Influence of Moisture Content and Position on the Tensile Strength of Four Air-Dried Bamboo Species

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Abstract Bamboo is one of the fastest growing plants globally, and it has been used for numerous applications, including in the construction industry. It also has been known that bamboo has an excellent mechanical property, especially in tensile. However, each species has different mechanical properties, and generally, moisture content and the bamboo position have a greater impact on the variation of bamboo properties along with the culm height. Thus, this study focuses on the effect of four bamboo species' moisture content and position: *Dendrocalamus asper, Bambusa vulgaris, Gigantochloa scortechinii,* and *Shizostachyum grande*. The test on the bamboo was conducted after the treatment and air-dried conditioning were completed. The moisture content test and tensile strength test were conducted for each species for 1, 5, and 7 months. The results show that the *D. asper* and *B. vulgaris* have the highest tensile strength value, followed by *G. scortechinii* and *S. grande*. Moreover, it was observed that the tensile strength of bamboo increased from the bottom to the top part of the bamboo. The moisture content of each species also differs, and the value also increased from the bottom to the top part of the bamboo. The moisture content decreased from 1 to 7 months while the tensile strength increased. It was concluded that the tensile strength of bamboo differs from each species and position, as well as the change in moisture content affects the tensile strength.

Keywords Bamboo · Mechanical properties · Tensile strength · Moisture content

1 Introduction

Bamboo is one of the fastest growing plants on the planet, with species ranging in height from a few centimeters to many meters. Some giant bamboo species can achieve their maximum height of up to 30 m in 2 to 4 months. In Malaysia, there are

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many bamboo species such as *Dendrocalamus asper* (Buluh Betung*), Gigantochloa scortechinii* (Buluh Semantan), *Shizostacyum grande* (Buluh Semeliang), *Bambusa vulgaris* (Buluh Minyak), and others. It was found that the tensile strength of some species of bamboo is relatively high and can reach 581 MPa [1]. In fact, the ratio of tensile strength to the specific weight of bamboo is six times greater than that of steel [2].

However, bamboo must be treated to enhance its durability and resistance to fungus attack. The durability of untreated bamboo is often influenced by its age, species, and storage method [3]. It is expected that untreated bamboo will last 10 to 15 years if stored and used properly [4]. The starch content of untreated bamboo culm attracts insects and fungi, which will nest inside the bamboo culm. Meanwhile, treated bamboo has a lifespan of more than 3–4 years when placed outdoors, but a bamboo structure has a lifespan of more than 50 years when placed under a roof and is not in direct contact with rain or sunlight.

There are numerous aspects that affect the quality and viability of bamboo as a broad and economically beneficial alternative to wood or steel. Physical and mechanical properties are among these factors. Due to inadequate basic information on the properties of different bamboo species, only a few different types of local bamboo have been used commercially in the industry [5]. Factors such as age, moisture content, and treatment are very crucial in determining bamboo's mechanical properties. The strength and lifespan of bamboo also depend on the moisture content. Similar to timber, moisture content is a key factor for its utilization whether as for research or as a structural element purpose. Higher moisture content in the bamboo eventually will attract the fungi and borer insects which will speed up the rotting process of the bamboo itself. Naturally, bamboo also has higher moisture content, just like other plants. The distribution of moisture content in bamboo are depended on whether they are raw or processed. Raw bamboo or fresh felling bamboo might have 100% of moisture on a dry weight basis [6]. As a fibrous material, bamboo can change dimensionally when they gain or lose moisture. The anisotropic material properties in bamboo affected the changes in their dimensions, weight, and strength, especially in tensile. These properties also can cause the bamboo to deform when the bamboo possesses very low moisture content.

The moisture content is influenced by age, species, and harvesting season [7]. However, it is also known that bamboo in the green state has a higher moisture content, and the value differs within other culms and in relation to age, species, and season. The season has a greater effect on the moisture content of the bamboo. Minimum water content is usually at the end of the dry season, while the maximum water content is in the rainy season. The bamboo stem can increase the water content capacity during the rainy season. In addition, the moisture variation due to the season is higher than the difference between the bottom and top parts and between the bamboo species. Even at a similar locality, the water content of bamboo also may vary. Thus, it is important to know the strength of different bamboo species, positions, and the effect of moisture content along the bamboo culm height. The behavior of moisture absorbing of bamboo along the period also needs to be highlighted. Thus, this study aims to investigate the influence of moisture content of the bamboo as well as the effect of position on the tensile strength along the bamboo height.

2 Materials and Procedures

As shown in Fig. 1, the bamboo species involved in this study are (a) *D. asper*, (b) *B. vulgaris*, (c) *G. scortechinii,* and (d) *S. grande.* These bamboos were selected because it is the most common species in Malaysia. The bamboos were obtained and treated at Bamboo Jungle Adventure, Perak, Malaysia. The treatment aims to enhance their durability and resistance to fungus attack. The combination of boric acid and borax in a 1:1.5 ratio produces an alkaline salt, which was obtained as a ready-to-use powder. This powder was poured into a rectangular tank and mixed with water, and the bamboo was soaked in the tank for about a week before being dried. The bamboo was then received in air-dried conditions and stored in a closed shed before testing. Then, the bamboo was cut into the desired dimension according to the tests involved, such as moisture content and tensile strength test. The tests periods were selected at 1, 5, and 7 months in an air-dried condition.

2.1 Moisture Content Test

The moisture content of bamboo specimens was carried out before completing the tensile strength test. The specimens for moisture content in this research were taken near to the extracted tensile specimens. The ISO-22157-1 (2004) procedure was followed for the tensile strength test [6]. The specimens were prepared like prism

Fig. 1 Harvested of 3-m length with different species of bamboo **a** *Dendrocalamus asper*, **b** *Bambusa vulgaris*, **c** *Gigantochloa scortechinii* and **d** *Shizostachyum grande*

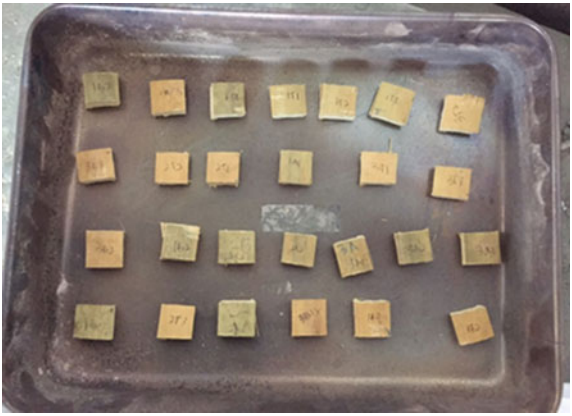

Fig. 2 Moisture content test specimens

form, approximately 25 mm high, 25 mm width, and thick as the wall thickness shown in Fig. 2.

The moisture content value can be calculated by using Eq. 1. The initial weight of the specimens was recorded as m_{i}. Then, using a hot-air oven, the specimens were dried at a temperature of 103 ± 2 °C for 24 h. The test specimens were weighed after 24 h and drying continued after that. The weighing process was carried out and recorded every 2 h until the successive determination of the mass did not exceed 0.01 g. The final reading of weighing was recorded as m_o.

$$\text{Moisture Content, } (\%) = \frac{m_{\mathrm{i}} - m_o}{m_o} \times 100 \quad (1)$$

2.2 Tensile Strength Test

The tensile strength test was conducted following the ISO-22157-1 (2004) procedure [8]. The bamboo specimen was cut into a dog-bone shape, and the tests were conducted in an air-dried condition. Figure 3 shows the completed bamboo test specimen for the tensile strength test. The bamboo test specimen had an overall length of 260 mm and a specimen grip width of 20 mm. The test specimen's effective length was 65 mm, its width was 10 mm, and its thickness was determined by the thickness of the bamboo itself. For each species, nine specimens were taken from the internode parts, which consisted of three samples at the top part, three samples at the middle part and three samples at the bottom part of the bamboo. All the measurements were taken by using Vernier caliper.

The tensile strength test was conducted by using a Universal Testing machine with a capacity of 1000 kN. First, all the bamboo dimensions, such as width and thickness, were recorded before performing the test. Then, the specimens were loaded

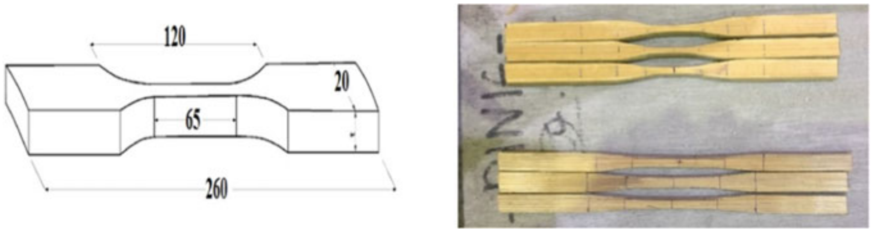

Fig. 3 Tensile strength test specimen

onto the tensile strength testing equipment, and both ends were tightened flat on the provided grips. Following that, pulling forces of 0.05 mm/s were applied with continuous movement until the maximum load was reached before the sample failed. An operational test set up for the tensile strength test is given in Fig. 4.

The tensile strength of bamboo specimens can be calculated in general by dividing the maximum load (P) with the area at the effective length, (A). The formula can be referred to the following Eq. 2.

$$\text{Tensile Strength, } \sigma = \frac{P}{A} \quad (2)$$

Fig. 4 Tensile strength test setup

3 Results and Discussions

3.1 Initial Moisture Content and Tensile Strength

Table 1 shows the results of the initial moisture content and tensile strength of bamboo species at a dried condition of 1 month. The results indicate that *D. asper* and *B. vulgaris* have the highest tensile strength among the other species, followed *by Gigantochloa scotechinii* and *S. grande*. Figure 5 shows average tensile strength trend of *B. vulgaris* where the tensile strength was observed to increase from the bottom to the top part of the bamboo culm. *G. scortechinii* and *S. grande* showed a strong incremental trend in tensile strength values. Even though *D. asper* did not show a consistent increase in tensile strength, the data can still be considered because the specimen on the top part of the bamboo culm gave a greater value than the specimen on the bottom part.

The increase in tensile strength along the height of the culm observed in this study for all species is believed to result from a simple mechanism. Fibers material that exists in the form of the sclerenchymatous sheath around the vessel in the culm is basically constant or increases along with the height of the culm [9, 10]. However, as height increases, the diameter and culm thickness decrease, reducing the area over which the stress is determined. As the wall thickness of the bamboo getting decreased at the top part of the bamboo, the condensation of the vascular bundle caused the attributed to increasing fibers density, thus, increasing the strength. Furthermore, since the fibers primarily convey the tensile strength, the apparent tensile strength of bamboo has increased. Thus, the fibers volume fraction increased along with the height of the culm [11].

Table 1 Average moisture content and tensile strength of bamboo at 1 month

Species	Part	Average moisture content (%)	Average tensile strength (MPa)
Dendrocalamus asper	Top	17.40	219.68
	Middle	20.25	198.35
	Bottom	22.30	214.06
Bambusa vulgaris	Top	16.25	219.08
	Middle	18.60	212.38
	Bottom	22.45	211.76
Gigantochloa scortechinii	Top	17.10	175.98
	Middle	18.20	149.29
	Bottom	20.19	147.36
Schizostachyum grande	Top	25.00	138.72
	Middle	26.79	107.83
	Bottom	27.14	105.83

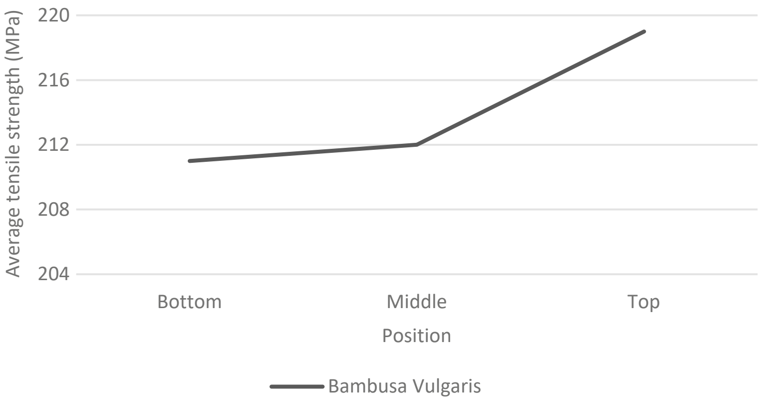

Fig. 5 Average tensile strength of *Bambusa vulgaris* species along with the height

Clearly seen that the moisture content also decreased from the bottom to the top part of the bamboo. The result on the change of moisture content obtained was also agreed upon in the previous study. Anokye et al. [5] conducted a study on the variation of the moisture content of green bamboo. They reported that the moisture content decreased from the bottom to the top part of the *B. vulgaris* species. Generally, water is transported from the bottom to the top part of bamboo [5]. This is because the bottom part has a smaller vascular bundle amount. However, the vascular bundle size at the bottom part is large, and the water is concentrated at the bottom, thus, contributing to decreasing trend of moisture content from the bottom to the top parts. Nevertheless, the moisture content variation along the culm did not differ significantly across the bottom, middle, and top parts.

3.2 Moisture Content Reduction and Tensile Strength Development

Figure 6 shows the trend of the average tensile strength graph from 1 to 7 months interval, while Table 2 shows the full data of bamboo specimens average moisture content and tensile strength at 5 and 7 months of closed shed storage. The tensile strength of all species was found to increase with time. The increment of tensile strength was associated with the moisture content of the specimens, which decreased at a different part of bamboo culm from 5 to 7 months. The moisture content of all bamboo species had been reduced gradually from 1 to 7 months. *Schizostachyum grande* shows the highest average moisture content followed by *D. asper*, while *B. vulgaris* and *G. scortechinii* possess only a small difference in average moisture content value.

Bamboo drying is a relatively slow process, which may take several days to several months, depending on the bamboo species, its thickness, and the drying

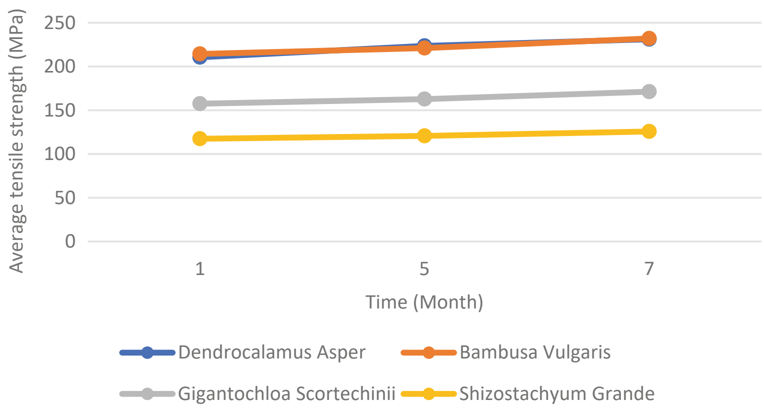

Fig. 6 Average tensile strength of bamboo (top part) against the time

Table 2 Average moisture content and tensile strength at 5 and 7 months

Species	Part	Average moisture content (%)	Average tensile strength (MPa)	Average moisture content (%)	Average tensile strength (MPa)
		5 months		7 months	
Dendrocalamus asper	Top	15.85	225.47	13.94	232.80
	Middle	17.91	222.75	16.36	228.59
	Bottom	18.44	222.48	17.23	232.32
Bambusa vulgaris	Top	14.01	222.31	13.86	231.67
	Middle	15.10	220.07	14.28	233.98
	Bottom	19.20	221.14	17.05	230.63
Gigantochloa scortechinii	Top	15.60	182.77	14.40	187.67
	Middle	16.95	154.10	15.30	163.97
	Bottom	18.09	151.48	16.15	162.44
Schizostachyum grande	Top	16.87	142.21	15.30	149.20
	Middle	17.98	110.61	16.84	114.93
	Bottom	19.63	109.20	18.80	113.01

methods used. In addition, bamboo is also a ‘hygroscopic material’, which means that its moisture content changes in response to its surroundings’ temperature and relative humidity [12]. In constant temperature and relative humidity conditions, the bamboo will eventually reach a constant moisture content or known as the “equilibrium moisture content”. However, in practice, such stability of conditions rarely occurs, and therefore a true equilibrium moisture content is never reached. It is also worth noticing that the strength of bamboo is weaker with the increasing moisture content. Further reduction of moisture content below optimum point will cause the

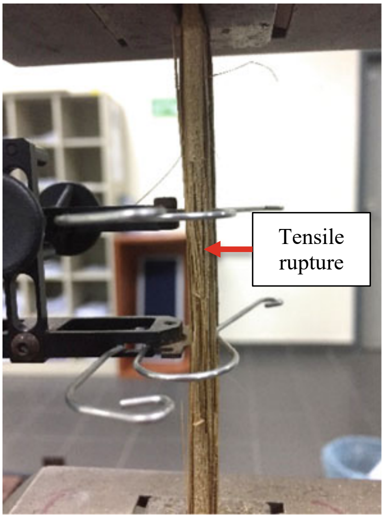

Fig. 7 Bamboo failure in tensile strength test

reduction of strength as the bamboo will start to show brittle characteristics due to loss of water [9].

3.3 Mode of Failure

Figure 7 shows the failure mode where the bamboo specimen experienced a tensile rupture along the gage length of the specimen. The bamboo specimen failure showed 'good' failure in the way of being mostly unaffected by the gripping process of the testing machine. Uneven grip pressure occurred when grip pressure was applied to the grip region because the bamboo itself had various material properties across the grip area, leading the apparent gripping pressure to that area to be uneven. It resulted in a single longitudinal splitting associated with a higher grip pressure area.

4 Conclusion

Understanding the factor that affects the mechanical properties of bamboo is essential because the material has numerous applications in the building industry. For example, it was known that moisture content is one factor that needs to be considered when using bamboo as a construction material. Therefore, the main purpose of this study was to present the effect of moisture content on the tensile strength of different bamboo species. Based on the extensive experimental testing conducted on tensile strength, it was found that *D. asper* and *B. vulgaris* have the highest tensile strength, with the average value of above 200 MPa. However, *G. scortechinii* and *Shizostacyum grande* species show the average tensile strength value below 200 MPa.

Moreover, the tensile strength for all species shows an incremental trend from the bottom part to the top parts. This trend may be attributed to moisture change and the variation of fibers distribution along with the height of bamboo. The study also has identified that the drying process of bamboo was relatively slow in an ambient condition due to the hygroscopic behavior of bamboo, and this was proved by the moisture content values recorded along the given periods. However, the tensile strength of bamboo was considered excellent when the moisture value was below 20%. Therefore, it can be concluded that bamboo also can be used as a construction material. It was also recommended to apply a protective layer such as a water repellent agent to cater to the hygroscopic behavior of bamboo. Thus, future works need to be done to widen the application of bamboo in the construction industry.

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