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Investigation on physical and mechanical properties of some Myanmar bamboo species

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Abstract: The basic data on physical and mechanical properties of most bamboos, which serve as basis for promoting their acceptance, are still lacking in Myanmar. So, with a view to promoting the utilization potential of some Myanmar bamboo species, their mechanical and physical properties were investigated. The moisture contents of bamboo generally are higher than those of most common Myanmar timber species and significantly decrease with height. Bamboos shrink more than most timber species and shrinkage is dependent upon green moisture content. The basic specific gravity of tested bamboo species ranges from 0.451 to 0.702 and is comparable to those of common Myanmar timber species. Specific gravity increases with height along the culm in all the tested bamboo species. As in wood, moisture content has a significant effect on most mechanical properties such as bending, compression and shearing strength. Most tested bamboo species have higher strength properties than some Myanmar lesser-used timber species, and are found suitable for construction uses.

Key words: Bamboo, moisture content, shrinkage, specific gravity, strength properties.

INTRODUCTION

Bamboos belong to the subfamily Bambusoideae of the family Poaceae, a large family of *ca.* 10,000 species and at least 600 genera (Armstrong, 2008). The subfamily Bambusoideae comprises both woody and herbaceous bamboos of about 1,575 species (Bystriakova *et al.*, 2003). Bamboo is naturally distributed in the tropical and subtropical belt between approximately 46° N and 47° S latitude, and is commonly found in Africa, Asia, and Central and South America. Some species may also grow successfully in mild temperate zones in Europe and North America.

Myanmar is rich with bamboo resources with the extent of natural bamboo forests estimated to be 859,000 ha and endowed with 17 genera, 97 species and 4 varieties. Bamboo has been used in scaffolding, building houses in the villages and for making

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fences. The major products from bamboo are household utensils like spoons. chopsticks, trays, tube-like containers to hold knives. *etc.* Mats are very common in villager's huts. Peeled bamboos are used as rope for binding packages and poles. Beautiful ladies umbrellas and lacquer wares are made from bamboos. Bamboo as raw material for paper industry and chopstick industry is also gaining momentum. In urban areas, some restaurants are built with round bamboos to enhance aesthetic beauty. Some hotels are floored with bamboo parquets. Other bamboo products are fishing rods, toothpicks, skewers, and bamboo charcoal.

Although bamboos have been used in various forms in traditional ways for a long time, knowledge on their physical and mechanical properties is meager (Lwin *et al.*, 2006). Information on these properties is of most importance, especially in the uses of bamboos as structural elements in constructions and furnitures, where strength is required. Physical and mechanical properties of nine species of bamboos were studied which will be very useful for comparison, for further processing and also for selection of species for specific purposes.

MATERIALS AND METHODS

Nine bamboo species, most well-known and abundant in Myanmar, were selected: *Bambusa burmanica* attains a culm height of 10-15 m and a culm diameter of 56-90 mm with a wall thickness of 20-30 mm. Internodes are often solid and 15-30 cm long (Moe *et al.*, 2006). The sample culms collected for this study attained an average height of 12 m, an average diameter of 47.47 mm and an average wall thickness of 15.89 mm. It is found in Lower Myanmar and Taungoo; it is also planted in Yangon Division.

B. longispiculata grows in Yangon Division. The sample culms attained a height of about 5-10 m, a diameter of 16.44 mm and a wall thickness of 2.70 mm. The culms are so small in size that they are best suited to uses as fishing rods and to making toys.

Dendrocalamus calostachyus is a large bamboo with culm height of 20-25 m and culm diameter of 130-180 mm (Rodger, 1963). Internodes are 30-40 cm long. Sample culms collected for this study had an average diameter of 106.90 mm and an average thickness of 13.03 mm. It is found in Upper Chindwin, Myitkyina, Bamaw, Maymyo, and the Northern Shan States (Rodger, 1963).

D. giganteus is found in Shwegyin, Thaungyin, Mawlamyine and Upper Chindwin. Culms are 24-30 m high, with diameter of 200-300 mm and a wall thickness of 20-25 mm with internodes of 35-40 cm. The sample culms collected for this study attained an average diameter of 105.07 mm and an average wall thickness of 11.14 mm.

D. hamiltonii covers large areas and grows in upper and northern parts of Myanmar (Rodger, 1963). It is normally 20-25 m in height, 150-250 mm in culm diameter and 12 mm in wall thickness (Moe *et al.*, 2006). The diameter of sample culms collected for this study was 56.30 mm and with the wall thickness of 7.14 mm.

Dinochloa maclellandii is an evergreen, lofty, often scandent bamboo. Culms are up to 30 m high with a diameter of 25-50 mm and an internode length of 10-20 cm. It grows in Bago and Taninthary Division. Sample culms attained an average height of about 12 m, an average diameter of 31.43 mm, and an average wall thickness of 7.82 mm.

Melocanna baccifera grows gregariously over large areas in the Rakhine Yomas, Taninthari Division, Western Chin Hills and Upper Chindwin (Rodger, 1963). The culms attain 10-20 m height and a diameter of 25-75 mm. The sample culms had average diameter of 39.24 mm and average wall thickness of 5.35 mm.

Thyrsostachys oliveri naturally grows and occurs chiefly in Bamaw, Katha and Shan State and Northern Myanmar (Rodger,1963). The sample culms attained an average diameter of 46.54 mm and an average wall thickness of 6.23 mm. The culms attain 15-25 m height and diameter of 37-76 mm with the internode length of 40-60 cm.

T. siamensis is grown in villages, school compounds, and monasteries, but rarely grows in natural forests of Myanmar. The culms attain 7.5 to 13 m height (Moe *et al.*, 2006). The sample culms attained average height of 10 m, average diameter of 42 mm, wall thickness of about 8 mm and average internode length of 150-300 mm.

METHODOLOGY

Bamboo clumps and culms were randomly selected from the bamboo forests or plantations. Six clumps for each species and six culms per clumps were sampled. They were sound and free from any defects, and were representative of average dominant bamboo culms of the locality. They were at least 3-years-old. In testing physical and mechanical properties, the specifications in ISO/DIS 22157 (Anon., 2001a,b) were followed. Each bamboo culm was cut into three equal parts: bottom (B), middle (M) and top (T). Specimens of 100 mm length were prepared from internode sections of each part for testing moisture content, shrinkage, specific gravity and density. They were free from any initial cracks.

Mechanical tests were done at green and air-dry conditions so that the effect of moisture content on the properties was analyzed. Bottom, middle and top parts of each culm were tested to analyze the effect of the position along the culms. The mechanical properties of bamboo tested include bending, shear and compression parallel to grain.

RESULTS AND DISCUSSION

Green moisture content

The mean green moisture content of tested bamboo species ranges from 47.97 per cent in *D. giganteus* to 102.92 per cent in *M. baccifera*. This variation between species might be due to the differences in some inherent factors such as structure and chemical composition, and certain external factors such as site, climate, *etc.* (Prawirohatmodjo, 1988). The moisture content of bamboo is found to be very high, compared to those of most Myanmar timber species (Anon., 2000).

Analysis of data showed that species and position of the specimen have a significant effect on moisture content of bamboo. It is found that moisture content decreases with height in almost all tested bamboo species. Similar results were reported by Li (2004). In the vertical direction, the amount of fiber increases with the decreasing parenchyma (Liese, 1980). Thus, the decreasing moisture content could be related to decreasing parenchyma and increasing fiber contents at the top.

Shrinkage from green to oven-dry condition

The longitudinal shrinkage of the tested bamboo species ranges from 0.119 per cent in *D. maclellandii* to 0.262 per cent in *D. calostachyus* (Table 1). Significant effects of species and position along the culm were observed on the longitudinal shrinkage from green to oven-dry condition. It is quite small as in wood; compared to diameter shrinkage and wall-thickness shrinkage, it is negligible.

The diameter shrinkage from green to oven-dry condition is highest in *B. burmanica* (12.377%) and least in *D. giganteus* (4.836%). Analysis of data showed that there are significant effects of species and culm height on the diameter shrinkage from green to oven-dry. It decreases with height in most tested bamboo species. The wall thickness shrinkage from green to oven-dry condition is not definitely increasing or decreasing with height. But, there are significant variations in wall thickness shrinkage along the culm. The effect of species on the wall thickness shrinkage is also significant. The highest wall thickness shrinkage is found in *B. burmanica* (14.762%) and the least shrinkage in *D. giganteus* (4.960%). The highest volumetric shrinkage is found in *B. burmanica* (25.149%) and the least in *D. giganteus* (8.964%). In most bamboo species, the volumetric shrinkage is decreasing with height. There are significant effects of species and culm height on volumetric shrinkage.

The shrinkage values of *T. oliveri* and *D. giganteus* are very low in comparison with those of other bamboos. This could be due to losses of some moisture before testing. Bamboo starts shrinking from green condition (Gnanaharan, 1993). As they could not be tested immediately on arrival at the Forest Research Institute from the field, it is believed that some shrinking had already taken place before testing.

Table 1. Physical properties of nine Myanmar bamboo species

Species	Seasoning	M.C	Specific gravity	Density	Shrinkage			
					Diameter	Wall thickness	Longitudinal	Volumetric
		%	-	kg/m³	%	%	%	%
B. longispiculata	Green	72.86	0.625	1072	-	-	-	-
	Air-dried	12.0	0.696	779	4.014	6.155	0.104	10.106
	Oven-dried	0	0.728	728	6.691	10.258	0.173	16.843
D. calostachyus	Green	83.15	0.618	1070	-	-	-	-
	Air-dried	12.0	0.683	836	5.391	4.853	0.157	14.085
	Oven-dried	0	0.777	773	8.985	8.088	0.262	23.476
D. giganteus	Green	47.97	0.614	898	-	-	-	-
	Air-dried	12.0	0.664	765	2.902	2.976	0.112	5.379
	Oven-dried	0	0.669	681	4.836	4.960	0.186	8.964
D. hamiltonii	Green	96.01	0.584	1088	-	-	-	-
	Air-dried	12	0.648	726	4.13	6.84	0.07	12.18
	Oven-dried	0	0.719	719	6.89	11.40	0.12	20.31
D. maclellandii	Green	52.58	0.682	1036	-	-	-	-
	Air-dried	12.0	0.766	858	4.362	6.102	0.071	10.649
	Oven-dried	0	0.830	830	7.270	10.171	0.119	17.748
M. baccifera	Green	102.92	0.451	885	-	-	-	-
	Air-dried	12	0.488	547	4.73	7.12	0.08	16.05
	Oven-dried	0	0.613	612	7.88	11.87	0.14	26.75
B. burmanica	Green	101.80	0.571	1137	-	-	-	-
	Air-dried	12.0	0.630	705	7.420	8.857	0.122	15.090
	Oven-dried	0	0.757	757	12.377	14.762	0.204	25.149
T. oliveri	Green	53.68	0.702	1082	-	-	-	-
	Air-dried	12.0	0.790	895	3.316	3.813	0.096	6.722
	Oven-dried	0	0.800	800	5.527	6.356	0.159	11.203
T. siamensis	Green	77.34	0.633	1096	-	-	-	-
	Air-dried	12.0	0.706	857	4.299	5.939	0.077	12.379
	Oven-dried	0	0.790	811	7.165	9.898	0.128	20.632

Note: n = 108 (6 clumps per species, 6 culms per clump, and 3 replications per culm).

Basic specific gravity and density

The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on the anatomical structure (Li, 2004). The basic specific gravity of tested bamboos ranges from 0.451 in *M. baccifera* to 0.874 in *T. oliveri*. Species, clumps and sections have significant effects on specific gravity. It also increases with height in all species. Density of the tested bamboos was found to decrease with height along the culms.

Maximum stress and modulus of elasticity in static bending

The maximum stress in bending of bamboos ranges from 26.22 N/mm² in *D. giganteus* to 109.10 N/mm² in *D. maclellandii* at green condition and from 32.09 N/mm² in *D. giganteus* to 137.00 N/mm² in *B. burmanica* at air-dry condition. There are significant effects of species, clump and sections on the maximum stress at green and air-dry conditions. It is found that the maximum stress increases with decrease in moisture content. Liese (1985) also stated that the moisture content has similar influence on the strength as it has in timber. The bending stress decreases with height along the culm (Widjaja *et al.*, 1985). This statement does not hold true for all, but for most of the tested bamboo species. The trend is, however, applicable only to the results at green condition. At air-dry condition, some species show an increasing trend in bending stress with height. The middle portion has the lowest value in other species.

The modulus of elasticity ranges from 11,108 N/mm^2 to 42,582 N/mm^2 at green condition and from 6,556 N/mm^2 to 41,899 N/mm^2 at air-dry condition. When conducting tests at air-dry condition, some bamboo species of large sized culms became cracked and failed under a relatively small force or the edges of supporting equipment made them crack, thus their modulus of elasticity becoming lower than at green condition. It was observed in *D. giganteus* and *D. hamiltonii*.

Maximum crushing strength

It ranges from 14.22 N/mm^2 in *M. baccifera* to 44.91 N/mm^2 in *T. siamensis* at green condition. *M. baccifera* has the least (44.92 N/mm^2) and *D. hamiltonii* the highest value (65.45 N/mm^2) at air-dry condition (Table 2). The maximum crushing strength of *M. baccifera* is very low, compared to those of other tested bamboos. This could be due to the effect of age.

In most bamboos, the strength increases with height. It supports the finding of Widjaja (1985) who found that compression strength as well as the percentage of sclerenchyma fiber increases from bottom to top in *D. giganteus* and *G. robusta*. There is a significant effect of species on maximum crushing strength at green and air-dry condition. But the effects of sections and clumps, and culms are significant in some bamboos only. It supports the statement of Liese (1985) that it seems resistance to compression parallel to the grain is more or less uniform, hardly being affected by the height of the culm.

Maximum shearing strength

At green condition, specimens with node have an average maximum shearing strength of from 5.61 N/mm^2 in *B. longispiculata* to 14.44 N/mm^2 in *T. siamensis*, and those without node from 4.03 N/mm^2 to 14.19 N/mm^2 (Table 2). At air-dry condition, the range is from 8.32 N/mm^2 to 25.03 N/mm^2 for specimens with node, and from 6.27 N/mm^2 to 21.62 N/mm^2 for those without node. It is found that the air-dry bamboo has higher strength, which increases with decreasing moisture content. Species and sections have significant effects on the maximum shearing strength in most species, but the effect of node/internode is not significant. In most cases, the shearing strength of the node specimens is found slightly higher than that of the internode specimens.

Table 2. Mechanical properties of Myanmar bamboo species

Sl. No.	Species	Seasoning		Static bending		Compression parallel to grain		Shear	
			MC	MS	MOE	MS	MOE	MS (N)	MS (WN)
			%	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
1	*B. longispiculata*	Green	75.57	54.00	26873	33.23	846	5.61	4.03
		Air-dried	12.00	86.82	31451	57.64	1326	8.32	6.27
2	*D. calostachyus*	Green	59.22	52.36	12952	35.80	1821	8.86	8.37
		Air-dried	12.00	71.86	24392	48.35	2110	10.46	10.84
3	*D. giganteus*	Green	48.83	26.22	11108	32.88	1661	9.88	9.59
		Air-dried	12.00	32.09	6556	60.91	2117	13.32	14.41
4	*D. hamiltonii*	Green	77.69	48.57	26417	29.72	2097	6.82	7.53
		Air-dried	12.00	70.93	18860	65.45	3404	15.3	15.06
5	*D. maclellandii*	Green	58.42	109.1	42582	40.34	1281	13.27	13.27
		Air-dried	12.00	126.0	41899	59.95	1824	25.03	21.62
6	*M. baccifera*	Green	87.02	42.21	18367	14.22	1012	7.20	7.82
		Air-dried	12.00	58.91	20330	44.92	2124	15.21	13.53
7	*B. burmanica*	Green	91.54	106.70	31124	34.06	1038	10.51	9.40
		Air-dried	12.00	137.00	36096	56.92	1946	15.20	18.19
8	*T. oliveri*	Green	69.02	47.30	20027	38.01	1628	12.92	9.89
		Air-dried	12.00	64.35	22396	59.10	2322	17.91	16.41
9	*T. siamensis*	Green	65.20	88.80	25560	44.91	1692	14.44	14.19
		Air-dried	12.00	119.59	30033	64.00	2349	21.71	18.95

Note: n = 108 (6 clumps per species, 6 culms per clump, and 3 replications per culm).
MC: Moisture content; MS: Maximum stress; MOE: Modulus of elasticity; N: Specimens with node; WN: Specimens without node.

Relationship between properties

The moisture content has a significant effect on shrinkage (Sattar *et al.*, 1991). The relationship between initial green moisture content and volumetric shrinkage of 15 bamboo species shows that the total volumetric shrinkage is dependent upon the initial moisture content (Fig. 1). Unlike wood, bamboo shrinks right from the beginning of drying (Sattar *et al.*, 1991). It is also stated that the higher percentage of shrinkage may be related to a higher percentage of moisture content (Sattar *et al.*, 1991).

Espiloy (1985) found that bamboos with high densities shrink more than those with lower densities. The correlation between basic specific gravity and shrinkage was constructed for 15 Myanmar bamboo species, but the relation is so weak that one outliner species was excluded. With data of 14 species, the correlation became stronger, but it is a negative one, meaning that the species with higher density shrink less (Fig. 2).

The classification of timber species for structural use in building is done on the basis of modulus of rupture and modulus of elasticity. Similarly, bamboos can be classified on the basis of modulus of rupture (MOR), modulus of elasticity (MOE), and maximum

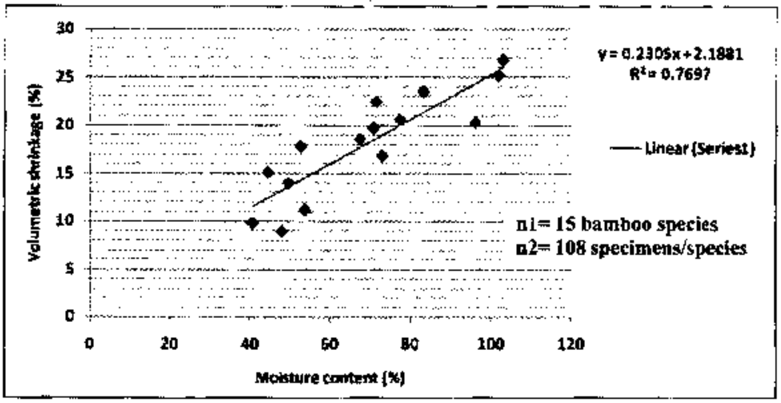

Figure 1. Relationship between volumetric shrinkage and initial moisture content of some Myanmar bamboo species.

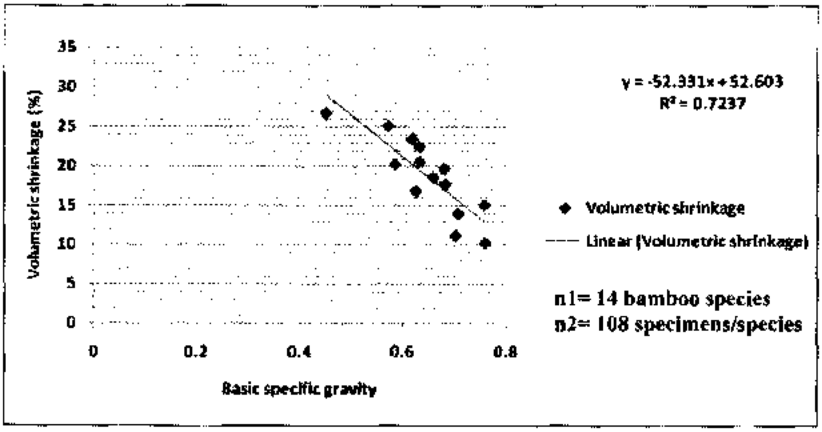

Figure 2. Relationship between basic specific gravity and volumetric shrinkage of Myanmar bamboo species.

crushing strength (MCS) at green condition. The limits of these properties of the three groups are given in Table 3 (Anon., 1993).

According to this classification, *T. siamensis* and *D. maclellandii* will be in Group I, which will be the best for construction uses. *B. burmanica, B. longispiculata* and *D.*

Table 3. Classification of bamboos for construction use

Group	MOR (in bending test)	MOE (in bending test)	MCS (in compression)
	(N/mm^2)	(N/mm^2)	(N/mm^2)
Group I	>70	>9000	>35
Group II	50-70	>6000	>30
Group III	30-50	>3000	>25

calostachyus will be in Group II, but *B. longispiculata* is too small in size to be used in construction inspite of its high strength. *D. hamiltoni* and *T. oliveri* will be in Group III, and *D. giganteus* and *M. baccifera* will not be suitable for construction purposes.

The basic specific gravity of the above tested bamboo species is 0.609 on average, the minimum being 0.451 and the maximum 0.702. In India, the average basic specific gravity of the bamboo species is 0.6, ranging from 0.4 to 0.8 (Li, 2004). The maximum basic specific gravity is found somewhat lower than that of Indian bamboos. Still, the basic specific gravity of the tested bamboos is comparable to those of some Myanmar construction timber species. Most tested bamboo species are higher than many lesser-used timber species in maximum crushing strength, in shearing strength parallel to grain, and bending strength.

CONCLUSION

The results show that the tested bamboo species are comparable to those of some construction timbers in terms of strength. Moreover, the rapid growth of bamboo is superior to that of any other plant. Therefore, it can be the best substitute of timber in the future. However, the natural durability of bamboos is very low compared to wood. Thus, it requires preservation treatment. Moreover, as bamboos contain high initial moisture content and shrink too much in diameter and wall thickness, they should be dried to the desired moisture content before putting them into uses.

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