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Comparison in the Physical and Strength Properties of 3 Year-Old *Gigantochloa brang* and *G. Scortechinii*.

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ABSTRACT

Relationships between physical and strength properties of *Gigantochloa brang* and *G. scortechinii* were investigated. The culms of the three-year-old bamboos were selected, harvested and processed for the studies. The moisture content (MC) of the bamboo in green condition ranged between 74.54 (*G. brang*) and 109.18 (*G. scortechinii*), the MC is higher in the internodes (94.45%) than in nodes (78.61%). Position in the internal layer has MC at 125.90%, middle at 83.82% and external at 49.87%. The basic density increases from internal to external layer which started from 0.58 at inner and increased to more than 0.95 at outer part of bamboo at 12% moisture content. Shrinkage at radial, tangential and the volumetric were at 6.29%, 10.71% and 10.72 respectively for *G. brang*, and 8.72%, 11.74% and 16.83% for *G. scortechinii*. Positions having a higher rate of shrinkage were recorded on the inner (8.63, 13.50, 15.45%), follow by middle (6.85, 9.72, 12.57%) and outer (5.04, 6.52, 10.40%) respectively. The tensile strength for the bamboos ranged between 103.39 MPa (*G. brang*) and 122.16 MPa (*G. scortechinii*). The tensile strength of dried bamboo is 138.87 MPa compared with 89.95 MPa for green bamboo. The tensile of modulus of air dried bamboo is 4003.85 MPa compared with 2786.96 MPa for green bamboo. The modulus of rupture (MOR) for the bamboos ranged between 91.81-135.93 MPa. The MOR for dried bamboo was 142.21 MPa compared to the green bamboo 99.56 MPa. The modulus of elasticity (MOE) varies between 1203 MPa (nodes) to 3086 MPa (internodes) for *G.scortechinii*) and 3227 MPa (nodes) to 2561 MPa (internodes) for *G. brang*.

Keywords: *Bamboo Gigantochloa brang, G. scortechinii, 3 year-old culms, physical, strength properties*

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INTRODUCTION

Bamboo has traditionally been considered as the poor man's timber. This is obviously due to the abundance of bamboo forests, and the relative low level machinery and expertise required in obtaining a useable building material in its natural form. It is used for everything from house framing, flooring, thatch cladding for walls and ceiling, and even as shingles for the roof. However, in many other countries where bamboo has not traditionally been used during the past, bamboo timber is starting to establish itself as a more exclusive building material into a niche upper class market. The superior strength and durability of bamboo have earned its successful use as a timber for flooring and bench tops. These applications are utilizing the more processed bamboo such as the laminated bamboo strips. However, processed bamboo even in its natural form (round bamboo) are in high demand as people are wanting to use it more and more for construction of gazebos, fences, screens, etc. The strength and hardness of bamboo timber are equivalent to hardwood timber whilst the cost is also comparable to hardwood timber [1]. Bamboo has the potential to be a direct substitute for hardwood timber in the future and thus reducing the pressure on natural hardwood forests [2,3].

The physical and mechanical properties of bamboo have been widely studied by many researchers all over the world. However, information about the relationship between the physical and strength properties in three-year-old *G. brang* and *G. scortechinii* is still limited. Assessments were analyzed on bamboo physical properties such as moisture content, basic density, maximum shrinkage (tangential, radial and volumetric). Tension (tensile) parallel to grain, and shear test for small size specimens were carried out. Advancement in the application of bamboo in modern era requires further understanding of the material such as properties of the anatomy, physical and strength at different location and position in the bamboo culms.

MATERIALS AND METHOD

Samples preparation

Sample culms of *Gigantachloa brang and G. scortechinii* were harvested from The Bambusetum Plot, Forest Research Institute Malaysia (FRIM), Kepong, Selangor, Malaysia. Culms of three-year-old were selected in the study as the culms of this age was found to be most suitable as material for industrial uses [4,5]. The bamboos had their age verified from the tags and had been monitored since the sprouting stage. The plants were harvested in January 2012. The bamboo culms were cut at about 30 cm aboveground level. These culms were taken from randomly selected clumps with diameter range from 8-17 cm diameter, depend on species. Each stem was marked and cut at nodes and internodes 8. An end-coating paint was applied over the cut surfaces before the samples were transported to the laboratory. This was done to minimize evaporation and prevent fungal and insect attacks on the bamboo. The numbers of bamboo taken were 10 culms per species.

Methods

Physical Properties

Moisture content (MC) values were determined using the difference between the green sample and the oven drying method described by ASTM D-143 [6],[7] (Determination of MC at green condition) standards. Basic density (BD) values were determined by the volumetric measurement method described by ASTM standard D-2395 (ASTM, 1997). The shrinkage was determined using ASTM D-143 [6]. The weight and volume of each bamboo sample were determined in green condition according to the American Standard Testing Materials D-2395-02 [7].

All samples were conditioned at 65% of relative humidity and 22°C of temperature (air-dried condition) and the weight/volume were measured for a second time. Oven-dried weight and volume were measured a third time once the samples were oven-dried at 105°C for 24 hrs. The wood density of the dry condition was calculated as weight divided by volume, while the moisture content was calculated as the difference between green and dry weight and divided by dry weight, both values expressed as percentages. The BD was calculated as the oven dried weight divided by volume in green condition, and air-dry weight divided by volume in green condition. The volume shrinkage was determined as the difference between green and dried volume, and divided by green volume.

Moisture Content (MC)

The sample for both species was randomly taken at node and internode location and was divided into 3 layers, which is outer, middle and inner position in the study. Then, the samples were cut to 30 mm x 30 mm x culms wall thickness to determine the moisture content at green condition. The weight of the samples was recorded. Then, samples were placed in the oven at 60°C and continued at 105°C for 24 hr. respectively. The bamboo samples were next taken out and placed into a desiccator for 30 minutes to cool off. The samples were next weighted for the second time and recorded.

Determination of Basic Density (BD)

The BD was determined by the density equipment with an electric balance, and a beaker of water was applied. Each sample block was cut into the size of 10 mm x 30 mm x culms wall thickness. The thickness of sample depends upon the culms wall thickness and divided to three positions (outer, middle and inner). The sample blocks were oven dried for 48 hr. 105±2^{o}C until a constant weight was attained. The sample blocks were then weighed for oven-dried weight. The sample blocks were placed in water under vacuum at 700 mm Hg for 24 hr. until fully saturated to attain green volume condition. The volume of fully saturated sample blocks was obtained using the water displacement method. The weight displaced is converted to volume to the sample as a green volume.

Shrinkage

The radial, tangential and volumetric shrinkages of bamboo were carried out with the guidance of the standard methods of testing small clear specimens of timber, ASTM D 143-94 [6,7].

Determination of Strength Properties

Tension Parallel to Grain

Tension tests parallel to the grain are seldom investigated for bamboo. There was no report on tension strength for *G. brang* and *G. scortechinii*. However, in order to design bamboo tension members loaded in direct tension, the tension strength value is a fundamental criterion. The tension parallel to grain test carried out was adjusted from the standard methods of testing small clear specimens of timber, ASTM D 143-94 [6,7]. Due to the nature of bamboo, it is impossible to cut similar specimen dimensions suggested in the standard. Instron Testing Machine with 100 kN maximum load was used in the tensile test. The samples were prepared with sized 300 mm x 20 mm x 5 mm in accordance followed the standard. The speed was 1.0 mm/min and length of span (gauge length) was 30 mm. The tension area of sample was 3 x 5mm.

Shear Test

The shear test was performed in accordance to BS EN 314-1 [8] using an Instron Model 4204 Testing Machine. The shear test was carried out using rectangular strips with dimensions of 20 mm x 20 mm x culm wall thickness. The shear tests were carrying out three times in one sample, but at difference position of layer. So, this method called roller shear test. The weight, lengths, widths and thickness of the samples were measured and recorded. Samples were tested at a crosshead speed of 1.5 mm/min. Dried specimens were conditioned at an ambient temperature of 25± 3^{o}C and at a relative humidity of 30% (± 2%) before testing. The green samples were tested directly.

RESULTS AND DISCUSSION

Moisture content

The results on the physical properties conducted on the two bamboo species are tabulated in Table 1. These included the moisture content, basic density and shrinkage (radial, tangential and volumetric). The analysis of variance was also included. In the green condition, *G. scortechinii* possesses higher moisture content (109.18%) compared to *G. brang* (74.54%). Tamizi et al. [2] found that *G. scortechinii* possesses anatomy features that enable it to absorb and hold more water than *G. brang*.

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Table 1: The physical, strength properties and analysis of variance (ANOVA) between *Gigantochloa brang* and *G. scortechinii* at different location and position

			Physical Properties			Strength Properties		
	Moisture Content	Basic Density	Shrinkage				Tensile	
			Radial	Tangential	Volume	Shear	Strength	Modulus
SPECIES								
G.brang	74.54c	0.77a	6.29b	10.71b	13.72c	5.22c	103.39b	2661.65c
G.scortechinii	109.18a	0.71c	8.72a	11.74a	16.83a	6.71b	122.16a	346.58b
CONDITION								
Air-dried	-	-	-	-		8.20a	138.87a	4003.85b
Green	-	-	-	-		5.76b	89.95b	2786.96a
LOCATION								
Internodes	94.45a	0.74b	7.00a	9.17b	14.83a	6.24b	144.68a	3545.49b
Nodes	78.61b	0.77a	6.68b	10.66a	10.78b	7.72a	84.14b	3245.33a
POSITION								
External layer	49.87c	0.95a	5.04c	6.52c	10.40c	7.85b	135.93a	4061.64c
In-between layer	83.82b	0.73b	6.85b	9.72b	12.57b	9.18a	115.49b	3344.80b
Internal layer	125.90a	0.58c	8.63a	13.50a	15.45a	3.90c	91.81c	2779.79a

Means followed by the same letter is not significant different at 0.05 probability level.

The MC was higher at internode (94.45%) than at the node (78.61%) for both species. Significant difference in MC was observed between the location at internode and node. The anatomical factor, may have contributed to the different in MC between the two location [4,5]. At the internode, the metaxylem vessel structure was similar and larger, while at the node is metaxylem vessel are smaller and not similar. The mean MC at the outer layer was 49.87%, middle layer 83.82% and for the inner, layer was 125.90%. MC was higher at the inner layer and reduced to a position an outer layers of the bamboo culm. Bamboo species show different moisture values, which might be due to the difference in some inherent factors such as age, anatomical features and chemical composition [4,5,9]. *G. scortechinii* possesses higher MC compared to *G. brang*. The higher MC at the inner layer could be influenced by the anatomical structure of bamboo. The inner layer contains lower vascular bundles' concentration lead to higher MC as compared to outer layer. The MC has a correlation to the number of vascular bundle, vascular bundle length and vascular bundle width [4,5] (see Table 1). This was probably due to the decreased in percentage of parenchyma cell (higher frequency of the vascular bundle), the site of water storage [10]. At the internodes, the cell structures were uniform in terms of the distribution and pattern of vascular bundle and parenchyma cell. The mean MC at outer layer was 40.87 % (47.12 -53.62%), middle layer was 83.82% (81.07 -86.57%) and for inner layer was 125.90% (123.00-128.65). The MC is lower at the outer position and increase toward inner position. This was because the area that contents high fiber strand has low capacity for water storage.

Basic Density

The results on basic density (BD) at difference location and position in the bamboo culms are shows in Table 1. The higher BD was obtained for the *G. brang* with values 0.77 follow with *G. scortechinii* at 0.71. The BD at the internodes was 0.74 and nodes 0.77. There was significantly different between the location at node and internode. This was due to the higher vascular bundles' concentration in outer layer compared to inner layer, which contains lower vascular bundles' concentration and higher amount of parenchyma. The bamboo BD has a close relation with vascular and ground tissues' percentages which according to Espiloy [11], Widjaja and Rashid [12], and Janssen [13]. The BD for outer layer was 0.95, middle layer 0.73 and the inner layer were 0.58. The differences of BD at both the nodes and internodes were due to the fiber wall thickness. In the nodes, fibers have thicker cell walls and the high proportion of fibers in every vascular bundle and the higher amount of vascular bundles, are probably responsible for the higher BD of this part of the culms. The results obtained showed that BD of internode and node part of each bamboo species is only slightly different in contrast to the report by Hamdan et al. [14] which noted that the nodes present in the culms height generally have higher density than those of the internodes due to lesser presence of parenchyma as well as lower MC and volumetric shrinkage. This was probably due to the techniques used in determining the density of the bamboo. In this study, the Radiation Densitometry was used to determine the density of the bamboo compared to the previous study which used the typical way to determine the density.

Shrinkage

Radial shrinkage

Higher shrinkage value of radial shrinkage occurred in *G. scortechinii* was 8.72% and *G. brang* 6.29% respectively and under one group (see Table 1). It shows there was significant difference between the location at node and internode. The radial shrinkage was higher at internodes compare to the node. It shows, there was significant different between position. The inner layer was the higher radial shrinkage, and it reduces toward the outer layers. The radial shrinkage for the both bamboo ranges from 5.04 to 8.63%.

Tangential shrinkage

The higher tangential shrinkage was observed for *G. scortechinii* (11.74%), follow by *G. brang* (10.71%). It shows, there was significant difference between the location at node and internode. The tangential shrinkage was higher at node compare to the internode. It shows, there was significant different between position. The inner layer was the higher tangential shrinkage, and it reduces toward the outer layers. The tangential shrinkage for both bamboo varies from 6.52-13.50%.

Volumetric shrinkage

High volumetric shrinkage occurred in *G.scortechinii* (16.83%) and *G.brang* with the values of 10.72% respectively (see Table 1). There was significant difference between the location at node and internode. The volumetrical shrinkage was higher at internode compare to the node. The volumetrical shrinkage for bamboo genera *Gigantochloa* ranged between 10.40-15.45%. The internal layer showed greater shrinkage compared to in-between and external layer. This is due to the higher amount of parenchyma in the internal layer compared to in-between and external layer [4,5]. Bamboo, like wood, changes its dimensions when it loses moisture. The MC changes to the changes in the relative humidity and temperature of the surrounding environment. The dimension of bamboo started to change as soon as it starts to lose moisture [3]. Once the bamboo is harvested, loss of water takes place leading to radial and longitudinal shrinkage. This will result in the setting up of internal stresses between the fibers. These stresses exceed the cohesion of the fibers leading to warping. It was also observed that the radial shrinkage is about 5.04 to 8.63%, and that of longitudinal shrinkage is negligible as in the case with other wood members [2].

Strength Properties

G. scortechinii has better strength properties as compared to the *G. brang* (Table 1). This is supported by Razak et al. [1] which stated that *G. scortechinii* has better strength properties compared to *G. brang, G. levis* and *G. wrayi*.

Shear strength tests

The mechanical properties of bamboo are directly related to the MC as it reduces the strength of the element. Bending and compression strength have shown significant variation of bamboo for green and air-dried conditions [15],[16]. In general, the internal layer of every species of the bamboo showed highest MC compared to middle and outer layer. The results of analysis of variance (ANOVA) and the mean average for shear strength are tabulated in Table 2. The shear strength in *G. scortechinii* was 6.71 MPa and *G. brang* at 5.22 MPa.

The result for shear tests for green was 5.76 MPa and for the air-dried was 8.20 MPa. The shear strength for air-dried sample was nearly 30% higher than the green sample. The shear strength for the air-dried bamboo showed that *G. brang* having values between 3.22-8.30 MPa and *G. scortechinii* 4.95-12.67 MPa for both internodes and nodes samples. Significant difference between green and air dry sample were observed. The shear strength increases from the central to the outer part. Rafidah et al. [17] noted that the shear strength increases with the increases of the number of vascular bundle from inner to outer part of the bamboo [17,18]. It is also noted that the number of vascular bundle increased from the bottom to the top section [19].

Tensile strength for MOR

Analyses of variance (ANOVA) on tensile MOR are tabulated in Table 2. The results show that the tensile strength for various bamboo species at difference condition (green and air-dry), location (nodes and internodes) and position (outer, middle and inner layer). Based on statistical analysis, there was two significant different group was observed between species at a 95% confidence level. The higher group was *G. scortechinii* (122.16 MPa) and the lower was *G. brang* (103.39 MPa). There was a significant difference between green and air-dried sample. The result for tensile strength for green was 89.95 MPa and for the air dry was 138.87 MPa. The result for green condition showed that the MOR for *G. brang* ranges from 56.17-96.94 MPa and *G. scortechinii* from 35.14-123.11MPa. For the air-dried condition, the tensile strength increased; the result showed that *G. brang* possessed strength of 69.63-184.80 MPa and *G. scortechinii* 74.08-208.06 MPa. It can be seen that air-dried samples showed better tensile strength almost 35% compared to green samples. This may be because bamboo behaves similar to wood whereby the mechanical properties increase with decrease in moisture content [14].

Table 2: Strength Properties of Shears, Tensile strength MOR and MOE between *Gigantochloa brang* and *G. scortechinii*.

Sample	Location in culm cross section	Shear Strength (MPa)		Tensile strength (MPa) for MOR		Tensile modulus (MPa) for MOE	
		G. brang	***G. scortechinii***	***G. brang***	***G. scortechinii***	***G. brang***	***G.scortechinii***
(Green)							
Internode	External	4.84 (±0.60)	4.23 (±0.75)	96.94 (±8.95)	123.11(±13.92)	2561 (±221)	3086 (±327)
	In-between	5.07 (±0.31)	5.64 (±0.88)	81.96 (±7.01)	86.62 (±10.78)	2062 (±207)	1833 (±153)
	Internal	2.13 (±0.70)	2.90 (±0.86)	75.18 (±6.67)	79.81 (±9.09)	1658 (±163)	1672 (±102)
Node	External	5.51 (±0.85)	5.61 (±1.00)	88.56(±10.73)	77.30 (±9.10)	3227 (±239)	2705 (±288)
	In-between	5.66 (±0.42)	6.14 (±0.48)	61.27 (±3.00)	69.81 (±5.63)	2486 (±252)	2205 (±201)
	Internal	1.87 (±0.14)	1.84 (±0.40)	56.17 (±5.38)	35.14 (±5.00)	2056 (±233)	1203 (±109)
(Air-dried)							
Internode	External	6.37 (±2.32)	9.22 (±2.22)	184.80 (±9.48)	204.92(±17.13)	3638 (±349)	5258 (±271)
	In-between	6.57 (±2.26)	9.92 (±0.91)	167.09(±14.84)	219.56(±14.40)	3627 (±263)	5036 (±251)
	Internal	3.22 (±0.59)	4.95 (±1.40)	135.33(±12.41)	152.10(±17.48)	3004 (±263)	4195 (±385)
Node	External	8.30 (±1.17)	8.90 (±4.17)	140.05(±12.67)	179.11(±15.68)	3409 (±301)	5362 (±470)
	In-between	9.62 (±1.04)	12.67 (±1.36)	83.70 (±9.49)	164.32(±11.83)	2189 (±220)	5532 (±456)
	Internal	3.51 (±0.60)	8.49 (±1.05)	69.61 (±9.10)	74.08 (±10.55)	2018 (±193)	3387 (±351)

Standard deviations shown in parentheses

The analysis of variance (Table 2) for tensile strength shows significant difference between the internodes and nodes samples. The internodes were higher tensile strength for MOR which ranges from 135.33 to 167.09 MPa for *G. brang* compared to the nodes which ranges 69.61 to 140.05 MPa. The MOR for *G. scortechinii* at internodes ranges 152.10 to 219.56 MPa and nodes ranges from 74.08 to 179.11 MPa. The difference in tensile strength in the internodes compared to the nodes might be due to the anatomical properties and microstructure features at the internodes and nodes of the bamboo [2]. The tensile strengths increase from internal to external part of the bamboos for both bamboo species. Analysis of variance shows significant difference between the external, middle and internal strips. This phenomenon can be related to the higher content of vascular bundles in which can lead to the higher density of the external part and increase the tensile strength of the external part than the inner part of the bamboo [18]. He also stated that tensile strength and means Young's modulus increase with increase cellulose content and decreasing micro-fibril angle.

Tensile Modulus for MOE

Analyses of variance (ANOVA) on tensile MOE are tabulated in Tables 2. The results show *G. scortechinii* (4195 to 5258 MPA at the internodes) having higher values compared to the *G. brang* (3004 to

3638 MPA at the internodes). There was a significant difference between green and air-dried sample. The results for tensile modulus for green ranging from 1658 to 2561 MPa for internodes *G. brang* and for the air-dried ranges 2056 to 3227 MPa for nodes, and for the *G. scortechinii* at 1672 to 3086 MPa for internodes and nodes 1203 to 2705 MPa. It can be seen that air-dried samples showed better tensile MOE compared to green samples. This may be due to the fact that bamboo behaves similar to wood whereby the mechanical properties increase with decrease in moisture content [14],[20]. The tensile modulus increases from internal to external part of the bamboo for the two bamboo species. This can be related to the higher content of vascular bundles in which can lead to the higher density of the external part and increase the tensile modulus of the outer part than the internal part of the bamboo [18].

CONCLUSIONS

Gigantochloa scortechinii contain more moisture compared to *G. brang* in the green condition. The basic density were higher in *G. brang* compared to *G. scortechinii*. *G. scortechinii* experiences shrinkage slightly higher than *G. brang* in radial, tangential and volume.

The shear strength at different thickness (Roller shear) ranged between 1.84 to 12.67 MPa with *G. scortechinii* having the higher values compared to *G. brang* in the air-dried condition. The green bamboo having shear strength ranging from 1.87 to 5.66 MPa for nodes and 2.13 to 5.07 MPa for internodes in *G. brang*. The strength for *G. scortechinii* were 1.84 to 6.14 and 2.90 to 5.64 MPa respectively for nodes and internodes. The strength for dried bamboo *G. brang* were 3.51 to 9.62 MPa for nodes and 3.22 to 6.57 MPa for internodes. While for *G. scortechinii* ranges from 8.49 to 12.67 MPa for nodes and internodes 4.95 to 9.92 MPa.

The tensile strength for the tested bamboos ranged between 135.33 to 204.92 MPa for internodes and 6AA9.61 to 179.11 MPa for nodes with *G. scortechinii* having the higher values compared to *G. brang* in the air-dried condition. The tensile strength of dried bamboo is 69.60 to 184.80 MPa for *G.brang* compared with 74.08 to 204.92 MPa for *G. scortechinii*. While the tensile strength of the green bamboo ranges from 56.17 to 96.94 MPa for *G. brang*. For *G. scortechinii,* the tensile strength ranges from 35.14 to 123.11 MPa in green condition. The tensile strengths were higher at the internodes compared to the nodes.

G. scortechinii has overall better tensile and compression strength properties compared to *G. brang*.

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