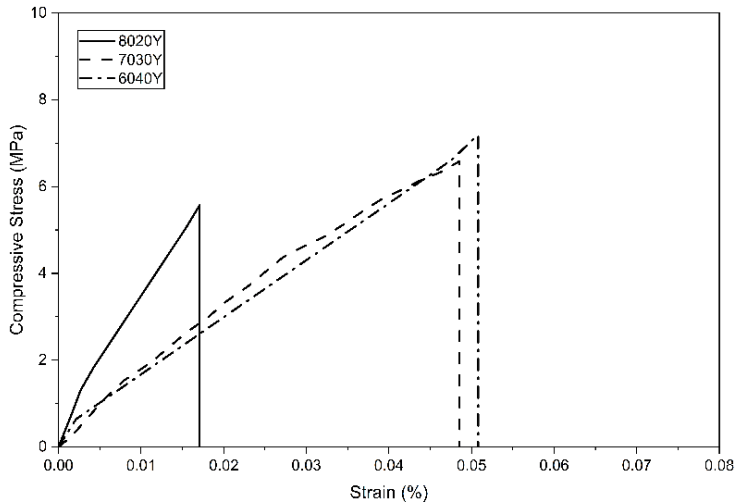


Fig. 10. Compressive stress-strain curves of yellow bamboo composites.

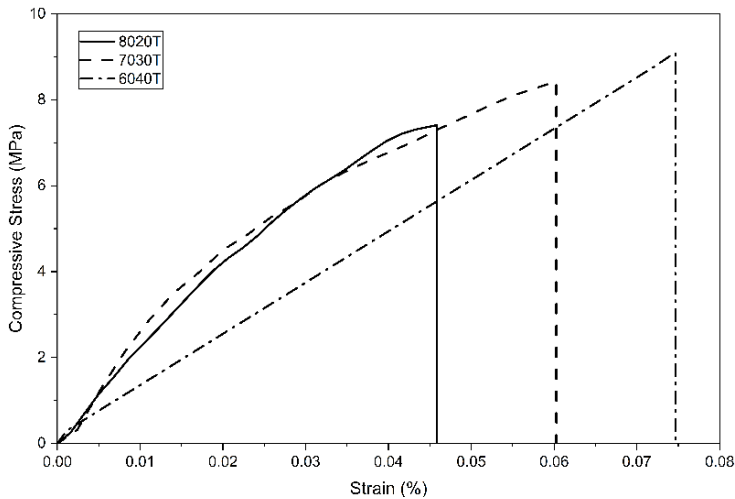


Fig. 11. Compressive stress-strain curves of thorn bamboo composites.

Fig. 12 presents the relationship between the bamboo fiber-to-polyester variation ratios (60:40, 70:30, and 80:20) and the corresponding compressive strength (MPa, left Y-axis) as well as modulus of elasticity (GPa, right Y-axis). Three bamboo species were evaluated, namely *Gigantochloa apus* (A), *Bambusa vulgaris* (Y), and *Bambusa blumeana* (T).

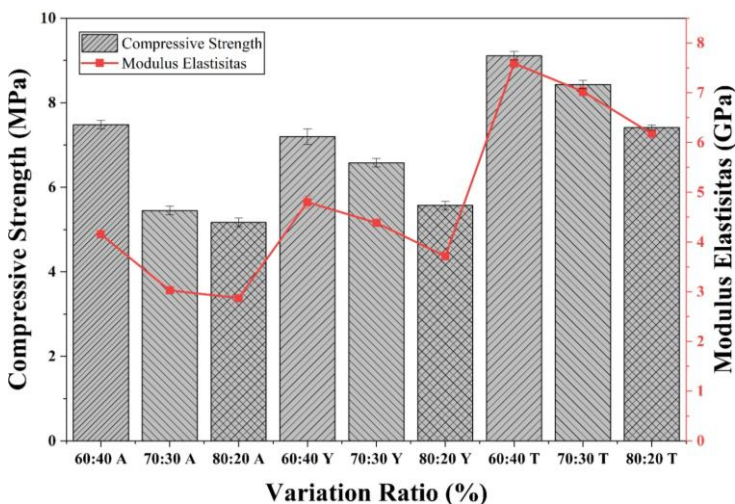


Fig. 12. Effect of composition ratio on compressive strength and elastic modulus.

The chart clearly demonstrates that increasing the fiber fraction to 40% enhances both the compressive strength and stiffness of the composites, with the 60:40T configuration yielding the highest values, approximately 9.0 MPa for compressive strength and 7.8 GPa for the elastic modulus. This finding indicates that the combination of higher fiber loading and the dense microstructure of *B. blumeana* improves stress distribution under compressive loading and enhances the interfacial bond between fiber and matrix [9].

Distinct variations in compressive performance among bamboo species are evident. The *B. blumeana* composites consistently outperform *B. vulgaris* and *G. apus* due to the species' higher fiber wall thickness and more compact vascular bundles, which contribute to greater resistance against compressive deformation [9]. Meanwhile, the 80:20 composition shows a noticeable reduction in both compressive strength and modulus, primarily due to insufficient fiber reinforcement and excessive resin volume that promote local buckling and void formation under load. The enhanced modulus observed at 60:40 is consistent with the rule of mixtures, where higher fiber incorporation increases stiffness until poor impregnation or weak bonding offsets the benefit [9]. Thus, the 60:40 fiber-resin ratio emerges as the most effective balance for optimizing compressive performance across all bamboo species.

The influence of fiber content on compressive performance was evident across all species. Increasing the fiber ratio enhanced strength by up to 45% for apus bamboo. However, the improvement was smaller for the thorn bamboo because its dense structure already provides high compressive resistance even at lower fiber loading.

Comparing the three species, thorn bamboo consistently produced higher compressive values, outperforming apus and yellow by 21–33%. Its dense vascular bundle structure and thicker fiber walls enable better load transfer and prevent premature buckling, which is consistent with the results discussed in [8].

The stress-strain responses confirm that the 60:40 specimens exhibited uniform deformation before crushing, whereas the 80:20 specimens failed abruptly. Similar failure patterns were also consistent with previous observations in [9].

3.3 Comparison with previous experimental findings

The mechanical results obtained in this study demonstrate that bamboo fiber composites made from Langsa bamboo species can perform as effectively as other bamboo fiber systems reported in recent literature. The tensile strength of 81.94 MPa for thorn bamboo surpasses the 41–55 MPa range reported in [7] and approaches the 80–85 MPa achieved in [8]. The maximum compressive strength of 9.11 MPa is also comparable to the 8.4–9.5 MPa reported in [5].

Three key factors explain these superior outcomes. First, the microstructural density of thorn bamboo promotes greater stiffness and resistance to axial deformation. Second, alkali treatment improved fiber-matrix bonding by increasing surface roughness and removing hemicellulose, enabling more effective stress transfer. Third, the 60:40 fiber-to-resin ratio optimized interfacial area while minimizing voids, ensuring uniform load distribution.

Failure observations across both tension and compression revealed cohesive fracture dominated by fiber rupture, local buckling, and matrix cracking. These mechanisms are consistent with previous microstructural studies of dense bamboo composites. Overall, the results confirm that locally available *Bambusa blumeana* offers strong, lightweight, and renewable reinforcement potential comparable to leading bamboo species used in structural composite applications.

4 Conclusions

This study investigated the tensile and compressive behavior of bamboo fiber-reinforced polyester composites fabricated from three locally available bamboo species in Langsa, Aceh:

Gigantochloa apus (apus), *Bambusa vulgaris* (yellow), and *Bambusa blumeana* (thorn). Resin-to-fiber ratios of 60:40, 70:30, and 80:20 were tested to determine the influence of composition and species on mechanical performance. The results demonstrate that both fiber type and fiber fraction strongly affect mechanical strength. The *B. blumeana* composite with a 60:40 resin-to-fiber ratio achieved the highest tensile strength of 81.94 MPa, representing a 95.8% improvement over the 80:20 composition and about 29% higher than *B. vulgaris* at the same ratio. The compressive strength of 9.11 MPa for *B. blumeana* also showed a 22.9% improvement compared with lower-fiber specimens. These increases are attributed to higher fiber density, compact vascular structure, and improved interfacial bonding achieved through 5% NaOH surface treatment. In summary, the 60:40 resin-to-fiber ratio yielded the optimal balance between fiber engagement and resin cohesion. The study highlights the mechanical feasibility of Langsa bamboo composites as sustainable, lightweight reinforcements for engineering use. Future research should incorporate microstructural analysis, fiber orientation effects, and hybrid configurations to further enhance performance and reliability.

Acknowledgments

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