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Influence of culm age, particle size and board density on the performance of particleboard made from Ethiopian highland bamboo (*Yushania alpina*)

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Abstract: *Yushania alpina*, one of the most widespread bamboo species in Ethiopia, was investigated for its suitability as a raw material for particleboard production. A total of 105 culms from three different age groups (1-, 2- and 3-year-old) were harvested from farmers' bamboo plantation in Ethiopia. Fine (0.5-1 mm) and coarse (1-2 mm) particle sizes from each age group were used for making single-layer particleboards at 600 and 750 kg/m^3 board target density levels. Urea formaldehyde resin was used as a binder at the rate of 10 per cent of the oven dry weight of the particles. The particleboards produced were tested for mechanical properties and dimensional stability. Performance characteristics including bending strength (MOR), stiffness (MOE), internal bond (IB) strength, thickness swelling (TS) and water absorption (WA) were assessed. The results showed that culm age, particle size and board density significantly affected the internal bond strength, thickness swelling and water absorption properties, whereas culm age did not show significant effect on bending and stiffness properties. The results obtained in this study showed that 2-year-old culms can be successfully used as an alternative lignocellulosic raw material for the manufacture of general purpose particleboard, using relatively low resin content.

Key words: *Yushania alpina*, culm age, board density, dimensional stability, particle size, particleboard, strength properties.

INTRODUCTION

In Ethiopia, the economic potential of bamboo has not yet been explored and the role of this resource in national economy is negligible. Bamboo resources have not been used for panel boards, pulp and paper production, or in any other large-scale industry. Currently, the natural forests of the country are declining at an alarming rate. Despite the decline, the country is still dependent on wood as a raw material for building construction, wood-based panel industries and furniture. The abundant resources of

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bamboo in Ethiopia can be used as an alternative raw material for wood–based panel boards and paper industries (Kelemwork, 2005).

Many investigations have reported that wood density is one of the most important variables that determines the suitability of woody species for particleboard manufacture. Maloney (1993) states that dense wood is generally not suitable for particleboard manufacture; boards made from lower density woods have greater modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) strength while water absorption and thickness swelling are little affected. The reason for this lies in the fact that a given weight of particles from lighter woods occupy a greater volume than that of a dense wood (Maloney, 1993; Moslemi, 1974). Most researchers have proved that board density is a measure of the compactness of the individual particles in a board, and is dependent mainly on the density of the raw material and the pressure applied during pressing. An increase in board density is accomplished essentially by increasing the weight of the wood in the mat or compression of the mat or by both. This results in an increase in resin efficiency by additional and improved glue bonds (Brumbaugh, 1960; Vital *et al.*, 1974). An increase in board density increases MOR, MOE and IB strength (Maloney, 1993; Moslemi, 1974; Nugroho and Ando, 2000). Increase in swelling of bamboo boards should be expected with increase in board density (Chen and Wang, 1981; Chew and Sudin, 1991; Lee *et al.*, 1996).

Technically it is possible to make particleboard from any bamboo of any age. However, at present, only a limited number of bamboo species of Asia-Pacific are used for particleboard production and information on African bamboo species is lacking. A major problem in utilizing bamboo is the density, which is influenced by age differences (Espiloy, 1992; Abd. Latif, 1996).

Several reports on bamboo anatomical properties have shown that ageing of a bamboo culm influences certain properties and, consequently, its processing and utilization. The density of bamboo increases with an increase in age from one year to three years. The additional cell wall substance deposited with age and fibre wall thickening are responsible for the increase in bamboo density as it gets older (Liese and Weiner, 1996). Early during maturation, fibres are relatively thin walled in bamboo (Sun Chengzhi and Xie Guoen, 1985; Alvin and Murphy, 1988).

Knowledge of age is thus important in understanding the properties of bamboo for particleboard manufacture. In this study, *Yushania alpina* culms, one to three years of age, were used to investigate the effect of age on properties of particleboard; particularly, the strength and dimensional stability of particleboards and the relationships between board density, particle size and bamboo density.

MATERIALS AND METHODS

Sample collection

Bamboo stands of *Y. alpina* were selected for the study from one of the major bamboo areas namely, Bore in Ethiopia. The experiment was conducted in Forest Research Institute Malaysia (FRIM) in 2003. The age of bamboo culms was assessed based on the culm colour and culm sheath. The young culms are usually dull in colour, having hair around the nodes with only few branches. Two-year-old culms seldom retain the sheaths; the internodes appear greenish and side branches are formed at the nodes. In three-year-old culms, the colour often turns yellowish with dry appearance. After harvesting, the mean density of culms was measured from fresh samples.

Sample preparation and board manufacturing

Sample culms were dried to 12 per cent moisture content (MC) in a drying kiln. Using a circular saw, the culms were cut into 2.5 cm lengths. The nodes were removed to avoid difficulty in splitting and flaking. Cut samples were further split into four parts manually. The split bamboo chips were flaked by using Pallmann ring flakers. The particles were screened on a circular vibrating screener. Particles of 0.5-1 mm and 1-2 mm mesh sizes were chosen for board fabrication. The accepted particles were then dried to 5 per cent MC in an oven set at 60 °C. Based on the oven-dry weight of the particles, four types of single-layer particleboards were manufactured from two particle sizes (0.5-1 mm and 1-2 mm) at target density levels of 600 kg/m^3 and 750 kg/m^3.

Semi-moist furnish that could be used for particleboard manufacture was prepared by mixing oven-dried particles, resin, a solution of hardener and wax in glue mixing machine. Urea formaldehyde resin, 10 per cent of the oven-dry weight of the particles, was used as binder. Three per cent solution of ammonium chloride based on the solid content resin and 1 per cent of liquid wax emulsion based on the oven-dry weight of the particles, were used as hardener and water repellent respectively. After blending, the resin-coated particles were uniformly spread in a 340 mm by 340 mm wooden forming box manually. The forming box was prepressed at 3.5 MPa for about 3 min in mat forming press. The consolidated mat was finally pressed in hot press with 3.5 MPa at 160 ± 2 °C for 6 min to obtain a board of 12 mm thickness. All the specimens were conditioned at 20 ± 2 °C room temperature with 65 ± 5 per cent RH for five days until the test specimen weight became constant.

Properties measured for board evaluation

The mechanical properties and dimensional stability of single-layer bamboo particleboards were evaluated according to the standard of the International Standards Organization (ISO, 2003) for wood-based panel products. The modulus of elasticity

(MOE) and modulus of rupture (MOR) were determined in accordance with ISO/DIS 16978 (ISO, 2003a) by applying a load to the centre of a test piece supported at two points over a span of 240 mm. Tensile strength perpendicular to the surface or the internal bond (IB) strength was determined in accordance with ISO/DIS 16984 (ISO, 2003c).

The increment in thickness swelling (TS) and water absorption (WA) of specimens after 24 h of soaking in water was determined in accordance with ISO/DIS 16983(ISO, 2003b) as percentage of the original thickness and weight. The compaction ratio of the boards (the amount of pressure required for board pressing) was determined according to the methods outlined by Maloney (1993). Compaction ratio was calculated from the mean density of bamboo and the density of the board.

Experimental design and analyses

Completely randomised design (CRD) with factorial experiment was used to conduct the study. Factorial experiments were conducted by considering three factors (3 age-groups, 2 board densities and 2 particle sizes) to evaluate the effect of culm age/original raw material density, board density and particle size. Statistical analysis software (SAS) was used to analyse the data using analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used for mean comparison.

RESULTS AND DISCUSSION

Single-layer particleboards from *Y. alpina* with desired properties were manufactured by adjusting production variables such as input of raw material density (culm age), board target density and particle size.

Mean density and compaction ratio

The mean densities of cum material were significantly different between age groups. Actual mean densities for 1-, 2- and 3-year-old culms were 446 kg/m^3, 518 kg/m^3, and 630 kg/m^3 respectively (Table 1). This led to analysis of board compaction ratios of 0.95 to 1.80 to achieve 600 kg/m^3 and 750 kg/m^3 of board density (Table 1).

Maloney (1993) has suggested that a compaction ratio of 1.3 is a good estimate of the degree of compaction needed to consistently make well-bonded boards. Thus, the two lower compaction ratios were below what would be considered adequate and the other four were adequate according to Maloney's (1993) guidelines. The highest compaction ratios obtained from 1- and 2-year-old culms were reasonably close to the maximum obtainable with this raw material for production of medium density particleboard.

Bending and stiffness properties

Boards manufactured from three age groups of bamboo culms, two particle sizes (fine

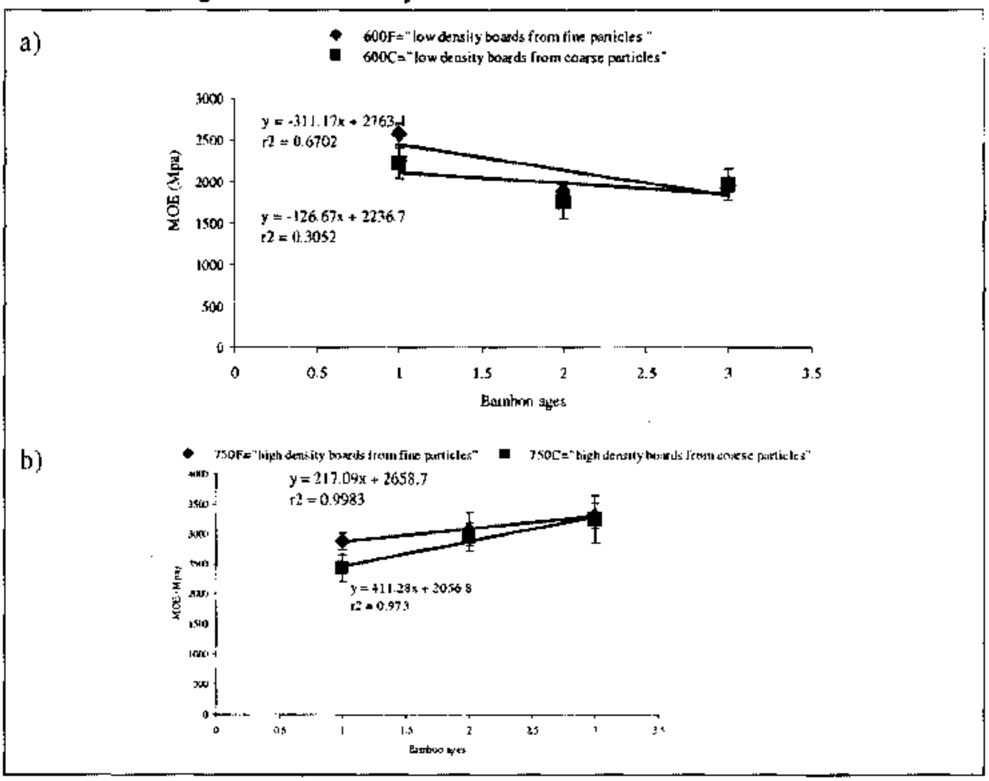
Table 1. Compaction ratio of particleboards made from three age-groups of bamboo and two target densities

Bamboo age-groups	Bamboo density based on age (kg/m³)	Board density level (kg/m³)	Compaction ratio*
1-year-old	416	600	1.44
		750	1.80
2-year-old	518	600	1.15
		750	1.44
3-year-old	630	600	0.95
		750	1.19

*compaction ratio =board density divided by bamboo density

and coarse) and two board target density levels (600 and 750 kg/m³) showed no significant 3-way interaction on the strength and stiffness of the boards among the variables studied (age × board density × particle size). Nevertheless, there was significant interaction between age and board density and between age and particle size.

Figures 1a and 1b show the MOE values of boards made from fine and coarse particles at 600 and 750 kg/m³ board density levels.

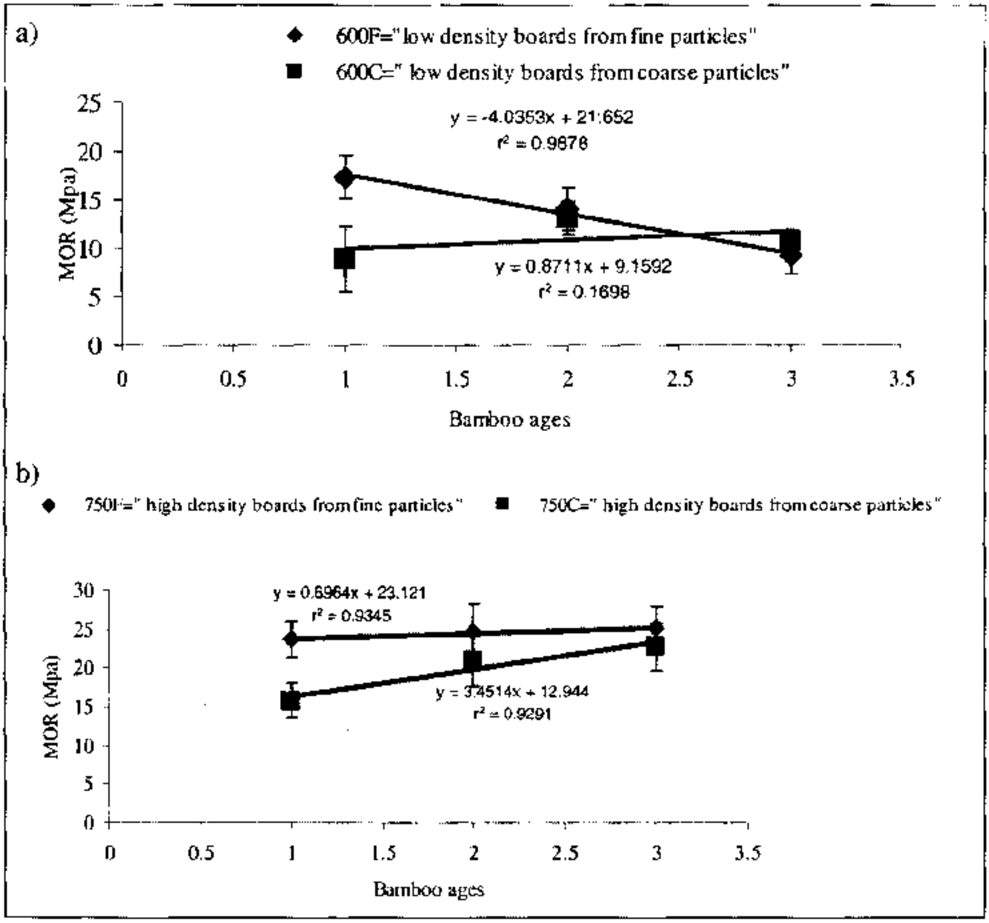


Note: Each value is the average of 9 specimens; bars indicate standard deviation of these values.

Figure 1a and b. Effects of age and particle size on MOE values of boards made at 600 and 750 kg/m³ board target density.

The MOE values of fine particleboard obtained from 1- and 2-year-old culms, irrespective of particle size, did not show significant variation.

Figures 2a and 2b show MOR values for boards made from fine and coarse particles at 600 and 750 kg/m^3 board target density levels. As shown in the Figures, MOR values showed insignificant effect of culm age and particle size



Note: Each value is the average of 9 specimens; bars indicate standard deviation of these values.

Figure 2a and 2b. Effects of age and particle size on MOR values of boards made at 600 and 750 kg/m^3 board target density.

Generally, MOE and MOR values for boards made at high density levels were higher than those at low density level (Table 2).

It can be seen that MOE and MOR values for boards made from fine and coarse particles at high density level were significantly higher than the standard value. Based on statistical analysis, it is possible to conclude that there was no significant effect of bamboo age on MOE and MOR.

Table 2. Mechanical properties and dimensional stability of *Y. alpina* particleboards made from three different age groups at two density levels and two particle sizes

Board density (kg/m³)	Age (years)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)	WA (%)
600F	1	17.35	2577.94	0.365	17.66	75.11
		(2.23)	(127.44)	(0.04)	(1.54)	(7.87)
	2	14.00	1888.67	0.476	13.73	74.41
		(2.18)	(120.63)	(0.06)	(1.3)	(7.5)
	3	9.28	1955.61	0.338	21.29	87.98
		(1.90)	(79.90)	(0.06)	(1.4)	(5.0)
750F	1	23.71	2880.93	0.387	18.27	40.53
		(1.22)	(142.27)	(0.23)	(1.05)	(2.50)
	2	24.72	3082.61	0.813	16.71	45.71
		(3.57)	(271.20)	(0.19)	(2.9)	(9.38)
	3	25.10	3315.12	0.521	27.73	60.82
		(207.75)	(0.20)	(1.3)	(2.68)	(5.0)
600C	1	8.91	2200.40	0.580	17.96	65.97
		(3.35)	(183.21)	(0.10)	(0.96)	(5.38)
	2	13.12	1762.69	0.287	18.90	83.90
		(1.62)	(203.27)	(0.04)	(1.8)	(8.6)
	3	10.66	1967.05	0.362	27.47	97.76
		(1.29)	(191.70)	(0.07)	(3.0)	(4.0)
750C	1	15.84	2428.58	0.936	17.85	52.67
		(2.24)	(226.91)	(0.09)	(0.93)	(4.73)
	2	20.94	2958.47	1.06	15.70	45.08
		(3.23)	(237.89)	(0.07)	(3.0)	(8.4)
	3	22.74	3251.15	0.606	26.26	58.97
		(3.00)	(397.81)	(0.15)	(2.4)	(4.4)
ISO*		13	1800	0.35	25.0	

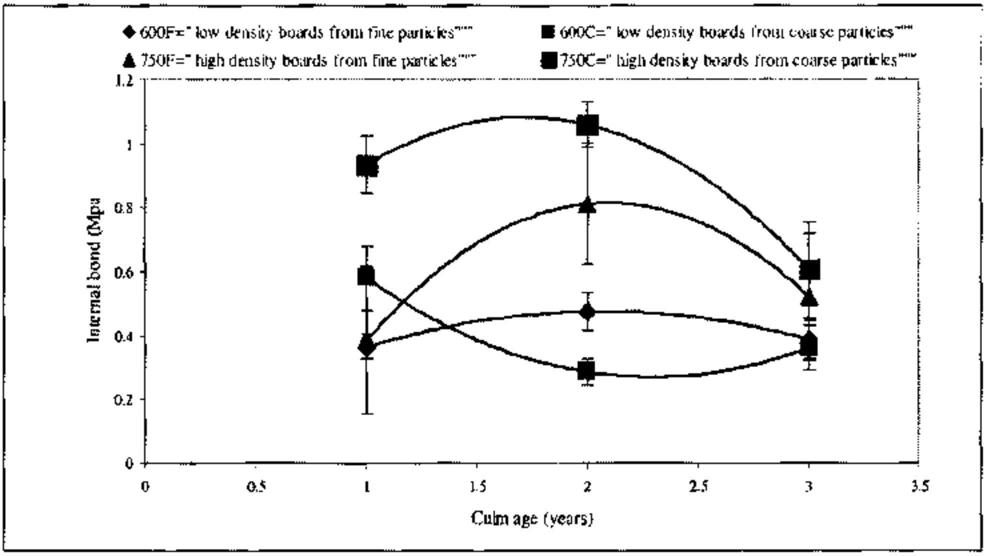
Note: values are averages of 9 samples; values in parentheses are standard deviations
600F = low-density boards from fine particle sizes; 600C= low-density boards from coarse particles; 750F=high-density boards from fine particle sizes; 750C= high-density boards from coarse particle sizes.
ISO,*= requirements for regular furniture grade particleboard for dry condition

Internal bond

The Internal bond (IB) strength of bamboo boards made at 600 and 750 kg/m³ target density were significantly affected by culm age and particle size. As indicated in Figure 3 the IB strength of particleboard reduced as the culm age increased.

The higher IB strength in younger culms could be associated with compaction ratios. Older bamboo is much stiffer due to its denser culm wall (Liese and Weiner, 1996; Alvin and Murphy, 1988). Hence, it requires relatively higher pressure to compress it into a well consolidated form. In addition to compaction ratio, other factors such as the wettability characteristics of bamboo and particle size might affect the IB strength of bamboo boards.

In general, boards made from 2-year-old culms had the highest IB values. This might



Note: Each value is the average of 9 specimens

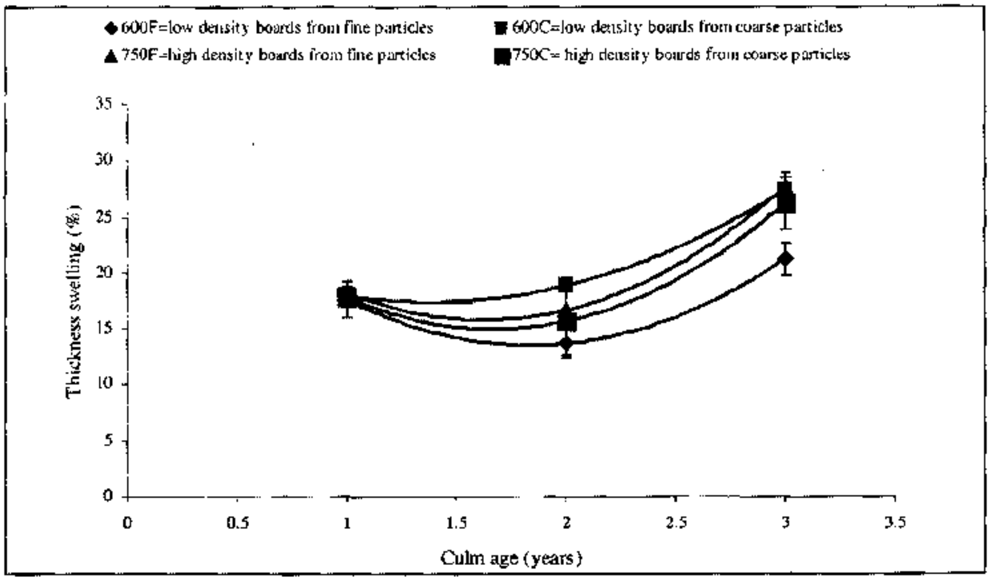
Figure 3. Effects of age and particle size on internal bond strength properties of particleboard made at 600 and 750 kg/m^3 board target density.

be related to wettability characteristics of bamboo. Wettability of a species is an indicator of its gluability (Boding, 1962). Kelemwork *et al.*(2004) reported that 2-year-old *Y. alpina* culms had low contact angle values compared to other age groups of culms. The smaller contact angle might increase the resin flow over the surface of the particles to fill completely every cell cavity, pore, or crevice (Herczeg, 1965). As reported by Paridah *et al.* (2001) the rate of adhesive penetration, rate of adhesive curing and the degree of adhesion between the wood and adhesive can be determined by the wettability characteristics of the wood.

Thickness swelling and water absorption

Culm age, board density, and particle sizes had a significant effect ($P<0.01$) on thickness swelling (TS) and water absorption (WA). Figure 4 shows the effects of age and particle size on thickness swelling properties of boards made at 600 and 750 kg/m^3.

It is observed in Figure 4 that the TS values of boards made from fine particles were higher than that of boards made from coarse particles. Thin flakes have the ability to create gap-free surfaces during board pressing as compared to large particles which have void spaces. On the contrary, boards from thick flakes have higher spring back from higher compression stress and that accompanied compression deformation for a given density on the thicker flakes (Brumbaugh, 1960; Lee *et al.*, 1996; Jamaludin *et al.*, 2001). For boards obtained from 1- and 2-year-old bamboo culms, thickness swelling seemed to be influenced by low contact angle (wettability) values.



Note: Each value is the average of 9 specimens

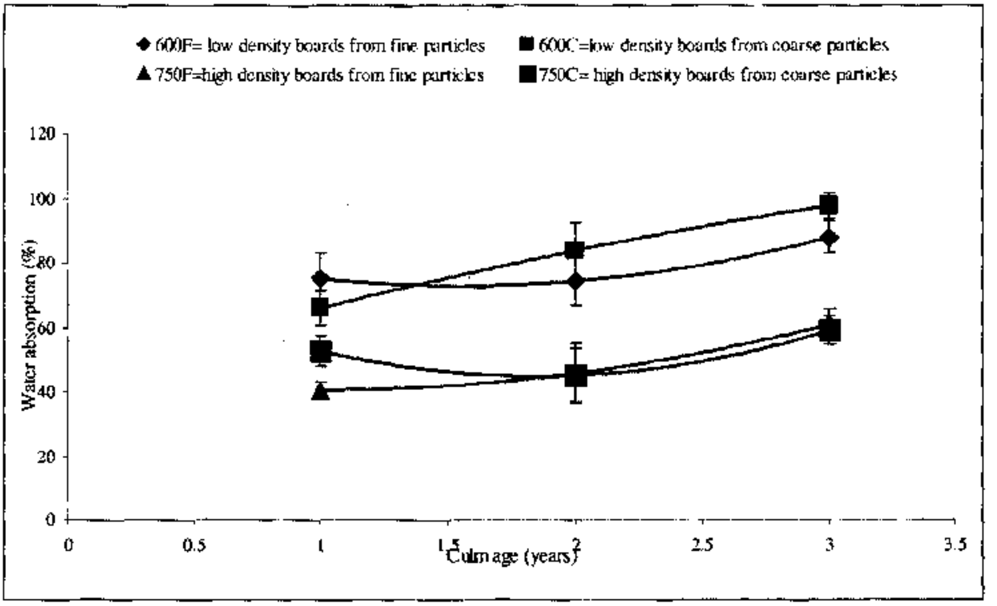
Figure 4. Effects of age and particle size on thickness swelling properties of particleboard made at 600 and 750 kg/m^3 board target density.

As indicated in Figure 4 almost similar TS values were recorded for boards made from fine and coarse particles after 24 h of water soaking. This shows that manufacturing bamboo boards at high density level from any particle sizes may result in good quality. Boards made from 2-year-old bamboo were more stable than other boards. This could be related to low contact angle (wettability) of this age group of bamboo.

As depicted in Figure 5, culm age and particle size had a substantial effect on the amount of water absorbed into particleboards. Results show that the amount of water absorption increased with increase in culm age.

The amount of water absorbed into the boards could be related to the compaction ratios. Figure 5 indicates that boards made from both particle sizes had high water absorption. This might be due to rapid entry of water into low compaction boards due to the higher porosity in them (Maloney, 1993; Vital *et al.*, 1974; Jamaludin and Abd. Jalil, 2000). On the other hand, boards made from fine particles had lower water absorption than boards made from coarse particles. This could be associated to the compression behavior of fine particles. Under hot press, small particles could be pressed easily which fit together very closely, thereby reducing void spaces between them and this might create intimate inter-particle contact and increase the internal bond strength.

Bamboo boards made at high density level absorbed less amount of water than boards



Note: Each value is the average of 9 specimens

Figure 5. Effects of age and particle size on water absorption properties of particleboard made at 600 and 750 kg/m³ board target density.

made at low density level. The amount of water absorbed into the boards could be related to the compaction ratios. Water enters slowly into high compaction boards due to the decreased porosity and increased amount of particles. High compaction ratio boards made from 1-year-old bamboo absorbed less amount of water than low compaction boards made from 3-year-old bamboo.

CONCLUSIONS

The manufacture of single-layer particleboards from *Y. alpina* appears to be technically feasible. Both strength and dimensional stability properties meet ISO standards for general purpose particleboard. From this study, it is concluded that age of culms bamboo has no significant effect on strength and stiffness of single-layer bamboo particleboard. It was also found that the internal bond strength of bamboo particleboards decreased as the culm age increased whilst thickness swelling increased. Particleboards obtained from 2-year-old culms gave higher mechanical and dimensional stability as compared to other age-groups. Therefore, it is possible to conclude that *Y. alpina* harvested at 2 years of age is more suitable for the production of particleboard. Similarly, particleboards fabricated at 750 kg/m³ board density from *Y. alpina* culms can replace timber in many applications such for ceiling and partition constructions, furniture, doors, windows, wardrobes, cabinets, flooring, etc.

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REFERENCES

Abd. Latif, M. 1996. Some Selected Properties of two Malaysian Bamboo Species in Relation to Age, Height, Site and Seasonal Variation. Ph.D. Thesis, Universiti Putra Malaysia, 282 p.

Alvin, K.L. and Murphy, R.J. 1988. Variation in fibre and parenchyma wall thickness in culms of bamboo *Sinobambusa toostik. IAWA Bull. n.s* 9: 353-361.

International Standards Organisation 2003a. ISO/DIS 16978. Wood-Based Panels–Determination of Modulus of Elasticity in Bending and of Bending Strength. International Standards Organisation.

International Standards Organisation 2003b. ISO/DIS 16983. Wood-Based Panels – Determination of Swelling in thickness after Immersion in Water. International Standards Organisation.

International Standards Organisation 2003c. ISO/DIS 16984. Wood-Based Panels – Determination of Tensile Strength Perpendicular to the Plane of the Panel. International Standards Organisation.

Boding, J. 1962. Wettability related to gluability of five Philippine mahoganies. *Forest Prod. J.* 12(6): 265-270.

Brumbaugh, I. 1960. Effect of flake dimensions on properties of particleboard. *Forest Prod. J.* 10(5): 243-246.

Chen Tsai-Yang and Wang Ying-Shen 1981. A study of structural particleboard made from bamboo waste. *Quarterly Journal of Chinese Forestry* 14(2): 39-60.

Chew, L.T. and Rahim Sudin 1991. *Bambusa vulgaris* for urea and cement–bonded particleboard manufacture. *Journal of Tropical Forest Science* 4(3): 249-256.

Espiloy, Z.B. 1992. Properties affecting bamboo utilization. Bamboo and its Use: International Symposium and Industrial Use of Bamboo, Beijing China: 139-142.

Herczeg, A. 1965. Wettability of Wood. *Forest Prod. J.* 15: 499-505.

Hse, C.Y. 1975. Properties of flakeboards from hardwoods growing on Southern pine particleboards. *Forest Prod. J.* 12(6): 265-270.

Jamaludin, K. and Abd. Jalil, A. 2000. Interior grade particleboard from bamboo (*Gigantochloa scortechinii*): Influence of age, particle size, resin and wax content on board properties. *Journal of Tropical Forest Products* 6(2): 142-151.

Jamaludin, K., Abd Jalil, A., Jalaludin, H., Zaidon, A. and Abd. Latif, M. 2001. Properties of three-layered urea-formaldehyde particleboard from bamboo. *Journal of Tropical Forest Products* 7(2): 153-160.

Kelemwork, S. 2005. Suitability of *Yushania alpina* for Oriented Particleboard. Ph.D. Thesis. Universiti Putra Malaysia, 228p.

Kelemwork, S., Paridah Md.Tahir, Wong Ee Ding, Rahim Sudin and Zaidon A. 2004. The effects of bamboo growing sites and age on mensurational attributes, buffering capacity and wettability of ethiopian highland bamboo. Proceedings of Malaysian Bamboo Research Association. Bamboo Workshop, 3-5 December 2004. Penang, Malaysia: 43-52.

Lee, A.W.C., Xuesong, B. and Perry, N.P. 1996. Physical and mechanical properties of strandboard made from moso bamboo. *Forest Prod. J.* 46(11/12): 84-88.

Liese, W. and Weiner, G. 1996. Aging of bamboo culms. *Wood Sci. Technol.* 30: 77-89.

Maloney, T.M. 1993. Modern Particleboard and Dry-process Fiberboard Manufacturing. Forest Products Society, Madison, WI.

Moslemi, A.A. 1974. Particleboard. Volume 1: Materials. Southern Illinois University Press. Carbondale and Edwardsville.

Nugroho, N. and Ando, N. 2000. Development of structural composite products made from bamboo: Fundamental properties of bamboo zephyr board. *Journal of Wood Science* 46: 68-74.

Paridah, M.T, Chin, A.M.E. and Zaidon, A. 2001. Bonding properties of *Azadirachta excelsa. Journal of Tropical Forest Products* 7(2): 161-171.

Suchsland, O. 1967. Behavior of a particleboard mat during the pressing cycle. *Forest Prod. J.* 17(2): 51-57.

Suchsland, O. 1973. Hygroscopic thickness swelling and related properties of selected commercial particleboards. *Forest Prod. J.* 23(7): 26-30.

Sun Chengzhi and Xie Guoen 1985. Fibre morphology and crystallinity of *Phyllostachys pubescens* with reference to age. In: A.N. Rao, G. Dhanarajan, and C.B Sastry, (Eds.). Proceedings of the International Bamboo Workshop, 6-14 October 1985, Hangzhou, China: 247-249.

Vital, B.R., Lehmann, W.F. and Boone, R.S. 1974. How species and board densities affect properties of exotic hardwood particleboards. *Forest Prod. J.* 24(12): 37-45.