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Characteristic strength of *Gigantochloa scortechinii* (or Buluh Semantan) of Malaysian species

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ABSTRACT

Bamboo has been identified as a future material for the primary, secondary, and tertiary sectors of the economy with reference to the Bamboo Industrial Development Action Plan in Malaysia 2021-2030 as bamboo is a natural material with high mechanical qualities and a quick reproduction rate. To support this vision, the construction industry needs structural design values. Currently the structural design values for structural bamboo for Malaysian species are not yet available as most of the R&D is focused on the upstream study and non-structural products. Therefore, this study investigates the physical and mechanical properties of a structural bamboo species namely Buluh semantan (Gigantochloa scortechinii) that is the prominent species being used in structural applications. The preparation of specimens and the physical and mechanical testing; bending, shear and compression in direction parallel to the fiber were conducted in accordance with ISO 22157. The properties obtained were used to derive the characteristic capacity of each property. The determination of allowable stresses is based on the characteristic capacity at 5th percentile in accordance with BS EN14358. These derived outputs provide new design data based on capacity grading for Malaysian bamboo and provide alternative environmental-friendly and sustainable construction materials. The results will be soon incorporated in the ISO Standard. This is aligned with the vision to foster green and sustainability building.

Keywords: Characteristic strength; bamboo culm; natural bamboo

INTRODUCTION

Bamboo is a natural material that reproduces rapidly and has exceptional mechanical qualities. The literature has demonstrated the feasibility of using bamboo for "green" buildings or as a substitute for steel reinforcing in low-cost dwellings (Moroz, 2014). Bamboo's great tensile strength allows it to substitute steel in reinforced concrete. The engineering aspect of bamboo is being overlooked and is not being exploited in modern construction. More engineering design, practical applications, and knowledge sharing utilizing bamboo technology are necessary. According to the Malaysia's National Timber Sector Policy and Bamboo Industry Development Action Plan 2.0 (2021-2030), there is a current attempt to prioritize the development of the bamboo industry as a game changer. The major objective is to launch a comprehensive bamboo industry program in order to develop it into a large-scale industry for both the upstream and downstream sectors. Having said that, study on bamboo species and manufacturing, particularly for the building industry, would stimulate the added value of bamboo in Malaysia. While bamboo has great potential, its development and use are impeded by a lack of engineering data regarding mechanical qualities and relevant construction codes. Previous work has focused only on producing mean bamboo strength capacities, but characteristic design capacity values have not been derived (Trujillo, Jangra and Gibson 2016).

An important note on bamboo properties is that the moisture content of bamboo is higher at the bottom section. The density increases from the bottom to the top section of the bamboo culm. The thickness of the wall of the bamboo culm also affects strength (Mohd-Daud et al, 2018). The more the thickness of the wall is, the higher the strength of bamboo. Nodes present along the bamboo culm generally have higher strength compared to the internodes. The flexural bending tests show that bamboo can revert to its original form after the load removal. Malaysia is home to at least 70 bamboo species belonging to ten genera. Peninsular Malaysia has the most bamboo species variety, with 59 species present. Buluh Semantan (Gigantochloa scortechinii), Buluh Betung (Dendrocalamus asper), and Buluh Beting (Gigantochloa levis or Gigantochloa thoii) have been identified as being of major use for building in order to strengthen the innovation and market-needs product, particularly for the construction industry. This species' scientific data is distributed, and there is a need for centralization. Furthermore, in order to make bamboo one of the materials for building construction, it is desirable to design a Malaysian Standard (MS) for bamboo that corresponds to the existing ISO standard.

The characteristic strength is defined as the strength of the bamboo below which not more than 5% of the test results are expected to fall. For design purposes, this characteristic strength value is derived by also incorporating different parameters such as region, density, moisture content. Characteristic strength of bamboo elements is an important parameter in the design of bamboo structures based on ISO 22156 Bamboo - Structural Design. Currently there are several standards that are and have been developed by the ISO and INBAR Task Force namely; i. ISO 19624 Bamboo structures — Grading of bamboo culms — Basic principles and procedures; ii. ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods; iii. ISO 22156 Bamboo – Structural Design; iv. ISO/NP 23478 – Bamboo structures — Glued laminated bamboo — Test methods for determination of physical and mechanical properties.

Currently, the characteristic strength for bamboo stems from Malaysian bamboo species has not been developed. Previous work on Malaysian bamboo only provided mean bamboo strength capacity for comparative purposes. (Abdullah Siam et al. 2020 & 2019 & 2017; Bahtiar et al. 2019) However, this data cannot be used to design bamboo structures. Investigations on bamboo from several ASEAN countries are also focused on the mean values. In contrast, countries like Philippines, UK, China, Korea etc. have already conducted research in developing structural design data and strength classes (Trujillo, Jangra and Gibson 2016; Gauss, Savastano and Harries, 2019; Liu et al. 2020). This strength class is based on the characteristic capacity of a bamboo species. Bamboo species that have characteristic capacity in a certain range will be grouped into a Strength Class (Strength Class) by considering the various species of bamboo and its density.

Gigantochloa scortechinii has unique mechanical qualities. From green to air-dried, its compressive strength increases. It has the maximum volumetric shrinkage at 16.83% and radial shrinkage at 13.07%, however its shear strength is 7.09 MPa. Despite these limits, its average flexural strength is 131.7 MPa, surpassing Gigantochloa levis (Bahrin et al. 2023). As the strength and characteristics of bamboo depend on the physical properties, species, moisture content, densities as well as environmental and climatic conditions of a place, therefore there is a need to investigate the properties of Malaysian bamboo and derive the structural characteristic capacity and compare this with the established structural capacity given in ISO standards. Currently, for structural application, the visual grading of Malaysian bamboo also not available. Hence, the objectives of this study are (i) to evaluate visually the condition and geometric properties of all bamboo specimens in accordance with ISO 19624, (ii) to determine the physical and mechanical properties (bending, compression, tension and shear parallel to the fiber as well as bending and tension perpendicular to fiber for *Buluh Semantan*, and (iii) to derive the characteristic capacity for all the stresses as well as characteristic Modulus of Elasticity and component flexural stiffness for *Buluh Semantan*.

MATERIALS AND METHODS

Test specimens for this study were supplied by SEAD Industries Sdn. Bhd., a company registered in Malaysia. For the experimental tests, a total of 6 culms sections were tested for parallel–to–fiber compression, 6 specimens for shear, and 6 for bending. A wide range of culm dimensions were considered in accordance with ISO 22157–1:2019. In order to conduct a compression test, it is necessary to measure the length and wall thickness of the specimen. Additionally, a loading rate of 0.01 mm/s is specified to guarantee precise testing. The specimen was cut to match its outer diameter. When it comes to bending, the length of the specimen was trimmed to 30 times the outer diameter. The culm was positioned on saddles at the supports using a flexural instrument. The process involved placing saddles in contact with the culm to precisely align it with the load beam and supports. The load was exerted at a velocity of 0.5 mm/s while fractures are observed and recorded. Failures occurring within the constant moment area are considered as bending failures. For the shear test, the length of the specimen was set to be the same as the length of the compression specimen setup. Shear plates were located at both the bottom and top of the specimen. The specimen was then aligned with the loading axis of the machine, ensuring that its centre matches the centre of the shear plates. Testing is performed using a The culm was positioned on saddles at the supports using a flexural instrument. The process involved placing saddles in contact with the culm to precisely align it with the load beam and supports. The load was exerted at a velocity of 0.5 mm/s while fractures are observed and recorded. Failures occurring within the constant moment area are considered as bending failures. For the shear test, the length of the specimen was set to be the same as the length of the compression specimen setup. Shear plates were located at both the bottom and top of the specimen. The specimen was then aligned with the loading axis of the machine, ensuring that its centre matches the centre of the shear plates. Testing is performed using a loading rate of 0.01 mm/s. Any specimens that fail within a time frame of less than 30 seconds are eliminated from the analysis. The applied load must be consistently maintained at 300$\pm$20 seconds throughout the experiment. The time to failure is measured for each specimen, and specimens are collected around the point of failure for moisture content analysis.

The moisture content, density and the number of tests conducted for each property are presented in Table 1. All tests for the determination of mechanical properties were conducted using a universal testing machine (Digital Control System). Temperature and relative humidity were recorded for all tests. The corresponding testing setups are shown in Figure 1.

RESULTS AND DISCUSSIONS

Six bamboo culms of the Gigantochloa scortechcinii species were subjected to four-point bending, compression, and shear tests to determine the mean bending strength, modulus of elasticity (MOE), compression strength, and shear strength. During the bending test, typical longitudinal splitting was observed, resulting in face fracture as the failure mechanism. Similarly, the compression test revealed typical splitting as the failure mechanism. The shear test also showed typical splitting as the consequence of the compression, aiming to establish the mean shear strength of the bamboo culms.

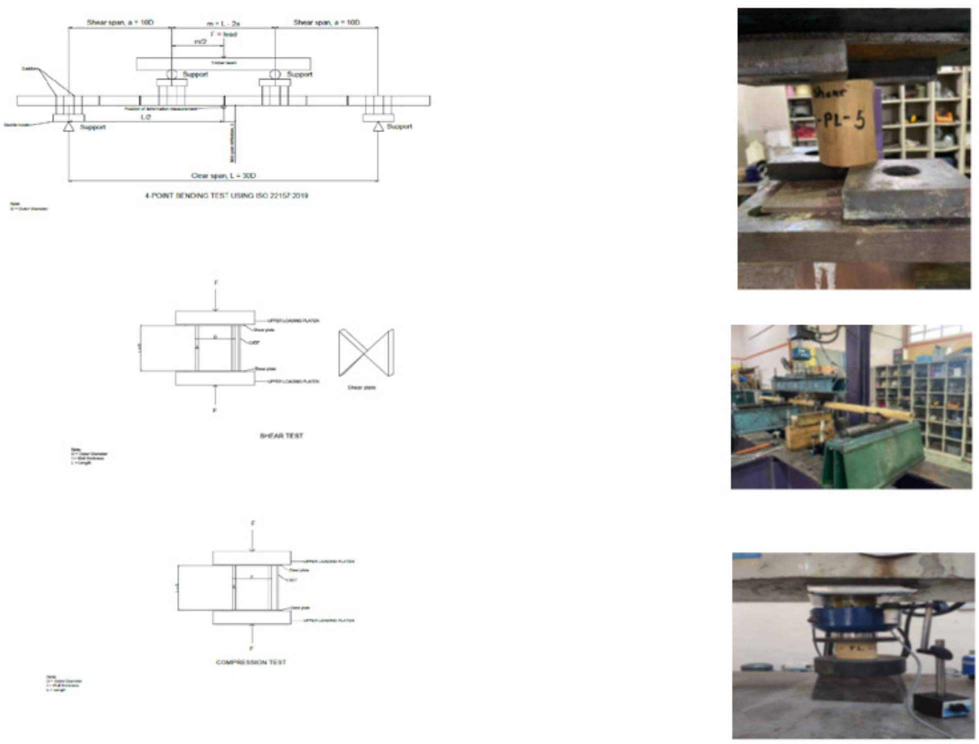

FIGURE 1. Test setups.

TABLE 1. Geometric and Physical properties.

Geometric/Physical Property	Testing	Sample size (n)	Mean
Diameter *D* (mm)	Bending	6	66.86
	Compression	6	71.04
	Shear	6	67.19
Wall thickness, *t* (mm)	Bending	6	6.81
	Compression	6	9.16
Moisture content (%)	Shear	6	8.08
			11.62
Density (kg/m^3)			
			734

The experimental results of the mechanical properties are summarized in Table 2, indicating the mean value and average test conditions (temperature and relative humidity). Additionally, 5th percentile values, as well as characteristic values calculated in accordance with BS EN 14358, are listed. Typical load-displacement curves for all tests are presented in Figure 2 as well as typical failure modes observed during testing. The mechanical behavior of Gigantochloa scortechinii is nonlinear even in the elastic range and followed by a relatively plastic increase in displacement after the ultimate strength has been attained. The typical two main failure modes were identified as longitudinal splitting and local crushing.

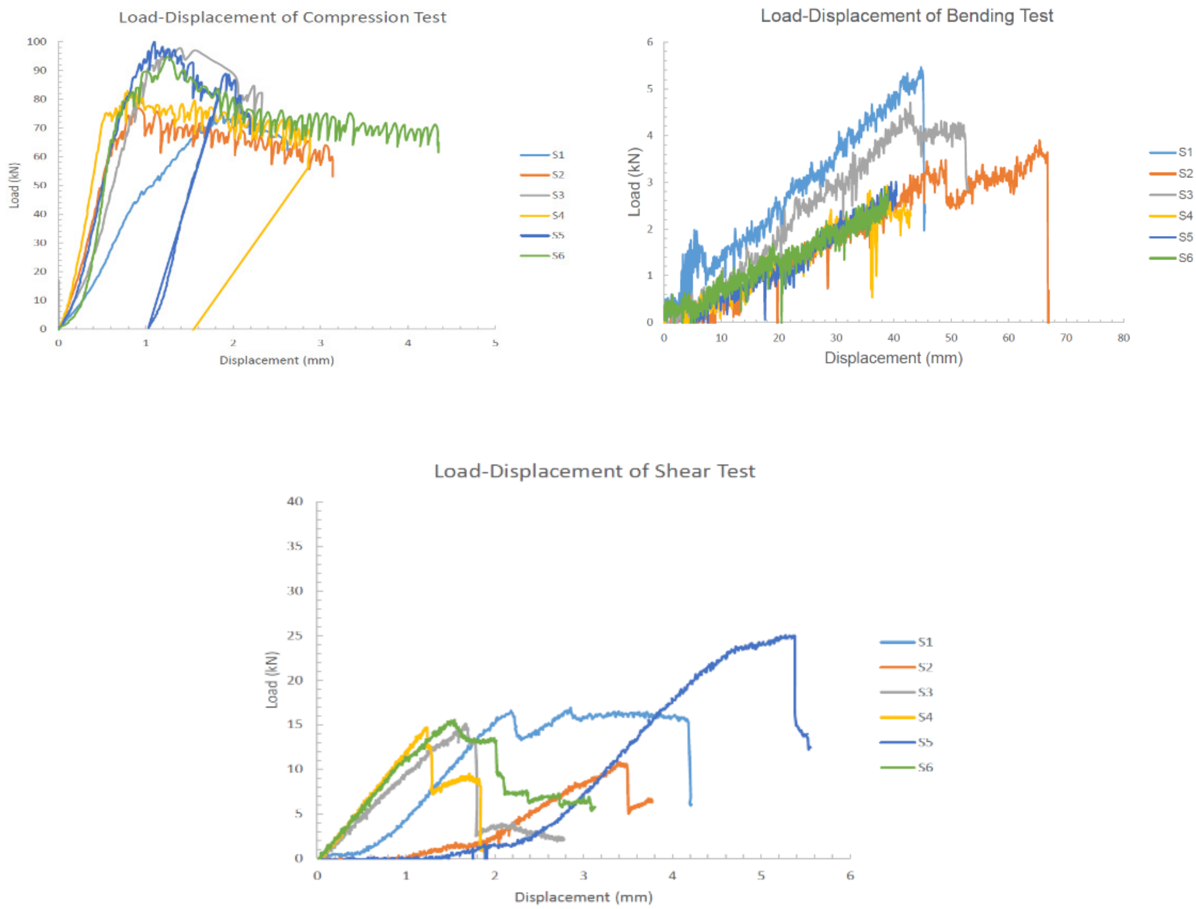

FIGURE 2. Load-displacement behaviour

TABLE 2. Mechanical and Physical properties.

Property	Mean	5th percentile	Characteristic BS EN 14358	Temperature (◦C)	Relative humidity (%)
Compression–parallel–to–fiber Ultimate strength (MPa)	49.53	33.58	28.22	29 ± 1	50 ± 1
Modulus of elasticity (MPa)	6334.01	-	6454.02	29 ± 1	50 ± 1
Shear–parallel–to–fiber Ultimate strength (MPa)	5.61	3.26	2.74	24 ± 1	41 ± 1
Static bending Ultimate strength (MPa)	57.36	36.64	30.78	24 ± 1	41 ± 1
Modulus of elasticity (MPa)	16489.83	-	16802.27	24 ± 1	41 ± 1

The compression-parallel-to-fiber ultimate strength has a mean value of 49.53 MPa, with a 5th percentile value of 33.58 MPa. The characteristic value is 28.22 MPa, providing a conservative estimate for design purposes. The modulus of elasticity for compression is 6334.01 MPa, reflecting the bamboo stiffness under compressive loads. The shear-parallel-to-fiber ultimate strength has a mean value of 5.61 MPa, with a 5th percentile drop to 3.26 MPa and a characteristic value further reduced to 2.74 MPa. This suggests significant variability and potential weakness in shear strength at lower percentiles, crucial for applications with significant shear stresses. In static bending, the ultimate strength averages at 57.36 MPa, with a 5th percentile value of 36.64 MPa and a characteristic value of 30.78 MPa. The modulus of elastic-ity in bending is relatively high, indicating good resistance to deformation under bending loads. The tests were conducted under consistent conditions, ensuring data reliability, although variance in temperature and humidity could slightly influence the material properties.

Generally, with the small dataset (6 samples), the calculated characteristic value assessment is not a decent representative of the actual material properties of the bamboo. Nonetheless, it provides some information about the type of bamboo being used for the project at hand. In comparison with the consolidation of all mechanical properties from previous studies (Bahrin et al. 2023), only compression fell within the range while shear and bending were lower than the lower bound of the range. It is imperative to mention that this finding was applicable to the project undertaken within the scope of this studies and further testing and expert consultation are re-quired for the computation of design value that is needed on other projects.

CONCLUSION

Six bamboo culms of the Gigantochloa scortechcinii species were tested for bending, compression, and shear strength. The results showed typical longitudinal splitting, face fracture, and compression splitting as failure mechanisms. The compression-parallel-to-fiber ultimate strength had a mean value of 49.53 MPa, with a 5th percentile value of 33.58 MPa. The modulus of elasticity for compression was 6334.01 MPa, reflecting the bamboo stiffness under compressive loads. The shear-parallel-to-fiber ultimate strength had a mean value of 5.61 MPa, with a 5th percentile drop to 3.26 MPa and a characteristic value further reduced to 2.74 MPa. The ultimate strength averaged at 57.36 MPa in static bending, with a 5th percentile value of 36.64 MPa and a characteristic value of 30.78 MPa. The modulus of elasticity in bending was relatively high, indicating good resistance to deformation under bend-ing loads. The tests were conducted under consistent conditions, ensuring data reliability, although variance in temperature and humidity could slightly influence the material properties. The calculated characteristic value assessment is not a decent representative of the actual material properties of the bamboo, but it provides some information about the type of bamboo used for the project. Further testing and expert consultation are required for the computation of design value for other projects.

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DECLARATION OF COMPETING INTEREST

None.

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