J Indian Acad Wood Sci (December 2017) 14(2):110–114
DOI 10.1007/s13196-017-0194-x

ORIGINAL ARTICLE

Physical and strength properties of *Bambusa striata*

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Received: 16 November 2016 / Accepted: 22 May 2017 / Published online: 6 June 2017

Abstract Strength properties of round bamboo *Bambusa striata* were determined under static bending and compression parallel to grain tests in air dry and green conditions taking with node and without node at centre of the test specimens from bottom, middle & top portions of the culms. The results show that strength properties i.e. fibre stress at elastic limit (FS at EL), modulus of rupture (MoR), modulus of elasticity (MoE), and maximum crushing stress (Max. CS) are always found higher in air dry than green condition. The presence of node at the centre of the specimen increases strength properties i.e. FS at EL, MoR, and MoE (except Max. CS) significantly in green condition. However difference in 'Max. CS' determined in presence and absence of node at the centre of the specimens is found to be statistically non –significant at 95% confidence level. The result also indicates that strength properties occurs maximum at the top and minimum at the middle portion and wall thickness minimum at top and maximum at bottom portion of the bamboo. *Bambusa striata* species has also been classified (strength wise) on the basis of MoE, MoR, and Max. CS in green condition and found to fall in Group-III for construction purposes.

Keywords Sp. gr. · FS at EL · MoR · MoE · Max. CS · Wall thickness

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Introduction

Bamboo is a natural material which abundantly grows in most of the tropical and subtropical zone; it attains maturity in 4–5 years that is very less compared to tree species. It is also one of the most versatile material in forest products utilization and used as a raw material in large scale for various end- uses including low cost house construction in various rounds and split forms especially in North-East part of our country based on traditional experiences. Various researchers have reported their findings on anatomical characteristics, physical and mechanical properties of bamboos(Sekhar, and Gulati 1973; Shukla et al. 1988; Rajput et al. 1992; Narasimhamurthy et al. 2013 etc.). A systematic study on the physical and mechanical properties of bamboos may be useful in the selection of species for various end-uses where load play a significant role. Strength properties of 20 species of bamboo have been investigated and 16 of them are classified as suitable for constructional use and graded into three structural groups on the basis of their MoR, MoE and Max. CS (Rajput et al, 1992). Physical and mechanical properties of 11 round bamboo in green condition, 4 round bamboo species in air dry condition and 5 bamboo species in the spilt form have been reported and found that strength properties of dry bamboo are always higher than the green bamboo (Shukla et al. 1988). On the basis of strength data of 11 bamboo species in green condition, Shukla et al. (1988) have also reported different types of relationships between external diameter and three properties (FS at EL, MoR and MoE) under bending test. Narasimhamurthy et al. (2013) studied physico- mechanical properties from three locations (top, middle and bottom) of *Thysostachy ssiamensis* (Kurz) Gamble and *Dendrocalmus membrances* (Munro) in Tumkur district, Karanataka, India and found

MoR, MoE and compressive strength more for *Thysostachy ssiamensis* than *Dendrocalmus membrances*. Falayi and Soyoye (2014) studied the influence of age and location on selected physical and mechanical properties of bamboo (*Phyllostachys pubesces*). Sakaray et al. (2012) reported properties of bamboo as reinforcing material in concrete and found that the compressive strength of bamboo is nearly same as the tensile strength of bamboo, this behaviour is similar to steel. The authors also reported that in the green building concept use of bamboo reinforced concrete may be recommendable. Wahab et al. (2012) reported relationship between physical, anatomical and strength properties of 3- years cultivated tropical bamboo (*Gigantochloa scortechinii*), the strength properties tensile strength, tensile modulus and shear strength were found higher for air dried bamboo compared to green bamboo and these strength properties related with anatomical characteristics viz. Number of vascular bundle, vascular bundle length, vascular bundle width, fibre length, fibre lumen diameter, fibre wall thickness. Mohamod et al. (1990) studied anatomical features and mechanical properties of three Malaysian bamboos (in green condition only), some of the mechanical properties viz. Shear, compression parallel to grain and bending where correlated to anatomical features (vascular bundle size and distribution, and fibre dimentions). On the basis of available information, it is found that strength properties of some bamboo species have been reported so far. Therefore in the present study, strength properties of *Bambusa striata* grown in New Forest, Dehradun are determined and results are reported

Materials and methods

Five mature culms of *Bambusa striata* of about 2.5 years age grown in Bambusetum of the Forest Research Institute, Dehradun were selected randomly for the present study. The physical characteristics viz. height of the culm, numbers of internode and internode length were recorded of each culm. For internode diameter and wall thickness measurement, eight readings per specimen (four readings at each ends of the specimen) totalling to 240 observations were recorded. As per normal practice for testing of Bamboos (Sekhar and Rawat 1956), each culm of *Bambusa striata* was divided into three equal parts. i.e. bottom, middle and top portions. The following two sets of specimens were made:

1. In one set, five specimens for static bending and compression parallel to grain tests were collected from each of the three portions in green condition so that they contained either one node or no node.
2. In the second set, similar set of samples were again collected in green condition and were dried at room temperature under shade. Out of ten samples (for static bending test), six samples from top portion got damaged in this set and were not tested. Testing of these specimens for strength properties determination was carried out as per IS: 6874 (Anon 1973) method of tests for round bamboo using Universal Testing Machine. Moisture content and specific gravity in air- dry and green conditions of the bamboo species were also determined as per IS: 6874.

Statistical analyses of data were carried out through one way ANOVA and *t* test at 95% confidence limit.

Results and Discussion

Data recorded on physical characteristics of the culms of *Bambusa striata* in green condition is reflected in Table 1. The data indicate that average values of both internode diameter and wall thickness decrease from bottom to top portions. Difference in the values of wall thickness from bottom to top portions of bamboo (Table 1) is found significant at 95% confidence level (Table 2). These observations are similar to the findings reported earlier for *Dendrocalmus membrances* in green condition (Narasimhamurthy et al. 2013).

Strength properties viz. fibre stress at elastic limit (FS at EL), modulus of rupture (MoR), modulus of elasticity (MoE) determined under static bending and maximum crushing stress (Max. CS) under compression parallel to grain tests of round bamboo specimens (one without node and other with node at centre) from each bottom, middle and top portions of the culm in air dry as well as in green conditions are presented in Table 3. Statistical analysis of the data on strength properties in green condition are reflected in Table 2 and values in bold shown in table indicates values are non-significant at 95% confidence level. Data on strength properties in air dry condition was not analyzed due to non availability of sufficient specimens from the top portion of the bamboo. Data in green condition reveal that the values of strength properties are similar at the middle bottom portions. The values except MoR are significantly higher at the top portion of the bamboo. The values of MoR indicate non-significant difference from bottom to top portions of the bamboo (Table 2). In both air-dry and green conditions, average values of strength properties worked out in presence and absence of node at the centre of the specimen shows that all properties except Max. CS increase significantly in the presence of node at the centre of the specimen.

Average values of strength properties presented in Table 4 are worked out pooling the data of individual

Table 1 Physical characteristics of *Bambusa striata* in green condition

Physical characteristics	Minimum	Maximum	Average	SD	CV (%)
Culm height (cm)	914	1324	1142	166.6	14.59
Number of internodes	34	50	46	6.8	14.87
Internode length (cm)	6.2	37.7	23.6	10.7	45.29
Internode diameter (cm)					
Bottom	6.8	8.8	8.0	0.75	9.34
Middle	6.7	8.7	7.7	0.82	10.72
Top	3.8	7.0	5.4	1.12	20.60
Culm wall thickness (cm)					
Bottom	0.64	1.18	0.88	0.21	23.92
Middle	0.42	0.69	0.55	0.09	16.40
Top	0.34	0.52	0.44	0.06	12.70

SD standard deviation, *CV* coefficient of variation

Table 2 Statistical analysis of the data recorded on strength properties and wall thickness of *Bambusa striata* in green condition

Properties	Degree of freedom (df) (Portions, Error)	Portions in the bamboo culm			*p* value
FS at EL (kg/cm^2)	2, 27	(LSD = 98.5)			0.0349*
		242	**203**	332	
		Bottom	Middle	Top	
MoR (kg/cm^2)	2, 27	(LSD = 114)			ns
		429	**371**	**479**	
		Bottom	Middle	Top	
MoE (10^3 kg/cm^2)	2, 27	(LSD = 20.2)			0.049*
		35.5	**33.9**	58.0	
		Bottom	Middle	Top	
Max. CS (kg/cm^2)	2, 27	(LSD = 68)			<0.001*
		317	304	475	
		Bottom	Middle	Top	
Wall thickness (cm)	2,57	(LSD = 0.10)			<0.001*
		0.88	0.55	0.44	
		Bottom	Middle	Top	
Presence/absence of node at the centre of the specimens on strength properties					(*p* value)
FS at EL (kg/cm^2)	28				0.0005*
MoR (kg/cm^2)	28				0.0012*
MoE (10^3 kg/cm^2)	28				0.0111*
Max. CS (kg/cm^2)	28				ns

ns non significant at 95% confidence levels, *LSD* Least Significant Difference

* Significant

strength property (including in the presence and absence of node at the centre of bamboo specimens) for each air dry and green condition. The result of strength properties reveals that all these values are always found higher in air dry than green condition in the bamboo species. These findings are similar to the results of eleven different bamboo species reported earlier by Shukla et al. (1988). The average value of strength properties (FS at EL, MoR, MoE and Max. CS) are also found lower except Max. CS than the value reported earlier by Mohamod et al. (1990) for same species in green condition, which may probably be due to the environmental condition. *Bambusa striata* species is classified (strength wise) on the basis of MoE, MoR and Max. CS in green condition as per criteria followed by Rajput et al. (1992) into Group-III for construction purposes.

Table 3 Mechanical properties of *Bambusa striata* along three locations (bottom, middle and top portion of the culm) in air dry and green condition)

Property	Portion in culm	Green condition		Air dry condition	
		With node	Without node	With node	Without node
FS at EL (kg/cm^2)	Bottom	290 (83.6)	195 (69.5)	273 (85.6)	242 (45.3)
	Middle	259 (53.2)	148 (36.7)	325 (105.9)	177 (45.8)
	Top	426 (114.2)	239 (116.6)	593 (151.5)	316 (134.2)
MoR (kg/cm^2)	Bottom	448 (69.5)	411 (78.1)	459 (67.6)	454 (128.6)
	Middle	426 (85.6)	316 (43.7)	430 (93.1)	296 (67.9)
	Top	607 (151.5)	351 (108.7)	743 (170.8)	491 (208.8)
MoE (10^3 kg/cm^2)	Bottom	36.0 (12.8)	35.0 (9.8)	38.4 (13.6)	35.8 (7.2)
	Middle	42.0 (10.7)	25.8 (6.1)	49.3 (11.1)	32.9 (12.4)
	Top	78.8 (34.4)	37.1 (20.5)	81.6 (22.5)	83.0 (47.2)
Max. CS (kg/cm^2)	Bottom	306 (73.7)	327 (91.1)	338 (36.5)	324 (72.6)
	Middle	292 (67.9)	317 (33.1)	319 (71.2)	314 (91.2)
	Top	466 (94.0)	485 (89.0)	535 (138.8)	573 (163.9)

Standard deviation value is given in parenthesis

Table 4 Average physical and mechanical properties of *Bambusa striata* in air dry and green conditions

Condition	Specific gravity	Moisture content (%)	Static bending test			Compression parallel to grain test Max.CS (kg/cm^2)
			FS at EL (kg/cm^2)	MoE (10^3 kg/cm^2)	MoR (kg/cm^2)	
Air dry	0.451	11.9	287	46.3	444	400
SD	0.02	0.39	132	22.6	148	139
CV (%)	3.25	5.33	45.9	48.9	33.4	34.7
Green	0.431	97.5	259	42.5	426	365
SD	0.03	10.12	117	24.0	128	107
CV (%)	6.01	10.38	45.2	56.5	30.0	29.2

SD standard deviation, *CV* coefficient of variation

Conclusions

Strength properties of *Bambusa striata* along three portions i.e. bottom, middle and top of the culms in air dry and green conditions are determined under static and compression parallel to grain tests. The results reveal that strength properties i.e. fibre stress at elastic limit, modulus of rupture, modulus of elasticity, maximum crushing stress are always found higher in air dry than green condition. Strength properties from bottom to top within the bamboo are not found uniform. Maximum value found for top portion and middle and bottom portions behave similarly. Presence of node at the centre of bamboo specimens also increases strength properties (except Max.CS). *Bambusa striata* species has also been classified (strength wise) on the basis of MoE, MoR and Max. CS in green condition and found into Group-III for construction purposes.

Acknowledgements The authors are thankful to the Director, Forest Research Institute, Dehradun for encouraging and providing facilities for carrying this work. Authors are also thankful to the Head, Forest Products Division, Dr. Sadhana Tripathi, Scientist–G, Forest Products Division and staff of Timber Mechanics Discipline for providing guidance, encouragement as and when required and for technical support.

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