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ORIGINAL ARTICLE

Exploring the Prospects of Young *Bambusa vulgaris* Properties for Sustainable Bamboo Plastic Composites

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ABSTRACT - This study delves into the properties of young *Bambusa vulgaris* and the fabrication of a bamboo/LDPE plastic composite, exploring their potential applications. Young bamboo, known for its rapid growth, strength, and versatility, emerges as an eco-friendly alternative as a raw material for engineered products. The study further integrates Low-Density Polyethylene (LDPE) with bamboo, opening avenues for sustainable materials in construction, furniture, and automotive industries. The physical and mechanical properties of *Bambusa vulgaris* are investigated according to the ISO standards, revealing variations in moisture content, density, swelling, and bending strength across different portions of the bamboo culm. Microstructure analysis enhances this understanding, offering insights into fiber arrangement and cell wall maturity. As followed the ASTM standards, the fabrication of bamboo plastic composites involves careful consideration of LDPE and bamboo fiber ratios, with the 50:50 ratio exhibiting optimal tensile and bending strength. The study emphasizes the importance of choosing appropriate ratios for specific applications, striking a balance between flexibility and strength. These findings contribute to a comprehensive assessment of bamboo's suitability for diverse applications, guiding the optimization of composite materials for enhanced performance and sustainability in various engineering and manufacturing contexts.

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INTRODUCTION

Bamboo, a member of the grass family Poaceae, has been a vital and versatile resource for various cultures globally for thousands of years [1]. Known for its remarkable strength, flexibility, and rapid growth, bamboo is a fast-growing plant with some species capable of growing several feet in a single day [2]. This unique feature, along with its eco-friendly properties, has positioned bamboo as a sustainable alternative in various industries [3]. The prospective outlook for young bamboo is highly promising across diverse sectors, driven by its unique characteristics and sustainable qualities [4]. In construction, young bamboo's rapid growth, strength, and flexibility position it as an eco-friendly alternative for bamboo craft and housing structures [5]. Young bamboo's also potential in bioenergy production is gaining traction, as its shoots can be utilized as a renewable energy source [6]. The fast growth of young bamboo makes it a significant player in carbon sequestration, aiding in climate change mitigation [7]. Rural communities benefit from bamboo cultivation, offering income opportunities through relatively quick harvest cycles [8].

Low-density polyethylene (LDPE) is a versatile polymer renowned for its unique properties, commonly finding application across various industries [9]. Chemically, LDPE is composed of long chains of ethylene monomers, with a production process involving high pressure and temperatures, resulting in a low-density, branched structure [10]. Environmental considerations include LDPE's recyclability, although its recycling rates are often lower compared to other plastics [11]. Ongoing efforts aim to enhance recycling

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technologies and improve the sustainability of LDPE [12]. While LDPE serves diverse industrial needs, the focus on environmental impact underscores the importance of advancing recycling practices and exploring eco-friendly alternatives in the ongoing quest for sustainable materials [13].

The integration of Low-Density Polyethylene (LDPE) and bamboo in composite materials presents a range of promising opportunities across various industries [11]. This innovative combination capitalizes on the unique properties of both materials, offering sustainable alternatives for diverse applications [8]. In construction, LDPE bamboo composites can be utilized to create eco-friendly materials such as boards and panels [14]. The synergy of LDPE's durability with bamboo's strength produces robust construction components, providing sustainable alternatives to conventional materials [15]. Furniture manufacturing also stands to benefit, as the flexibility and formability of LDPE bamboo composites enable the creation of aesthetically pleasing and sustainable furniture items [16].

In this study, the properties of young bamboo were investigated and the bamboo/LDPE plastic composite was fabricated. The different ratios of composition were set and the strength performance was tested according to the ASTM standard.

MATERIALS AND METHODOLOGY

Moisture Content

The moisture content was conducted based on the International Organization for Standardization ISO 3130-1977(I). The air-dry (AD) samples were weighed and dried in the oven at 103°C ± 2°C for 24 hours with three replications. The moisture content was calculated using the formula as shown in Equation 1:

Moisture Content (MC), % =

$$\frac{\text{Air dry weight (AD)} - \text{Oven dry weight (OD)}}{\text{Air dry weight (AD)}} \times 100 \qquad (1)$$

Basic Density and Density

Density is defined as the mass per unit volume. The moisture content (MC) of the sample was conditioned at 12%, and basic density was described as the mass per unit volume as the sample reached its constant weight. The sample was sliced into 25 mm x 25 mm x bamboo thickness based on the International Organization for Standardization ISO 3131-1975.

$$\text{Density, Kg/m}^3 = \frac{\text{Mass sample at 12\% of MC (Kg)}}{\text{Volume of sample (m}^3\text{)}} \qquad (2)$$

$$\text{Basic density, Kg/m}^3 = \frac{\text{Oven dried weight (Kg)}}{\text{Volume of sample (m}^3\text{)}} \qquad (3)$$

Thickness Swelling and Water Absorption

For thickness swelling analysis, the sample was cut into 50 mm x 50 mm x bamboo thickness based on the International Organization for Standardization ISO 9424:2003. For water absorption determination, the weight of air-dried samples was measured, followed by the immersion of samples in water for 24 hours. The method was obtained from EN 317, 1993. The calculation formulas are as follows:

$$\text{Water Absorption, WA} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \qquad (4)$$

$$\text{Thickness Swelling, TS} = \frac{\text{Final thickness} - \text{Initial thickness}}{\text{Initial thickness}} \times 100 \qquad (5)$$

Bending Strength

The bending strength test was used to determine the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). The single-point bending determination was performed on bamboo species samples with a dimension of 20mm x 380mm x thickness of bamboo based on the International Organization for Standardization (ISO).

Light Microscopy (LM)

The bamboo was cut into a dimension cross section 10mm x 10mm x thickness (depending on the species of bamboo thickness) as a sample size. Then, the samples were directly analyzed and photographed by using light microscopy (Model Olympus SZX9, Olympus Optical, Japan).

Scanning Electron Microscopy (SEM)

The SEM micrographs were taken from a sample cross-section of 5mm x 5mm size from the sample block [17]. The samples with dry conditions were coated with gold by an ion sputter coater (Polaron SC515, Fisons Instruments, United Kingdom). Subsequently, the specimens were visualised by Scanning Electron Microscope (LEO SUPRA 55 VP, Field Emission SEM, Carl-Zeiss, Oberkochen, Germany).

Bamboo Plastic Composite Fabrication

Bamboo plastic composite fabrication was conducted at the Composite Laboratory, University of Technology Sarawak. The bamboo obtained from STIDC plot research at Sabal, Sarawak was oven-dried at 103±2 °C for 24 hours before grinding and sieved for 0.5-1.5 cm of fiber length. Low-density polyethylene (LDPE) was used as a plastic content. Then, 8% wt Urea-Formaldehyde (UF) adhesives are mixed to improve the bonding of composite residues.

In the manufacturing process, the composite was formed at a temperature of 190°C, and 3 Mpa pressure. The mould volume is 20 cm x 20 cm x 0.5 cm and the target density of the composite fabrication is 1300 kg/m³.

Mechanical Testing for Composite Fabrication

Test samples were prepared using a hot press machine, with each parameter tested thrice, resulting in a total of 36 samples. Tensile strength assessments were conducted at a rate of 5 mm/min, following ASTM D638 guidelines, while flexural strength tests were performed at a speed of 3 mm/min, adhering to ASTM D790 standards. A Hegewald & Peschke universal tensile machine, equipped with a 10 kN test table capacity, facilitated both tests. Every formulation underwent testing in triplicate, and the mean values were calculated to ensure accuracy and reliability in the results. The repetition of tests and adherence to standard procedures contribute to the robustness of the findings and enhance the credibility of the study.

RESULTS AND DISCUSSION

Determination of Physical and Mechanical Properties

The analysis of the physical and mechanical properties of *Bambusa vulgaris* reveals important insights into the characteristics of different portions of the bamboo culm as represented in Table 1. Moisture content increases gradually from the bottom (62.82%) to the top (67.66%), suggesting that the upper portion may be more prone to changes in environmental conditions. Basic density follows a decreasing trend from the bottom (386.07 kg/m³) to the top (280.09 kg/m³), indicating variations in inherent mass across the bamboo culm. The overall density, including voids, also decreases from the bottom (916.96 kg/m³) to the top (628.57 kg/m³). This reduction in density may impact the mechanical properties of the bamboo, with potential implications for its structural applications [2; 6; 17].

Thickness swelling and water absorption percentages provide insights into the bamboo's dimensional stability. The top portion exhibits higher thickness swelling (2.69%) and water absorption (34.03%) compared to the bottom and middle portions. This indicates that the upper part of the bamboo may be more susceptible to swelling and moisture absorption, potentially affecting its structural integrity and long-term durability [18].

Examining the bending strength properties, the Modulus of Rupture (MOR) for bending strength decreases from the bottom (65.99 MPa) to the top (46.68 MPa). This suggests that the bottom portion may possess higher resistance to bending stress. The Modulus of Elasticity (MOE) for bending strength, however, shows fluctuating values across portions. The top portion exhibits lower stiffness (11920.23 MPa), while the middle portion has the highest stiffness (12382.91 MPa). These variations highlight the importance of considering specific portions of *Bambusa vulgaris* for different applications, taking into account their distinct mechanical characteristics [19; 20].

In conclusion, the comprehensive examination of moisture content, density, swelling, water absorption, and bending strength properties across different portions of *Bambusa vulgaris* provides valuable information for understanding its suitability for various applications. These insights are crucial for optimizing the use of bamboo in construction, furniture, and other engineered products, considering the distinct physical and mechanical characteristics exhibited by different sections of the bamboo culm.

Table 1. Physical and mechanical properties for *Bambusa vulgaris*

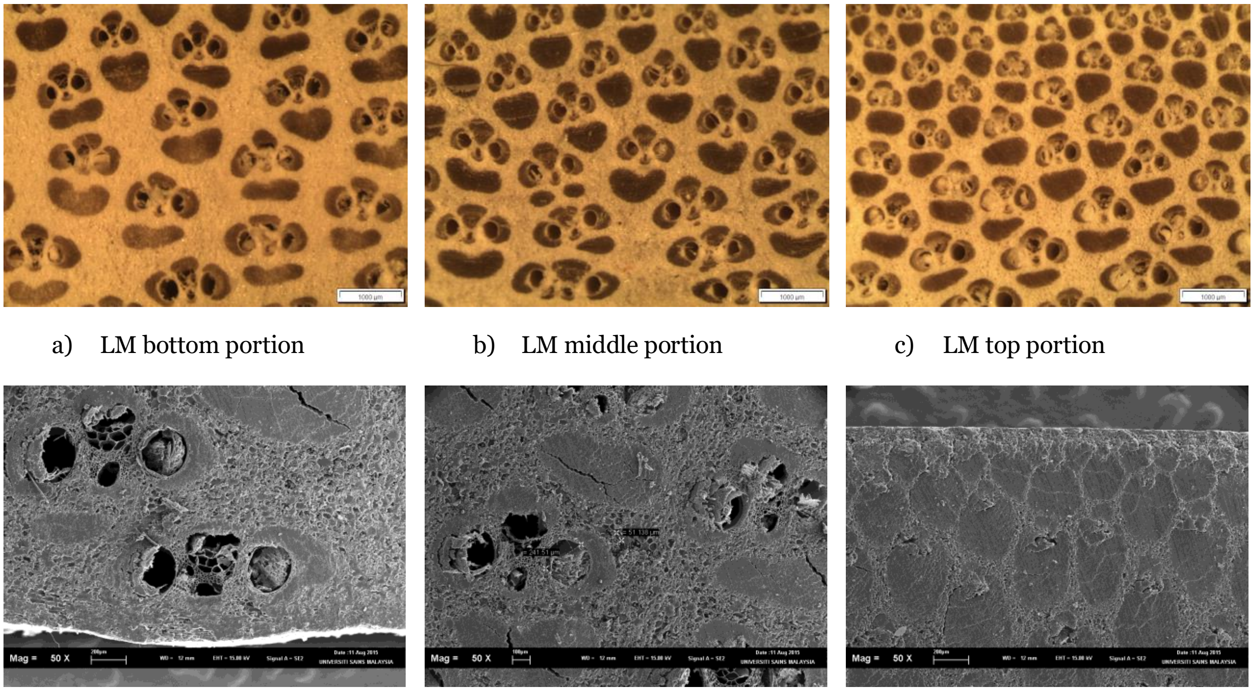
	Bottom	Middle	Top	Average	Std. dev.
Moisture Content (%)	62.82	66.98	67.66	65.82	2.14
Basic density (kg/m3)	386.07	307.19	280.09	324.45	44.95
Density (kg/m3)	916.96	724.54	628.57	756.69	119.91
Thickness Swelling (%)	0.80	1.05	2.69	1.51	0.84
Water Absorption (%)	3.38	19.72	34.03	19.04	12.52
MOR for Bending Strength (Mpa)	65.99	63.17	46.68	58.61	8.52
MOE Bending Strength (Mpa)	11710.98	12382.91	11920.23	12004.71	280.74

Illustration of Bamboo Microscopy Structure

The investigation into *Bambusa vulgaris* reveals a nuanced relationship between its physical and mechanical properties, as outlined in the provided in Table 1, and its microstructure analysis as represented in Figure 1 was analyzed at 25x magnification for light microscopy and 50x magnification for scanning electron microscopy (SEM). The increase in moisture content from the bottom to the top of the bamboo suggests potential microstructural variations, potentially reflecting differences in cell wall structures that influence water absorption [1; 21]. Basic density, representing mass without voids, correlates with microstructural features observed under light microscopy, indicating denser regions with tightly packed fibers from the bottom to the top (a to c).

Variations in thickness swelling and water absorption across bamboo portions are likely tied to microstructural differences, which can be elucidated through light microscopy. Microscopic analysis, particularly with SEM at 50x magnification (indicated from Figures 1 (d) to the (f)), offers insights into fiber arrangement, cell wall maturity, and vascular bundle sizes, influencing the bamboo's bending strength. The Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) for bending strength demonstrate variations possibly linked to fiber alignment, density, and microstructural irregularities [22].

In conclusion, microstructure analysis complements the understanding of physical and mechanical properties, providing a more holistic view of *Bambusa vulgaris* characteristics [23]. This integrated approach, examining moisture content, density, swelling, and bending strength in conjunction with microstructural features, contributes to a comprehensive assessment of bamboo's suitability for diverse applications [24]. This knowledge is crucial for optimizing bamboo utilization in composite fabricating, enhancing the material's performance and sustainability.



a) LM bottom portion b) LM middle portion c) LM top portion

d) SEM bottom portion e) SEM middle portion f) SEM top portion

Figure 1. Illustration of *Bambusa vulgaris* from bottom to the top portions on Light microscopy (LM) at 25x magnification and Scanning electron microscopy (SEM) at 50x magnification

Strength of bamboo Plastic Composite

As indicated in Figure 2, the tensile strength of the composite increases with higher bamboo fiber content. The 50:50 ratio exhibits the highest tensile strength at 5.08 MPa, emphasizing the reinforcing effect of bamboo fibers. In contrast, the 70:30 ratio shows a decrease in tensile strength to 3.05 MPa, potentially indicating that an excess of bamboo fibers may not contribute positively to tensile properties. Tensile strength is crucial in applications where materials experience stretching forces, such as packaging or structural components [25].

Similar to tensile strength, the bending strength of the composite is influenced by the ratio of LDPE to bamboo fiber. The 50:50 ratio demonstrates the highest bending strength at 45.96 MPa, indicating a balanced composition that enhances the material's ability to withstand flexural stresses. The 70:30 ratio shows a notable decrease in bending strength to 23.20 MPa, possibly due to an excessive amount of bamboo fibers negatively impacting the composite's flexibility [22; 26; 27].

The results underscore the importance of carefully choosing the ratio in composite fabrication. The 50:50 ratio appears to strike a balance between LDPE and bamboo fiber, resulting in optimal tensile and bending strength. The 30:70 ratio may provide more flexibility due to a higher LDPE content, while the 70:30 ratio prioritizes bamboo strength at the expense of bending strength.

The tensile and bending strength results for the LDPE Bamboo composite highlights the influence of different ratios on the material's mechanical performance [12; 25; 28]. This information is crucial for tailoring the composite to specific applications, balancing flexibility and strength based on the intended use in various engineering and manufacturing scenarios.

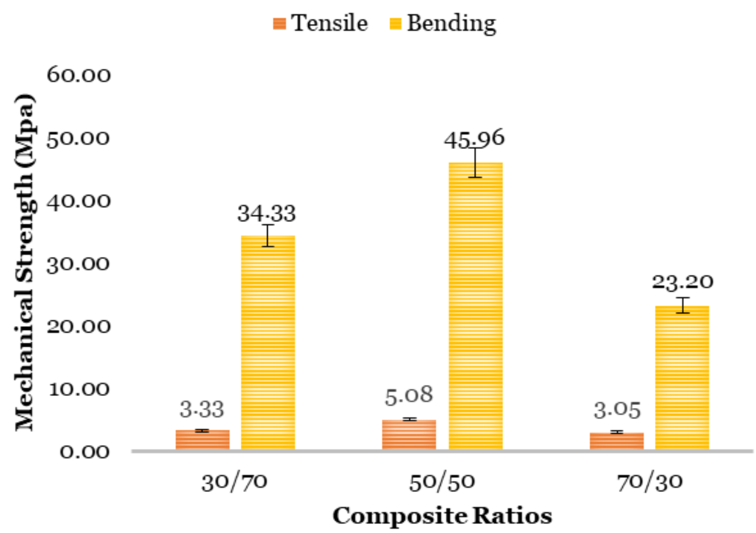


Figure 2. Bending and flexural strength for LDPE/bamboo fiber composite

CONCLUSION

Overall, the investigation into the physical and mechanical properties of *Bambusa vulgaris* culm revealed key characteristics such as moisture content, density variations, and bending strength along its length. These bamboo properties, including microstructural features analyzed through light microscopy and scanning electron microscopy, are integral to understanding how bamboo behaves structurally. The fabricated LDPE/Bamboo composite, utilizing three different ratios (30:70, 50:50, and 70:30), showcased a nuanced relationship between the bamboo and LDPE components. Moisture content and water absorption properties of bamboo could influence the composite's susceptibility to environmental conditions. Bamboo density variations along its length contribute to the overall density of the composite, affecting its mechanical properties. The bending strength of bamboo, observed in its microstructure, directly influences the composite's ability to withstand flexural stresses. The outcome of the LDPE/Bamboo composite fabrication demonstrated that the composition of bamboo fibers significantly impacted tensile and bending strengths. The 50:50 ratio exhibited an optimal balance, emphasizing the importance of carefully selecting the LDPE to bamboo ratio for desired mechanical properties. These findings underscore the need for tailored material optimization based on specific application requirements, where flexibility and strength play crucial roles. The investigation into bamboo properties serves as a foundational understanding guiding the utilization of bamboo as a reinforcing component, highlighting its role in achieving the desired mechanical characteristics in composite materials for diverse engineering applications.

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