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The Strength of Several Types of Bamboo from Around Palu City as a Substitute for Wood in Construction

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Abstract: The use of bamboo as a substitute for wood for construction needs is increasing along with the decreasing availability of wood. Meanwhile, on the other hand the strength and durability of bamboo are different from wood, so it is necessary to conduct research to determine the strength of bamboo before it is used as a raw material for construction needs to replace wood. Based on this, this study aims to determine the types of bamboo found around Palu City and to test the strength of bamboo as a substitute for construction wood or other uses. This study was conducted in July–October 2025 at the Forestry Laboratory and Mechanical Engineering Laboratory of Tadulako University. The raw materials used in this study were types of bamboo that are widely found around Palu City aged 4–5 years. The tools used in this study were handsaws, calipers/vernier calipers, ovens, digital scales, and Universal Testing Machines (UTM) for testing the mechanical properties of bamboo. The results showed that the type of bamboo and the position of the base, middle, and tip affected the water content and density of the bamboo studied. The density value of bamboo showed a tendency from the base to the tip of bamboo; the value became higher. The flexural strength of bamboo batu is equivalent to wood of strength class IV, and the flexural strength of bamboo betung and bamboo tali is higher than the flexural strength of wood of the same strength class. The shear and tensile strength values of bamboo are not affected by the type and axial position. The tensile strength values of bamboo studied have met the allowable stress limit of bamboo for tensile stress.

Keywords: Bamboo; Mechanical properties; Physical properties

Introduction

It is estimated that around 159 species of bamboo exist in Indonesia out of a total of 1,250 species of bamboo found worldwide. Research by Evita [2015] on the Diversity and Spatial Distribution of Bamboo Species in Sulawesi (Long et al., 2023; Allo et al., 2024). This study revealed 32 species of bamboo from 9 genera on the island of Sulawesi and the surrounding small islands. Research by Yuan et al. (2017), Ahmad et al. (2025), in the Southeast Sulawesi region showed that there are 13 species of bamboo as seed sources: Gigantochloa apus, Bambusa arundinacea wild, Bambusa blumeana, Dendrocalamusasper Schult. F. Backer, Bambusa atralindl, Bambusa vulgaris vittata, Melocana baccifera, Asparagus cochinchinensis, Bambusa multiplex, Bambusa vulgaris, Dinochlo amalayana, Gigantochloa atter, and Schizostachyum mosum (Rathour et al., 2022; Kumar et al., 2023).

The most widely distributed bamboo as seed source is Gigantochloa apus (Apus Bamboo), and the least widely distributed is Dinochloa malayana. Traditional uses of bamboo are diverse, ranging from household furnishings, furniture, kitchen utensils, craft materials, pulp and paper raw materials to house and building construction (Li et al., 2023; Wulf et al., 2024). Bamboo culms are very commonly used as the main material for making various Various products, such as building

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materials, furniture, and household items. Bamboo can be processed using both conventional and traditional methods and using machine production technology (Patel et al., 2025; G. Wang et al., 2025). The structure of bamboo stems has a compressive strength comparable to that of wood, making it a viable alternative to wood (Adebowale & Agumba, 2025; Kelkar et al., 2023).

Beyond its traditional uses, bamboo holds immense potential in supporting a green economy and sustainable development (Iroegbu et al., 2021). Bamboo's rapid growth, adaptability to a wide range of soil types, and role in rehabilitating degraded land make it a superior renewable resource (Singh et al., 2020). In the context of climate change mitigation, bamboo is known for its high carbon dioxide (CO_2) absorption capacity, even surpassing that of some hardwood trees (Pan et al., 2023, 2025). In the modern era, research has shifted to increasing bamboo's added value through product innovation. Products developed are no longer limited to its natural form, but also include engineered bamboo products such as plybamboo, laminated veneer lumber (LVL), and bamboo composite materials (Sewar et al., 2024; Jafarnia et al., 2025). This development allows bamboo to be used in more sophisticated and durable building structures, positioning it as a competitive substitute for wood in the global construction industry. Furthermore, bamboo fiber has found applications in textiles, cosmetics, and even biomass for energy (Awogbemi et al., 2025; Xu et al., 2023).

Despite bamboo's immense potential, challenges remain, including susceptibility to pests and fungi, and a lack of standardization in processing and construction. To address this, further research is needed focusing on environmentally friendly preservation technologies, selecting superior disease-resistant varieties, and optimizing cultivation techniques to increase productivity are crucial to ensure their optimal and sustainable use. Based on the background above, research was conducted with the aim of determining the types of bamboo found around Palu City and testing the strength of bamboo as a substitute for construction wood or other uses.

Method

Time and Place

This research was conducted from July to October 2025 at the Forestry Laboratory and Mechanical Engineering Laboratory of Tadulako University.

Tools and Materials

The raw materials used in this research were 4-5 years-old bamboo species commonly found around Palu City. The tools used in this study included a handsaw, calipers/vernier calipers, an oven, a digital scale, and a Universal Testing Machine (UTM) for testing the bamboo's mechanical properties.

Research Procedure

Harvesting Several Bamboo Species

Data collection was conducted through primary data collection in the field. The bamboo species found were identified by genus and species based on herbarium records and bamboo identification books. Documentation of the bamboo harvesting in the field can be seen in the following image:

Preparation for Test Samples

The bamboo species commonly found around Palu City were collected from 4–5-year-old clumps. Five culms of each bamboo species were taken. Each bamboo cane was divided into base, middle, and tip sections. Test samples were prepared according to the standards used, referring to research by Li et al. (2024).

Physical Property Testing

Property test samples were prepared using the following formula:

$$KA = \frac{BKU - \mathrm{BKT}}{\mathrm{BKT}} \times 100\ \% \quad (1)$$

Density

Density is the ratio of the mass of bamboo (BKU) to the volume of bamboo (VKU), both in air-dry conditions. The density value can be obtained using the formula:

$$\mathrm{BJ} = \frac{BKU}{VKU} \quad (2)$$

Mechanical Property Testing

Shear Test

The shear strength test for parallel-grain bamboo in this study was modified using bamboo strips, adapting to the laboratory equipment. The shear strength of parallel-grain bamboo can be calculated using the equation:

$$\tau = V / A \quad (3)$$

Where: τ = shear strength (N/mm^2); V = maximum shear force (N); A = cross-sectional area of the test specimen (mm^2).

Tensile Test

Tensile strength can be calculated using the formula:

$$\sigma_{\mathrm{ult}} = \frac{F_{\mathrm{ult}}}{A} \quad (4)$$

Where, σult = tensile strength; Fult = maximum load at fracture (N); A = cross-sectional area of the test specimen (mm^2).

Flexural Strength (MoE) and Fracture Strength (MoR)

The MoE and MoR test samples refer to BS (British Standard) 373:1957. The MOE and MOR test samples measure 30 cm (length) x 2 x m (width), while the thickness depends on the thickness of the bamboo. All test samples were made from knot-free bamboo sections, using only the skin. MOE (Modulus of Elasticity) is the ability of a material to withstand a load without permanent deformation, while MOR (Modulus of Rupture) is a measure of a material's strength when subjected to the maximum load that causes damage (Yankelevsky & Packer, 2021). MoE and MoR values are calculated using the following formula:

$$MOE = \frac{P' L^3}{4\Delta' b h^3} \quad (5)$$

Where, MOE= Modulus of Elasticity (kg/cm^2); MOR= Modulus of Fracture (kg/cm^2); P= Maximum Load (kg); P'= Load at the Limit Proportion (kg); L= Support Span (cm); Δ'= Deformation at the Limit Proportion (cm); b= Width (cm); h= Thickness (cm).

Data Analysis

The test data were analyzed using a factorial RAL with five replications. Analysis of Variance (ANOVA) was used to determine the differences in the effects between the tested levels.

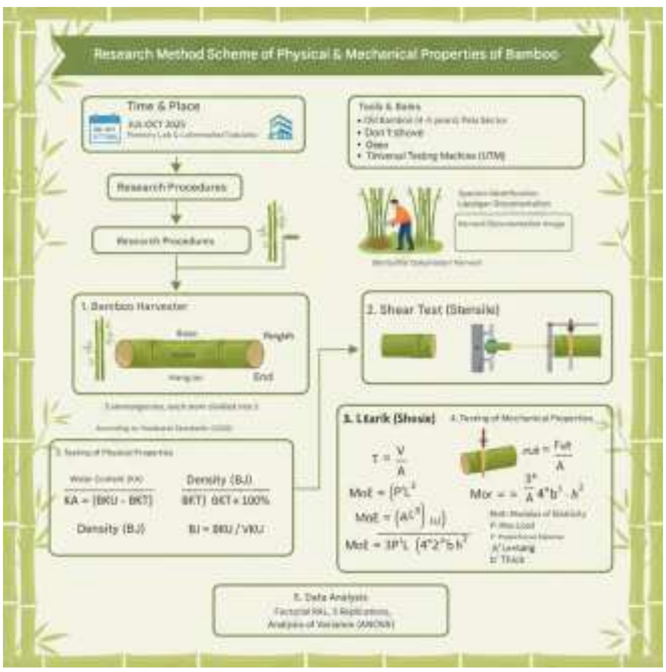

Figure 1. Method scheme

Results and Discussion

Physical Properties of Bamboo

Water Content

The moisture content of the bamboo studied, namely betung bamboo, batu bamboo, and tali bamboo, can be seen in the following Figure:

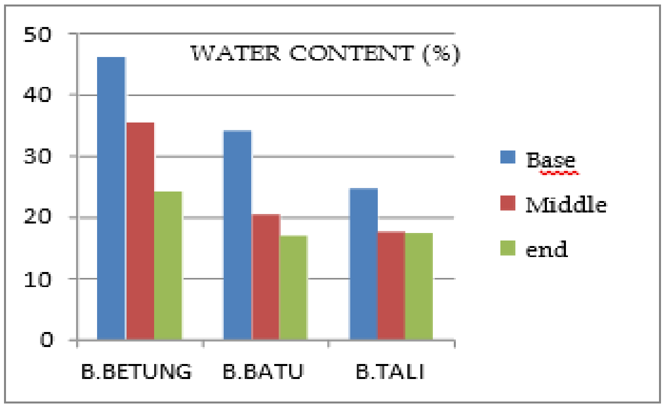

Figure 2. Moisture content diagram of several bamboo types in the axial direction

The high moisture content of the bamboo studied, ranging from 17 to 45%, is due to the fact that the moisture content calculations in this study were conducted approximately 10 days after felling, so it had not yet reached air-dry moisture content. The diagram shows that the moisture content of the bamboo at the base is higher than that of the middle and decreases towards the tip. This is likely due to the thickness of the bamboo wall at the base and its thinning towards the tip. Thicker walls contain more cellular components, such as cellulose and hemicellulose, which can bind with water, resulting in a higher moisture content. This aligns with the statements of (Khajouei-Nezhad et al., 2023; Irawan et al., 2025) statement that the thicker the bamboo blade, the greater the cellulose and hemicellulose content, which can increase the water content at the base of the bamboo due to the long, thin-walled fibers and large diameter. The opposite occurs at the tip. The research results also showed that betung bamboo had the highest water content, followed by batu bamboo, and the lowest water content was found in tali bamboo. This is due to the bamboo's thickness, with betung bamboo ranging from 0.80 to 1.30 cm, batu bamboo 0.60 to 0.90 cm, and tali bamboo 0.60 to 0.70 cm.

The thicker the bamboo, the greater the number of cells, meaning cellulose and hemicellulose, which can bind with water. Analysis of variance (ANOVA) results showed that both bamboo species, their axial location (base, middle, and tip), and the interaction between the two significantly affected the bamboo's water content. Further tests showed that batu bamboo and tali bamboo had the same effect on water content, but both had a different effect on betung bamboo. Axially, the positions of the base, middle, and tip each had a different effect on bamboo water content. According to Awotwe-Mensah et al. (2023), Zhan et al. (2022), bamboo water content is influenced by age, bamboo species, and harvest season. According to Roszyk et al. (2024), Li et al. (2022), for further use, a suitable water content of bamboo is around 10–11% so that shrinkage and swelling are more stable. This indicates the need for a drying process for bamboo, either naturally or artificially, so that a lower water content can be achieved. However, considering that Indonesia has a tropical climate and relatively high humidity, an artificial drying process is needed so that the bamboo can reach a water content of 10–11%.

Density

Bamboo density calculations were performed under kiln-dry conditions. The density values of the bamboo studied ranged from 0.70 to 0.90 g/cm3 and tended to be relatively similar at the base and middle, but slightly higher at the tips, as seen in the Figure below:

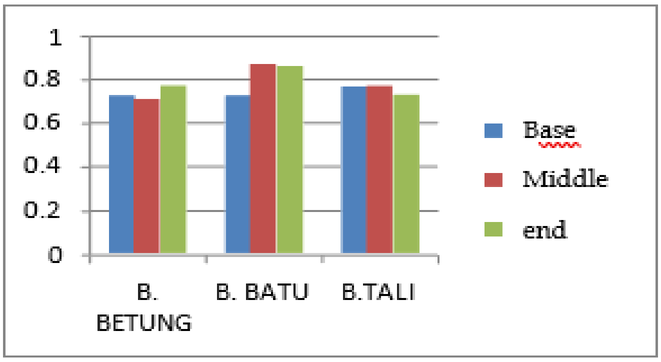

Figure 3. Density diagram of several bamboo species in the axial direction

The diagram shows a tendency for density values to increase from the base to the tip. The lower density at the base compared to the tip may be due to the higher silica content at the tip of the bamboo as cited in Ma et al., (2024), Saffer et al. (2023), Analysis of variance results show that differences in bamboo species significantly affect density (probability 0.02 is less than the alpha value of 0.05), while differences in the position of the base, middle, and tip have no effect (probability 0.09 is greater than 0.05). Further testing using Duncan's test showed that betung bamboo had no difference in density compared to tali bamboo, but showed a difference compared to batu bamboo. Further testing was not performed on the position of the base, middle, and tip because the ANOVA results showed no effect on bamboo density. This is due to the relatively uniform solid content that influences density, as stated by Wang et al. (2024), Liang et al. (2020), who stated that the amount of solids contained within cells is relatively uniform. According to Li et al. (2025), the specific gravity of bamboo ranges from 0.50 to 0.90 g/cm^3, which is relatively similar to the results of this study, which range from 0.6 to 0.9 g/cm3. Compared to wood strength classes, a specific gravity of 0.60-0.90 g/cm^3 falls into strength class II. Das et al. (2025), Osezuah et al. (2025), state that bamboo has a very high strength-to-weight ratio, making it efficient and effective for use as a building material.

Mechanical Properties of Bamboo

Flexural Strength (Moe)

The results of the MOE calculation show that batu bamboo has a lower MOE value, with an average of 475.01 kg/cm^2, compared to betung bamboo with an average of 1741.36 kg/cm^2 and tali bamboo with an average of 1690.19 kg/cm^2, as shown in the following Figure:

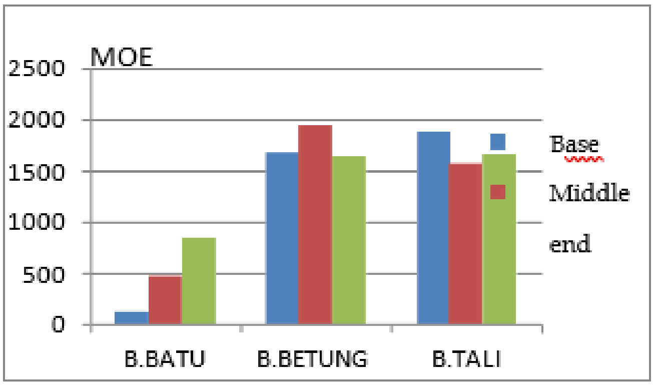

Figure 4. Flexural strength diagram of several bamboo species in the axial direction

When compared to wood strength classes, the flexural strength of batu bamboo is equivalent to wood strength class IV (350-500 kg/cm2), while the flexural strength of betung bamboo and tali bamboo is greater than that of wood strength class I (≥ 1100).

Brain Strength of Bamboo

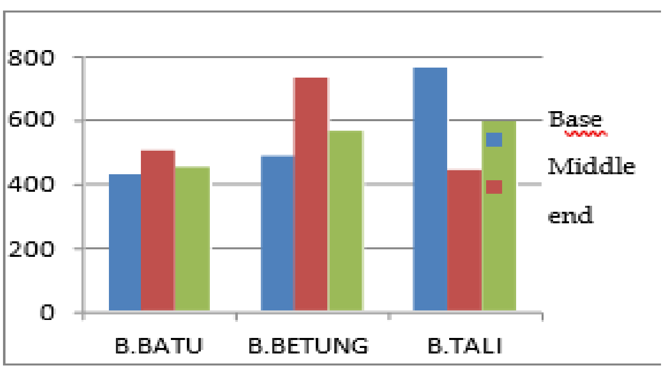

Figure 5. Fracture strength diagram of several bamboo species in the axial direction

The results of the fracture strength study showed that batu bamboo had a lower fracture strength value than betung bamboo and tali bamboo, as shown in Figure 4. The results of the analysis of variance show that neither the type of bamboo nor the location of the base, middle, or tip affected the compressive strength (MOR) of the studied bamboo.

Bamboo Shear Strength

The average shear strength of the studied bamboo ranged from 4.09 to 9.70 MPa, as shown in the following Figure:

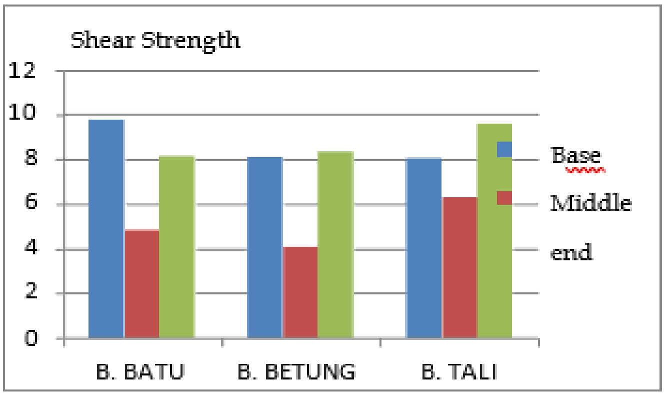

Figure 6. Shear strength diagram of several bamboo species in the axial direction

The results above indicate that tali bamboo has a higher average shear strength, and the strength tends to be almost the same at the base, middle, and tip. Although the analysis of variance (ANOVA) results show that neither the type of bamboo nor the position of the base, middle, and tip significantly affects the bamboo's shear strength, when compared to the research results of Seixas et al. (2024), which showed that the shear strength of unpreserved petung bamboo with nodes was 8.06 MPa and internodes 7.41 MPa, the shear strength values for betung bamboo (petung) in this study were relatively similar, ranging from 4 to 8 MPa.

Bamboo Tensile Strength

The results of the tensile strength calculations for the bamboo studied showed average values ranging from 61.84 to 171.02 MPa. Tali bamboo had a higher tensile strength than betung bamboo, with the lowest tensile strength being found in batu bamboo, as shown in Figure 7.

The results of the analysis of variance indicate that the type of bamboo and the position at the base, middle, and tip do not significantly affect the tensile strength of the bamboo. However, the results showed that the average tensile strength was higher for tali bamboo, followed by betung bamboo, and the lowest for batu bamboo. Compared to the tensile strength limit requirement of 98.1–392 MPa and the allowable stress limit for bamboo of 29.42 MPa (G. Wang et al., 2025), the tensile strength values of the bamboo studied met these limits. Bamboo has a unique biological structure that makes it an exceptional natural engineering material. A thorough understanding of bamboo's anatomy and chemical composition is essential to maximize its use in non-traditional applications, particularly as a wood substitute.

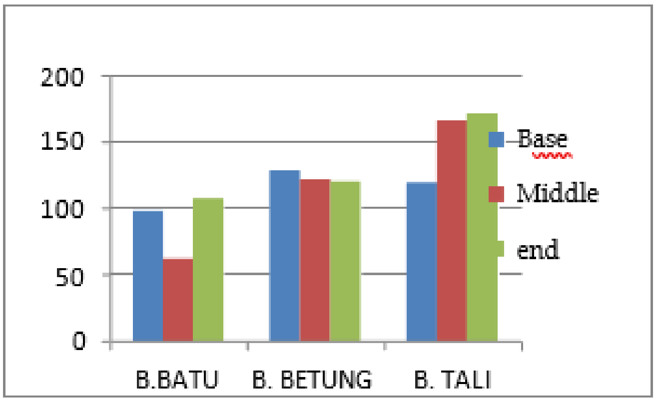

Figure 7. Tensile strength diagram of several bamboo species in the axial direction

Culm Anatomy and Structure

The bamboo culm is a hollow tube divided by dense nodes, providing strength and resistance to buckling (Adier et al., 2023; Al-Rukaibawi et al., 2021). The culm wall consists of ground tissue with vascular bundles embedded within it. The distribution of vascular bundles shows that the concentration of vascular bundles, which are reinforcing fibers, is much higher in the outer portion of the culm wall and decreases toward the inner portion (pith). This uneven distribution creates a strength gradient—the outer portion of the bamboo is much stronger and stiffer than the inner portion. This significantly contributes to its superior mechanical properties.

Primary Chemical Composition

Like wood, bamboo's strength comes from three primary chemical components that make up the cellulose matrix: Cellulose: This is the primary structural polymer, crystalline in nature, and provides the bamboo fiber with very high tensile strength. Hemicellulose (Hemicellulose): Is a non-crystalline polymer that acts as a filler matrix and helps transfer pressure between fibers; Lignin (Lignin): Functions as a natural adhesive that binds cellulose and hemicellulose fibers, providing stiffness and resistance to compression in the material (Voutetaki & Mpalaskas, 2024; Mahmud et al., 2023).

Conclusion

The results of the study show several things that can be concluded as follows: The type of bamboo and the position of the base, middle, and tip affect the water content and density of the bamboo studied; The density value of bamboo shows a tendency from the base towards the tip of the bamboo, with the value increasing; The flexural strength of bamboo batu is equivalent to wood of strength class IV, and the flexural strength of bamboo betung and bamboo tali is higher than the flexural strength of wood of strength class I; The shear and tensile strength values of bamboo are not affected by the type and axial position; The tensile strength value of the bamboo studied meets the allowable stress limit of bamboo for tensile stress.

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Author Contributions
Conceptualization; E.; methodology; validation; A; formal analysis.; investigation; S. A resources; data curation; M...; writing—original draft preparation; A.; writing—review and editing.; visualization; R. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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