SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF MOSO BAMBOO (*PHYLLOSTACHYS PUBESCENS*)

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Received September 2007

YU, H. Q., JIANG, Z. H., HSE, C. Y. & SHUPE, T. F. 2008. Selected physical and mechanical properties of moso bamboo (*Phyllostachys pubescens*). Selected physical and mechanical properties of 4–6 year old moso bamboo (*Phyllostachys pubescens*) grown in Zhejiang, China were investigated at different vertical and horizontal positions. Two way analysis of variance and Tukey's mean comparison tests indicated that layer had effects on all physical and mechanical properties. Height had effects on all selected properties except for tensile strength. Relative density, tangential shrinkage, tensile modulus of elasticity (MOE) and tensile strength of bamboo increased greatly from the inner layer outwards. However, longitudinal shrinkage decreased greatly from the inner layer outwards. Relative density, tangential shrinkage and tensile MOE at 1.3 m were less than those at 4.0 m from the base.

Keywords: Relative density, shrinkage, tensile modulus of elasticity, tensile strength

YU, H. Q., JIANG, Z. H., HSE, C. Y. & SHUPE, T. F. 2008. Ciri-ciri fizikal dan mekanik terpilih buluh *Phyllostachys pubescens*. Ciri-ciri fizikal dan mekanik terpilih buluh *Phyllostachys pubescens* berusia antara 4 tahun hingga 6 tahun dari Zhejiang, China dikaji. Buluh ini dikaji pada ketinggian dan kedudukan mendatar yang berlainan. Analisis varians dua hala dan ujian perbandingan purata Tukey menunjukkan yang lapisan buluh mempengaruhi kesemua ciri-ciri fizikal dan mekanik buluh. Ketinggian mempunyai kesan ke atas semua ciri-ciri yang dikaji kecuali kekuatan tegangan. Ketumpatan relatif, kekecutan tangen, modulus kekenyalan (MOE) tegangan dan kekuatan tegangan buluh bertambah dengan banyaknya dari lapisan dalam ke luar. Namun, kekecutan membujur berkurang dengan banyaknya dari lapisan dalam ke luar. Ketumpatan relatif, kekecutan tangen dan MOE tegangan pada 1.3 m kurang daripada nilainya pada 4.0 m dari aras tanah.

INTRODUCTION

In many countries, especially in Asia, moso bamboo (also called giant timber bamboo) is an enormous natural resource. Due to its rapid growth rate, short rotation age, excellent flexibility and high tensile strength, moso bamboo has been made into a wide variety of products used in our daily lives ranging from domestic household products to industrial applications, such as platforms (floors for transport vehicles such as trucks, buses and rail coaches), concrete moulding boards (in building industries), flooring, furniture, pulp and handicraft works (Jiang 2002).

To optimize the utilization of moso bamboo, its fundamental physical and mechanical properties must be fully understood. Previous studies have demonstrated that the physical and mechanical properties of moso bamboo vary with respect to position in the culms. Lee *et al.* (1994) found that the physical and mechanical properties of moso bamboo are affected by height location of culms. Xian *et al.* (1995) studied the variation in mechanical properties of moso bamboo and established an equation for predicting the tensile modulus of elasticity from the radial position. Li (2004) investigated the variation of the specific gravity and bending properties of moso bamboo, and found that the specific gravity and bending properties decrease from the outer to inner layers of the bamboo culms.

In processing and utilization, an understanding of the patterns of variation in bamboo properties can be crucial to optimizing value recovery. Therefore, the objectives of this work were to obtain data on the physical and mechanical properties of moso bamboo and to compare the properties at different horizontal and vertical sampling positions of the culms. This information can facilitate optimal utilization of bamboo culms for manufacturing composite products and other applications.

MATERIALS AND METHODS

Six moso bamboos, all 4–6 years old, were cut close to the base. The bamboo culms were 5.5 to 6.5 m in length with diameter at breast height ranging from 7 to 9 cm.

Two sections (each having two internodes) at the heights of 1.3 and of 4.0 m were cut. A strip of 1.5 cm in width was cut respectively from these two sections. The bamboo skin (cutin) for each strip was removed, then each strip was split evenly into six thin laminae and gently sanded to make the surface smooth, designated as layers 1, 2, 3, 4, 5 and 6 respectively from the inner layer to the outer layer (near the cutin). After sanding, the thickness of the samples was 0.7 ± 0.2 mm. From each of the lamina, one relative density (RD) sample (1.5 cm wide and 3 cm long with the thickness of the bamboo lamina) and one tension sample (1.5 cm wide, 14 cm long and 1 cm in centre with the thickness of the bamboo lamina) were obtained as illustrated in Figure 1. The tensile specimens were placed in a conditioning chamber (relative humidity: 65%, dry bulb temperature: 20 °C) for three weeks before they were used for the experiments. Average moisture content of the specimens was 9.7% at the time of testing.

RD is the weight of the sample after conditioning at room conditions divided by the weight of an equal volume of water, as determined using a water immersion method following ASTM D2395 (ASTM 1997). Tangential and longitudinal shrinkages of the samples were measured from water saturation to oven-dry conditions. Tensile strength was determined using a Universal Testing Machine. Strain was measured with strain gauges at a cross head speed of 0.5 mm min^{-1}. The tension strength parallel to the grain was tested at cross head speed of 3 mm min^{-1}.

The data were analyzed with a two way factorial analysis of variance (ANOVA) and Tukey's studentized range tests at $\alpha = 0.05$. The general linear model (GLM) of statistical analysis software was used to determine the effects of the longitudinal position (height) and the radial positions (layer) on the properties.

RESULTS

The mean RD of moso bamboo at different horizontal and vertical locations ranged from 0.553 to 1.006 g cm^{-3} (Table 1). The analysis of variance indicated that both height and layer had significant effects on RD, but the interaction between height and layer had no significant effect on RD.

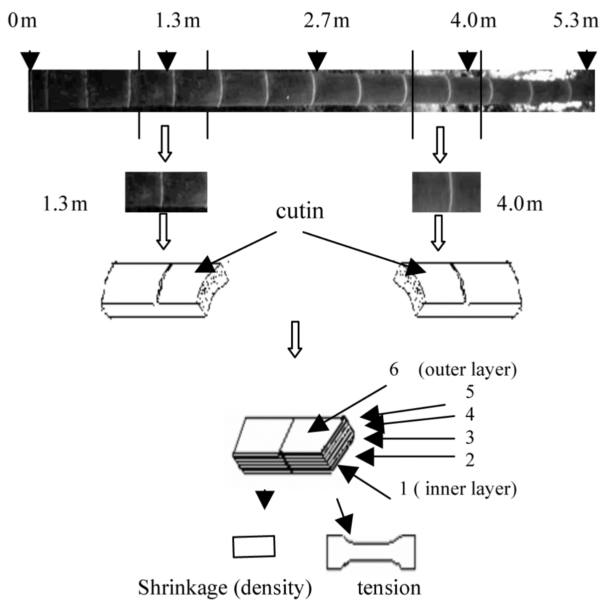

Figure 1 Sampling sequence for the moso bamboo specimens

Table 1 Mean physical properties of moso bamboo at different positions

Property	Height (m)	Layer					
		1	2	3	4	5	6
Relative density (g cm^{-3})							
Mean	1.3	0.553	0.566	0.607	0.632	0.712	0.942
SD		0.043	0.051	0.059	0.058	0.074	0.059
Mean	4.0	0.572	0.630	0.633	0.725	0.855	1.006
SD		0.023	0.075	0.052	0.048	0.050	0.034
Tangential shrinkage (%)							
Mean	1.3	4.870	5.151	5.721	6.649	7.554	7.623
SD		0.359	0.399	0.580	0.563	0.653	0.432
Mean	4.0	5.089	5.637	5.613	7.387	7.769	7.745
SD		0.361	0.489	0.509	0.626	1.004	0.742
Longitudinal shrinkage (%)							
Mean	1.3	0.279	0.285	0.291	0.183	0.173	0.132
SD		0.073	0.014	0.152	0.050	0.060	0.062
Mean	4.0	0.298	0.222	0.242	0.149	0.134	0.087
SD		0.042	0.027	0.074	0.041	0.044	0.038

SD = standard deviation

Figure 2 shows the results of the Tukey's studentized range test for multiple comparisons. Average RD decreased significantly from the outer layer (layer 6) to the middle layer. Thereafter, the difference in RD between the layers towards the inner surface was not significant. The mean RD at 4.0 m in height was slightly greater than that at 1.3 m.

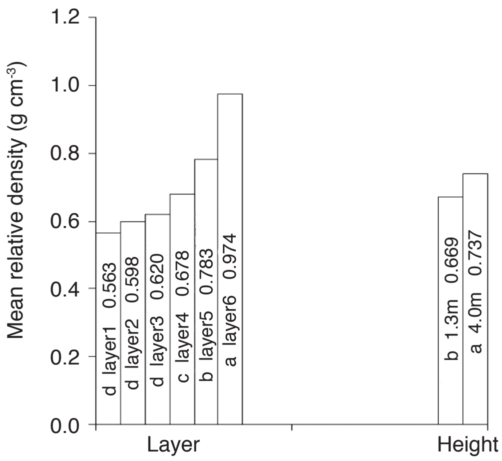

Figure 2 The variation of relative density for moso bamboo. Means with the same letter are not significantly different at $\alpha = 0.05$.

Dimensional stability

Shrinkage varied widely, ranging from 4.870 to 7.769% and 0.087 to 0.298%, for tangential and longitudinal shrinkages respectively (Table 1). The analysis of variance indicated that both height and layer had significant effects on tangential and longitudinal shrinkages, but the interaction between height and layer had no significant effect on shrinkage.

Figures 3 and 4 show the results of the Turkey's studentized range test of the effects of layer and height on the tangential and longitudinal shrinkage respectively. The tangential and longitudinal shrinkages appeared to be divided into two 3-layer zones (i.e. outer 3-layers consisting of layers 4, 5 and 6 and inner 3-layers consisting of layers 1, 2 and 3). The tangential shrinkage of the outer 3-layers was significantly greater than that of the inner 3-layers, but the shrinkage within either the outer or inner 3-layers was not significant (Figure 3). On the contrary, the longitudinal shrinkage of the outer layer was significantly less than that of the inner layer (Figure 4). Similar to the tangential shrinkage, the shrinkage within either the outer or inner 3-layers was not significantly different.

The tangential shrinkage was slightly greater at 4.0 m. The longitudinal shrinkage was slightly greater at 1.3 m.

Tensile modulus of elasticity and tensile strength

The mean tensile modulus and mean tensile strength at different positions varied widely, ranging from 9.0 to 27.4 GPa and from 115.3 to 309.3 MPa respectively (Table 2).

The analysis of variance indicated that layer had significant effect on the tensile modulus of elasticity (MOE) and tensile strength. On average, tensile MOE decreased as the layer decreased from the outer (layer 6) to the inner (layer 1) layers, but the difference between layers 3 and 4, and between layers 1 and 2 were not significant (Figure 5). Similarly, tensile strength decreased from the outer to the inner layers, but the difference between the inner 3-layers was not statistically significant (Figure 6).

The significant effect of height on tensile MOE is shown in Figure 5. However, height had no significant effect on tensile strength (Figure 6).

DISCUSSION

Some of the most unique characteristics of bamboo are greater tangential shrinkage, smaller longitudinal shrinkage, and greater MOE and moduls of rupture (MOR) of the outer layers as compared with the inner layers. These characteristics can be traced to the effects of anatomy and fine structure of bamboo. The

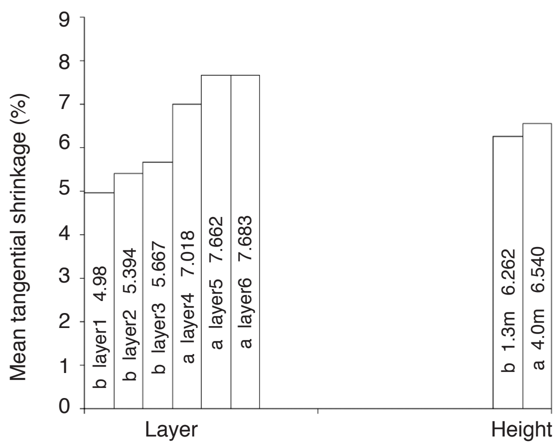

Figure 3 The variation of tangential shrinkage from water saturation to air-dry condition. Means with the same letter are not significantly different at $\alpha = 0.05$.

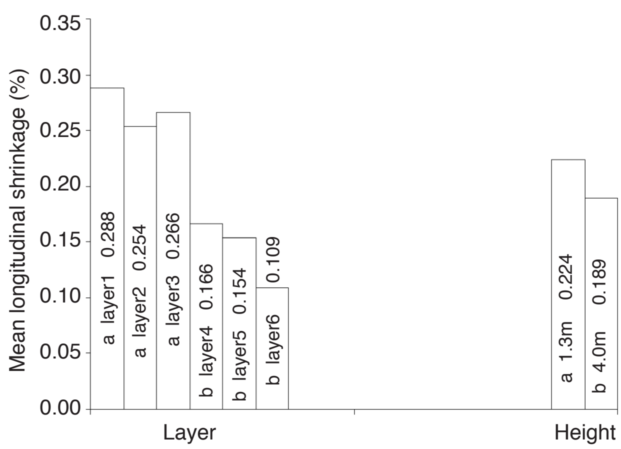

Figure 4 Longitudinal variation of shrinkage from water saturation to air-dry condition. Means with the same letter are not significantly different at $\alpha = 0.05$.

Table 2 Mean tensile modulus of elasticity and tensile strength parallel to the grain of moso bamboo at different positions

Property	Height (m)	Layer 1	2	3	4	5	6
Tensile modulus of elasticity (GPa)							
Mean	1.3	9.0	9.8	13.3	14.7	19.3	26.3
SD	1.3	1.7	1.3	0.9	1.5	2.5	2.4
Mean	4.0	10.3	12.9	15.1	16.8	21.8	27.4
SD	4.0	1.0	1.2	1.4	2.4	1.8	2.0
Tensile strength (MPa)							
Mean	1.3	115.3	115.9	132.7	179.1	228.8	281.9
SD	1.3	8.0	8.8	16.7	26.9	32.5	28.8
Mean	4.0	111.5	118.7	148.2	175.0	204.3	309.3
SD	4.0	11.7	17.1	18.2	18.8	20.8	20.3

SD = standard deviation

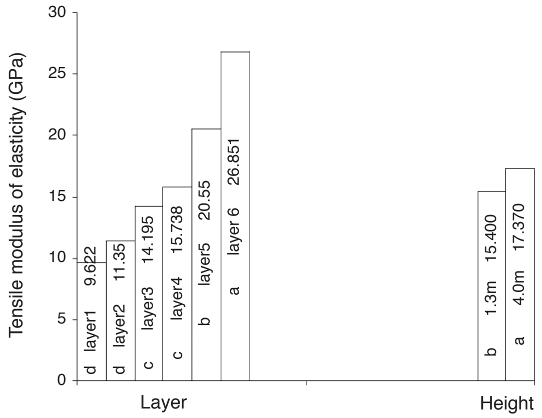

Figure 5 Variation in tensile modulus of elasticity. Means with the same letter are not significantly different at $\alpha = 0.05$.

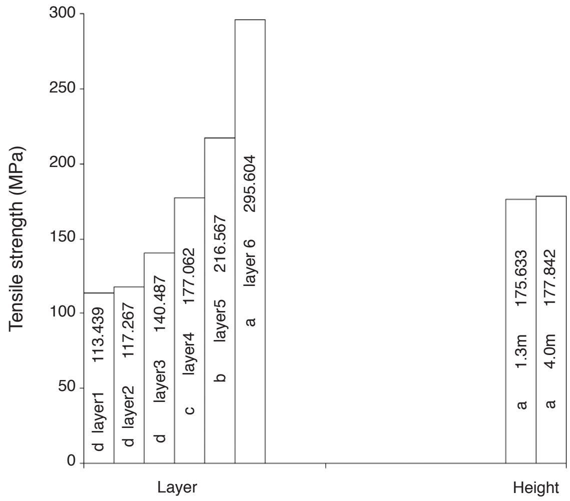

Figure 6 Variation in tensile strength. Means with the same letter are not significantly different at $\alpha = 0.05$.

bamboo culm consists mainly of parenchyma cells, fibres and conducting tissue (vessels and sieve tubes). The total culm comprises about 50% parenchyma, 40% fibres and 10% conducting tissue (Liese 1987). Although there are some variations in properties according to species, there is a definite distribution in horizontal and vertical pattern within one culm. Previous studies have shown that from the outer to inner layers and from the top to bottom within bamboo culms the percentage of fibre decrease and the percentage of parenchyma increase greatly (Grosser & Liese 1971, Ma & Ma 1996, Wang 2001). This distribution pattern of fibres and parenchyma is likely contributing to the variation pattern of tangential shrinkage, longitudinally shrinkage and strength properties of bamboo.

There appears to be widespread agreement that earlywood shrinks more longitudinally than latewood. Tangential shrinkage of earlywood, however, is less than that of latewood (Koch 1972). Continuing with the earlier assumption that a bamboo fibre bundle functionally resembles the latewood of conifers and bamboo parenchyma functionally resembles the earlywood of conifers, it would be logical that the outer layers and the top sections of bamboo culms would have higher tangential shrinkage and lower longitudinal shrinkage, and that the inner layer and the bottom section would have lower tangential shrinkage and higher longitudinal shrinkage. The data in this study support this assumption.

The distribution patterns of fibres and parenchyma of bamboo are also correlated with the relative density variation pattern of bamboo culm. The results show that from the outer to inner layers and from top to bottom within bamboo culms, relative density greatly decreased. Similar results were also reported in previous studies (Mansur 2000, Wang 2001, Li 2004). It should be noted that the relative density variation pattern also correlates well with dimensional shrinkage. The results supported the earlier observation on southern pine by Yao (1969) that tangential shrinkage was positively correlated and the longitudinal shrinkage was negatively correlated with specific gravity.

CONCLUSIONS

The relative density ranged from 0.553 to 1.006 g cm^{-3}. The tangential shrinkage from water saturation to oven-dry condition ranged from 4.870 to 7.769%. The longitudinal shrinkage from water saturation to oven-dry condition ranged from 0.087 to 0.298%. The mean longitudinal tensile MOE ranged from 8.987 to 27.397 GPa. The mean longitudinal tensile strength ranged from 115.349 to 309.322 MPa.

Layer had a significant effect on all of the selected properties. Height also had a significant effect on all of the studied properties except for tensile strength. Relative density, tangential shrinkage, tensile MOE and tensile strength of bamboo increased greatly from the inner layer outwards. Longitudinal shrinkage decreased greatly from the inner layer outwards. Relative density, tangential shrinkage and tensile MOE at 1.3 m were less than those at 4.0 m.

ACKNOWLEDGEMENTS

This work was supported by "China's Tenth Five-Year Program" (2001BA506B) and "The 948 NIR Program" of the Chinese National Forestry Bureau. The authors thank B. H. Fei and H. Q. Ren for helpful comments on this paper.

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