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Mechanical properties of sweet bamboo *Dendrocalamus asper*

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Abstract: The basic properties of *Dendrocalamus asper* and its suitability as a raw material for manufacture of composite panels were studied. Macroscopic characteristics, physical and mechanical properties, pH value, buffer capacity and bonding quality using different types of glue were studied. This paper deals with the mechanical properties in relation to the position along bamboo culm. *D. asper* shows high mechanical strength. The mean values of the modulus of rupture (MOR), modulus of elasticity (MOE), compression strength perpendicular to grain and shear strength parallel to grain are 198.52 MPa, 15,363 MPa, 14.39 MPa and 11.91, respectively. They vary with the position in the culm and depend significantly on the specific gravity. On the other hand, shear strength parallel to grain is not dependent on the specific gravity. The value slightly differs along the culm length. It is concluded that *D. asper* has superior mechanical properties which are comparable to certain softwood and hardwood species. It should therefore be promoted as a substitute for wood in the manufacture of structural composite lumber like Oriented Strand Board or Oriented Strand Lumber.

Keywords: Dendrocalamus asper, mechanical properties, Oriented Strand Lumber, Oriented Strand Board.

INTRODUCTION

Bamboo is considered as a composite material because it consists of cellulose fibers embedded in a lignin matrix. Cellulose fibers are aligned in the length of the bamboo providing high strength and rigidity in that direction (Liese, 1998). Bamboo has been used for a very long period by humans. It has received increasing attention owing to its easy propagation, vigorous regeneration, fast growth, high productivity and quick maturity. Furthermore, it is an efficient user of land, and produces more biomass per unit area than most wood species. Hence, bamboo products have found increasing uses in various applications. Additionally, bamboo as raw material is used for pulp, paper, veneer, decorative boards and panels. Bamboo could be an excellent raw material to replace traditional wood in the industries since there is only a slight difference in

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the anatomical structure and even in the chemical composition (Abd. Razak *et al.,* 1995; Liese, 2004). Recently, bamboo has been regarded as a raw material for structural composite products such as Oriented Strand Lumber (OSL) and Oriented Strand Board (OSB). Since its morphology, micro- and macroscopic characteristics, physical and mechanical properties differ from those of wood, methods, technology and equipment for wood processing cannot be applied indiscriminately for bamboo utilization. According to Abd. Latif and Liese (2002), the bamboo properties, which affect its utilization, depend on many factors, such as age, culm height, growth location among others. For this reason, information on macroscopic characteristics, physical and mechanical properties and gluability of bamboo are necessary for assessing its suitability for end products.

The suitability of bamboos for structural composite products is proven by its mechanical properties. Analysis of mechanical properties is the study of behaviour of the materials under different loading conditions. Information about the deformation behaviour, stress and the failure behaviour of bamboo in different forms is important for the effective use of bamboo as an alternative raw material for OSL and OSB.

MATERIALS AND METHODS

Some of the investigations were done at Wood Science and Engineering Research Unit, Walailak University in Nakhon Sri Thammarat, South of Thailand and further in the Department of Wood Science, University of Hamburg, Germany.

Three *Dendrocalamus asper* culms were harvested in April, 2007 from a private plantation, located in Nakhon Sri Thammarat province, South of Thailand. The terrain is mostly rugged hilly forest area with an elevation of about 600 m a.s.l., 217†mm mean annual rainfall and 27^{o}C mean temperature. The culms were three-years-old as confirmed by macroscopic features.

The culms were cut into each internode along their length. From following internode, three specimens were randomly selected and cut into size to the requirement of ASTM (1997) requested by each standard (ASTM D 143-94). Altogether, 84 specimens were cut from each culm and analyzed for the various tests. The air-dried specimens, (MC 50-60%) were placed for 8 weeks in a conditioning chamber, at 20∞C and relative air humidity of 65 per cent until the MC reached 12 per cent, before determination of the mechanical properties.

Static bending

The static bending test method was performed with some modification to the ASTM standard D 143-94 because the specimen shape changes along the culm height. The specimen width depended on the culm-wall thickness, while the thickness was kept equal to the width. The specimen length, which was parallel to grains, varied depending on the thickness of the specimen. The span was established to maintain a minimum span-to-depth ratio of 14. The test was carried out in the 50 kN Karl Frank Universal Testing Machine. Load was applied at mid-span of the specimen culm-wall thickness with a constant speed of the movable crosshead of 2.5 mm/min until specimen failure occurred. The maximum load at failure was recorded for Modulus of Rupture (MOR) calculation, while the resulting load and the deflection at the proportional limit were measured for Modulus of Elasticity (MOE) calculation. The specimens were cut near the point of failure in the length of 25 mm for specific gravity and moisture content determinations.

Compression perpendicular to grain

Specimens for the compression strength perpendicular to grain test were also taken from each internode along the culm length (6 cm length × 1 cm × culm wall thickness). The testing method was performed with some modification to the ASTM standard D 143-94, since the specimen width varied depending on the culm-wall thickness. The trials on the specimens were done using a universal testing machine (LLOYD 150 kN) equipped with a computerized data acquisition system. The load was applied through a metal bearing plate 50 mm in width, which was placed cross the upper surface of the culm-wall thickness and at right angles to its length. This was applied continuously throughout the test at a constant speed of the movable crosshead of 0.305 mm/min. The compression stress perpendicular to grain was calculated at 2.5 mm deflection. The specific gravity and moisture content were determined for each specimen.

Shear parallel to grain

For the determination of shear strength parallel to grain, specimens were also taken from each internode. The testing method was performed with some modification to the ASTM standard D 143-94, because the specimen shape changes along the culm height. All specimens were cut parallel to grains with the size of 2 cm × 1 cm × culm wall thickness. The specimens were tested on 50 kN Karl Frank Universal Testing Machine. The load was applied continuously throughout the test at constant speed of the movable crosshead of 0.6 mm/min. Only the maximum load was recorded for shear strength calculation. The specific gravity and moisture content were determined for each specimen.

RESULTS AND DISCUSSION

Static bending

Figure 1 shows the variation of MOR along the culm height. The values are in the range of 127.52 to 253.45 MPa, and the average specific gravity for bamboo specimens at 10.97 per cent moisture content is 0.766. The result demonstrates that MOR

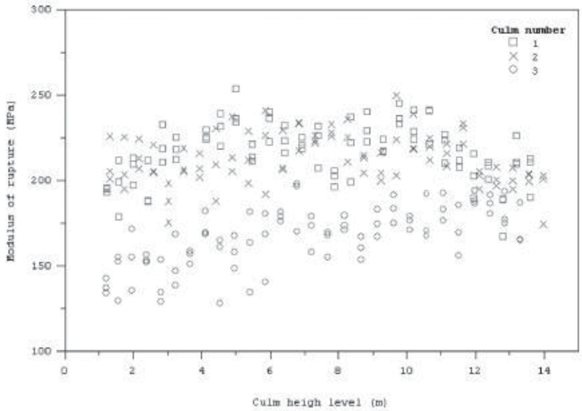

Figure 1. Variation of modulus of rupture along the culm of *D. asper*.

appreciably varies in relation to culm height location but the variant pattern from the bottom to the top of the culm is not clear. The study of Royal Forest Department (2003) observed the mechanical properties of *D. asper* in Thailand and reported that MOR value varies from 92-100 MPa and that it slightly differs between locations of the culm. This result also agrees with findings of Gnanaharan *et al*. (1994). The third culm has an average value lower (approximately 25% less) than the other two culms because of its lower specific gravity, as mentioned below.

The result further reveals that MOR is strongly related to specific gravity, as shown in Figure 2. The regression equations with the coefficient of determinations (R^2) are plotted to perform the strong relation between MOR and specific gravity. The MOR increases, when specific gravity increases. This observation is consistent with Anwar *et al*. (2005) and Yu *et al*. (2008) who found that the strengths of bamboo (*i.e*, MOR, MOE, compressive strength parallel to grain and tensile strength) depend on its specific gravity. Abd. Razak *et al.* (1995) explained that the bamboo specific gravity is closely

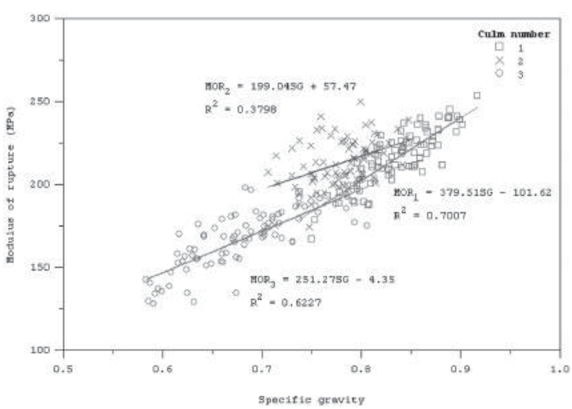

Figure 2. Correlation of specific gravity on modulus of rupture.

related to the relative proportions of vascular bundles and ground tissues; especially as the proportion of thick-walled sclerenchyma cells within the culm. Interestingly, bending failure of bamboo often occurs by horizontal shear. Along with low shear strength, as mentioned below, bamboo has low strength to splitting.

MOE for the three culms of *D. asper* along the length is presented in Figure 3. The values are in the range of 8,465-25,255 MPa at an average moisture content of 10.97 per cent and an average specific gravity of 0.766. It is evident that MOE slightly

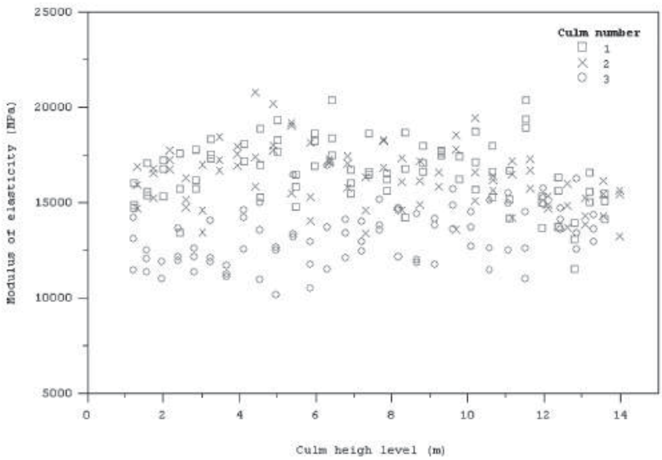

Figure 3. Variation of modulus of elasticity along the culm of *D. asper.*

varies with the position in the culm, although the variant pattern from the bottom to the top of the culm is not clear. Furthermore, the MOE values vary significantly in relation to specific gravity (Fig. 4). The linear regression equation and coefficient of determination (R^2) indicate a small relationship between the two properties. This result is in conformity with the findings of Abd. Latif *et al.* (1990, 1994). They found that

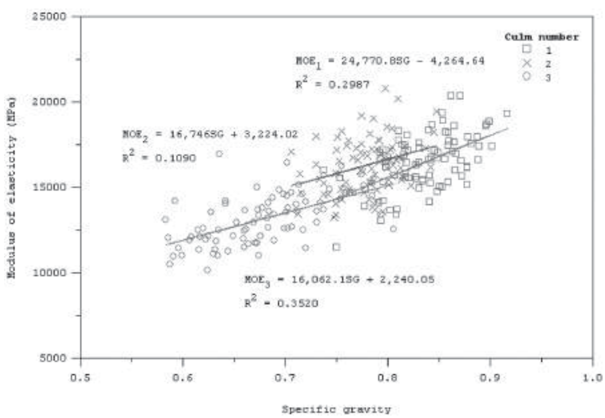

Figure 4. Correlation of specific gravity on modulus of elasticity of *D. asper.*

the mechanical properties of bamboos vary significantly with culm height. Additionally, the mechanical properties of bamboo are also correlated to anatomical features, such as vascular bundle size, distribution and fiber dimensions. It is generally accepted that the variation of bamboo specific gravity is mainly due to the variability of anatomical structures of bamboo along the culm. Hence, some deviations of MOE could be explained by the variation of the specific gravity from the bottom to the top of the culms.

Compression perpendicular to grain

The compression strength perpendicular to grain is illustrated in Figure 5. The values

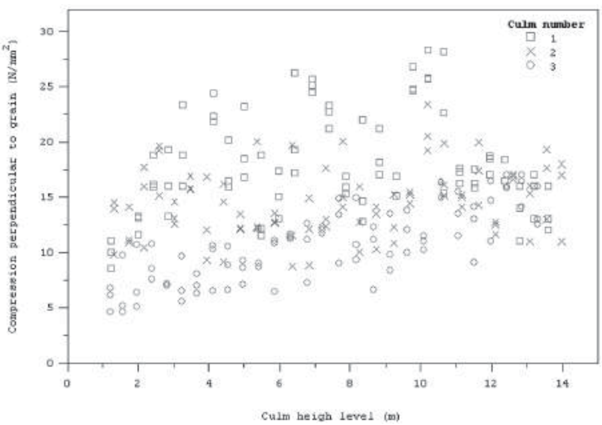

Figure 5. Variation of compression strength perpendicular to grain along the culm of *D. asper.*

vary from 4.57 to 28.30 MPa at an average moisture content and specific gravity of 8.25 per cent and 0.767, respectively. The result indicates that the location along the bamboo culm is also significant for this property. For the effect of the height, the compression strength slightly increases from the bottom to the top of the culm. The third culm also has lower compression strength than the other culms. It could be explained by its lower specific gravity. In accordance to the increase in specific gravity, the strength value gradually increases. This is mainly due to the variation of microstructure in the bamboo culm, as mentioned above.

Shear parallel to grain

The shear strength parallel to grain varies in the range of 8.05-15.36 MPa, presented in Figure 6, at an average moisture content of 9.92 per cent and an average specific gravity of 0.746. This result agrees with some part of the report of the Royal Forest Department (2003) which studied the shear strength parallel to grain of *D. asper* in Thailand and found that the value varies from 8.4 to10.0 MPa. In contrast to the

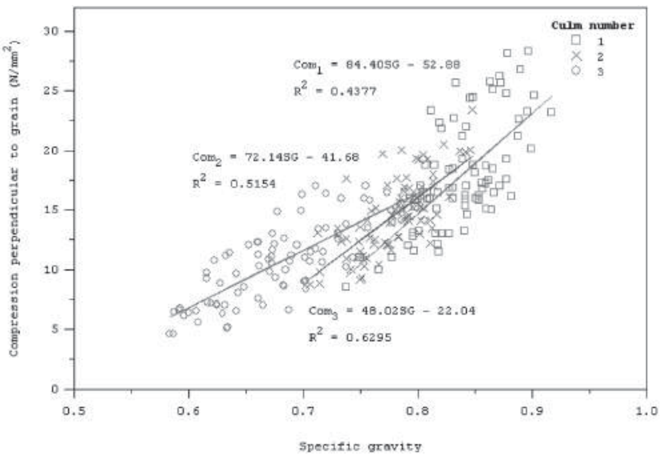

Figure 6. Correlation of specific gravity on compression strength perpendicular to grain of *D. asper.*

findings of other properties, shear strength parallel to grain is constant along the culm location and does not depend on specific gravity. A comparison of the mechanical properties of *D. asper* to those of other wood species which are used as raw material for wood composite manufacture is presented in Table 1. In general, the strength and stiffness of bamboo is higher than that of wood. The mean MOR of *D. asper* is approximately 2 to 3 times higher than softwood and hardwood species, while the mean MOE is slightly higher compared to other wood species. Its compression strength perpendicular to grain is also higher than wood species approximately 2 to 3 times. Interestingly, *D. asper* shows quite similar shear strength parallel to Rubberwood and a slightly higher strength than other species. However, all the above mentioned wood species have lower specific gravity by 15 to 50 per cent.

From a practical point of view, the strength of *D. asper* in grain direction is extremely high, especially MOR and MOE. It might be suitable as the raw material for such products as oriented structural boards which bears unidirectional load. Additionally, its low shear strength parallel to grain might encourage easy strand preparation.

Table 1. Comparison of the average values for physical and mechanical properties of *D. asper* and wood species used for panels manufacturing

Species	SG	MOR (MPa)	MOE (GPa)	Com ⊥ (MPa)	Shear // (MPa)
Dendrocalamus asper	0.75	199	15	14.4	11.9
Douglas-fir (*Pseudotsuga menziesii*) [1]	0.48	85	13	5.5	7.8
Red Pine (*Pinus resinosa*) [1]	0.46	76	11	4.1	8.4
Yellow poplar (*Liriodendron tulipifera*) [1]	0.42	70	11	3.4	8.2
American Aspen (*Populus tremuloides*) [1]	0.38	58	8	2.6	5.9
Rubberwood (*Hevea brasilliensis*) [2]	0.65	87	9	9.2	11.8

Source: [1] USDA Forest Service (1999); [2] Hong and Sim (1994)

Nevertheless, the strong variation of material properties is a disadvantage to take into consideration. The results show that the mechanical properties of *D. asper* vary along the culm length. Furthermore, its strength is more variable than that of wood. According to the mechanical properties, the raw material for composite products should be considered based on their strength to weight ratio. As a result, *D. asper* has a low strength to weight ratio, it is not desirable for some applications because of its high specific gravity. All these complex features must be taken into consideration for the bamboo utilization in the wood composite manufacture. However, its strength (*i.e*, bending strength) and availability may outweigh this disadvantage.

CONCLUSIONS

1. The mechanical properties of *D. asper*, except for shear strength parallel to grain, vary in relation to culm height location. Generally, the top of the culm shows the highest mechanical properties.
2. The mechanical properties of *D. asper*, except for shear strength parallel to grain, are strongly related to specific gravity. The properties will increase, when specific gravity value increases.
3. The bending strengths (*i.e*, MOR and MOE) of *D. asper* are approximately 2 to 3 times higher than those of traditional wood species used for panel manufacturing.
4. The variability of some mechanical properties from the third culm to the others is higher than that of wood logs and depends significantly on the microstructure and specific gravity variations.

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