DIFFERENCES IN STRUCTURE AND STRENGTH BETWEEN INTERNODE AND NODE SECTIONS OF MOSO BAMBOO

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SHAO ZP, ZHOU L, LIU YM, WU ZM & ARNAUD C. 2010. Differences in structure and strength between internode and node sections of moso bamboo. Bamboo node is crucial to improve stiffness and stability of the slender bamboo culm during growth. However, for industrial utilisation, there is no research report on whether the node makes an impact on mechanical properties. In this article, moso bamboo (*Phyllostachys pubescens*) was used to analyse the structural difference between a culm without nodes (internodes) and a culm with nodes. Two different types of samples, prepared from two different processing methods, were used to carry out this study, namely, intact and planed samples. Meanwhile, the structure of bamboo nodes was investigated to study the influence of vascular bundles in the nodes on mechanical properties of the culm. Results indicated that in both planed and non-planed samples, the node did not have a reduced effect on bending strength, longitudinal shearing strength and compressive strength. Instead, the node had a reinforced effect of different degrees. However, the node reduced the longitudinal tensile strength.

Keywords: Bending strength, longitudinal shearing strength, compressive strength

SHAO ZP, ZHOU L, LIU YM, WU ZM & ARNAUD C. 2010. Perbezaan struktur dan kekuatan antara ruas dengan buku buluh *Phyllostachys pubescens*. Buku buluh penting untuk menambah kekerasan dan kestabilan kulma buluh yang halus semasa pertumbuhan. Bagaimanapun, bagi kegunaan industri, tiada terdapat laporan penyelidikan yang menunjukkan sama ada buku buluh memberi kesan terhadap ciri-ciri mekanik buluh atau tidak. Dalam artikel ini, buluh *Phyllostachys pubescens* dipilih untuk analisis perbezaan struktur antara kulma tanpa buku (ruas) dengan kulma yang mempunyai buku. Dalam kajian ini, dua jenis sampel disediakan menggunakan dua kaedah pemprosesan yang berbeza. Sampel tersebut ialah sampel berkulma dan sampel tanpa kulma (diketam). Sementara itu, struktur buku buluh dikaji untuk mengkaji pengaruh berkas vaskular dalam buku terhadap ciri mekanik kulma. Keputusan menunjukkan bahawa dalam kedua-dua sampel yang dikaji, buku tidak mengurangkan kekuatan lentur, kekuatan ricih memanjang dan kekuatan mampat. Sebaliknya buku meningkatkan ciri-ciri ini pada tahap berbeza. Namun buku mengurangkan kekuatan tegangan memanjang.

INTRODUCTION

In terms of morphology and mechanics, bamboo has a perfect optimised structure. Its fibre bundles increase from interior to exterior as a result of evolution to bear the bending load caused mainly by snow or wind. Some of its particular characters, such as the hollow structure and nodes, play an important role in allowing the plant to achieve optimal stiffness and stability with the least material.

Bamboo nodes appear at intervals of about 10 cm along the stem. A connection between the longitudinal and the cross direction is made by the crossing walls of nodes. The nodes are vital for hardness and stability of the slender culm. Internodes of culm consist of three parts, namely, inner, middle and outer sections. The various types of cells in bamboo can generally be classified into two groups, namely, parenchymatous ground tissue, which can pass loads and take the role of matrix of composite, and sclerenchymatous tissue, which are made up of vascular bundles. The ground tissue and bundle sheaths account for about 55 and 40% respectively of the whole bamboo tissue while the rest are vessel and

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primary xylem (Liese 1987, Abd Latif & Mohd Tamizi 1992). Fibres of vascular bundles mainly determine mechanical characteristics of bamboo. In the culm wall, the numbers of vascular bundles increase from the inner to the outer part of the culm but vice versa for ground tissues. The node of bamboo culm consists of a sheath scar, nodal ridge, diaphragm and the intranode between nodal ridge and sheath scar (Liese 1987, Abd Latif & Mohd Tamizi 1992). They strengthen the culm and conduct water.

With great strength and stiffness, and also abrasion resistant, bamboo is widely utilised as engineering structure materials in industry including as high quality composites (Jain *et al.* 1992, Zhao 1995, Nugroho & Ando 2000, 2001, Jiang 2007). Extensive research has been done on the structure, physical and mechanical properties and also chemical composition of moso bamboo (e.g. Lakkad & Patel 1980, Liese 1987, Abd Latif *et al.* 1990, Xian & Xian 1990, Abd Latif & Mohd Tamizi 1992, Abd Latif 1993, Yao 1993, Suzuki & Itoh 2001, Yu 2003, Kamruzzaman *et al.* 2008, Yu *et al.* 2008). However, most of these studies focused on properties of bamboo internodes, not the nodes. Therefore, moso bamboo culm with node and without node was studied to determine the influence of node on the strength of the bamboo. Results from samples without nodes could provide useful data for industrial utilisation of bamboo.

MATERIALS AND METHODS

Six moso bamboos were selected from the Anhui Province in China. They were three years old and about 15 m high. The diameter at breast height (dbh) varied from 110 to 125 mm and the average thickness of the culm wall was 12 mm at dbh. After cutting, the bamboo stems were air dried in the laboratory. The moisture content of the dried samples was about 12% and the average air-dry density of internodes of moso bamboo was 0.712 g cm^{-3}.

The structure differences between internode and node of moso bamboo were compared and analysed specifically on the macroscopic forms and distribution of fibre bundles. Mechanical properties of bamboo were tested according to the China National Standard (1995). Tests conducted were longitudinal tensile strength, bending strength, longitudinal shear strength and compressive strengths across and parallel to grain. Two types of moso bamboo were used, namely, that with culm intact (i.e. intact sample) and the other, with the innermost and outermost parts of culm removed by double planing (i.e. planed sample). Samples were then divided into four groups which were intact samples with nodes and without nodes, and planed samples with nodes and without nodes. When preparing materials for samples with nodes, the nodes were positioned at the centre of the samples. Samples with and without nodes were taken from neighbouring sections of the same culm (Figure 1), thus, giving an almost uniform thickness of samples.

Dimensions of tensile and tearing experiment at longitudinal–tangential (LT) plane are as in Figure 2. General dimensions of sample for bending test were 160 × 10 × t mm (width of culm), and for compressive strength across grain test, 20 × 20 × 6 mm. At compressive strength parallel to grain, the dimensions were 30 (longitudinal) × 10 (tangential) × t mm (~10 mm) for intact sample. However, when periderm and inner tissues of the bamboo were removed by double-side planing, the width of residual sample became too thin (approximately 6 mm) for compressive test. In order to avoid samples being unstable during compression, the height of processed sample was decreased from 30 to 20 mm, so dimensions were 20 × 10 × t mm.

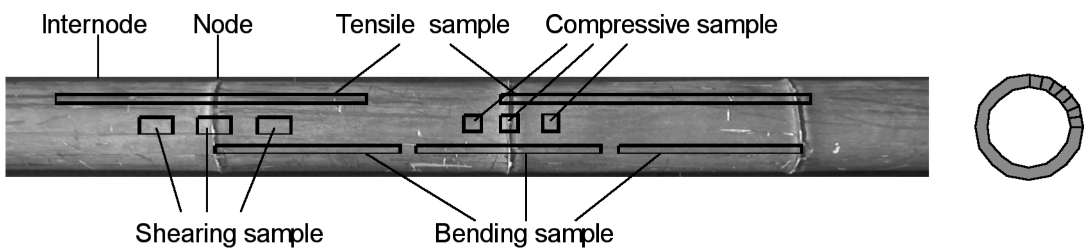
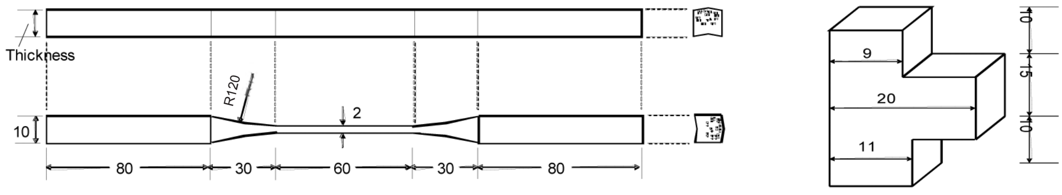


Figure 1 Testing samples produced from bamboo culm



(a) (b)

Figure 2 Dimensions of (a) tensile and (b) shear test samples (parameters are in mm)

For intact culm with nodes, dimensions are difficult to measure because its shape is irregular. Thus, maximum load was the only parameter presented in this paper for intact culm with node. However, the processed bamboo stick had smooth nodes. So, stress could be calculated based on the formula used.

All experiments were carried out by a mechanical testing machine controlled by a computer. The speed of cross-head was 2 mm min^{-1}. The laboratory temperature was between 15 and 18 °C, and the humidity of the room was 60–65%.

RESULTS AND DISCUSSION

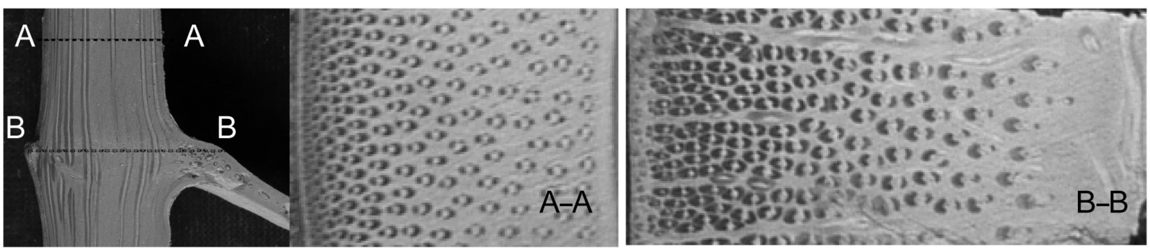
Structure comparison between internode and node sections of the culm

Bamboo cells between two nodes are strictly oriented axially (Figure 3a) and transverse ray cells, which are normally present in wood structure, are not observed. When going through the node area, vascular cells from the internode will spread in a continuous longitudinal direction and cross the node with a slight bend. The other part of the vascular will change its original direction. When the direction of bamboo cell changes, vascular cells extend in different ways. Vascular cells located in the inner part of the culm extend into the outer part. Simultaneously, vascular cells at the outer part of the culm stretch into the inner part. There are some vascular cells inserted into the diaphragm. These cells lay transversely around the periphery of the diaphragm, or go across the diaphragm as a complicated net with each other before reaching the opposite side of the culm. Due to the increase in the bending section of the vascular cells, the width of the node will be always bigger than neighbouring internode (Figure 3c).

Comparison of mechanical properties between culms at internode and node

Tensile test parallel to grain

Breaking tensile loads of intact samples with node and without nodes were 2436 and 2987 N respectively (Table 1); the existence of node decreased the load by 18%. The tensile strengths for planed samples with node and without node were 103 and 154 MPa respectively. The strengths of samples with nodes were lower than samples without nodes in a range of 33%. The failure surface of samples with nodes showed that the break started from both sides of the nodes (Figure 4). This could be due to the discontinuity of vascular tissues when they cross the node of the bamboo. Samples without nodes split longitudinally and showed a typical ductile fracture.



(a) (b) (c)

Figure 3 Comparison between internode and node of culm; (a) radial section, (b) cross-section of internode A–A and (c) cross-section of node B–B

Table 1 Mechanical properties of culms with and without nodes

Character	Processing	Unit	Sample without node			Sample with node			Ratio (without node/ with node)	Result of ANOVA	
			Average	Standard distance	Variation coefficient (%)	Average	Standard distance	Variation coefficient (%)		df	F value
Tensile strength parallel to grain	Intact	N	2987.3	457.0	15.30	2435.7	386.0	15.80	1:0.82	45	19.11**
	Planed epidermis	MPa	154.24	13.92	9.00	102.7	15.81	15.40	1:0.67	50	164.76**
Bending strength	Intact	N	850.8	115.3	13.60	1047.9	142.5	13.60	1:1.23	47	27.74**
	Planed epidermis	MPa	150.96	14.3	9.50	155.7	16.7	10.70	1:1.03	47	1.55 ns
Shearing strength parallel to grain	Intact	N	1954.3	436.6	22.30	2516.2	546.6	21.70	1:1.29	57	19.83**
	Planed epidermis	MPa	18.33	3.12	17.00	18.92	2.62	13.80	1:1.03	66	0.71ns
Compressive strength parallel to grain	Intact	N	13.71	1.03	7.50	14.7	1.04	7.10	1:1.07	59	14.18**
	Planed epidermis	MPa	56.4	4.97	8.80	59.8	5.65	9.50	1:1.06	40	6.37*
Compressive strength across grain	Planed epidermis	MPa	28.33	3.59	12.68	32.98	3.11	9.43	1:1.16	58	28.32**

* = Significant at 5% significance level; ** = significant at 1% significance level; ns = not significant

Bending test

Maximum bending loads of intact samples with nodes and without nodes were 1048 and 851 N respectively, a difference of 23% (Table 1). The bending strengths for planed samples with nodes (156 MPa) and without nodes (151 MPa) were similar. This suggests that the anti-bending ability of the node part in the intact culm is enforced by swelling of local tissues at the bamboo node. Thus, since nodes do not cause any negative effects on bending strength of planed samples, they should not be considered as defects in industrial utilisation.

Shear test parallel to grain

Maximum shearing loads of intact samples with and without nodes were 2516 and 1954 N respectively (Table 1); the shearing strength of samples with nodes was higher by 29%. For planed samples, shearing strengths were similar, i.e. 18.9 and 18.3 MPa for nodes and without nodes respectively. This showed that nodes could enforce the anti-shearing ability of bamboo culm by swelling of local tissues at nodes. For planed samples, nodes did not reduce the shearing strength. Tearing failures of the samples are shown in Figure 5. The periphery decumbent fibre bundles were not found in the culm; only a few fibre bundles were detected at the node. Failure plane in shear test is generally caused by slipping of the two planes comprising ground tissues of fibres. The snipping of fibre bundles in the cross direction did not contribute to the failure. Hence, effects of nodes on shear strength are almost negligible for the processed samples.

Compressive test parallel to grain

Maximum compressive loads parallel to grain for intact samples with and without nodes were 14.7 and 13.7 N respectively (Table 1). Compressive strengths parallel to grain for planed samples with node and without node were 59.8 and 56.4 MPa respectively. The compressive strength for samples with nodes was slightly higher than that of samples without node both in the intact and planed samples. This could be attributed to the higher proportion of bamboo fibres in the node area (see Figure 2).

Compressive test across grain

The strengths across the grain for samples with and without nodes were 33.0 and 28.3 MPa respectively. The difference of 32% between these two types of samples could also be explained by the higher proportion of fibres in the node area of the bamboo.

CONCLUSIONS

The study of mechanical properties of bamboo indicated that nodes did not impart any negative

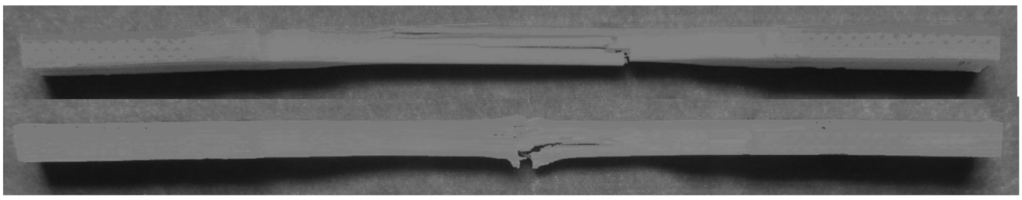
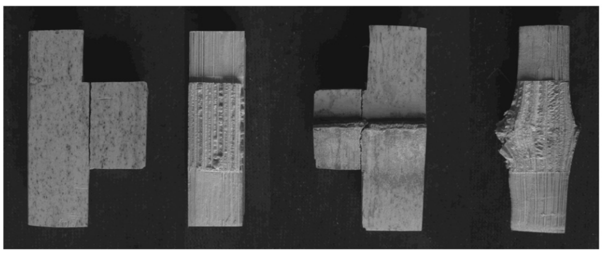


Figure 4 Tensile failure of a specimen without node (top) and with node (bottom)



(a) (b)

Figure 5 Shear failure for culm (a) without node and (b) with node effects on tensile strength, bending strength and compressive strength parallel or transverse to grain; on the contrary, they had certain positive effects. For intact samples, nodes enhanced maximum bending, shear strength and compressive loads by 23, 29 and 7% respectively. The enhancement effect initiated by nodes was not obvious for planed samples. However, negative effects of nodes on the tensile strength parallel to grain for both types of samples, i.e. intact and planed samples, were significant, in which the resistance decreased by 18 and 33% respectively.

Bamboo is a biological compound material reinforced by long natural fibres which give it a high resistance. Different extents in bending and some discontinuity of the vascular tissue were observed at bamboo nodes. However, tumefaction of bamboo nodes could increase the loading area and vascular bundles could be thickened, circuitous, flexuose and entwined. So, the ability to anti-bending and anti-shearing of the culm under transverse load is increased by bamboo nodes. The tensile load of the culm was relatively low during growth of bamboo. Therefore, enlargement of nodes and the development of nodes could improve tensile strength in the longitudinal direction.

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