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Tensile strength of bamboo across the radial direction

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Abstract: Tensile strength of bamboo from the innermost centre to the outermost skin increased from 72.8 to 187.3 MPa. This shows gradient tensile characteristics in bamboo. The experimental data match with the FEM analysis done using ABAQUS. Outermost section had the maximum tensile strength of 187.3 MPa. The reason for this large difference in tensile strength is that the innermost section has maximum amorphous material such as parenchyma as compared to outer surface. Density and hardness values determined also show gradient characteristics from innermost to outermost side. A continuous increase in hardness (Shore D, 48-70) is observed from centre to the outer surface. Density increases from 520 to 800 kg/m^3 from centre to the outer surface of bamboo.

Key words: FEM, bamboo, gradient, tensile strength.

INTRODUCTION

Natural fibres are renewable and cheaper as compared to glass and carbon fibres, which are conventionally used as reinforcement in making structural components. Bamboo is an important lignocellulosic material. Bamboo has emerged as a major source of renewable natural fibre for making high value added products. Among all the known natural fibres, bamboo has the lowest density and high mechanical strength. Also, difference in growth conditions and ageing have apparently no significant effect on composition and structure of the tissue (Ota, 1951). The structure of bamboo is much simpler when compared to that of wood (Liese, 1992.); the differences among the species are also very small.

Flexural strength of bamboo has been reported in the past. The mechanical properties of bamboo are highly dependent on the radial direction. In this paper, density, hardness and tensile strength along the grain of *Dendrocalamus strictus* in radial direction have been determined. Stress-strain values under tensile loads are also determined

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by using ABAQUS FEM software and tensile failure load patterns have been generated and analyzed.

MATERIALS AND METHODS

Culms of *D. strictus* were obtained from Sehore, Madhya Pradesh, India. Density of the bamboo was 660 kg/m^3.

Tensile strength

Four strips, 5, 10, 15 and 20 mm from the outer periphery to centre were cut from the bamboo culm (Fig.1). These strips were used for preparing test specimens as per ASTM D-638 (American Society for Testing and Materials) Standard. The tests were carried out at 27°C using a tensile tester (Scientific Instruments, India, model UT-10) with a crosshead speed of 10 mm/min. Gauge length was kept as 50 mm.

Hardness

Durometer (Hiroshima Hardness Tester model RHT-1) was used to determine the hardness of bamboo specimens. Strips were cut as explained under 'Tensile strength'. The hardness was measured at room temperature from the outer skin side of bamboo to the central inner core.

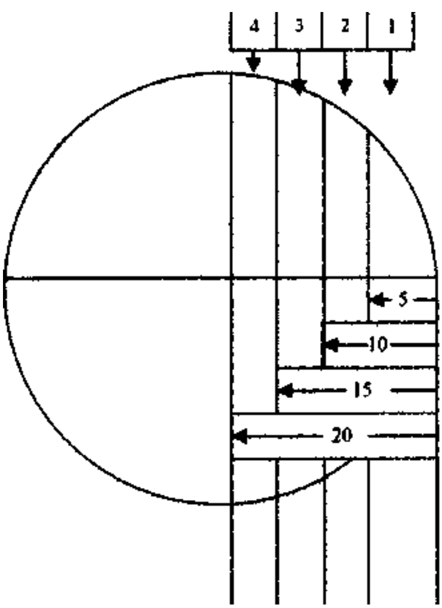

Figure 1. Distance of each strip from periphery in mm.

Density

The bamboo strips (Fig.1) were used for determining density. The volume was measured by water displacement method using a balance (Mettler Toledo).

FEM analysis

FEM simulation of tensile behaviour of all the four samples was carried out using FEM software, ABAQUS Version 6.5 (Anon., 2005). Bamboo is treated as transversely isotropic and the engineering constants used are listed in Table 3. The equation $E = 2G(1 + \nu)$ has been used for the isotropic relationship between elastic moduli (E), Poisson's ratio (ν) and shear moduli of rigidity (G). An 8-noded linear brick with reduced integration and hourglass control elements of size 1.0 were used for the three dimensional simulation.

RESULTS AND DISCUSSION

Density and hardness values determined for samples are listed in Table 1. As expected, there exists a gradient in properties in the radial direction of bamboo. Tensile strength values of the bamboo strips along the grain direction are reported in Table 2. The difference in tensile strength can be explained on the basis of the micro structural differences present in different samples observed by a scanning electron microscope (Chand *et al.*, 2006). Amorphous and cellulose cell structure which changes radially is responsible for this difference. Innermost central portion is highly amorphous in nature while the outermost portion is very crystalline. Literature reports that the ultimate tensile strength varies from 187 to 205 N/mm^2 in the internodal region and from 79 to 117 N/mm^2 in the nodal region (Liese, 1992). This shows that our results

Table 1. Density and hardness values at various positions

Sample No.	Density (kg/m^3)	Hardness (Shore D)
4	520	48
3	630	58
2	680	65
1	800	70

Table 2. Tensile strength of bamboo along the grain in the radial direction

Sample No.	Tensile strength (MPa)	Tensile strain	Young's modulus (MPa)
4	72.86	0.202	360.69
3	87.90	0.166	529.51
2	113.32	0.175	647.54
1	187.38	0.175	941.60

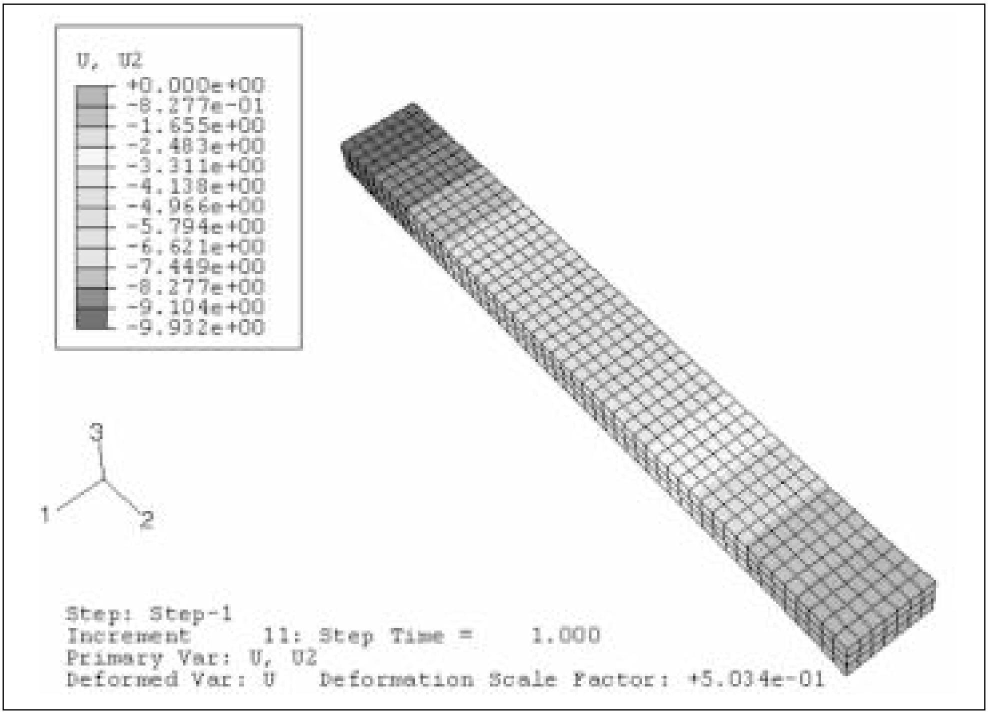

Figure 2. Deflection contour plot for the outermost sample.

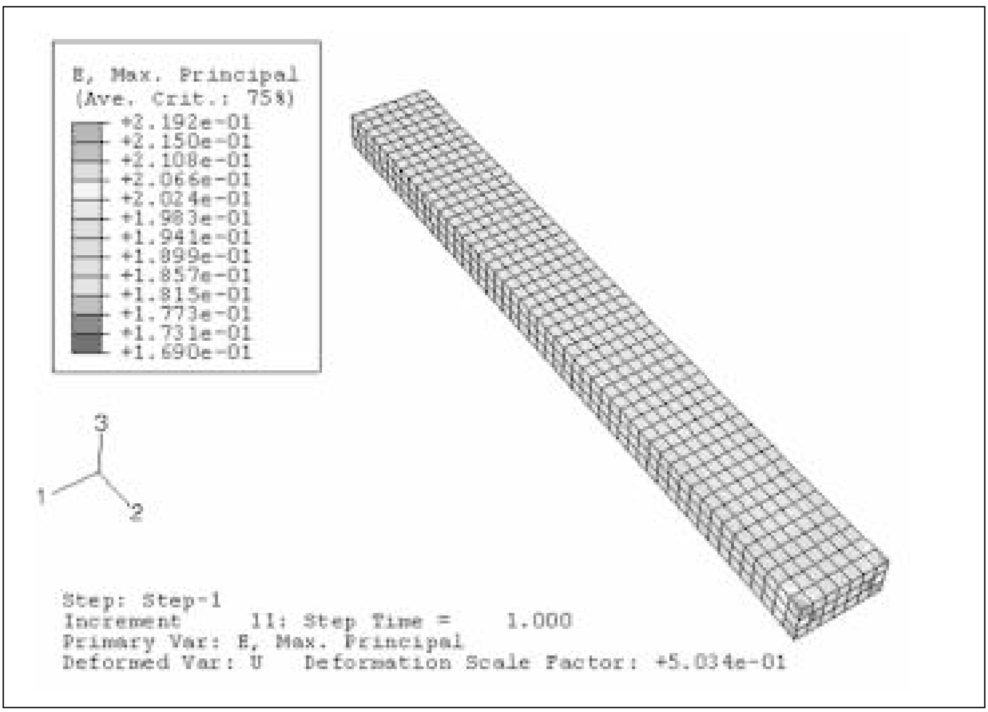

Figure 3. Strain contour plot for the outermost sample.

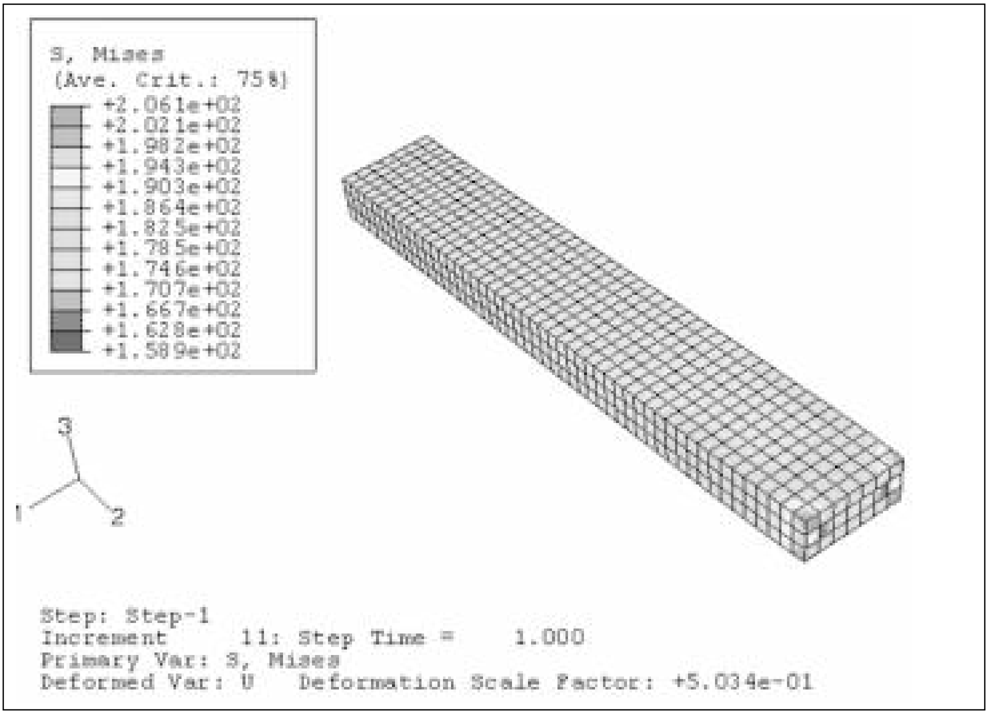

Figure 4. Mises stress contour plot for the outermost sample.

are very similar to the findings of Liese (1992). Grosser and Liese (1971) also found that across the culm wall the fibre length often decreased towards the inner part.

Typical FEM analysis plots for the outermost sample are given in Figures 2-4. In the case of tensile load, a contour plot of axial deflection shows a maximum value of approximately 10 mm (Fig. 2), tensile strain of 0.198 (Fig. 3) and von Mises stress of 206.1 MPa (Fig. 4). These stress results match perfectly with the experimental results obtained (Table 4).

Table 3. Engineering constants for ABAQUS FEM analysis

Sample No.	Elastic modulus (MPa)			Poisson's ratio			Shear modulus (MPa)		
	E_1	E_2	E_3	ν_{12}	ν_{13}	ν_{23}	G_{12}	G_{13}	G_{23}
4	360.69	36.64	36.64	0.48	0.48	0.45	121.85	121.85	12.63
3	529.55	36.64	36.64	0.48	0.48	0.45	178.90	178.90	12.63
2	647.57	36.64	36.64	0.48	0.48	0.45	218.77	218.77	12.63
1	941.68	36.64	36.64	0.48	0.48	0.45	318.13	318.13	12.63

Table 4. Gradient output of FEM analysis for gradient bamboo samples from centre (4) to outermost skin (1) along the fibre

Sample No.	Mises stress (MPa)		Tensile strain		Maximum longitudinal elongation (mm)		
	Maximum	In majority areas	simulated	experi-mental	simu-lated	experi-mental	% Error
4	90.13	71-75	0.201	0.202	10.06	10.1	3.96
3	102.8	84-87	0.165	0.168	8.279	8.3	2.53
2	133.8	109-112	0.17-0.175	0.175	8.729	8.7	-3.33
1	206.1	178-184	0.198	0.175	9.932	10	6.82

CONCLUSION

Tensile strength values of *D. strictus* culm decrease from outer periphery (187 MPa) to the inner core (73 MPa). The values of maximum elongation, tensile strength (Mises stress) and tensile strain determined by FEM analysis are in excellent agreement with the experimentally determined values.

REFERENCES

Anonymous 2005. ABAQUS 6.5 User Manual. HKS Inc.

Chand, N., Jain, D. and Nigrawal, A. 2006. Investigation on gradient dielectric characteristics of bamboo (*Dendrocalamus strictus*). *J. Appl. Polym. Sci.* (In Press).

Grosser, D. and Liese, W. 1971. On the anatomy of Asian bamboos with special reference to their vascular bundles. *Wood Sci. Technol.* 5: 290-312.

Liese, W. 1992. Bamboo and its use: The structure of bamboo in relation to its properties and its utilization. Int. Symp. on Industrial Use of Bamboo, Beijing, China.

Ota, M. 1951. Studies on the properties of bamboo stem. Part 7: Influence of the percentage of structural elements on the specific gravity and compressive strength of bamboo splints. *Journal of Japanese Forest Society* 19: 25-47.