J. Bamboo and Rattan, Vol. 3, No. 4, pp. 393–400 (2004)

Also available online - www.vsppub.com

The potential of utilising bamboo culm (*Gigantochloa scortechinii*) in the production of structural plywood

U. M. K. ANWAR [1,*], A. ZAIDON [2], M. T. PARIDAH [2] and W. RAZAK [3]

[1] *Forest Product Division, Forest Research Institute Malaysia, 52109 Kuala Lumpur, Malaysia*
[2] *Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[3] *School of International Forestry, Universiti Malaysia Sabah, Locked Bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia*

Abstract—The potential of utilising 4-year-old *Gigantochloa scortechinii* culms for structural plywood was evaluated based on their gluing, physical and mechanical properties. Bamboo strips (without epidermis) were glued together edge to edge using polyvinyl acetate to produce a ply of 400 mm × 400 mm × 4 mm. The plies were assembled perpendicularly to each other to form a bamboo plywood of three plies. Phenol formaldehyde was used as a binder. The assembly time of the adhesive was 30 min. The hot press temperature and pressure were 140°C and 1.4 N/mm^2, respectively, and they were maintained for 6.5 min. A commercial structural grade 5-ply plywood (*Hopea* sp.) with the same thickness of the bamboo plywood (12 mm) was used for comparison purposes. The bonding strength of bamboo plywood meets the minimum standard requirement of the Malaysian Standard. The modulus of rupture (MOR), modulus of elasticity (MOE) and compression parallel to grain of the bamboo plywood were significantly higher compared to commercial plywood. The values were 65.4 *vs.* 42.0 N/mm^2 for MOR and 8955 *vs.* 4583 N/mm^2 for MOE and 35.39 *vs.* 19.93 N/mm^2 (compression parallel to grain). The width expansion and thickness swelling of bamboo plywood (after soaking in water 24 h) were markedly higher than commercial plywood, i.e. 1.51 *vs.* 0.43% and 5.44 *vs.* 4.42%, respectively.

Key words: Bamboo plywood; *Gigantochloa scortechinii*; ply; phenol formaldehyde.

INTRODUCTION

Bamboo has been getting attention as a substitution material for wood [1]. It has similar morphological properties. Due to its fast growth and availability, and attractive and unique appearance this material can be converted into engineered products, such as composites, laminated boards and plywood. These products have gained commercial importance in China and Japan. Due to the nature of the

*To whom correspondence should be addressed. E-mail: mkanwar@frim.gov.my

plants, the utilization of bamboo culm can be done using full culms or through lamination. Sekhar and Bhartari [2] noticed that bamboo possesses excellent mechanical properties, especially with regard to tensile strength. The production of bamboo plywood begins with the selection of bamboo with large breast high diameter. The selected culms are usually cut into segments of definite length, with each segment split into two or three pieces. The bamboo is then softened at high temperature, flattened, dried and lastly coated with adhesives. Sulastinigsih and Sutigno [3] used *Gigantochloa apus* to manufacture bamboo plywood bonded with urea formaldehyde. The properties of bamboo plywood are extremely high in modulus of rupture, bending strength and modulus of elasticity, and it probably ranks as the highest among all the structural boards and even as good as the solid wood of high-density commercial timber [4].

This paper discusses the suitability of utilising 4-year-old *G. scortechinii* culms for structural plywood. The gluing, mechanical and physical properties of the bamboo plywood are also reported and are compared with commercial grade structural plywood.

MATERIALS AND METHODS

Preparation of samples

Four-year-old *G. scortechinii* culms were harvested from a plantation in the northern part of peninsular Malaysia. The culms were air-dried before further processing into strips. Only culms having a wall thickness of 7 mm were used. Splitting of the bamboo into 20-mm splits was done with a sizing and splitting machine. The epidermis of the splits was removed by planing on a single face-planing machine, and finally the splits were dressed into strips of final dimensions 420 mm (length) × 20 mm (width) × 4 mm (thickness).

The strips were then glued edge-to-edge using polyvinyl acetate resin to form a 410 mm × 410 mm × 4 mm laminate. The laminates were then bonded perpendicularly to each other using phenol formaldehyde resin to produce three-ply bamboo plywood. The adhesive formulation was slightly modified from the original formulation which was specifically made for commercial plywood [5]. Earlier study [6] showed that the wettability of *G. scortechinii* strips was very high (i.e. contact angle 4–15°). The modified adhesive formulation had acceptably high viscosity to control over penetration of adhesive. The assembly time was set at 30 and 50 min. The bamboo plywood was consolidated by hot pressing at 140°C and pressure of 1.4 N/mm^2 for 6.5 min. All boards were conditioned in a conditioning room before cutting into test specimens.

For comparison purposes, similar tests were conducted on commercial merawan (*Hopea* sp.) structural grade plywood (Grade A) of the same thickness (12 mm). The plywood was obtained from a local manufacturer.

Evaluation of bonding properties

A plywood shear test was conducted on an 100 mm × 25 mm × 25 mm sheared area in accordance with the Malaysian Standard MS 228: 1991 [7]. The panels were tested in dry and cyclic boiling conditions. Upon completion of the test, the specimens were dried and examined for the estimated percentage of wood failure along the glue line. The wood failures of individual specimens were recorded to an accuracy of 10% and the average shear strength and wood failure were compared with the standard requirement.

Evaluation of mechanical properties

For compression parallel to grain and for the dimension stability test ASTM standards for wood-based structural panels [8, 9] were used, due to the absence of established standard test methods for bamboo plywood. A total of 40 specimens each for bamboo plywood (tested parallel to the direction of the strips) and merawan plywood were tested for static bending and compression parallel to grain. The tests were performed on a universal testing machine (10 kN). Prior to testing, all specimens were conditioned in a conditioning room maintained at 20 ± 3°C and 65% relative humidity (EMC 12%). Static bending tests were conducted in accordance with the Chinese standard [10]. The specimens (300 mm × 30 mm × 12 mm) were placed on two supports over a span of 240 mm. The load was applied at the mid-span with a constant load rate of 3500 N/min [10].

For compression tests specimens of 60 mm × 50 mm × 12 mm were placed in a vertical position in the testing machine between two parallel metal plates. A constant load was introduced at the top of the samples at a rate of 6.5 mm/min [9].

Evaluation of physical properties

The dimensional stability of the product was evaluated based on thickness swelling and linear expansion after soaking in water. The specific tests followed ASTM [9]. Forty specimens (50 mm × 50 mm × 12 mm) were prepared and the width and thickness of all samples were measured before and after horizontally immersion in water (30 mm below the water surface) for 2 and 24 h. The same specimens were used for the determination of water absorption. The weight of the specimens before and after immersion in water (2 and 24 h) was measured. The weight of soaked samples was measured immediately after removing the excess water with a dry cloth.

RESULTS AND DISCUSSION

Bonding properties

Information on the shear strength and wood failure percentage is important to evaluate the glue bond quality of bonded products. Theoretically, when both the shear strength and wood failure percentage values are high, a good bonding has occurred. If one of them is high and the other is low, it indicates that either the wood or the adhesive is poor.

The mean shear strength and wood failure percentage of the bamboo plywood is summarized in Table 1. All the shear strengths and wood failure percentages of bamboo plywood meets the minimum standard requirement of the Malaysian standard [7]. When tested in dry condition, the shear strength of the bamboo plywood at both 30 and 50 minutes assembly time was 3.4 N/mm^2. For the cyclic boiling test (CBR), the shear values were 1.7 N/mm^2 and 1.3 N/mm^2, respectively, for 30 and 50 min assembly times. The wood failure percentage ranged from 58 to 62% for the dry specimens and 32 to 44% for the wet specimens. These results indicate that, in severe conditions, the bamboo plywood with shorter adhesive assembly time (30 min) was relatively stronger than those with longer assembly time (50 min).

The dry shear strength value of *G. scortechinii* plywood was relatively higher than Eucalyptus and Parana pine plywood, which were 2.0 and 1.3 N/mm^2, respectively [11]. However, this bamboo plywood was somewhat lower than plywood manufactured from some hardwood, like Lauan (5.0 N/mm^2) and Kapur (5.5 N/mm^2) [12].

Table 1 also shows that there were sharp decreases in the shear bond strength and wood failure percentage after the boards were exposed to the CBR test. This has been expected due to extensive stress developed during boiling and drying treatments specified by the tests.

Wood failure is commonly used to detect the strength of glue joints. In this study, even though the wood failure percentage was relatively low (40–60%), it does not mean that bamboo plywood has inferior bonding quality. Based on shear test values the results showed that bamboo plywood has high strength value. The adhesives were found to have significantly penetrated into the bamboo strips forming a good

Table 1.
Shear strength and wood failure percentage of bamboo plywood bonded with phenol formaldehyde adhesive as compared to Ref. [7]

	Assembly time	Average shear strength, τ (N/mm^2)		Average wood failure (%)		Minimum average wood failure in any test piece (%)	
		Dry	CBR	Dry	CBR	Dry	CBR
Bamboo plywood	30 min	3.4	1.7	62	32	48	28
	50 min	3.4	1.3	58	44	44	38
MS standard		0.35–0.7		>75		25	
		0.7–1.7		>50		15	
		1.7–2.5		>25		5	
		>2.5		>15		0	

anchorage between the bamboo layers [6]. In lieu of this more studies on adhesive formulation for the bamboo plywood is worth conducted.

Mechanical properties

The final moisture content of the bamboo plywood and merawan plywood were about 10% (20 ± 3°C and 65% relative humidity) with densities of 719 kg/m^3 and 600 kg/m^3, respectively. The mean values for the mechanical properties of both bamboo and merawan plywoods are given in Table 2. In general, the strength properties of bamboo plywood were higher than merawan plywood. The modulus of rupture (MOR), modulus of elasticity (MOE) and compression parallel to grain for bamboo plywood were 68 N/mm^2, 9642 N/mm^2 and 35 N/mm^2, respectively. The MOR and MOE values of bamboo plywood were 36% and 57% higher than merawan plywood, whereas the mean values for compression parallel to grain test, in bamboo plywood was 43% higher than merawan plywood.

Table 2 also shows the specific strength (i.e. strength/density) of each type of plywood. The specific strength for bamboo plywood was 0.09 Nm^3/kg mm^2 and for merawan was 0.07 Nm^3/kg mm^2, whereas the MOE values for bamboo plywood and merawan plywood were 13.4 Nm^3/kg mm^2 and 6.9 Nm^3/kg mm^2, respectively. The specific strength values in compression parallel to grain were 0.05 Nm^3/kg mm^2 and 0.03 Nm^3/kg mm^2, respectively. The results indicate that at equal density level, bamboo plywood can sustain greater load compared to merawan plywood.

Chen [4] also found that bamboo plywood had extremely high MOR and MOE, and these properties probably rank the highest among all the structural boards, even as good as the solid wood of high-density commercial timber. Bamboo plywood was also found to have higher bending strength parallel to the grain compared to Gadog plywood [3]. Huang [13] revealed that under uniform distributed load, the strength of bamboo plywood platform board was superior to that of timber platform

Table 2.
Mechanical properties of *G. scortechinii* plywood as compared to merawan plywood

Specimen	MC (%)	Density (kg/m^3)	Mean value (N/mm^2)			Specific strength (strength/density, Nm^3/kg mm^2)		
			MOR	MOE	Comp. to the grain	MOR	MOE	Comp. to the grain
G. scortechinii plywood	9.97 (0.4)	719 (36.3)	68^a (20)	9642^a (2572)	35^a (4)	0.09	13.4	0.05
Merawan plywood	9.52 (0.4)	600 (17.3)	44^b (6)	4166^b (497)	20^b (2)	0.07	6.9	0.03

Values in parentheses are standard deviations, number of specimens is 80. Means with the same letter are not significantly different at $P < 0.01$.

board, whilst under concentrated load, the strength of the former was about 2 times that of the latter.

The higher MOR, MOE and compression parallel to the grain of bamboo plywood compared to merawan plywood were probably caused by the fibre length of the bamboo material. Most mechanical strength of wood is influenced by the fibres, which are long, narrow, thick walled and with pointed end cells [14]. Latif and Tarmeze [15] found the MOE and stress at proportional limit in bamboo were positively correlated with fibre length and the size of vascular bundle. The fibre length of *G. scortechinii* was higher (2.55–2.87 mm) than some of the hardwood (1.00–1.10 mm) [16, 17].

Physical properties

The dimensional stability and water absorption of the two types of plywood after 2 and 24 h of soaking in water can be seen in Table 3. It seemed that bamboo plywood had a higher tendency towards swelling in thickness compared to merawan plywood. After 2 h of soaking, the thickness of bamboo plywood swelled 3.27%, while merawan plywood swelled 2.89%. Statistical analysis showed that the difference was not significant. However, after long hours of soaking (24 h), a further increase in thickness swelling was observed for bamboo plywood (5.44%) and merawan plywood (4.42%) and at this point the difference in swelling was significant. At the early stage of soaking in water, bamboo plywood absorbed more water (28.3%) than merawan plywood (22%), but after 24 h of soaking the water absorption for both plywoods was about the same (34–36%). The higher thickness swelling attained by the bamboo plywood was probably due to the collapse of the parenchyma cells of bamboo during pre-press and hot pressing towards the preparation of bamboo plywood. In presence of water, the collapsed cells tend to recover to its original dimension. Haygreen and Bowyer [18] indicate that thickness swelling in plywood may be slightly more than normal wood if excessively high

Table 3.
Dimension stability and water absorption of bamboo plywood and merawan plywood during short- (2 h) and long-term (24 h) soaking

Specimen	Thickness swelling (%)		Linear expansion parallel to grain (%)		Linear expansion perpendicular to grain (%)		Water absorption (%)	
	2 h	24 h	2 h	24 h	2 h	24 h	2 h	24 h
G. scortechinii plywood	3.27^a (0.94)	5.44^a (1.47)	0.36^a (0.2)	0.89^a (0.36)	0.83^a (0.39)	1.51^a (0.35)	28.3^a (2)	34^a (4)
Merawan plywood	2.89^a (0.69)	4.42^b (0.55)	1.38^b (0.32)	1.67^a (0.3)	0.29^b (0.12)	0.43^b (0.19)	22^b (3)	36^a (5)

Values in parentheses are standard deviations, number of specimens is 80. Means with the same letter are not significantly different at $P < 0.05$.

pressures occurred during the pressing time. Wood that is compressed will tend to partially recover its original dimension when rewetted.

Bamboo plywood recorded a lower linear expansion parallel to the grain compared to merawan plywood after soaking in water, i.e. it ranged from 0.36 to 0.89% for the former and 1.38 to 1.37% for the latter. However, for expansion perpendicular to grain, the value was higher in bamboo plywood (0.83–1.51%) than in merawan plywood (0.29–0.43%).

CONCLUSIONS

Technically, 4-year-old *Gigantochloa scortechinii* has shown potential as raw material in bamboo plywood. The results show that the bonding strength of the bamboo-ply when subjected to dry and wet conditions satisfies the minimum standard requirement. The average density of the board was approximately 700 kg/m^3, which was relatively higher than commercial plywood (600 kg/m^3). Compared to commercial plywood, the modulus of rupture (MOR) and modulus of elasticity (MOE) and compression parallel to grain of the bamboo ply were significantly higher ($P < 0.05$). Specific strength values (strength/density) were also higher for bamboo plywood than for commercial plywood. However, this product was less stable than commercial plywood after long hours of soaking in water.

REFERENCES

1. M. N. Salleh and K. M. Wong, The bamboo resource in Malaysia: Strategies for development, in: *Research on Bamboos. Proceedings of the International Bamboo Workshop*, 1986, Hangzhou, A. N. Rao, G. Dhanarajan and C. B. Sastry (Eds), pp. 45–50 (1987).
2. A. C. Sekhar and R. K. Bhartari, Studies on the strength properties of bamboos: a note on its mechanical behaviour, *Indian Forestry* **86** (5), 296–301 (1960).
3. I. M. Sulastiningsih and P. Sutigno, Some properties of bamboo plywood (Plybamboo) glued with urea formaldehyde, in: *Bamboo and its Uses. Proceedings of the International Symposium on Industrial Use of Bamboo*, Beijing, China, 1992. S. Zhu, W. Li, X. Zhang, Z. Wang (Eds), pp. 112–117 (1992).
4. G. Chen, Bamboo plywood — A new product of structural material with high strength properties, in: *Research on Bamboos. Proceedings of the International Bamboo Workshop*, 1986, Hangzhou, A. N. Rao, G. Dhanarajan and C. B. Sastry (Eds), pp. 337–338 (1987).
5. A. Zaidon, M. T. Paridah, C. K. Manja Sari, W. Razak and M. Y. Nur Yuziah, Bonding characteristics of *Gigantochloa scortechinii*, *Journal of Bamboo and Rattan* **3** (1), 57–65 (2004).
6. U. Mohd Khairun Anwar, Properties and utilisation of tropical bamboo (*Gigantochloa scortechinii*), for structural plywood, MSc Thesis, Universiti Putra Malaysia, Malaysia (2003).
7. Anonymous, Specification for plywood (first revision). MS 228: 1991. *Standard and Industrial Research Institute of Malaysia*, Malaysia (1991).
8. Anonymous, Standard test methods for wood based structural panels in compression, *Annual Book of ASTM Standard*, ASTM Des D 3501-94, Vol. 4-10. ASTM, Philadelphia, PA (1995).

9. Anonymous, Standard test methods of for evaluating properties of wood based fiber and particle panel materials. *Annual Book of ASTM Standard*, ASTM Des D 1037-96a, Vol. 4-10. ASTM, Philadelphia, PA (1997).
10. Anonymous, The forestry trade standard of the People's Republic of China: LY 1055-91. Bamboo strip plywood for automobile carriage base plates, 1992, in: *Bamboo Panel Boards a State of the Art Review. Technical Report No. 12. International Network for Bamboo and Rattan*, P. M. Ganapathy, H.-M. Zhu, S. S. Zoolagud, D. Turcke and Z. B. Espiloy (Eds), pp. 75–92. INBAR, Beijing (1999).
11. H. Yoshida, Strength properties of weathered tropical wood plywoods, in: *Adhesive Technology and Bonded Tropical Wood Products*, 1993, Y. H. Chung, S. J. Branham and C. Chun (Eds), pp. 445–463 (1993).
12. M. R. Gaiotto, L. T. Watai and I. P. Jankowsky, Evaluation of experimental eucalypt plywood, in: *Adhesive Technology and Bonded Tropical Wood Products*, 1993, Y. H. Chung, S. J. Branham and C. Chun (Eds), pp. 438–444 (1993).
13. H. L. Huang, Bamboo plywood used as platform board of lorry, in: *Bamboo and its Uses. Proceedings of the International Symposium on Industrial Use of Bamboo*, Beijing, China, 1992, S. Zhu, W. Li, X. Zhang and Z. Wang (Eds), pp. 192–198 (1992).
14. W. P. K. Findlay, *Timber: Properties and Uses*. Crosby Lockwood Staples. London (1975).
15. M. Abd. Latif, W. A. Wan Tarmeze and A. Fauzidah, Anatomical features and mechanical properties of three Malaysia bamboos. *Journal of tropical Forest Products* **2** (3) 227–234 (1990).
16. M. A. Ashaari, Variation in certain wood properties of rubber tree (*Hevea brasiliensis*) Muell, Agr, MSc Thesis, Louisiana State University, Baton Rouge, LA (1980).
17. M. Abd. Latif, M. Mohd. Tamizi, S. Mohd. Rashid and M. Mohd. Shukari, Wear resistance of two commercial bamboo species in Peninsular Malaysia and their suitability as a flooring material, in: *Bamboos Current Research, Proceedings of the International Bamboo Workshop*, Cochin, 1988, I. V. Ramanuja Rao, R. Gnanaharan and C. B. Sastry (Eds), pp. 223–230 (1990).
18. J. G. Haygreen and J. L. Bowyer, *Forest Products and Wood Science*. Iowa State University Press, Ames, IA (1998).