Transactions on Science and Technology Vol. 6, No. 1-2, 95 - 101, 2019

Physical and Mechanical Properties of *Dendrocalamus asper* and *Bambusa vulgaris*

Nurfitrah Adam#, Ismail Jusoh

Faculty of Resources Science and Technology, Universiti Malaysia Sarawak (UNIMAS), 94300 Kota Samarahan, Sarawak, MALAYSIA

Corresponding author. Email: adamnurfitrah@gmail.com; Tel: 60-137540546

Abstract Physical and mechanical properties of bamboo are important that determine its potential for high quality end products. There is insufficient information on physical and mechanical properties of *Dendrocalamus asper* and *Bambusa vulgaris* from Sarawak. The objectives of this study were to determine, compare and evaluate the physical and mechanical properties of *D. asper* and *B. vulgaris* from the southern part of Sarawak with respect to height levels. Harvested bamboo culms of *D. asper* and *B. vulgaris* were sampled at 5^{th}, 10^{th}, 15^{th}, 20^{th}, 25^{th} and 30^{th} internodes. Moisture content and basic density of the designated were determined according to ASTM D4442-13 and ASTM D2395-13, respectively. Determination of Modulus of rupture (MOR) and Modulus of elasticity (MOE) was based on three-point bending test following ASTM D1037-12 standard. Compression parallel to the grain was determined in accordance with ASTM D143-09 standard. One-way analysis of variance (ANOVA) was conducted to determine the differences of physical and mechanical properties between internodes level of each bamboo species. Pearson Correlation coefficients were calculated to determine the correlation among the physical and mechanical properties. Bamboo culms of *D. asper* and *B. vulgaris* were studied and sampled according to internodes. Results showed that the basic density of both species at the top portion were significantly higher than the bottom portion. Moisture content at the bottom portion was significantly higher than the top portion. Modulus of rupture (MOR), Modulus of elasticity (MOE) and compression strength at the top portion were significantly higher than the bottom portion. Basic density, MOR, MOE and compression strength increased with height. It can be concluded that the middle to the top portion of the culm can be used for strength purposes while the middle down to bottom portion can be utilized for general utility.

KEYWORDS: *Dendrocalamus asper*, *Bambusa vulgaris*,internodes, physical properties, mechanical properties

I **Received** 28 August 2018 II **Revised** 27 September 2018 II **Accepted** 17 October 2018 II **Online** 28 April 2019 II © **Transactions on Science and Technology** I

INTRODUCTION

Bamboo is one of the oldest building materials that has been utilized by mankind worldwide. It has been recognized as light material that is comparable to steel in tension and concrete in compression (Sharma *et al*., 2015). Bamboo is in the family of grass, Graminaceae and under subfamily Bambusoideae. It grows rapidly and is renewable material. Thus utilization of bamboos for great variety of products should be promoted to develop green economy. Bamboo has been recognized as the second major non-timber forest products of Malaysian government (Azmy *et al*., 2004). The physical and strength properties of bamboo have been widely studied by many researchers worldwide (Li, 2004; Rafidah *et al*., 2010). Physical and mechanical properties of bamboo depend on species, site, soil, climate condition, position in the culm as well as node or internode part (Lee *et al*., 1994). The hollow circular cross section of bamboo allows them to retain its strength as the vessels are well distributed from top to bottom part of bamboo and the structural function are well contributed by the presence of nodes and diaphragm (Janssen, 1985). The compressive tensile strength and bending strength of bamboo are equivalent to wood and steel but weaker in shear (Janssen, 1981). Bamboo has elevated mechanical properties as in better MOE than any other natural fiber (Sen and Reddy, 2011).

Information on the morphology, characteristics, physical, mechanical and chemical properties of different age groups of cultivated bamboo in Malaysia especially in the state of Sarawak is rather limited. Bamboo properties differ with species, topography, external factor and climatic condition (Soeprayitno *et al*., 1988). The current utilization of bamboo is for ornamental, shots as food and high end products. The utilization of bamboo has the potential to be intensified as an alternative raw material for timber in producing high value-added products. Lack of knowledge on the properties of bamboo species and the low level of processing has hindered its extensive use especially as building and construction material (Owusu *et al*., 2014). This study aims to determine and compare the physical and mechanical properties along the culm of *D. asper and B. vulgaris* from southern part of Sarawak. The correlation among the properties with respect to height level was also determined. By determining the strength at internode location, the parts to be used when manufacturing product can be specified. The fundamental information on physical and mechanical properties must be fully understood to determine the advancement of bamboo utilization.

METHODOLOGY

Sample Collection

The bamboo culms for *D. asper* was obtained from Sabal reforestation area in Sarawak while *B. vulgaris* from Kg. Pinang, Kota Samarahan. Mature culms of approximately four to five years old were selected. The culms were cut at about 15 cm above ground level. Three culms of each species were felled. The total length of each felled culm was measured and the designated 5th, 10th, 15th, 20th, 25th and 30th internodes were marked and measured for length and diameter.

Sample Preparation

The designated internodes of the culm were utilized for the study. Specimen blocks intended for physical properties were placed in a container with ice to keep it at green condition. Samples for mechanical properties were air dry for two months before tested.

Determination of Physical Properties

The samples for physical properties were extracted upon felling. Internode length, diameter and culm wall thickness was measured upon felling. The method used in the physical study to assess moisture content and basic density was based on Razak *et al*., (2007) with modification. Specimens were cut at least 2.5 cm long with 2.5 cm width upon felling and kept in a zip lock plastic bag then placed in a polystyrene box to preserve their green condition.

Moisture content (MC) was determined using oven drying method based on ASTM D-4442 standard (ASTM, 2013). Green samples were weighed and subsequently oven-dried at the temperature of 105°C ± 2°C for 48 hours. The samples were then placed in a desiccator for 15 minutes prior to weighing. Moisture contents of *D. asper* and *B. vulgaris* were calculated and determined by using the formula below:

$$MC = \left(\frac{m - m_o}{m_o} \right) x100 \qquad (1)$$

where MC is moisture content, m is green weight and m_o is the oven-dry weight

Determination of basic density was conducted using volumetric measurement method based on ASTM D-2395 standard (ASTM, 2013). Green volume of each sample was determined using water displacement method. The water was kept at 4°C to maintain its maximum density of 1g/1cm^3 of pure water state. Sample block were then oven dried at temperature of 105°C ± 2°C for 48 hours until a constant weight was attained and re-weighted to obtain oven-dried weight. Basic densities of *D. asper* and *B. vulgaris* were calculated and determined by using this formula:

$$BD = \left(\frac{Oven-dry\ Weight\ (g)}{Green\ volume\ (cm^3)} \right) \qquad (2)$$

Determination of Mechanical Properties

Mechanical properties assessed were three-point static bending and compression parallel to the grain. Three points static bending test was conducted in accordance to ASTM D1037-12 (ASTM, 2012). Compression parallel to the grain test was carried out in accordance to modification of ASTM standard D143-09 for small clear timber specimen (ASTM, 2010). All the mechanical tests were performed using Instron universal testing machine model 5569 with load capacity of 50 KN.

Samples of 10 mm in width and 160 mm in length were cut from each designated internodes for bending test to obtain MOR and MOE values. The load was applied continuously with span of 12.7 cm at an approximately uniform rate of motion of the movable crosshead at 0.6 cm/min until a definite failure occurred. Samples of 12 mm (width) and 12 mm (length) were used to assess the compressive strength (CS) parallel to grain. The MOE, MOR and CS values of each test samples were automatically calculated by the built-in software in the Instron universal testing machine.

RESULT AND DISCUSSION

Features of D. asper and B. vulgaris

The culm height of both species was averaged at 22.3 m for *D. asper* and 24.3 m for *B. vulgaris*. The total of internodes for *D. asper* and *B. vulgaris* were averaged at 60 and 64, respectively for each culm. The internodes length for *D asper* shows that the length increases from internode no. 5 (25.5 cm) to 16 (43.4 cm) but slightly decreases at internode no. 20 (40.2 cm) then gradually increases to internode no. 30 (42.7 cm). *Bambusa vulgaris* showed similar trend at internode no.5 (28.0 mm) to internode no. 15 (37 mm), decrease at internode no. 20 (35 mm) then increases at internode no. 30 (37.2 mm). Internode diameter and culm wall thickness and of both bamboo species decreased with height. Diameter of *D. asper* internode ranged from 9.6 to 14.7 cm. Smaller internode diameter was observed for *B. vulgaris* ranging from to 6.1 to 9.8 cm. Thicker culm wall thickness was observed for *D. asper* (12 to 28.8 mm) than *B. vulgaris* (7 to 14.9 mm). The internode diameter and culm wall thickness of *D. asper* studied by Thaipetch (2004) were smaller in ranges of 7.8 cm to 10.2 cm and 7.8 mm to 14.8 mm, respectively. The observed features recorded for *B. vulgaris* in this study was also higher than *Bambusa* sp and *B. blumeana* studied by Thaipetch (2004).

Physical and Mechanical Properties of D. asper and B. vulgaris

Results of physical and mechanical properties of *D. asper* and *B. vulgaris* are summarized in Table 1 and Table 2. Moisture content decreased from the basal to the top position of the culm. The highest average of green moisture content recorded for *D. asper* was 143% at internode no. 5 while the lowest was at the internode no. 30 at 64%. The highest average moisture content recorded for *B. vulgaris* was 116% at internode no. 5 and lowest was at internode no. 30 at 59%. The decrease in moisture content with height is consistent with the results obtained by Razak *et al.*, (2010). Moisture content affects the strength of bamboo. The MC of bamboo is very crucial since it can affect the physical properties especially the strength when it changes below the fiber saturation point. The variation of MC is attributed to the distribution of vascular bundles within culm (Qisheng *et al*., 2002). The culm wall thickness was the largest at the bottom part of bamboo, thus the higher content of parenchyma cells with higher water holding capacity. Meanwhile, culm wall thickness decreases towards the top thus reducing the water holding capacity.

Basic density recorded from both species showed that BD increases from the bottom portion to the top portion along the culms. The highest BD recorded for *D. asper* was at internode no. 25 at 737 kg/m^3 at the top portion of the culm while the lowest was at internode no. 5 (485 kg/m^3). The highest average BD recorded for *B. vulgaris* was 703 kg/m^3 at the internode no. 30 and lowest at internode no. 5 at 490 kg/m^3. A study by Thaipetch (2004) showed that density of *D. asper* also increased with height. The density in woody material increasing as a bigger amount of vascular bundle massed in a smaller space reducing the total air volume within that particular area (Nordahlia *et al.*, 2012). These can be associated with the decrease in culm wall thickness for both *D. asper* and *B. vulgaris* that reduced in moisture content but increased in density. The significant increase of density also attributes in general increased of compressive and bending strength (Espiloy, 1985).

Average MOR values for *D. asper* and *B. vulgaris* increases with internode height (Tables 1 and 2). The highest average value of MOR recorded for *D. asper* was 228 MPa at internode no. 25 while the lowest value was 48 MPa recorded at internode no. 5. The highest average MOR value for *B. vulgaris* was 271 MPa at internode no. 30 and lowest was 145 MPa at internode no. 5. The highest MOE for *D. asper* recorded was 10672 MPa at internode no. 25 and lowest was at no. 5 (1163 MPa). The highest MOE recorded for *B. vulgaris* was 15543 MPa at internode no. 30 and lowest at no. 5 (5668 MPa). A study by Othman *et al*., (1995) recorded MOR (85.65 MPa) and MOE (63000 MPa) for *D. asper*. Mbuge (2013) recorded MOR (137.7 MPa) and MOE (3594.0 MPa) of *B. vulgaris* in Kenya. The MOE and MOR of both species recorded in this study exceeded the values recorded from other's study.

The result obtained from this study shows that top portion possessed higher MOR than the middle and bottom portion of the *D. asper and B. vulgaris*. It indicates that BD increased with height along with MOR and MOE. Study on *Gigantochloa levis* culm by Nordahlia *et al*. (2012) also showed that MOR and MOE were positively correlated to the density therefore strength increases with height in the bamboo culm. *Gigantochloa scortechinii* also showed increasing trends along the culm for MOR and MOE (Hamdan, 2004).

The highest average values of compression parallel to the grain recorded for *D. asper* was 65 MPa at internodes no. 30 and lowest was 42 MPa at internode no. 5. The average CS parallel to the grain for *B. vulgaris* recorded were highest at 72 MPa at internode no. 20 and 30. The lowest CS was 43 MPa at internode no. 5. Both *D. asper* and *B. vulgaris* showed increasing strength for compression parallel to the grain along the culm. Compression parallel to the grain recorded for *D. asper* by Othman *et al*., (1995) was 32 MPa and 56.7 MPa. Compressive strength tends to increase with height (Espiloy, 1987; Liese, 1987; Sattar *et al*., 1990; Lee *et al*., 1994; Lo *et al*., 2004). The increased in the compression strength was the inverse of that of moisture content for both species studied. The increment in bamboo compressive strength is the opposite of moisture content (Chung & Yu, 2004). The compression parallel to the grain was significantly higher due to the highest concentration of vascular bundles distribution in the outer layer of bamboo (Gutu, 2013).

Table 1. Average physical and mechanical properties along the culm of *D. asper*
**Average values followed by different letter within a column are significantly different at 5% level*

Internode no.	MC (%)	BD (Kg/m^3)	MOR (MPa)	MOE (MPa)	CS (MPa)
5	143b	485a	48a	1163a	42a
10	100a	613ab	160b	6226b	52ab
15	75a	693b	213c	8909c	60b
20	72a	700b	205c	9272cd	59bc
25	67a	734b	228c	10672d	57bc
30	64a	727b	226c	10289cd	65c

Table 2. Average physical and mechanical properties along the culm of *B. vulgaris*
**Average values followed by different letter within a column are significantly different at 5% level*

Internode no.	MC (%)	BD (Kg/m^3)	MOR (MPa)	MOE (MPa)	CS (MPa)
5	116d	490a	145a	5668a	43a
10	109d	500a	171a	9340b	50ab
15	90c	570ab	232b	12746c	59bc
20	84bc	569ab	252b	13413c	72c
25	68ab	667bc	263b	15091c	63bc
30	59a	703c	271b	15543c	72c

Correlation of Physical and Mechanical Properties of D. asper and B.vulgaris

The correlation among physical and mechanical properties determined for both *D. asper* and *B. vulgaris* are shown in Tables 3 and 4. Basic density, MOR, MOE and CS parallel to the grain were positively correlated. The only variables with negative correlation to other variables studied were moisture content. Result indicated that as moisture content increases, the other variable decreases. Moisture content of about 120% to 200% reduces the strength and drying provides the required strength and dimensional stability of bamboo (Razak *et al.*, 2013). These data were found to be consistent with *B. blumeana*, *B. vulgaris* and *G. schortenii* studied by Abd. Latiff (1990). Thus it can be concluded that the moisture content of bamboo should be reduced to optimize the strength of bamboo for various usage. Mansur (2000) also found the mechanical properties to be greater at the top portion when internodes were tested at dry condition.

Table 3. Pearson correlation coefficient among properties of *D. asper*

	MC	BD	MOR	MOE	CS
MC	1				
BD	-0.939	1			
MOR	-0.823	0.808	1		
MOE	-0.679	0.606	0.877	1	
CS	-0.782	0.777	0.685	0.489	1

** Correlation coefficient significant to 99% level

Table 4. Pearson correlation coefficient among properties of *B. vulgaris*

	MC	BD	MOR	MOE	CS
MC	1				
BD	-0.85	1			
MOR	-0.606	0.694	1		
MOE	-0.658	0.682	0.935	1	
CS	-0.517	0.638	0.797	0.789	1

** Correlation coefficient significant to 99% level

CONCLUSION

Results showed that bamboo species differ in terms of their features, physical and mechanical properties. Mechanical properties between *D. asper* and *B. vulgaris* were significantly different. Basic density, MOR, MOE and CS parallel to the grain were positively correlated which indicate that a change in one property will proportionately change the other property. Based on this study, bamboo utilization can be separated for different purposes when determining the end product to be manufactured. The middle to the top portion of the culm can be used for strength purposes while the utilization for general utility can be taken from the bottom to middle portion.

ACKNOWLEDGEMENTS

We thank the staffs of Applied Forest Science and Industry Development (AFSID) Division, Sarawak Forestry Corporation for the assistance in mechanical testing. Authors would also like to thank the Ministry of Education (Higher Education) for the financial support under the FRGS/STWN02/ (02)/1142/2014(09) grant.

REFERENCES

[1] Abd. Latif, M., Wan Tarmeze, W., & Fauzidah, A. (1990). Anatomical Features and Mechanical Properties of Three Malaysian Bamboos. *Journal of Tropical Forest Science,* **2**(3), 227-234

[2] ASTM Standard D143-09. (2010). *Standard test methods for small clear specimens of timber*. West Conshohocken, PA: ASTM International

[3] ASTM Standard D1037-12. (2012). *Standard test methods for evaluating properties of wood-base fiber and particle panel materials*. West Conshohocken, PA: ASTM International

[4] ASTM Standard D4442-13. (2013). *Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials*.West Conshohocken, PA: ASTM International

[5] ASTM Standard D2395-13. (2013). *Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials.* West Conshohocken, PA: ASTM International

[6] Azmy, M., Razak, W., Hashim, W.S. and Othman, S. (2004). Application of organic fertilizers on natural stand bamboos for sustainable management in Peninsular Malaysia. *Journal of Bamboo and Rattan,* **5**(4), 301-309

[7] Chung, K.F. and Yu, W.K., (2004). Mechanical properties of structural bamboo for bamboo scaffoldings. *Engineering structures*, **24**(4), 429-442.

[8] Espiloy, Z.B, (1985), October. Physico-mechanical properties and anatomical relationships of some Philippine bamboos. In *International Bamboo Workshop. China. p* (pp. 257-264).

[9] Espiloy, Z. B. (1987). Mechanical properties and anatomical relationship of some Philippine bamboos. In *Research on Bamboos*. *Proceedings of the International Bamboo Workshop 1986* (pp. 257-265).

[10] Gutu, T., (2013). A study on the mechanical strength properties of bamboo to enhance its diversification on its utilization. *International Journal of Innovative Technology and Exploring Engineering*, **2**(5), 314-319.

[11] Hamdan, H. (2004). *Characterizing the mechanical properties and behavior of Gigantochloa scortechinii bamboo for structural application.* PhD thesis, University of Wales, Bangor.

[12] Janssen, J. J. (1981, September). The relationship between mechanical properties and the biological and chemical composition of bamboo. In *Bamboo production and utilization. Proceedings of the XVII IUFRO World Congress* (pp. 6-17).

[13] Janssen, J. J. (1985). The mechanical properties of bamboo. Technical University, Eindhouen, Post Pus, 513, 250-256.

[14] Lee, A.W., Bai, X. and Peralta, P.N., (1994). Selected physical and mechanical properties of giant timber bamboo grown in South Carolina. *Forest Products Journal*, **44**(9), 40.

[15] Li, X., (2004). Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing.

[16] Liese, W., (1987). Research on bamboo. *Wood Science and Technology*, **21**(3), 189-209.

[17] Lo, T.Y., Cui, H.Z. and Leung, H.C., (2004). The effect of fiber density on strength capacity of bamboo. *Materials letters,* **58**(21), 2595-2598.

[18] Mansur, A. (2000). *Analysis of Calcutta bamboo for structural composites material.* PhD Thesis. Virginia Polytechnic University.

[19] Mbuge, D. (2013). *Mechanical properties of bamboo (Bambusa vulgaris grown in Muguga,* (Master dissertation, University of Nairobi).

[20] Nordahlia, A.S., Anwar, U.M.K., Hamdan, H., Zaidon, A., Paridah, M.T. and Razak, O.A., (2012). Effects of age and height on selected properties of Malaysian bamboo (*Gigantochloa levis*). *Journal of Tropical Forest Science*, pp.102-109.

[21] Othman, A.R., Mohmod, A.L., Liese, W. and Haron, N., (1995). Planting and Utilization of Bamboo in Peninsular Malaysia in Research Pamphlet No. 118, 1994. *Forest Resesarch Institute Malaysia (FRIM). Kepong, 52109.*

[22] Owusu, F.W., Appiah-Kubi, E., Tekpetey, S.L., Essien, C., Arthur, P.I and Zorve, G.K., (2014). Products development of laminated panel doors from plantation grown bamboo species in Ghana. *Journal of Bamboo and Rattan*, **13**(3/4), 91-105.

[23] Qisheng, Z., Shenxue, J. and Yongyu, T. (2002). *Industrial utilization on bamboo*. International network for bamboo and rattan.

[24] Rafidah, S., Razak, W. and Zaidon, A. (2010). Effect of oil heat treatment on chemical constituents of Semantan bamboo (*Gigantochloa scortechinii* Gamble). *Modern Applied Science,* **4**(2), 107.

[25] Razak, W., Janshah, M., Hashim, W. S., & Shirley, B. (2007). Morphological and anatomical characteristics of managed natural bamboo stands *Gigantochloa scortechinii*. *Journal of Bamboo and Rattan*, **6**(2), 115-122.

[26] Razak, W., Mohd Tarmizi, M., Othman, S., Aminuddin, M., Affendy, H. and Izyan, K., (2010). Anatomical and physical properties of cultivated two-and four-year-old *Bambusa vulgaris. Sains Malaysia*, **39**(4), 571-579.

[27] Razak, W., Othman, S., Tarmizi, M. M., Norashikin, M. S., & Izyan, K., (2013). *Bamboo*. Kota Bharu: Universiti Malaysia Kelantan.

[28] Sattar, M. A., Kabir, M. F., & Bhattacharjee, D. K. (1990). Effect of age and height position of muli (*Melocanna baccifera*) and borak (*Bambusa balcooa*) bamboos on their physical and mechanical properties. *Bangladesh Journal of Forest Science*, *19*(1/2), 29-37.

[29] Sen, T. and Reddy, H.J., (2011). Application of sisal, bamboo, coir and jute natural composites in structural upgradation. *International Journal of Innovation, Management and Technology*, *2*(3), p.186.

[30] Sharma, B., Gatoo, A., Bock, M., Mulligan, H. and Ramage, M., (2015). Engineered bamboo for structural applications. *Construction and Building Materials, 81,* pp.66-73.

[31] Soeprayitno, T., Tobing, L. and Widjaja, E.A., (1988). Why the Sundanese of West Java Prefer Slope-inhibiting *Gigantochloa pseudoarundinaceae* to those growing in the valley. In *International Workshop on Bamboo held in Cochin* (pp.14-15).

[32] Thaipetch, S., (2004). Physical and Mechanical Properties of Five Bamboo Species in Thailand, *In:* Final Technical Report, Project: PD 56/99 Rev. 1(1) Promotion of the Utilization of Bamboo from sustainable Sources in Thailand, Royal Forest Department and International Tropical Timber Organization. Pp. 41-45.