ANATOMICAL FEATURES AND MECHANICAL PROPERTIES OF THREE MALAYSIAN BAMBOOS

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ABD. LATIF MOHMOD, WAN TARMEZE WAN ARIFFIN & FAUZIDAH AHMAD. 1990. Anatomical features and mechanical properties of three Malaysian bamboos. The mechanical properties and anatomical features of one to three-year-old *Bambusa blumeana* Schult., *Bambusa vulgaris* var.*striata* Schrad. and *Gigantochloa scortechinii* Gamble are reported here. The mechanical properties such as shear, compression parallel to grain and static bending were correlated to anatomical features, such as vascular bundle size and distribution, and fibre dimensions. Results showed an increase of shear, and compressive and bending strength with the increment of age and portion of the culms. Lumen diameter has the strongest correlations with the mechanical properties except in compression which has a strong correlation with fibre wall thickness. The results further indicate that age not only influences the mechanical properties but also the suitability and durability of bamboo for construction and manufacturing purposes.

Keywords: Malaysian bamboos - mechanical properties - anatomical features

Introduction

Bamboo is a fast growing monocotyledon belonging to the Gramineae (family Bambusoideae). It has many uses and, even occupies an important place in the daily life of people in rural areas where it grows naturally. It is one of the oldest building materials used by mankind.

In Malaysia, bamboo is found locally abundant, but widely scattered, and in approximately 5% of the total forest reserve area (Abd. Latif 1987). Bamboo has received comparatively little attention until recently. The dwindling of supply of other major raw materials such as timber and rattan gave rise to the sudden interest in bamboo.

The selection of bamboo for industrial uses, construction and housing is closely related to its physical and mechanical properties. Proper selection of the age and species of bamboo affects the final use and durability (Abd. Latif 1987).

In this context, we studied the mechanical properties of some wild Malaysian bamboo species in relation to its anatomical characteristics for assessing their potential use in furniture, building and general construction. This knowledge

will further serve as a basic guide and also promote its acceptance of some of the species for commercial purposes.

Materials and methods

Three species of bamboo, namely *Bambusa blumeana* (buluh duri), *Bambusa vulgaris* var. *striata* (buluh gading) and *Gigantochloa scortechinii* (buluh semantan) were used in this study. Samples of bamboo (1 to 3-y-old) whose growth have been recorded since their sprouting stages were obtained from wild clumps in Forest Research Institute Malaysia compound.

Each bamboo sample was divided into three portions of butt, middle and top. Strength tests of shear, compression parallel to grain and static bending were conducted according to Indian Standard UDC 691.12: 620.1. (IS6874 - 1973) using the Shimadzu Computer Controlled Universal Testing Machine.

The fibro vascular bundles were examined by the method as described by Jane (1933). A bamboo split of $1 \times 1 \times 1$ *cm* was boiled for 4 *h* and then cut into 30 to 45 μm thick sections by microtome with 15° angle. Each section was dipped in alcohol for a moment and then laid on a glass slide. A drop of 1% safranin was applied for 3 to 8 *min* on the section which was then washed with distilled water to make the section clear. A 0.5% Astrabla FM (Chroma-gessellschaft) was applied for 3 to 5 *min* on the section and was subsequently washed with 75, 95 and 100% alcohol series. The section was then mounted on glass slide with Canada Balsam and covered with a cover slip. The distribution of fibro vascular bundles was determined within an area of 1 cm^2 of each sample.

For fibre dimensions measurement, the samples from each bamboo split were cut into matchstick sized splints and macerated with a 50-50 mixture of 15% nitric acid and 10% chromic acid. Three slides were prepared from each sample. The lengths of 100 fibres were then measured microscopically from each slide.

Results and discussion

The physical characteristics of all the three bamboo species studied are presented in Table 1. Their anatomical characteristics are tabulated in Table 2 and their mechanical properties in Table 3. Summaries of analyses of variance on the the anatomical characteristics and mechanical properties are shown in Tables 4 and 5.

Table 1. Physical characteristics of some Malaysian bamboos tested in green condition

Bamboo	Age (y)											
	1				2				3			
	B	M	T	A	B	M	T	A	B	M	T	A
	Basic density ($kg\ m^{-3}$)											
a	1200	1080	1030	1103	1070	1050	990	1037	1010	1000	990	1000
b	320	290	270	293	470	490	560	507	510	550	570	543
c	440	470	500	470	490	540	570	533	520	550	600	557
	Moisture content (%)											
a	118.67	104.30	94.80	105.92	91.20	82.83	69.97	81.33	118.47	95.53	69.50	94.50
b	193.63	242.63	238.63	224.96	93.43	87.27	79.27	86.66	93.44	87.70	88.87	89.95
c	117.00	107.30	101.43	108.58	98.60	93.80	87.23	93.21	95.80	92.00	83.93	90.57
	Diameter (*cm*)											
a	8.29	8.21	7.62	8.04	8.17	7.74	7.20	7.70	8.50	8.71	8.00	8.40
b	9.30	9.39	8.32	9.00	8.87	9.34	8.58	8.93	8.45	8.62	8.33	8.47
c	7.67	8.72	8.50	8.30	7.02	7.12	6.02	6.72	7.15	7.52	6.32	6.99
	Thickness (*cm*)											
a	1.08	0.84	0.69	0.87	1.06	0.70	0.64	0.80	1.43	0.98	0.79	1.07
b	1.34	0.93	0.72	0.99	1.46	1.08	0.79	1.11	1.50	0.91	0.73	1.05
c	0.83	0.64	0.59	0.69	0.75	0.67	0.49	0.64	0.81	0.58	0.40	0.60

(Bamboo: a = *Bambusa blumeana*; b = *B. vulgaris* var. *striata*; c = *Gigantochloa scortechinii*; *B - Butt, M - Middle, T- Top, A - Average; Notations follow for Tables 2 & 3)

The results show that all the mechanical properties (Table 5) assessed vary significantly between species of all ages and portions. This agrees with some findings of other researchers including Suzuki (1948), Limaye (1952), Anonymous (1972), Janssen (1981), Kawase (1981), Espiloy (1987), Siopongco and Munandar (1987), and Widjaja *et al.* (1987). The results further show that as the bamboos get older, their strength properties increase significantly. Except for the modulus of rupture (MOR), the shear, compression parallel to grain, the modulus of elasticity (MOE) and stress at proportional limit increase significantly toward the top portion of the culm.

None of the anatomical characteristics (Table 3), are significantly different between ages of the bamboos. Except for the fibre length, there is no significant difference in the characteristics between portions of the culms. However, with the exclusion of the radial/tangential ratio and fibre diameter, the differences in the remaining anatomical characteristics between species are significant.

Table 2. Anatomical characteristics of some Malaysian bamboos

Bamboo	Age (y)											
	1				2				3			
	B	M	T	A	B	M	T	A	B	M	T	A
	Vascular bundle: Distribution (Number cm^2)											
a	212	200	290	234	247	258	365	290	237	300	330	289
b	255	223	245	241	270	215	307	264	278	227	252	252
c	188	132	145	155	198	167	223	196	182	167	200	183
	Vascular bundle: Radial/tangential ratio											
a	1.33	0.80	0.88	1.00	1.06	0.81	0.87	0.91	1.22	0.88	0.76	0.95
b	1.47	1.29	1.38	1.38	1.64	1.30	1.05	1.33	1.42	1.29	1.27	1.33
c	0.94	0.59	0.99	0.84	1.44	1.03	1.62	1.36	1.14	0.90	1.28	1.11
	Fibre: Length (*mm*)											
a	2.06	2.13	1.76	1.99	1.94	1.92	1.74	1.87	1.99	2.00	1.85	1.95
b	3.12	3.45	3.44	3.34	3.11	3.66	3.12	3.30	4.16	3.85	3.28	3.76
c	3.83	3.46	3.23	3.50	3.92	3.76	3.72	3.80	5.004	4.41	3.31	4.24
	Fibre: Diameter (*mm*)											
a	0.018	0.019	0.016	0.018	0.019	0.020	0.020	0.020	0.021	0.017	0.021	0.020
b	0.019	0.017	0.016	0.017	0.016	0.019	0.017	0.017	0.017	0.017	0.018	0.017
c	0.019	0.017	0.016	0.017	0.016	0.019	0.017	0.017	0.017	0.017	0.018	0.017
	Fibre: Wall thickness (*mm*)											
a	0.004	0.005	0.006	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005
b	0.007	0.007	0.006	0.007	0.007	0.008	0.006	0.007	0.006	0.006	0.006	0.006
c	0.008	0.006	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.010	0.008
	Fibre: Lumen diameter (*mm*)											
a	0.010	0.009	0.010	0.010	0.010	0.008	0.010	0.009	0.010	0.009	0.008	0.009
b	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.002	0.002
c	0.003	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.003	0.003

The statistical analyses of the effect of anatomical characteristics on mechanical properties of the bamboos are presented in Table 6. The analyses indicate that the vascular bundle size (radial/tangential ratio) and fibre length are positively correlated with the MOE and stress at proportional limit. This implies that the increase in the size (mature stage) might be accompanied by the increase in both strength properties while the bamboo with longer fibre might be able to withstand higher load before it is permanently deformed and fails. Moreover, given the same magnitude of load, the bamboo with longer fibre and higher vascular bundle size should deflect less than the others.

Table 3. Mechanical properties of some Malaysian bamboos tested in green condition

Bamboo	Age (y)											
	1				2				3			
	B	M	T	A	B	M	T	A	B	M	T	A
	Shear (*MPa*)											
a	3.99	4.44	4.58	4.34	4.31	4.54	4.69	4.51	4.65	4.84	4.95	4.81
b	3.37	3.39	4.40	3.72	3.75	4.03	4.38	4.05	4.14	4.60	4.84	4.53
c	3.65	3.95	4.33	3.98	3.87	4.21	4.57	4.22	4.10	4.59	4.86	4.52
	Compression parallel to grain (*MPa*)											
a	19.46	20.72	22.08	20.75	22.23	26.50	27.61	25.45	25.15	27.62	28.48	27.08
b	20.50	22.05	25.68	22.74	23.95	25.92	27.17	25.68	26.74	27.77	30.01	28.17
c	21.63	23.34	25.54	23.50	25.29	26.82	29.24	27.12	25.91	28.18	32.29	28.79
	Static bending: Stress at proportional limit (*MPa*)											
a	21.19	23.54	22.07	22.27	23.34	23.88	38.90	28.71	22.29	23.26	41.14	28.90
b	28.66	29.02	29.07	28.92	34.15	38.53	42.61	38.43	39.83	40.81	41.19	40.61
c	33.99	31.06	31.08	32.04	31.16	32.21	43.88	35.75	39.91	41.25	42.23	41.13
	Static bending: Modulus of rupture (*MPa*)											
a	98.36	70.37	43.14	70.62	128.71	88.60	56.13	91.15	156.44	107.91	68.42	110.92
b	60.57	50.16	58.10	56.28	69.06	57.58	42.26	56.30	78.41	58.14	46.15	60.90
c	68.95	43.41	35.92	49.43	72.37	47.94	38.68	53.00	76.94	58.04	43.32	59.43
	Static bending: Modulus of elasticity (1000 *MPa*)											
a	2.62	2.82	3.85	3.10	2.84	3.10	4.40	3.45	3.26	3.44	5.63	4.11
b	4.07	5.05	5.81	4.98	6.22	5.81	6.08	6.04	6.70	6.10	8.08	6.96
c	3.71	4.01	5.09	4.27	3.92	4.22	5.40	4.51	4.13	4.83	5.92	4.96

There is a negative correlation between fibre length and shear strength which suggests that shear failure is more likely to occur when the fibres are longer. The fibre wall thickness is positively correlated with compression strength and MOE, but negatively with MOR. Strong correlation exists between lumen diameter and all the mechanical properties except for compression strength.

Table 4. Summary of analyses of variance on anatomical characteristics of some Malaysian bamboos

		Mean squares and statistical significance					
		Anatomical properties of bamboo					
Source of variation	Df	Vascular bundle distribution	Radial tangential ratio	Fibre length	Fibre diameter	Fibre wall thickness	Lumen diameter
Species	2	1079.2407**	3.24074ns	19.986**	1.985×10^{-5}ns	5.34×10^{-5}**	4.39×10^{-4}**
Age	2	129.796296ns	12.96296ns	0.63176ns	4.24×10^{-6}ns	1.41×10^{-6}ns	1.30×10^{-7}ns
Portion	2	185.351852ns	8.79629ns	1.40306**	1.469×10^{-5}ns	1.035×10^{-5}ns	1.69×10^{-6}ns
Species × Age	4	14.685185ns	3.24074ns	0.1434ns	9.85×10^{-6}ns	5.60×10^{-6}ns	1.44×10^{-6}ns
Species × Portion	4	56.407407ns	7.4074ns	0.2503ns	7.71×10^{-6}ns	1.146×10^{-5}ns	1.24×10^{-6}ns
Age × Portion	4	34.129630ns	8.796ns	0.40119ns	2.31×10^{-5}ns	1.171×10^{-5}ns	4.60×10^{-7}ns
Species × Age × Portion	8	6.351852ns	7.4074ns	0.1429ns	1.563×10^{-5}ns	5.70×10^{-6}ns	2.14×10^{-6}ns

(ns = not significant at 95% probability level; ** = highly significant at 95% probability level)

Table 5. Summary of analyses of variance on mechanical properties of some Malaysian bamboos

		Mean squares and statistical significance				
		Mechanical properties of bamboo				
Source of variation	Df	Shear	Compression	Stress	MOR	MOE
Species	2	1.0087**	16.457222**	498.749**	8162.452**	26697716.67**
Age	2	1.5592166**	151.3176167**	398.095**	1601.631**	6391516.67**
Portion	2	1.8312389**	77.9147056**	211.8378**	7892.8853**	11968016.67**
Species × Age	4	0.04858889**	1.4916472**	20.3427**	530.6273**	592733.33**
Species × Portion	4	0.07701944**	1.3702694**	53.094**	1064.3692**	270341.67**
Age × Portion	4	0.0393222**	0.5225306**	75.589**	195.92301**	505441.67**
Species × Age × Portion	8	0.044911**	1.4514778**	20.117**	68.05124**	327608.33**

(** highly significant at 95% probability level; MOR - Modulus of rupture, MOE - Modulus of elasticity; Notations follow for Table 6)

Table 6. Summary of correlation coefficients of some mechanical properties with anatomical characteristics of Malaysian bamboos

	Compression parallel to grain	Shear	Stress at proportional limit	MOE	MOR
Fibrovascular bundle distribution	0.0134 ns	0.1135ns	-0.0375ns	0.0190 ns	0.0820ns
Fibrovascular bundle size	0.0245 ns	-0.3628 ns	0.2708*	0.5450**	-0.1898ns
Fibre length	0.1472 ns	-0.3794 *	0.5252**	0.3739**	-0.3677ns
Fibre wall thickness	0.3408*	3.7412×10^{-5}ns	0.3483ns	0.2895 *	-0.3286*
Fibre diameter	0.0662ns	0.1454ns	9.7330×10^{-5}ns	-0.0803ns	0.0685ns
Lumen diameter	-0.2211ns	0.4185**	-0.5480**	-0.5228**	0.6389**

(ns : not significant; * : significant at 95% probability level; ** : highly significant at 95% probability level)

Conclusion

This study has shown that for *B. blumeana, B. vulgaris* var. *striata* and *G. scortechinii,* generally the strength properties are correlated to anatomical characteristics of the bamboos. From the results, lumen diameter has the strongest correlations with the mechanical properties, especially shear strength, stress at proportional limit, modulus of elasticity and modulus of rupture. The strongest correlations with compression, parallel to grain is observed in fibre wall thickness.

Age has strong influence on the mechanical properties of the bamboos. Owing to the fact that it is easier to estimate the age of a bamboo than to identify its anatomical characteristics, this age factor could serve as the best guidance in determining the strength of the bamboo and thus its suitable harvesting age.

References

ABD. LATIF MOHMOD. 1987. Guideline on the manufacturing of blinds and satay-sticks. *Forest Research Institute Malaysia Technical Information Number 2.* 8 pp.

ANONYMOUS. 1972. *The use of bamboo and reeds in building construction.* Department of Economic and Social Affair, United Nations, New York.

ESPILOY, Z.B. 1987. Physico-mechanical properties and anatomical structure relationships of some Philippine bamboos. Pp. 257 - 264 in Rao, A.N., Dhanarajan, G. & Sastry, C.B. (Eds.). *Recent research on bamboos.* Proceedings of the *International Bamboo Workshop.* Hangzhou, China. October 6 - 14, 1985.

INDIAN STANDARD. 1973. *Method of test for round bamboos.* UDC.691.12:620.1 (IS 6874-1973).

JANE, F.W. 1933. The microscopic examination of woody material. *Watson's Microscope Record Number 30 (September 1933).* 9 pp.

JANSSEN, J.J.A. 1981. The relationship between the mechanical properties and the biological and chemical composition of bamboo. Pp. 27 - 32 in Higuchi, T. (Ed.). *Bamboo production and utilization.* Proceedings of the *Congress Group 5.3A.* Production and utilization of bamboo and related species. *XVII IUFRO World Congress.* Kyoto. Japan. September 6 - 17, 1981.

KAWASE, K. 1981. Distribution and utility value of Sasa bamboo. Pp. 391 - 392 in Higuchi, T. (Ed.). *Bamboo production and utilization.* Proceedings of the *Congress Group 5.3A.* Production and utilization of bamboo and related species. *XVII IUFRO World Congress.* Kyoto, Japan. September 6 - 17, 1981.

LIMAYE, V.D., 1952. Strength of bamboo (*Dendrocalamus strictus*). *Indian Forester* 78:558-575.

SIOPONGCO, J.O. & MUNANDAR, M. 1987. *Technology manual on bamboo as building materials.* UNDP/UNIDO Regional Network in Asia for Low Cost Building Materials Technologies and Construction Systems. 20 pp.

SUZUKI, Y. 1948. Distribution of specific gravity and bending strength along the culm. *Bulletin Tokyo University Forestry* 36: 188.

WIDJAJA, E. & RISYAD, Z. 1987. Anatomical properties of some bamboo utilized in Indonesia. Pp. 244 - 246 in Rao, A.N., Dhanarajan, G. & Sastry, C.B. (Eds.). *Recent research on bamboos.* Proceedings of the *International Bamboo Workshop.* Hangzhou, China. October 6 - 14, 1985.