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The classical mechanics engineered of *Bambusa vulgaris* and *Schizostachyum brachycladum*

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Abstract

Physical and mechanical properties of *Bambusa vulgaris* and *Schizostachyum brachycladum* were investigated. The sample were classified into two different ages which are young and mature for each culm of bamboo. The aim of this study to investigate the physical properties such as density, basic density, moisture content, water absorption and thickness swelling. Other than that, the mechanical properties also help to determine their flexural test for modulus of rupture (MOR) and modulus of elasticity (MOE). The method used to analyse physical and mechanical properties were following the ISO standard. From this study, young *Bambusa vulgaris* has indicated the higher content of moisture content, water absorption and thickness swelling with 67.66%, 2.69% and 34.03%, respectively while mature *Schizostachyum brachycladum* has shown the higher value in basic density, density, and flexural test for MOR and MOE with 876.33 kg/m^3, 1084.49 kg/m^3, 317.01 N/mm^2 and 122986.18 N/mm^2, respectively.

1. INTRODUCTION

Bamboo is one of the most abundant non-timber forest resources in Asia (Hunter, 2002). According to Shanmughavel et al. (2001), over 75 genera and 1250 species can be found in tropical and subtropical areas, especially in the monsoon and wet tropics (Musa et al., 2009) while in Peninsular Malaysia bamboo covers around 7% of the forest land, which means that there was forecasted as 421,722 ha, of forest area of about 59 bamboo species, whereby 25 species are known in cultivation and other 34 species are indigenous (Bahari & Krause, 2016). It is a fast-growing species and can matured within 3-4 years after cultivating (Wahab et al., 2018).

The distinctive part of bamboo is a stem or called as culm, which has upper ground part that contains most of the woody material. It also has a straight, hollow and cylindrical formed of nodes and internodes. Its diameter tapers from the bottom to the top with the reduction in culm wall thickness (Biswas et al., 2011).

Traditionally, bamboo is widely used as bamboo basket, toothpicks, joss-sticks, chopsticks, joss papers, bamboo blinds, cage-making and handicrafts products (Azmy et al., 2004). However, in engineered technology applied bamboo have become important in world markets due to modern technological advances in form of pulp for papers, parquet, plywood bamboo and as a canned vegetable (Asari & Suratman, 2010).

According to the previous study, the strength of bamboo is relatively influenced by their age (young to mature) and the strength also is depending on the diameter, thickness, density, moisture content (Sekhtar & Bhartari, 1960) species and position along to the culm (Wahab et al., 2005) of the bamboos. As hollow tube, bamboo is efficient in resisting bending forces as a completely due to its large ratio of moment of inertia to cross-sectional area. However, it is difficult to be used for specific application and also hard to connect to each other. The strength properties of a bamboo have been found to be increasing from inner to outer layer of the culm (Karuiki et al., 2002).

Furthermore, the physical characteristics of water absorption and thickness swelling properties are directly related to moisture content and higher water absorption results in higher thickness swelling in the panels of bamboo (Rahman et al., 2002). According to Liese, (1985) the fibre density of sclerenchyma tissue within the bamboo is a good indicator of the strength of a bamboo. On the mechanical side, the bending strength is increased from the inner part to the periphery of the culm wall. However, based on Wahab et al., (2005), bending strength has indicated a decrease in value alongside the height of the bamboo.

In this study, *Bambusa vulgaris* and *Schizostachyum brachycladum* are analyse based on the

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characteristics that were used to identify their physical properties such as moisture content (MC), thickness swelling (TS) and water absorption (WA), density and basic density. Then, the mechanical properties were used to identify the strength of selected bamboo based on flexural test which is manipulate the modulus of rupture (MOR) and modulus of elasticity (MOE). As a result, the selected bamboo species had the best possible alternative to replace timber in the future because it is one of the species that spread rapidly and has the fastest growth rate in tropical forest before they are ready for harvesting and utilization.

2. MATERIALS AND METHODS

In this study, the physical and mechanical properties of *Bambusa vulgaris* and *Schizostachyum brachycladum* that are analysed by using Universal Testing Machine (UTM) type DBBMTCL-5000kg-1.5-000, Testometric, Rochdale England. *Bambusa vulgaris* and *Schizostachyum brachycladum* with different ages (young and mature) were used in the experiment. The moisture content, density, basic density, thickness swelling and water absorption for physical properties and also flexural test for mechanical properties were investigated. The samples of physical and mechanical properties were cut according to the ISO standard.

2.1. Moisture content

The method that was used to determine the moisture content of these two selected bamboo species is based on oven-dry weight. In this study, each species of bamboo was divided into young and mature category. Then, the samples were cut following the indicator of 25 mm x 25 mm x bamboo thickness with weight approximately 1–8g. The moisture content was conducted based on ISO 3130-1977(I).

2.2. Determination of density and basic density

Density can be defined as the mass per unit volume, which is moisture content of sample, is at 12%. Furthermore, basic density is defined as the mass per unit volume in oven dry condition. In this study, each species of bamboo was cut to 25 mm x 25 mm x bamboo thickness. The density and basic density were conducted based on ISO 3131-1975. The air-dry (AD) samples volume was measured and followed by the drying process in the oven until samples had reached 12% moisture content for density while for basic density samples were dried for 24 hours and weight were obtained.

2.3. Determination of thickness swelling and water absorption

The method used for determining the thickness swelling and water absorption is based on water immersion and oven dry weight. Each bamboo samples were selected by different ages (young and mature). Then, the sample was cut to 50 mm x 50 mm x bamboo thickness. The thickness swelling, and water absorption was conducted based on ISO 9424:2003.

2.4. Determination of modulus of elasticity and modulus of rupture

The method used to determine modulus of rupture (MOR) and modulus of elasticity (MOE) of two selected bamboo species were according to the flexural test using Testometric universal testing machine, M500-50CT, United Kingdom. By choosing two bamboo species, samples were collected based on different ages (young and mature). Furthermore, samples dimension of single-point bending test was performed on 20mm x 380mm x thickness of bamboo (width x length x thickness). A cross-head speed of 10 mm min^{-1} and mid-span for bending test of 320 mm were utilized according to ISO standard.

3. RESULTS AND DISCUSSION

In this study, physical and mechanical properties on *Bambusa vulgaris* and *Schizostachyum brachycladum* was determined to analyse their characteristic against to the strength of bamboo.

3.1. Moisture content of two selected bamboo species in different age

According to Table 1, *Bambusa vulgaris* has demonstrated a slightly higher value of moisture content compared to *Schizostachyum brachycladum* bamboo. The table also indicated, the young age of *Bambusa vulgaris* had the higher moisture content compared to the mature age from *Bambusa vulgaris* species. *Schizostachyum brachycladum* also indicated that the young age had the higher moisture content compared to the mature age. Moreover, the table also shows that the young age of *Bambusa vulgaris* species had the highest moisture content compared to the others. According to Wahab et al. (2010), the moisture content has decreased with age (young to mature), from bottom portion to top portion, and from inner to outer layer in the culms wall. Therefore, the percentage of moisture content demonstrated by *Schizostachyum brachycladum* had 50.73% and 37.61% for young and mature age respectively. On the other hand, the percentage of moisture content for *Bambusa vulgaris* which are 66.98% and 30.26% for young and mature age respectively. The analysis of variance (ANOVA) has indicated that there was significant different between their ages and species with P-value less than 0.05 as shown on Table 6 and Table 7. Based on previous study, moisture content varies within one culm and influenced by its age (young and mature), height, position in the culms wall thickness (Wahab et al., 2010), the season of country and also the species. Other than that, in the green stage has shown greater differences which exist within one culm as well as in relation to age, season and species (Liese, 1985).

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Moreover, according to Wahab et al. (2012) bamboo species were showing different moisture values which might be due to the difference in some inherent factors such as age, anatomical features and chemical composition.

Table 1: Means for groups in homogeneous of moisture content on two selected bamboo species

Parameter	Moisture Content (%)
Young *S.brachycladum*	50.73^{c} (1.37)
Mature *S.brachycladum*	37.61^{b} (0.58)
Young *B.vulgaris*	66.98^{d} (0.83)
Mature *B.vulgaris*	30.26^{a} (5.71)

*Values in bracket represents the standard deviation
*Means followed by the same letter are not significantly different at 0.05 probability level

3.2. Comparison of density and basic density

According to Table 2, young *Schizostachyum brachycladum* has shown the higher value of basic density compare to the young *Bambusa vulgaris* bamboo species while the mature *Bambusa vulgaris* is slightly higher compared to the mature *Schizostachyum brachycladum.* The table also showed the mature age from *Schizostachyum brachycladum* with 715.10 kg/m^3 which had the higher value of basic density compared to the young age of the species with 506.63 kg/m^3. Moreover, the *Bambusa vulgaris* also showed mature age with 727.10 kg/m^3 had slightly higher value of basic density compared to the young age from this species with 307.19 kg/m^3. In addition, it can be seen that the mature age from *Bambusa vulgaris* had the highest value of basic density with 727.10 kg/m^3 compared than others. As shown on ANOVA, there was significant different between ages and species to the basic density value which is $P \leq 0.05$. According to previous research, the percentage of basic density increased when the value of swelling decreased (Liese, 1985). Other hand, basic density was an important factor because it reflects the amount of cell wall material per unit volume of culms and relates directly to the strength properties (Wahab et al., 2010).

According to Table 2, density value of mature *Bambusa vulgaris* indicated a slightly higher number compared to the mature *Schizostachyum brachycladum* species while young *Schizostachyum brachycladum* was slightly higher compared to the young *Bambusa vulgaris*. The table also showed that the mature age from *Schizostachyum brachycladum* with 893.58 kg/m^3 had the slightly higher density value compared to young age from this species with 840.20 kg/m^3. On the other hand, the *Bambusa vulgaris* also indicated that mature age with 904.76 kg/m^3 has slightly higher density value compared to the young age from the species at about 724.54 kg/m^3. In addition, it can be seen that the mature age of the *Bambusa vulgaris* has the highest density value compared than others. As shown in Table 6 and Table 7, the analysis of variance (ANOVA) value on density indicated that there is significant different between ages and species with $P \leq 0.05$. Based on previous study, moisture content, thickness and width swelling has decreased when density values directly increased while the density were also influencing the measuring of the strength properties on a material used (Espiloy, 1985).

Table 2: Means for groups in homogeneous of density and basic density on two selected bamboo species

Parameter	Density (kg/m^3)	Basic Density (kg/m^3)
Young *S.brachycladum*	840.20^{b} (14.44)	506.63^{b} (25.47)
Mature *S.brachycladum*	893.58^{c} (12.09)	715.10^{c} (21.93)
Young *B.vulgaris*	724.54^{a} (5.30)	307.19^{a} (10.76)
Mature *B.vulgaris*	904.76^{c} (15.25)	727.10^{c} (73.49)

*Values in bracket represents the standard deviation
*Means followed by the same letter are not significantly different at 0.05 probability level

3.3. Thickness swelling and water absorption of *Schizostachyum brachycladum* and *Bambusa vulgaris*

Table 3 shows the *Schizostachyum brachycladum* which had a slightly higher value of thickness swelling compared than *Bambusa vulgaris* bamboo species. The table also showed the young *Schizostachyum brachycladum* with 2.41% of the higher value of thickness swelling compared to the mature age of the species with 1.32%. In addition, *Bambusa vulgaris* also showed the young age with 1.06% which had slightly higher value of thickness swelling compared to the mature age from this species with 0.28%. Moreover, It can be highlighted that the young *Schizostachyum brachycladum* had the highest value of thickness swelling compared than others portion. On Table 6 and Table 7, statistical analysis of variance (ANOVA) showed that the thickness swelling were significant different between their ages and species which is $P \leq 0.05$. It was supported by Rahman et al. (2002) whereby higher thickness swelling were proportionally higher in water absorption of samples.

Table 3: Means for groups in homogeneous of thickness swelling and water absorption on two selected bamboo species

Parameter	Thickness Swelling (%)	Water Absorption (%)
Young *S.brachycladum*	2.41^{c} (0.58)	11.89^{a} (1.46)
Mature *S.brachycladum*	1.65^{bc} (0.80)	22.82^{b} (3.79)
Young *B.vulgaris*	1.05^{ab} (0.31)	19.72^{b} (6.86)
Mature *B.vulgaris*	0.28^{a} (0.03)	5.08^{a} (0.76)

*Values in bracket represents the standard deviation
*Means followed by the same letter are not significantly different at 0.05 probability level

According to the Table 3, young *Bambusa vulgaris* had the higher value of water absorption compared to the young *Schizostachyum brachycladum* while mature *Schizostachyum brachycladum* indicated higher water absorption than mature *Bambusa vulgaris*. On the other hand, the young *Bambusa vulgaris* with 16.38% showed that the higher value of water absorption compared than mature age from the same species with 5.08%. The table also showed the mature *Schizostachyum brachycladum* is 21.48% with a higher value of water absorption compared to the young age from this species with 11.89%.

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Furthermore, the mature *Schizostachyum brachycladum* had the highest value of water absorption compared than others. On the statistical analysis of variance (ANOVA) on Table 6 and Table 7 indicated that the water absorption value had significant different between their ages and species with alpha value which is less than 0.05. According to previous study, researcher believed that the water absorption and thickness swelling properties are directly related with moisture content (Rahman et al., 2002) whereby higher water absorption and swelling proportionally increased the moisture content of bamboo. According to Liese, (1985) the moisture content of about 20% on mature bamboo from green condition has led to a shrinkage of 4% to 14% in the wall thickness and 3% to 12% in diameter, then shrinkage process were affecting both the thickness of the culm walls and the circumference.

3.4. Flexural test on *Schizostachyum brachycladum* and *Bambusa vulgaris*

From Table 4 showed that the modulus of rupture (MOR) or also known as bending strength of the flexural test. According Table 5, the modulus of elasticity (MOE) or known as young modulus to the two selected bamboo species in different ages determined. Based on Table 4, the *Schizostachyum brachycladum* showed slightly higher value of MOR compared to *Bambusa vulgaris* bamboo species. The table also showed, the mature age from *Schizostachyum brachycladum* with 245.28 N/mm^2 with the higher value modulus of rupture compared to the young age on this species with 102.68 N/mm^2. While, the *Bambusa vulgaris* species also showed the mature age with 185.52 N/mm^2 had the higher MOR compared than young age with 63.17 N/mm^2. Moreover, the table also showed the mature *Schizostachyum brachycladum* has already had the highest value MOR compared to others. Based on previous study, it can be seen that the physical and anatomical structure of bamboo culms are closely related to the unique mechanical properties (Li et al., 2014).

Moreover, the process of bamboo culm to mature within an age were changes from soft and fragile to sprout becomes hard and strong (Sulaiman et al., 2016).

Table 4: Means for groups in homogeneous on MOR for two selected bamboo species

Parameter	MOR (N/mm^2)
Young *S.brachycladum*	102.68^b (2.93)
Mature *S.brachycladum*	245.28^d (4.94)
Young *B.vulgaris*	63.17^a (1.16)
Mature *B.vulgaris*	179.65^c (2.68)

*Values in bracket represents the standard deviation
*Means followed by the same letter are not significantly different at 0.05 probability level

Table 5 shows the *Schizostachyum brachycladum* which had slightly higher value of young modulus compared to the *Bambusa vulgaris*. Moreover, the table also shows that the mature *Schizostachyum brachycladum* species with 50671.92 N/mm^2 had the higher young modulus value compared to the young age from the same species with value is 37236.70 N/mm^2. On the other hand, the value of young modulus of *Bambusa vulgaris* also showed the mature age with 25218.25 N/mm^2 and was slightly higher compared to young age from this species with 13006.08 N/mm^2. Moreover, mature *Schizostachyum brachycladum* had the highest value of young modulus compared to the other portions according to the two selected bamboo species. As shown on Table 6 and Table 7 the statistical analysis of variance (ANOVA) highlighted that the MOR value for flexural test has significant different between their ages and species $P \leq 0.05$. Nevertheless, MOE value was indicated that there were significant different to their ages and species with $P \leq 0.05$. According to Rahman et al. (2002) the higher mechanical strength of bamboo might have proportionally higher value on MOE in bamboo and possesses higher mechanical strength that influence by larger fibre length and thick cell wall of bamboo fibres which affects the mechanical properties of bamboo.

Table 5: Means for groups in homogeneous on MOE for two selected bamboo species

Parameter	MOE (N/mm^2)
Young *S.brachycladum*	37236.70^c (261.66)
Mature *S.brachycladum*	50671.92^d (1524.05)
Young *B.vulgaris*	12382.91^a (616.77)
Mature *B.vulgaris*	25218.25^b (545.35)

*Values in bracket represents the standard deviation
*Means followed by the same letter are not significantly different at 0.05 probability level

Table 6: ANOVA analyses in between group on physical and mechanical properties of two bamboo species:

Parameter	SS^a	df^a	MS^a	F	Sig.
Moisture Content	2340.79	3	780.27	87.78	*
Density	61184.72	3	20394.91	132.58	*
Basic Density	356022.31	3	118674.10	71.42	*
Thickness Swelling	7.39	3	2.46	13.40	*
Water Absorption	573.78	3	191.26	11.95	*
MOR	59148.66	3	19716.22	1902.10	*
MOE	2416007304	3	805335768	1049.64	*

* Significant at $P \leq 0.05$

Table 7: ANOVA analyses in within group on physical and mechanical properties of two bamboo species:

Parameter	SS[b]	df[b]	MS[b]	F	Sig.
Moisture Content	71.11	8	8.89	87.78	*
Density	1230.65	8	153.58	132.58	*
Basic Density	13293.55	8	1661.69	71.42	*
Thickness Swelling	1.47	8	0.18	13.40	*
Water Absorption	128.07	8	16.01	11.95	*
MOR	82.92	8	10.37	1902.10	*
MOE	6137975.29	8	767246.91	1049.64	*

* Significant at $P \leq 0.05$

4. CONCLUSION

The study of physical and mechanical properties of *Bambusa vulgaris* and *Schizostachyum brachycladum* can be concluded as the young age of *Bambusa vulgaris* had the higher level of moisture content compared than other age and species of bamboo. This is because the age is a one of the factor that influence moisture content in elementary fibre and also on the part consisting the higher content of parenchyma fibre that is believed to have water storage in anatomical structure of bamboo. In addition, mature *Schizostachyum brachycladum* had the higher strength properties and most stability in their structure. This is because the part was supported by unique physical properties such as density, basic density and dimension stability that has the larger and longer fibre length that can be supported by anatomical structure with high content of lignin (as a binder). Moreover, *Bambusa vulgaris* was the most hydroscopic compared to the *Schizostachyum brachycladum*, naturally, the part had the thick spongy fibre that consist of high water capability in water absorption to parenchyma cell. On the other hand, mature *Schizostachyum brachycladum* were showing high value of MOR and MOE compared to others. This is because the part had stable structure of fibre which is believed to be capable of supporting the higher load. It is also assisted by high density which can help to influence the hardness and strength of bamboo oriented.

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