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Some Properties of Bamboo Composite Lumber Made of *Gigantochloa pseudoarundinacea*

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Abstract: The objective of the study was to determine the effect of bamboo-wood layer compositions on the properties of bamboo composite lumber. Laboratory scale bamboo composite lumbers (BCLs) with four different core layer materials, i.e., bamboo strips glued vertically, jabon wood plank (*Anthocephalus cadamba* Miq.), manii wood plank (*Maesopsis eminii* Engl.) and sengon wood plank (*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes) were fabricated using Andong bamboo (*Gigantochloa pseudoarundinacea* (Steud.) Widjaja) strips glued horizontally as the outer layers and Andong bamboo zephyrs used as the second and the fourth layers. BCLs were manufactured using water based polymer-isocyanate (WBPI) adhesive with the glue spread of 250 g/m^2, and the cold pressing time applied was 1 h. Results showed that physical and mechanical properties of BCLs were significantly affected by the layer compositions. The BCL consisted of 100% bamboo strips exhibited higher density (0.754 g/cm^3) and mechanical properties (modulus of rupture (MOR) 1,162 kgf/cm^2, modulus of elasticity (MOE) 173,757 kgf/cm^2, compression strength 644.7 kgf/cm^2 and hardness 553 kgf), compared to BCLs, of which the core layer was made of wood plank (density 0.533 g/cm^3, MOR 648 kgf/cm^2, MOE 77,893 kgf/cm^2, compression strength 389.7 kgf/cm^2 and hardness 355 kgf, respectively). No delamination occurred in all samples, indicating a high bonding quality. BCL made of 100% bamboo strips had strength values comparable to wood strength class I, while BCL with core layer made of wood plank of jabon, manii or sengon had strength values similar to wood strength class III. All BCLs produced are suitable for solid wood substitute.

Key words: Bamboo strip, bamboo zephyr, wood plank, isocyanate, physical and mechanical properties.

1. Introduction

Until now, Indonesia still undergoes the discrepancy between supply and demand of good quality timber for furniture and building materials. Therefore, investigation for wood substitution material becomes an urgent concern. Due to its ability to grow fast in various soils with desirable properties, bamboo can be an alternative material. However, the utilization of bamboo is limited with its shape and dimension, thus to use it, the circular and hollow shapes of bamboo should be converted into flat and relatively thick materials [1]. This effort may allow the bamboo material to become more flexible in its application. Producing bamboo composite lumber (BCL), such as laminated bamboo products, is one technique to overcome the problem.

On the other hand, in recent years, plantation forests become the major suppliers of logs for wood industries in Indonesia. The timber is dominated with short rotation of fast growing species and relatively with small diameter logs. The quality of small diameter logs originated from plantation forest is normally inferior, compared to mature logs from natural forest. The intensive timber production creates changes in the wood anatomical and technical properties, and as a result, the suitability of the wood for high quality products is being reduced [2]. To improve the utilization, wood from fast grown species can be used as the core layer of BCL.

Some studies on the properties of products made of bamboo and fast grown timber have been conducted. Three layers vertically glued laminated bamboo beam (LBB) were manufactured by trying six different layer compositions by using bamboo and wood planks of

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manii (*Maesopsis eminii* Engl.) or sengon (*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes) as the core layer. The study indicated that the layer compositions affected the properties of LBB, and the utilization of wood increased the dimensional stability of the products [3]. Furthermore, Supriadi et al. [4] investigated the characteristics of jabon-bamboo laminated board (JBLB), and the result showed that this technique could increase the density, modulus of elasticity (MOE), modulus of rupture (MOR) and compression strength of JBLB, compared to jabon wood properties itself. The strength class of jabon wood raised one level to strength class III.

Previous study using Andong bamboo (*Gigantochloa pseudoarundinacea* (Steud.) Widjaja) combined with mangium (*Acacia mangium*) and pine (*Pinus merkusii*) glued with tannin resorcinol formaldehyde also indicated the increase in the density of composite bamboo boards, if compared to the initial density of the timber used [1]. This paper describes the effects of layer compositions on the properties of BCL made of Andong bamboo and some fast grown species glued with isocyanate adhesive.

2. Materials and Methods

2.1 Materials

Twenty mature culms of Andong bamboo (*G. pseudoarundinacea* (Steud.) Widjaja) and two logs each of small diameter logs of jabon (*Anthocephalus cadamba* Miq.), manii (*M. eminii* Engl.) and sengon (*F. moluccana* (Miq.) Barneby & J.W. Grimes) were collected from Sukabumi, West Java. Boron solution and water based polymer-isocyanate (WBPI) were used as preservative and adhesive, respectively.

2.2 Preparation of Bamboo Strips and Bamboo Zephyr

Only middle part of bamboo culms were used in the experiment. Twelve bamboo culms were converted into strips, while the rest eight culms were used for zephyrs. Each culm in ± 4 m length was cross cut into segments in 90 cm length. To produce bamboo strips, each bamboo segment was manually fed into a bamboo splitter machine. Six to seven of 2 cm wide strips were obtained from each segment. Only straight bamboo strips were used for this study. Furthermore, to produce bamboo zephyr, each bamboo segment was split open and flattened manually.

After scraping out the inner and outer skins, the selected strips and zephyrs were then planned to targeted thickness of about 5 mm and then stacked for air drying at room temperature for one week. Then, the bamboo strips and zephyrs were immersed in 7% boron solution for 4 h to targeted retention of 6 kg/m^3, after which they were air dried for one night and then followed by sun dried until reach about 12% moisture content.

2.3 Preparation of Wood Plank

Small diameter logs (25-30 cm diameter with 2 m in length) of jabon, manii and sengon were converted into wood plank with targeted thickness of ± 2.5 cm. The planks then were stacked for air drying at room temperature for one month. Afterwards, the wood planks were planned to targeted thickness of ± 2.0 cm and were immersed in 7% boron solution for 20 h to targeted retention of 6 kg/m^3. Furthermore, they were air dried for a night and then followed by sun dried until reach about 12% moisture content. The dry wood planks then were cross cut into 90 cm in length.

2.4 Producing Bamboo Sheet

For surface layers, the bamboo strips were glued horizontally. Each bamboo sheet comprised of eight bamboo strips. The bamboo strips were assembled side-by-side and edge-glued using WBPI adhesive. The glue mix (main fluid 100 g and crosslinker 15 g) of 250 g/m^2 for a single glue line was then hand-spread on each side surface of bamboo strips using a sponge rubber spatula. The assemblies were cold-pressed for 1 h using a wooden clamp. For core layer, the bamboo strips were glued vertically. Each bamboo sheet comprised of 32 bamboo strips. The bamboo strips were assembled side-by-side with wide-surface-glued using WBPI adhesive. The glue mix (main fluid 100 g and crosslinker 15 g) of 250 g/m^2 for a single glue line was then hand-spread on each wide surface of bamboo strips using a sponge rubber spatula. The assemblies were cold-pressed for 1 h using a wooden clamp.

2.5 Producing BCL

Laboratory scale of BCL with four different core layer materials, i.e., bamboo strips vertically glued (A), jabon wood plank (B), manii wood plank (C) and sengon wood plank (D) were manufactured using horizontally glued Andong bamboo strips as the outer layers. For the BCL combination of B, C and D, the second and the fourth layers were made of Andong bamboo zephyrs. BCLs were produced by assembling the bamboo sheets, bamboo zephyrs and wood planks in symmetric structure with the grain in parallel direction. BCLs were manufactured using WBPI adhesive with the glue spread of 250 g/m^2 and cold-pressed using a wooden clamp for 1 h. Four replications for each type of BCL were prepared. The BCLs produced were conditioned for two weeks before testing. The layer compositions of BCL were presented in Table 1.

2.6 Testing

The BCLs were cut into desired specimen dimensions and measured for density, moisture content, thickness swelling, water absorption, MOR, MOE, compression strength and hardness. The tests of density, moisture content, thickness swelling and water absorption were performed using the American Standard ASTM D 1037-93 [5], with modification by using smaller specimen dimension for testing thickness swelling and water absorption. The moisture content of each specimen was measured based on oven drying method, whereas the tests of compression strength and hardness were performed using ASTM D 143-94 [6], using smaller specimen dimension for hardness testing. The hardness tests were performed only on the surface of the specimen (side hardness). Japanese Standard for Glued Laminated Timber [7] was applied for evaluating the bonding quality (immersion delamination test) and bending properties (MOR and MOE of center point loading) of BCL. A completely randomized design was used in the experiment with the layer compositions as the treatment factor. Four replications were prepared for each treatment.

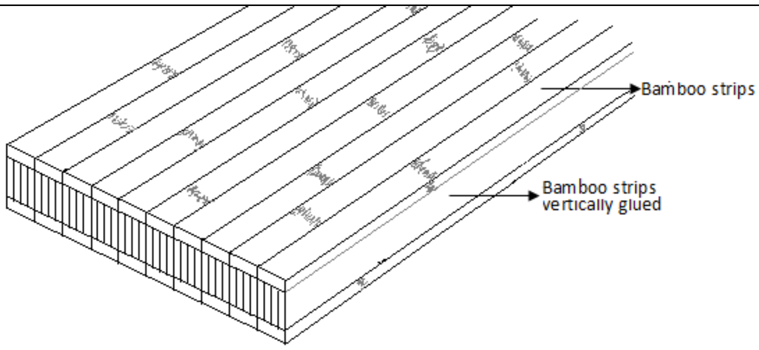
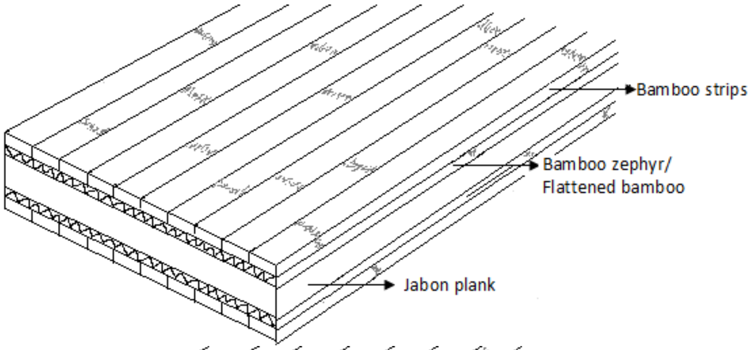
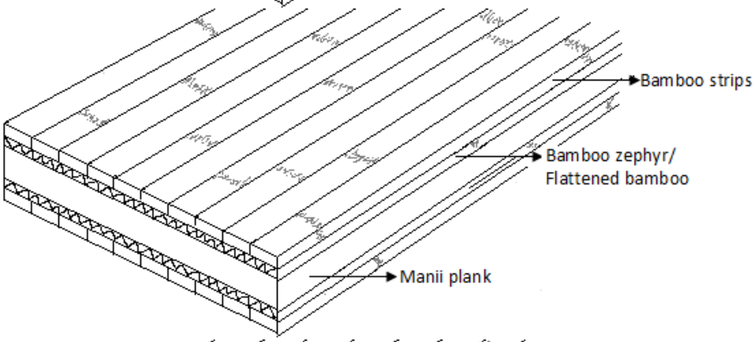
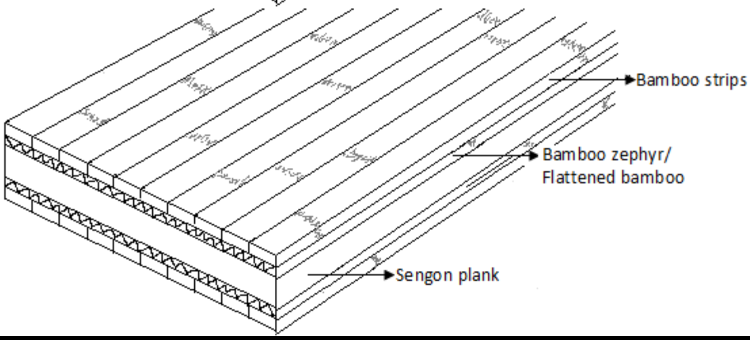
2.7 Data Analysis

Tests to determine whether the data were normally distributed were conducted by using Saphiro-Wilk W test (Statistica®). To analyze whether the layer compositions affect the properties of BCL, analysis of variance (ANOVA; Statistica®) was applied for normal distributed data, while non-parametric statistic Kruskal-Wallis ANOVA test (Statistica®) was used for not normally distributed data. Furthermore, to evaluate which layer compositions were different, post hoc tests were conducted. Multiple comparisons of mean ranks for all groups (Statistica®) were applied when the data were not normally distributed, but Tukey honest significant difference (HSD) test (Statistica®) was applied when the data were normally distributed. The results on the normality test were presented in Appendix 1. Moisture content was normally distributed, while the rest six parameters were not distributed normally.

3. Results and Discussion

The mean values of physical and mechanical properties of BCL and the effect of the composite layer compositions were presented in Table 2. The moisture content of BCL varied from 12.2% to 13.7% with an average of 13%. These values are still within the range of air dried moisture content. Moisture content of each BCL speciment was measured based on an oven drying method. The density of BCL produced varied from 0.491 g/cm^3 to 0.754 g/cm^3 with

Table 1 Layer compositions of BCL.

Code	Scheme	Layer compositions
A		All layers consisted of bamboo strips. The outer layers are bamboo strips glued horizontally, the core layer is bamboo strips glued vertically.
B		The first and the fifth layers are bamboo strips glued horizontally, the core layer is jabon (*A. cadamba* Miq.) wood plank, the second and the forth layers are bamboo zephyrs.
C		The first and the fifth layers are bamboo strips glued horizontally, the core layer is manii (*M. eminii* Engl.) wood plank, and the second and the forth layers are bamboo zephyrs.
D		The first and the fifth layers are bamboo strips glued horizontally, the core layer is sengon (*F. moluccana* (Miq.) Barneby & J.W. Grimes) wood plank, the second and the forth layers are bamboo zephyrs.

an average of 0.588 g/cm^3. The densities were calculated based on the obtained air drying moisture content, and they were not corrected to 12% moisture content. The density value of BCL with core layer made of bamboo strips glued vertically was higher than the original air dry density of bamboo strips raw material, and the density of BCL with core layer made of wood plank was higher than the original air dry density of wood raw material. The average air dry density of *G. pseudoarundinacea* strips used in this study was 0.72 g/cm^3, while the average air dry density of *A. cadamba*, *M. eminii* and *F. moluccana* used in

Table 2 Physical and mechanical properties of BCL.

Properties	Layer compositions				Effect of the layer compositions
	A	B	C	D	
MC (%)	12.6 (0.1)	12.2 (0.5)	13.7 (0.1)	13.4 (0.3)	0.00**
Density (g/cm^3)	0.754 (0.002)	0.491 (0.058)	0.555 (0.023)	0.552 (0.018)	0.008**
TS (%)	2.55 (0.22)	2.90 (0.19)	1.68 (0.10)	2.82 (0.07)	0.00**
WA (%)	19.9 (0.3)	30.5 (0.3)	25.4 (0.5)	24.4 (0.1)	0.00**
Delamination (%)	0	0	0	0	-
MOR (kgf/cm^2)	1,162 (63)	682 (40)	649 (10)	613 (61)	0.02*
MOE (kgf/cm^2)	173,757 (3,454)	83,985 (7,158)	74,936 (5,181)	74,758 (7,180)	0.02*
CS (kgf/cm^2)	644.7 (35.0)	407.0 (9.9)	397.7 (26.4)	364.6 (14.3)	0.01*
Hardness (kgf)	552.7 (65.1)	356.7 (49.6)	357.3 (41.6)	352.3 (10.5)	0.03*

Each value was the average of four specimens. Values in parentheses are standard deviations.
MC: moisture content; TS: thickness swelling; WA: water absorption; MOR: modulus of rupture; MOE: modulus of elasticity; CS: compression strength.
* Significant; ** very significant (results obtained from ANOVA and Kruskal-Wallis ANOVA).

this study was 0.291, 0.365 and 0.332 g/cm^3, respectively. The specific gravity of *G. pseudoarundinacea* [8] is 0.5-0.7 (internodes) and 0.6-0.8 (nodes). The presence of adhesive and the pressure applied during BCL manufacture possibly produced a denser product at BCL type A. Whereas for BCL types B, C and D, besides the use of adhesive and the pressure applied during BCL manufacture, another factor that contributed to the higher value of density is that they contained bamboo laminate, which has been proved that bamboo lamination has higher density than the original air dry density of the bamboo raw material. The Kruskal-Wallis ANOVA test showed that the density of BCL was highly affected by the layer compositions.

Thickness swelling of BCL varied from 1.68% to 2.90% with an average of 2.50%. The data on thickness swelling were subjected to ANOVA, and the result revealed that layer compositions affected thickness swelling of BCL (Table 2). The BCL with core layer made of manii wood plank (type C) had the lowest thickness swelling, while the three other types of BCL (types A, B and D) had no significant differences in thickness swelling. A previous study [9] showed that the average thickness swelling of four-layer laminated bamboo lumber made of moso bamboo (bamboo zephyr mats) glued with resorcinol-based adhesive was 12.13%. Other study showed that the thickness swelling of laboratory made three-layer laminated bamboo lumber and natural bamboo flooring made from moso bamboo strips was 1.0% and 0.7%, respectively [10].

Thickness swelling of BCL made from Andong bamboo strips glued with tannin resorcinol formaldehyde and the layer composition in combination with acacia and pine wood varied from 0.8% to 3.3% [1]. Parallel and crossed-laminated bamboo panel made from *Dendrocalamus yunnanicus* had thickness swellings of 3.5% and 3.6%, respectively [11]. Other previous study showed that the thickness swelling of five-ply veneer-bamboo zephyr composites, which consist of keruing veneer as face and back layers and the core made of three layers of bamboo zephyr was 5.9% [12]. Whereas thickness swelling of laminated bamboo board made from bamboo strips of *Gigantochloa apus* and *Gigantochloa robusta* glued with tannin resorcinol formaldehyde varied from 2.5% to 4.1% [13]. Seven layer parallel strand lumber from Calcuta bamboo (*D. strictus*) glued with phenol formaldehyde had 2.85% thickness swelling after 24 h immersion in water [14]. From this information, it can be concluded that BCL made from bamboo strips had better dimensional stability than BCL made from bamboo zephyr mats.

The water absorption of BCL varied from 19.9% to 30.5% with an average of 25.1%. Kruskal-Wallis ANOVA showed that the water absorption of BCL was affected by the layer compositions (Table 2). The water absorption of BCL decreased with increasing the density of BCL. The probable reason was that the higher density BCL has smaller voids, as a result, water entry into the lumber occurred at a slower rate, and lesser amount of water is admitted into the lumber. Previous study by Ahmad and Kamke [14] showed that the water absorption after 24 h immersion in water of seven-ply parallel strand lumber from Calcuta bamboo (*D. strictus*) glued with liquid phenol formaldehyde was 14.29%.

The delamination test was carried out to determine the bonding quality of BCL glued with WBPI adhesive. The result of the delamination test showed that there was no delamination in all samples; therefore, the bonding quality of the BCL was considered acceptable.

The MOR of BCL varied from 613 kgf/cm^2 to 1,162 kgf/cm^2 (Table 2). The data on MOR of BCL were subjected to Kruskal-Wallis ANOVA test, and the results showed that the MOR of BCL was highly affected by the layer compositions. This finding is in agreement with the previous study conducted by Sulastiningsih et al. [1]. Compared to Indonesian wood strength classification [15], based on MOR value, the BCL produced from all bamboo strips had strength value comparable to wood strength class I (> 1,100 kgf/cm^2). MOR of five-layer BCLs with core layer made of wood plank varied from 613 kgf/cm^2 to 682 kgf/cm^2 and was comparable to wood strength class III (500-725 kgf/cm^2). The results of post hoc test (Table 3) showed that there is no significant difference in MOR among the three types of BCL with core layer made of wood plank (Types B, C and D). The use of wood plank as the core layer of BCL reduced the MOR value of BCL up to 44.25%. A previous study [9] reported that MOR of four-layer laminated bamboo lumber made of moso bamboo (bamboo zephyr mats) glued with resorcinol-based adhesive varied from 639 kgf/cm^2 to 707 kgf/cm^2.

Other study by Guo [11] reported that MOR of parallel and crossed laminated panels made of *D. yunnanicus* was 210 MPa and 195 MPa, respectively, while the panels made of *Heterocycla pubescens* were 175 MPa and 136 MPa, respectively. Those strength values are comparable to Indonesian wood strength class I (> 1,100 kgf/cm^2). The MOR of Colombian glued laminated bamboo (*Guadua angustifolia* Kunth), which used polyvinyl acetate (PVA) as adhesive [16], was 81.9 MPa or 835 kgf/cm^2 (comparable to Indonesian wood strength class II). MORs of a three-layer BCL made from bamboo strips of *G. apus* and *G. robusta* glued with tannin

Table 3 Post hoc test results on physical and mechanical properties of BCL.

No.	Properties	Comparison of mean values			
		A	B	C	D
1	MC (%)	12.6^b	12.2^b	13.7^a	13.4^a
2	Density (g/cm^3)	0.754^a	0.491^b	0.555^b	0.552^b
3	TS (%)	2.55^b	2.90^a	1.68^c	2.82^{ab}
4	WA (%)	19.9^d	30.5^a	25.4^b	24.4^c
5	MOR (kgf/cm^2)	1,162^a	682^b	649^b	613^b
6	MOE (kgf/cm^2)	173,757^a	83,985^b	74,936^b	74,758^b
7	CS (kgf/cm^2)	644.7^a	407^b	397.7^b	364.6^b
8	Hardness (kgf)	552.7^a	356.7^b	357.3^b	352.3^b

MC: moisture content; TS: thickness swelling; WA: water absorption; MOR: modulus of rupture; MOE: modulus of elasticity; CS: compression strength.
Values followed by the same letter within the same row are not significantly different.

resorcinol formaldehyde [13] were 969.39 kgf/cm^2 and 895.34 kgf/cm^2, respectively, whereas the MOR of a three-layer BCL made of bamboo strips of *G. pseudoarundinacea* glued with urea formaldehyde was 1,236 kgf/cm^2 [17]. Based on this information, it can be summarized that in general the BCL made of bamboo strips had higher MOR than BCL made of bamboo zephyr mats and BCL made of bamboo strips in combination with bamboo zephyr and wood plank.

MOE of BCL varied from 74,758 kgf/cm^2 to 173,757 kgf/cm^2 with an average of 101,859 kgf/cm^2. The result of ANOVA in Table 2 showed that the layer compositions affected the MOE value of BCL. As presented in Tables 2 and 3, the BCL type A, which composed of 100% bamboo strips had the highest MOE value. The use of wood plank as the core layer reduced the MOE value of BCL up to 55.17%, while the three other types of BCL (Types B, C and D) had no significant differences in MOE. The MOE of three-layer BCL made of *G. pseudoarundinacea* strips glued with tannin resorcinol formaldehyde [1] was 133,615 kgf/cm^2. The MOE of BCL made of horizontal laminate of bamboo strips was 17,300 MPa or 176,411 kgf/cm^2, whereas the MOE of BCL made of vertical laminate of bamboo strips was 16,570 MPa or 168,968 kgf/cm^2 [18]. Study by Sulastiningsih and Nurwati [13] showed that MOE of three-layer laminated bamboo board made of bamboo strips of *G. apus* and *G. robusta* glued with tannin resorcinol formaldehyde was 102,290 kgf/cm^2 and 100,030 kgf/cm^2, respectively. Other previous study [14] showed that the MOE of seven-ply parallel strand lumber from Calcuta bamboo (*D. strictus*) glued with liquid phenol formaldehyde was 71.9 MPa or 733 kgf/cm^2.

The compression strength parallel to the grain of BCL varied from 364.6 kgf/cm^2 to 644.7 kgf/cm^2 with an average of 453.5 kgf/cm^2. Kruskal-Wallis ANOVA (Table 2) showed that the compression strength parallel to the grain of BCL was significantly affected by the layer compositions. The result of HSD (Table 3) showed that there is no significant difference in compression strength parallel to the grain among three types of BCL with core layer made of wood plank (Types B, C and D). The use of wood plank as the core layer of BCL reduced the compression strength parallel to the grain of BCL up to 39.54%. Compared to Indonesian wood strength classification [15], based on compression strength parallel to the grain value, the BCL type A made of 100% bamboo strips had comparable strength to wood strength class II (425-650 kgf/cm^2), while BCL with core layer made of wood planks of jabon, manii or sengon had comparable strength to wood strength class III (300-425 kgf/cm^2).

Study by Sulastiningsih and Nurwati [13] reported that the compression strength of laminated bamboo board made of *G. apus* and *G. robusta* bamboo strips glued with tannin resorcinol formaldehyde varied from 503 kgf/cm^2 to 571 kgf/cm^2 (comparable to Indonesian wood strength class II). Other previous study conducted by Sulastiningsih and Santoso [17] showed that the compression strength of BCL made of *G. pseudoarundinacea* bamboo strips glued with urea formaldehyde varied from 522 kgf/cm^2 to 580 kgf/cm^2 with an average of 562 kgf/cm^2 (comparable to wood strength class II). The compression strength of Colombian glued laminated bamboo (*G. angustifolia* Kunth), which used PVA as adhesive [16] was 47.6 MPa or 485 kgf/cm^2 (comparable to Indonesian wood strength class II). Other researchers [18] reported that the compression strength of BCL made of horizontal laminate of bamboo strips was 87.9 MPa or 896 kgf/cm^2 (comparable to Indonesian wood strength class I), whereas the compression strength of BCL made of vertical laminate of bamboo strips was 84.7 MPa or 864 kgf/cm^2 (comparable to Indonesian wood strength class I).

The hardness of BCL varied from 352.3 kgf to 552.7 kgf with an average of 405 kgf. The data on hardness of BCL were subjected to Kruskal-Wallis ANOVA test, and the results showed that the hardness of BCL was highly affected by the layer compositions (Table 2). The use of wood plank as the core layer of BCL reduced the hardness of BCL made of 100% bamboo strips up to 35.7%. Hardness is one of important properties used to assess the suitability for flooring material [19]. The wood species commonly used for fancy flooring is teak (*Tectona grandis* L.f.). The hardness of *T. grandis* [20] is 428 kgf. The hardness of BCL type A, which made of 100% bamboo strips was 552.7 kgf and higher than that of teak. Based on that information, it can be considered that the BCL type A is suitable for flooring material. Other wood species that can be used as flooring material [20] is nyatoh (*Palaquium* spp.), and the side hardness of *P. burckii* was 302 kgf. The average hardness of BCL types B, C and D was 355.4 kgf and therefore these BCLs are suitable for flooring material.

4. Conclusions

From this study, it can be concluded that the physical and mechanical properties of BCL were affected by the layer compositions. Based on the Indonesian wood strength classification, BCL made from 100% Andong bamboo strips and glued with WBPI adhesive had strength values comparable to wood strength class I, while bamboo composite lumber with core layer made of wood plank of jabon, manii or sengon had strength values comparable to wood strength class III. All BCLs produced are suitable for solid wood substitute.

References

[1] Sulastiningsih, I. M., Nurwati, and Santoso, A. 2005. “Effect of Wood Layer on the Laminated Bamboo Board Properties.” *Journal of Forest Products Research* 23 (1): 15-22. (in Indonesian)

[2] Saranpää, P., Roberts, J. A., and Usherwood, P. N. R. 2003. “Wood Density and Growth.” In *Wood Quality and Its Biological Basis*, edited by Barnett, J. R., and Jeromidis, G. Garsington, UK and Carlton, Australia: Blacwell Publishing Ltd., 226.

[3] Sulastiningsih, I. M., Santoso, A., and Krisdianto. 2016. “Characteristic of Vertically Glued Laminated Bamboo Beam Made of Andong (*Gigantochloa pseudoarundinacea* (Steud.) Widjaja) Bamboo Strips.” *Journal of Forest Products Research* 34 (3): 167-77. (in Indonesian)

[4] Supriadi, A., Sulastiningsih, I. M., and Subyakto. 2017. “Characteristics of Bamboo Lamination on Jabon Board.” *Journal of Forest Products Research* 35 (4): 263-72. (in Indonesian)

[5] American Society for Testing and Materials (ASTM). 1995. *Standard Test Methods for Evaluating Properties of Wood-Based Fiber and Particle Panel Materials.* Annual Book of ASTM Standard, ASTM D1037-93, Philadelphia.

[6] American Society for Testing and Materials (ASTM). 1995. *Standard Methods of Testing Small Clear Specimen of Timber.* Annual Book of ASTM Standard, ASTM D143-94, Philadelphia.

[7] Japan Plywood Inspection Corporation (JPIC). 2003. *Japanese Agricultural Standard for Glued Laminated Timber.* JAS, MAFF, Notification No. 234. Tokyo, Japan: Japan Plywood Inspection Corporation.

[8] Dransfield, S., and Widjaja, E. A. 1995. *Plant Resources of South-East Asia No 7: Bamboos.* Leiden: Backhuys Publishers.

[9] Nugroho, N., and Ando, N. 2001. “Development of Structural Composite Products Made from Bamboo II: Fundamental Properties of Laminated Bamboo Board.” *Journal of Wood Science* 47 (3): 237-42.

[10] Lee, A. W. C., and Liu, Y. 2003. “Selected Physical Properties of Commercial Bamboo Flooring.” *Forest Products Journal* 53 (6): 23-6.

[11] Guo, Z. W. W. 2007. “Laminated Panel Manufacture of Two Kinds of Bamboo for Architecture Material and Property Comparison.” Accessed June 28, 2007. http://www.inbar.int/publication/pubdownload.asp.

[12] Roh, J. K., and Ra, J. B. 2009. “Effect of Moisture Content and Density on the Mechanical Properties of Veneer-Bamboo Zephyr Composites.” *Forest Products Journal* 59 (3): 75-8.

[13] Sulastiningsih, I. M., and Nurwati. 2009. “Physical and Mechanical Properties of Laminated Bamboo Board.” *Journal of Tropical Forest Science* 21 (3): 246-51.

[14] Ahmad, M., and Kamke, F. A. 2011. “Properties of Parallel Strand Lumber from Calcutta Bamboo (*Dendrocalamus strictus*).” *Wood Sci. Technol.* 45 (1): 63-72.

[15] Oey, D. S. 1990. *Specific Gravity of Indonesian Woods and Its Significance for Practical Use.* Communication No. 13. Bogor, Indonesia: Forest Products Research and Development Centre. (in Indonesian)

[16] Correal, J., and Lopez, L. 2008. “Mechanical Properties of Colombian Glued Laminated Bamboo.” In *Modern Bamboo Structures*, edited by Xiao, Y., Paudel, S. K., and Inoue, M. London: Taylor & Francis, 121-7.

[17] Sulastiningsih, I. M., and Santoso, A. 2012. “Effects of Bamboo Species, Pressing Time and Pre-treatment of Bamboo Strips on the Properties of Laminated Bamboo Board.” *Journal of Forest Products Research* 30 (3): 198-206. (in Indonesian)

[18] Rittironk, S., and Elnieiri, M. 2008. “Investigating Laminated Bamboo Lumber as an Alternate to Wood Lumber in Residential Construction in the United States.” In *Proceedings of First International Conference on Modern Bamboo Structures (ICBS-2007).* Abingdon, UK: Taylor & Francis, 83-96.

[19] Damayanti, R. 2016. “Wood Quality of Young Fast Grown Plantation Teak and the Relationships among Ultrastructural and Structural Characteristics with Selected Wood Properties.” Ph.D. thesis, The University of Melbourne.

[20] Martawijaya, A., Kartasujana, I., Kadir, K., and Prawira, S. A. 2005. *Indonesian Wood Atlas, Vol. I.* 3rd ed.. Bogor, Indonesia: Forestry Research and Development Agency. (in Indonesian)

Appendix 1 Normality test of the properties of BCLs.

Properties	W-Statistic (Normality test, Shapiro-Wilk)	*p* value	Results of normality test
Moisture content (%)	0.948	0.46	Passed
Density (g/cm^3)	0.831	0.01	Failed
Hardness (kgf)	0.829	0.01	Failed
MOR (kgf/cm^2)	0.735	0.00	Failed
MOE (kgf/cm^2)	0.682	0.00	Failed
Thickness swelling (%)	0.842	0.01	Failed
Water absorption (%)	0.885	0.05	Failed

A test that passes indicates that the data match the pattern expected, if the data were drawn from a population with a normal distribution.