PHYSICAL AND MECHANICAL PROPERTIES OF LAMINATED BAMBOO BOARD

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SULASTININGSIH IM & NURWATI. 2009. Physical and mechanical properties of laminated bamboo board. This study investigated the potential of laminated bamboo board (LBB) as a wood substitute, with particular focus on the effects of bamboo species and number of layers on its physical and mechanical properties. The bamboo species used in these tests were *Gigantochloa apus* and *Gigantochloa robusta* collected from private gardens in West Java. Results showed that the density of LBB varied from 0.71–0.75 g cm^{-3}. The MOR and MOE of LBB which ranged from 393.7–969.4 kg cm^{-2} and 74 100–102 290 kg cm^{-2} respectively were affected by the number of layers; they decreased as number of layers increased. No delamination occurred in all samples using tannin resorcinol formaldehyde glue, indicating high bonding quality. The average bonding strength (dry test) of LBB made from *G. robusta* was higher (55.8 kg cm^{-2}) than that of *G. apus* (40.8 kg cm^{-2}). Three-layer thick LBB had comparable strength to wood strength class II while five-layer board, to class IV. LBB provides an alternative wood source for furniture, interior design and building materials. Developing LBB industry can reduce the rate of logging activity as well as fulfil wood shortages.

Keywords: Wood substitute, number of layers, tannin resorcinol formaldehyde, bonding strength

SULASTININGSIH IM & NURWATI. 2009. Ciri fizikal dan mekanik papan buluh berlaminasi. Kajian ini melihat kepada potensi papan buluh berlaminasi (LBB) sebagai pengganti kayu. Tumpuan khusus kajian adalah kepada kesan spesies buluh serta jumlah lapisan terhadap ciri fizikal dan mekanik LBB. Spesies buluh yang digunakan ialah *Gigantochloa apus* dan *Gigantochloa robusta* yang diambil dari ladang persendirian di Jawa Barat. Keputusan menunjukkan ketumpatan LBB berjulat antara 0.71–0.75 g cm^{-3}. Nilai MOR dan MOE LBB yang masing-masing berjulat antara 393.68–969.39 kg cm^{-2} dan 74 100–102 290 kg cm^{-2} dipengaruhi oleh bilangan lapisan buluh; nilainya berkurangan apabila bilangan lapisan bertambah. Pelekangan tidak berlaku dalam semua sampel yang menggunakan tanin glu resorsinol formaldehid; ini menunjukkan kualiti pengikatan yang tinggi. Purata kekuatan pengikatan (ujian kering) LBB daripada *G. robusta* adalah lebih tinggi (55.8 kg cm^{-2}) berbanding *G. apus* (40.8 kg cm^{-2}). Kekuatan LBB yang mempunyai tiga lapisan adalah setara dengan kekuatan kayu kelas II sementara papan lima lapisan adalah setara dengan kelas IV. LBB dapat diguna sebagai sumber kayu alternatif bagi bahan perabot, bahan reka bentuk dalaman dan bahan bangunan. Industri LBB dapat mengurangkan aktiviti pembalakan selain memenuhi kekurangan bekalan kayu.

INTRODUCTION

Bamboo in Indonesia is one of the most important non-wood forest products and has long been recognized as a multi-purpose plant. Bamboo can be used for construction materials (village houses, bridges), furniture, household utensils and handicrafts. Bamboo is also used to mark village boundaries and to control erosion along riverbanks. Its shoot, especially that of *Dendrocalamus asper*, is eaten as vegetable. Bamboo is found in natural and plantation forests and also in agroforests (called pekarangan in Javanese) in many villages in Indonesia (Yudodibroto 1987).

The occurrence of bamboo in Indonesia extends from peat swamp areas up to highlands at the altitude of 2500 m (Widjaja 1999). However, the bamboo forest is mostly found in disturbed forests except for *Dinochloa* spp. which grow well in the primary and dipterocarp forests. Several areas in Indonesia have large bamboo forests e.g., Kerinci Seblat National Park (Sumatra), Alas Purwo National Park (Java), Meru Betiri National Park (Java), Langkat District (Sumatra), Loksado (Central Kalimantan), West Sumbawa (Lesser Sunda Island), Maros (South Sulawesi) and Bukit Barisan Selatan National

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Park (Sumatra). There are about 143 species of bamboo in the country of which 60 are found in Java island (Widjaja 2001).

The rapid development of wood industry in Indonesia since 1980s has contributed to the scarcity of wood raw materials in the forest. In addition, the increase in population contributes to the increase in demand for wood for housing materials. The total population of Indonesia in 2005 was 219.2 mil with a growth rate of 1.34% per annum (Anonymous 2006). The annual need for housing in Indonesia is about 2.9 mil units, consuming 8.6 mil m^3 of sawn timber (Supriana *et al.* 2003). With such high demand for wood, finding a substitute wood is an urgent necessity.

Bamboo can be used as an alternative source of raw materials for the wood industry due to its ability to grow in various soils, fast growth, short rotation and other desirable properties. For generations, villagers have been using bamboo for construction materials, furniture, household utensils and handicrafts. However, there are problems associated with the utilization of bamboo for housing materials and one example is the limitation in shape and dimensions of bamboo. Due to its circular and hollow shape, for timber substitute materials, bamboo must first be converted into a flat and a relatively thick material. By using certain adhesives, it is possible to use bamboo strips to produce timber-like material, called laminated bamboo board (LBB), to meet many service requirements especially for furniture.

LBB, lumber-like in dimensions (the thickness, width and length can be designed to meet targeted dimensions common in lumber) consists of several plies of bamboo sheets bonded together with the grain in parallel direction. Depending on its thickness and width, LBB can resemble a plank or a beam. Producing LBB with a longer service life can reduce logging activity and at the same time support the natural resource conservation. Understanding physical and mechanical properties of LBB is imperative before it can be used as housing material. This paper describes results of an experiment to determine the effects of bamboo species and number of layers on physical and mechanical properties of LBB glued with tannin-based adhesive.

MATERIALS AND METHODS

Two bamboo species *(Gigantochloa apus* and *Gigantochloa robusta)* were used in the experiment because these bamboo species are widely planted in West Java. Twenty mature culms each of *G. apus* and *G. robusta* were collected from private gardens in Bogor, West Java. The culms used in the experiment were obtained by taking out the first segment at about 60 cm in length from the bottom. The remaining culms (only the bottom and middle parts) measuring about 4 and 5 m in length for *G. apus* and *G. robusta* respectively were cross cut into segments. Each segment was 90 cm in length and generally had two internodes. The total bamboo segments collected were 80 for *G. apus* and 100 for *G. robusta*. All bamboo segments were brought to the Wood Composite Laboratory, Forest Products Research and Development Center, Bogor. Using a pair of callipers, the average diameter and wall thickness of segments of *G. apus* were 7.92 and 0.94 cm while those of *G. robusta*, 9.27 and 0.83 cm respectively.

Preparation of bamboo strips

To produce bamboo strips, each bamboo segment (90 cm in length) was manually fed into a bamboo splitter machine. The bamboo splitter machine was specially designed in the Wood Composite Laboratory. Five to seven strips were obtained from each segment, each about 2 cm wide. Only straight bamboo strips were used for this study. After scraping out the inner and outer layers, the selected strips were then planed and stacked for air drying at room temperature for one week. Then the bamboo strips were immersed in 5% boron solution (obtained from free market) for two hours after which they were sun-dried to 12% moisture content.

Producing bamboo sheet

Each bamboo sheet comprised nine bamboo strips. The bamboo strips were assembled side-by-side and edge-glued using liquid tannin resorcinol formaldehyde (TRF) extracted from *Acacia mangium* bark(Santoso *et al.* 2003). The content of solids in the TRF was 36%. Wheat flour (20% w/w and obtained from free market) was then added to the TRF. The glue mix (170 g m^{-2} for a single glue line) was then hand-spread on each side surface of the bamboo strip using a metal spatula. The assemblies were cold-pressed for four hours using a wooden clamp.

Producing laminated bamboo board

LBBs were produced by assembling several layers of bamboo sheets (each bamboo sheet consisted of nine bamboo strips) with the grain in parallel direction using the same mixture and amount of glue mix as before (liquid TRF and 20% w/w wheat flour, 170 g m^{-2} for each glue line). The assemblies were also cold-pressed using a wooden clamp for four hours. Four replications for each treatment of LBB were prepared. The LBBs produced were conditioned for two weeks before testing.

Testing

The laminated bamboo boards were cut into desired specimen dimensions and measured for density, moisture content, thickness swelling, linear expansion, modulus of rupture (MOR), modulus of elasticity (MOE), compression strength and bonding strength. The tests to evaluating properties of LBBs were performed using the American Standard ASTM D 1037-93 (Anonymous 1995) with some modifications and the Japanese Standard for Glued Laminated Timber (Anonymous 2003). A completely randomized design with factorial experiment was used with bamboo species and number of layers as treatment factors. Four replications were prepared for each treatment combination.

RESULTS AND DISCUSSION

The mean values of physical and mechanical properties of LBBs and results of the analysis of variance (ANOVA) are presented in Table 1. The moisture content of LLB varied from 12.7 to 13.7% with an average of 13.0%. These values are still within the range of air-dried moisture content.

Table 1 Physical and mechanical properties of laminated bamboo boards

Property	A_1		A_2		ANOVA		
	B_1	B_2	B_1	B_2	A	B	AB
MC (%)	13.07 (1.16)	13.68 (0.34)	12.81 (1.57)	12.67 (0.71)			
Density (g cm^{-3})	0.75 (0.01)	0.75 (0.01)	0.71 (0.02)	0.72 (0.03)	**	ns	ns
TS (%)	2.47 (0.29)	3.00 (0.74)	4.08 (0.69)	3.75 (0.68)	*	ns	ns
LE (%)	0.11 (0.01)	0.17 (0.02)	0.07 (0.01)	0.10 (0.01)	ns	ns	ns
MOR (kg cm^{-2})	969.39 (94.04)	462.44 (53.22)	895.34 (123.46)	393.68 (47.59)	ns	**	ns
MOE ($\times 10^3$ kg cm^{-2})	102.29 (8.14)	96.77 (8.53)	100.03 (4.97)	74.10 (10.84)	ns	**	ns
CS (kg cm^{-2})	564.79 (66.39)	518.76 (16.04)	571.98 (51.40)	503.17 (35.58)	ns	*	ns
BS (kg cm^{-2})	40.77 (3.64)		55.82 (4.39)				
Delamination (cm)	0		0				

Each value was the average of four specimens except for bonding strength which had eight specimens. Numbers in parentheses represent one standard deviation; MC = moisture content; TS = thickness swelling; LE = linear expansion; MOR = modulus of rupture, MOE = modulus of elasticity; CS = compression strength; BS = bonding strength; A = bamboo species; A_1 = *Gigantochloa apus*; A_2 = *G. robusta*; B = number of layers; B_1 = three layers; B_2 = five layers; ns = not significant; * = significant at $p < 0.05$; ** = highly significant at $p < 0.01$.

The average density of LBB produced was 0.73 g cm^{-3}. The average air-dried densities of *G. apus* strips and *G. robusta* strips in this study were 0.71 and 0.59 g cm^{-3} respectively. These values are higher than 0.65 g cm^{-3} reported by Suryokusumo and Nugroho (1994) for *G. apus* and 0.55 g cm^{-3} by Widjaja and Risyad (1987) for *G. robusta*. Possible reasons that contributed to the higher values are the use of adhesive and the pressure applied during LBB manufacture in this study, which produced a denser product. ANOVA showed that density of LBB was highly affected by bamboo species.

Thickness swelling of LBB varied from 2.5 to 4.1% with an average of 3.3% and *G. apus* (2.73%) had lower values than *G. robusta* (Table 1). A previous study by Nugroho and Ando (2001) showed that the average thickness swelling of four-layer laminated bamboo lumber made from moso bamboo (bamboo zephyr mats) glued with resorcinol-based adhesive was 12.2%. Thickness swelling of laboratory made three-layer laminated bamboo lumber and natural bamboo flooring made from moso bamboo (bamboo strips) were 1.0 and 0.7% respectively (Lee & Liu 2003). Thickness swelling of LBB made from bamboo strips of *G. pseudoarundinacea* and in combination with acacia and pine wood varied from 0.8 to 3.3% (Sulastiningsih *et al* 2005). Parallel and crossed-laminated bamboo panel made from *Dendrocalamus yunnanicus* had thickness swellings of 3.5 and 3.6% respectively (Guo 2007). From this information it was found that LBB made from bamboo strips had better dimensional stability than laminated bamboo lumber made from bamboo zephyr mats. ANOVA showed that the thickness swelling of LBB was only affected by bamboo species (Table 1).

The linear expansion of LBB varied from 0.07 to 0.17% (Table 1) and both bamboo species and number of layers did not affect the linear expansion of LBB. The linear expansion of the four-layer laminated bamboo made from bamboo zephyr mats glued with resorcinol-based adhesive was 0.48% (Nugroho & Ando 2001). A three-layer laminated bamboo lumber made from moso bamboo (bamboo strips) had a linear expansion of 0.09% (Lee & Liu 2003). Our previous investigation showed that the linear expansion of LBB made from bamboo strips of *G. pseudoarundinacea* and in combination with acacia and pine wood varied from 0.38 to 0.60% (Sulastiningsih *et al.* 2005). From this information it can be seen that LBB made from bamboo strips had better dimensional stability than that of bamboo zephyr mats. Incorporating wood layer in LBB composition also reduced the dimensional stability of LBB. Also, the surface of bamboo strips was smooth and it was only 2 cm in width, whereas the surface of bamboo zephyr mats was not smooth because there were a lot of splits which occurred during manufacturing. In addition, the width of bamboo zephyr mats was about 10 to 12 cm depending on the diameter of bamboo culm. Thus, the appearance of LBB made from bamboo strips is far better than LBB made from bamboo zephyr mats.

The MOR of LBB made from *G. apus* and *G. robusta* glued with TRF varied from 393.7 to 969.4 kg cm^{-2} (Table 1). A previous study has shown that the MOR of three-layer and five-layer LBBs made from bamboo zephyr mats of *D. asper* glued with urea formaldehyde were 1031 and 962 kg cm^{-2} respectively (Sulastiningsih *et al.* 1996). In another study, the MOR of a three-layer LBB made from *G. pseudoarundinacea* glued with TRF was 1241 kg cm^{-2} (Sulastiningsih *et al.* 2005). MOR values of the three-layer LBB made from *G. apus* (969.4 kg cm^{-2}) and *G. robusta* (895.3 kg cm^{-2}) obtained in the present study were lower than that of *G. pseudoarundinacea* (1241 kg cm^{-2}). The glue composition and the pressing period applied in this study are different with that of the previous studies and these may be the reasons for the lower MOR values. In the previous study TRF glue was used without addition of wheat flour and the pressing period was 20 hours. In this study wheat flour equalling to 20% w/w of TRF was added to the glue and the pressing period was four hours.

MOR of a four-layer laminated bamboo lumber made from bamboo zephyr mat glued with resorcinol-based adhesive varied from 639 to 707 kg cm^{-2} (Nugroho & Ando 2001). MOR of parallel and crossed laminated panels made from *D. yunnanicus* were 210 and 195 MPa respectively, while panels made from *Heterocycla pubescens* were 175 and 136 MPa respectively (Guo 2007). Idris *et al.* (1994) reported the MOR of *G. apus* was 502.3 kg cm^{-2} for parts with nodes and 1240.3 kg cm^{-2} for internodes. Widjaja and Risyad (1987) showed that the MOR of *G. robusta* was 1355.7 kg cm^{-2}. It can be seen that the MOR of LBB was lower than the MOR of the original bamboo especially for five-layer LBBs. This was due to the fact that in LBB bamboo sheets there are many small splits which occurred from some imperfection joints among strips and, thus, reduced the strength of LBB. Conversely, the specimen used in determining MOR of the original bamboo strip was clear and free from defects.

Our study showed that the MOR of LBB was not affected by the bamboo species (Table 1). This result was in contrast with Guo (2007) who reported that mechanical properties of parallel and crossed *D. yunnanicus* panels were higher than those of *Heterocycla pubescens*. On the other hand, we observed that the number of layers greatly affected the MOR of LBB (Table 1). MOR decreased as the number of layer increased. This result is not in agreement with that reported by Sulastiningsih *et al.* (1996) which showed that MOR of laminated bamboo made from bamboo zephyr mats *of D. asper* glued with urea formaldehyde was not affected by number of layers. In this study, based on MOR value, the three-layer LBB had comparable strength with Indonesian wood strength class II while the five-layer board, wood strength class IV (Seng 1964). Further research is still needed to obtain optimum conditions for the manufacture of high quality LBB glued with TRF.

MOE values of LBB in this study had a similar trend as MOR values (Table 1). The MOE of LBB made from *G. apus* and *G. robusta* varied from 74 100 to 102 290 kg cm^{-2}. Unlike results reported by Sulastiningsih *et al.* (1996), MOE in this study was greatly affected by number of layers and the values decreased as the number of layers increased.

The compression strength of LBB varied from 503.1 to 572.0 kg cm^{-2} (Table 1). Idris *et al.* (1994) reported the compression strength of *G. apus* was 505.3 and 521.3 kg cm^{-2} for parts with nodes and internodes respectively. According to Widjaja and Risyad (1987), the compression strength of *G. robusta* was 520.9 kg cm^{-2}. Thus, the compression strength of LBB is higher than that of the original bamboo. This could be due to the density of LBB which was higher than the specific gravity of the original bamboo. The higher the density of LBB, the higher its compression strength. Compared with the Indonesian wood strength classification (Seng 1964), based on compression strength value, all LBB produced had comparable strength to wood strength class II.

ANOVA showed that the compression strength of LBB was not affected by bamboo species but was greatly affected by the number of layers. The compression strength decreased as the number of layers increased. However, Sulastiningsih *et al.* (1996) found that compression strength of laminated bamboo made from bamboo zephyr mats of *D. asper* glued with urea formaldehyde was not affected by the number of layers.

The bonding quality of any composite product is very important. To determine the bonding quality of LBB glued with tannin-based adhesive, delamination and glue shear strength tests were carried out. Results showed that there was no delamination in all samples and, therefore, the bonding quality of the LBB was considered acceptable. The glue shear strength test showed that the bonding strength (dry test) of LBB made from *G. robusta* was higher (55.82 kg cm^{-2}) than that from *G. apus* (40.77 kg cm^{-2}). The bonding strength values of LBB in this study were much lower than that of *G. pseudoarundinacea* (242.16 kg cm^{-2}, dry test) reported by Sulastiningsih *et al.* (2005). Again this could be due to the 20% w/w wheat flour used in this study. We also used a shorter pressing period, i.e. 4 hours compared with 20 hours by Sulastiningsih *et al.* (2005). Therefore, further research is still needed to find the optimum condition which covers both glue composition and pressing condition in manufacturing LBB glued with TRF with good dimensional stability, high mechanical strength and good bonding quality.

CONCLUSIONS

The density of LBB glued with tannin-based adhesive was only affected by bamboo species. The average density of laminated bamboo board made from *G. apus* was higher than that from *G. robusta*.

The mechanical properties of LBB were not affected by the bamboo species. MOR, MOE and compression strength of LBB were significantly affected by its number of layers. MOR, MOE and compression strength decrease as the number of layer increased. Based on the Indonesian wood strength classes, the three-layer LBB glued with tannin-based adhesive had comparable strength to the wood strength class II, while the five-layer, to wood strength class IV.

LBB provides an alternative wood appearance for furniture, interior design and building materials. Developing LBB industry can reduce the rate of logging as well as fulfil wood shortage. It is recommended that further research be done to study the effect of various treatments on improving LBB appearance and quality.

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