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Some important properties of strandboard manufactured from andong bamboo (*Gigantochloa pseudoarundinacea*)

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Abstract. Andong bamboo (*Gigantochloa pseudoarundinacea*) is one of the most important bamboo species widely planted in West Java, Indonesia, and play a prominent role in the rural economy. The bottom and the middle parts of Andong bamboo culms are suitable for laminated bamboo lumber raw material. To improve the efficiency of bamboo utilization, the upper part of Andong bamboo culms were use as raw material for strandboard production. The objective of the study was to determine the effect of strand length and specific pressure on the properties of bamboo strandboard. Laboratory scale of bamboo strandboards were fabricated using three different strand lengths (75, 100, and 150 mm), two different specific pressures applied (25 kg/cm^2 and 30 kg/cm^2) and glued with phenol formaldehyde with the targeted density of 0.75 g/cm^3. Some physical and mechanical properties of bamboo strandboards were determined. Results showed that the average physical properties of bamboo srandboards were 9.3% (moisture content), 0.76 g/cm^3 (density), 3.1% (thickness swelling), 1.6% (wide expansion), and 25.1% (water absorpsion). The average mechanical properties of bamboo srandboards were 760.5 kgf/cm^2 (MOR), 92.3 $10^3 kgf/cm^2$ (MOE), 5.6 kgf/cm^2 (IB), and 56.5 kgf (screw holding power). Some physical and mechanical properties of bamboo strandboard were significantly affected by strand length and specific pressure.

1. Introduction

Indonesia as one of the highest diversity in the world, consist of 160 bamboo species which consists of introduced species (38 species), origin species (122 species). Only 76 species (about 50% of the total species) are used by local people for their daily life, but only 9-10 species are commonly or commercially used in Java and Bali. From the west, bamboo has bigger diameter than in the east, however, bamboo in the highland has smaller diameter than bamboo in the lowland. In the western of Indonesia the genus *Dendrocalamus*, *Gigantochloa* and *Bambusa* grow abundantly compare to the eastern part [1]. Bamboo in Indonesia is one of the most important non timber forest products and has long been recognized as a multi-purpose plant. Bamboo has the potential to be an alternative to furniture and housing materials due to its ability to grow fast in various soils with desirable properties.

In two decades research on bamboo utilization as raw material for laminated bamboo lumber especially those made of bamboo strips have been carried out by many researchers [2] [3] [4] [5] [6] [7] [8] [9] [10]. Bamboo strips as composite product element are produced by splitting bamboo culms which have big in diameter and relatively thick wall. The bamboo culms used to produce bamboo strips as raw material for laminated bamboo lumber are commonly taken from the bottom and middle parts while the top parts are left unused, and therefore resulted in a lot of bamboo waste. To optimize bamboo utilization, the top part of bamboo culm (bamboo waste) was used as raw material for manufacture composite product other than laminated bamboo lumber such as strandboard since the element has smaller in dimension. This paper describes the results of an experiment to determine the effect of strand length and specific pressure on the properties of bamboo strandboard glued with phenol formaldehyde adhesive.

2. Materials and Methods

2.1. Materials
The Andong bamboo *(Gigantochloa pseudoarundinacea)* culms used in the experiment were only the top parts. Twenty bamboo culms with approximately 2 m in length were cross cut into 30 – 40 cm bolts. The total bamboo bolts collected were 80. The average diameter *of G. pseudoarundinacea* was 7.25 cm while average wall thickness was 0.57 cm. Liquid phenol formaldehyde was the adhesive used in the production of the strandboards.

2.2. Preparation of bamboo strands
Each bamboo bolt (30 - 40 cm in length) was manually splited green into the bamboo strips. The width of bamboo strips was approximately 2 cm. Strands were manually produced using a sharp knife with the targeted length (75 mm, 100 mm, and 150 mm), width of 2 cm and thickness of 0.5 – 0.8 mm. Only the inner part of bamboo strips were converted into bamboo strands. The bamboo strands produced were then dried in an oven until about 4% moisture content.

2.3. Strandboard fabrication
Type of strandboard produced was a homogeneous uni-directionally orientation bamboo strandboard, where three different strand lengths were separately used as its composing matters. The strandboard dimensions prepared in this study was 30 cm by 30 cm by 1.2 cm. The amount of liquid phenol formaldehyde (PF) adhesive used was 7% (resin solid) based on the dry weight of strands. Based on the PF weight, 1% of para formaldehyde was used as hardener and 0.5% of wax emulsion based on the dry weight of strands was added to PF. The mixture of PF glue, para formaldehyde and wax emulsion was intensely agitated until becoming homogeneous. A specified quantity of strands was sprayed with certain amount of glue mixture in a blender. The mixture was then hand-formed into a loos mat in a wooden deckle box (30 x 30 cm internal dimensions). The wooden deckle box was removed and iron sticks (12 mm thick) were placed on the sides of the mat. The mat then loaded in a hot press set at temperature of 150ºC and specific pressure of (25 kg/cm^2 or 30 kg/cm^2) for six minutes. Targeted density of strandboard produced was 0.75 g/cm^3. Three replications for each type of board were manufactured. The strandboards produced were conditioned for about 2 weeks before testing.

2.4. Testing
Each board was cut to yield the specimens required to determine the board properties. The tests were performed using Japanese Industrial Standard (JIS A 5908) [11] for evaluating the properties of bamboo strandboards.

2.5. Data analysis
A completely randomized design with factorial experiment was used in which the strand length and the specific pressure applied as the treatment factors. Three replications were prepared for each treatment combination.

3. Results and Discussion

3.1. Physical properties of bamboo strandboard

The mean values of physical properties of strandboards are presented in Table 1. The data on physical properties of bamboo strandboard were subjected to analysis of variance (ANOVA) and the results are presented in Table 2.

The moisture content of bamboo strandboard varied from 9.0% to 9.7% with an average of 9.35%. These values are still within the range of air-dried moisture content and meet the Japanese Standard requirement for particleboard since the values are below 13%. The density of bamboo strandboard produced varied from 0.744 g/cm^3 to 0.772 g/cm^3 with an average of 0.760 g/cm^3. According to Dransfield and Widjaja [12] the specific gravity of *Gigantochloa pseudoarundinacea* is 0.5-0.7 (internote) and 0.6-0.8 (nodes). The bamboo strands used in the experiment were only the inner part (without the outer layers) of bamboo culms. The average density of andong bamboo strands used in this experiment was 0.56 g/cm^3. Therefore the compression ratio of bamboo strandboard varied from 1.33 to 1.38 with an average of 1.36.

Table 1. Physical properties of bamboo strandboard.

Properties	Specific pressure, kg/cm^2	Strand length		
		75 mm	100 mm	150 mm
Moisture content, %	25	9.7 (0.25)	9.0 (0.08)	9.5 (0.13)
	30	9.0 (0.12)	9.2 (0.07)	9.7 (0.06)
Density, g/cm^3	25	0.769 (0.02)	0.766 (0.03)	0.754 (0.01)
	30	0.744 (0.01)	0.772 (0.01)	0.755 (0.01)
Thickness swelling, %	25	3.26 (0.20)	2.57 (0.21)	2.75 (0.36)
	30	4.51 (0.35)	3.08 (0.21)	2.69 (0.40)
Wide expansion, %	25	1.49 (0.02)	1.59 (0.03)	1.39 (0.08)
	30	1.65 (0.13)	1.56 (0.08)	1.70 (0.02)
Water absorption, %	25	25.61 (0.37)	25.33 (1.08)	22.88 (1.64)
	30	24.52 (0.44)	29.55 (0.49)	22.75 (1.72)

Each value was the average of three speciments.
Values in parentheses are standard deviations.

According to Maloney [13] to achieve high properties in medium density particleboard, the minimum compression ratio should be 1.3. Compression ratio is defined as the ratio of the density of the board to the density of the raw material [13]. The higher compression ratio resulted in sufficient interparticle contact area which is developed during the pressing operation to achieve good bonding. The results of ANOVA in Table 2 showed that the density of strandboard was not affected by both strand length and specific pressure.

Table 2. Summarized ANOVA of physical properties of bamboo strandboard.

Properties	F calculated		
	Strand length (A)	Specific pressure (B)	Interaction (AB)
Density	1.67 ^{ns}	0.72^{ns}	1.85 ^{ns}
Thickness swelling	27.46**	15.88**	7.08**
Wide expansion	0.26 ^{ns}	18.86**	8.15**
Water absorption	26.02**	3.64^{ns}	9.75**

^{ns} not significant
** highly significant

Thickness swelling is one indicator of dimensional stability and perform as an important property of bamboo strandboard. The thickness swelling of bamboo strandboard varied from 2.57% to 4.51% with an average of 3.14%. If the data on thickness swelling in Table 1 are compared with the Japanese Industrial Standard for Particleboard (JIS A 5908) [11] it can be seen that all bamboo strandboards produced meet the standard requirement since the values are less than 12% . The results of ANOVA in Table 2 showed that thickness swelling of strandboard was significantly affected by strand length and specific pressure. It was observed that the values of thickness swelling decreased with increasing strand length but increased with increasing specific pressure.

Hiziroglu [14] studied the properties of strandboard panels manufactured from Eastern Redcedar. The strandboard panels were produced using 8% liquid phenol formaldehyde adhesive based on oven-dry weight of strands. The results showed that thickness swelling of strandboard were 15.24 % for strandboard with the density of 0.65 g/cm^3 and 18.42% for strandboard with the density of 0.78 g/cm^3. Febrianto *et al.* [15] reported that thickness swelling of oriented strandboard prepared from steam-treated bamboo strand glued with methylene diphenyl diisocyanate (MDI, Type H3M) varied from 8.65% to 14.14%. Based on that information it can be concluded that the bamboo strandboards produced in this study are more stable than that of other composite products.

Dimensional stability of bamboo strandboard can also be measured from its wide expansion property. The values varied from 1.39% to 1.70% with an average of 1.56%. Analysis of variance was also carried out on wide expansion data. Table 2 shows that wide expansion of bamboo strandboard is only affected by strand length. Nevertheless the strong interaction between strand length and specific pressure can be found in Table 2, therefore it was seen that one can not generalize about the strand length or specific pressure effect to wide expansion property without taking into account its interaction.

Water absorption of bamboo strandboards varied from 22.9% to 29.6% with an average of 25.1%. The results of ANOVA in Table 2 showed that water absorption values was significantly affected by the strand length. It was observed that water absorption of bamboo strandboards decreased as the strand length increased. The water absorption of strandboard made from moso bamboo (*Phyllostachys pubescens*) glued with liquid diphenylmethane diisocyanate (MDI) with 6% resin content were 23.61% for board density of 0.73 g/cm^3 and 39.34% for board density of 0.65 g/cm^3 [16]. Other researchers [17] reported that water absorption of oriented strandboard made from mixture of wood strands comprising 60% *Calophyllum inophyllum* and 40% *Paulownia coreana* glued with 4.5% phenol formaldehyde was 47.2%.

3.2 Mechanical properties of bamboo strandboard

The mean values of mechanical properties of bamboo strandboards are presented in Table 3. The data on mechanical properties of bamboo strandboard were subjected to analysis of variance (ANOVA) and the results are presented in Table 4.

The MOR of bamboo strandboards (Table 3) varied from 564.9 kgf/cm^2 (55.4 MPa) to 962.3 kgf/cm^2 (94.4 MPa) with an average of 760.5 kgf/cm^2 (74.6 MPa). These values meet the Japanese Industrial Standard (JIS A 5908) [11] requirement for particleboard. The results of ANOVA in Table 4 showed that the MOR of bamboo strandboard was significantly affected by strand length. This finding was in agreement with the previous finding [18] [19] [20]. With the MOR data in Table 3 it was observed that the bamboo strandboards made of 100 mm strand-length produced the highest MOR whereas those made of 75 mm strand-length produced the lowest MOR and the strandboard made of 150 mm strand-length had MOR value higher than that of 75 mm strand-length but lower than that of 100 mm strand-length. This indicates that the distribution of strands at a 100 mm strand-length was more uniform and resulted in more sufficient interparticle contact area. Study conducted by Laemlaksakul [21] showed that the MOR value of particleboard from bamboo waste of *Dendrocalamus asper* Backer (bamboo chips) depends on density of particleboard.

Table 3. Mechanical properties of bamboo strandboard.

Properties	Specific pressure, kg/cm^2	Strand length 75 mm	Strand length 100 mm	Strand length 150 mm
MOR, kgf/cm^2	25	564.9 (76)	955.2 (108)	731.3 (117)
	30	601.2 (55)	962.3 (49)	748.1 (59)
MOE, 1000 kgf/cm^2	25	99.0 (10.2)	100.7 (9.9)	67.5 (5.3)
	30	80.8 (4.3)	99.3 (6.6)	106.2 (9.4)
Internal bond, kgf/cm^2	25	5.13 (0.47)	4.62 (0.34)	5.58 (0.64)
	30	6.35 (0.75)	4.88 (0.31)	7.22 (0.70)
Screw holding power, kgf	25	53.9 (5.4)	64.8 (6.1)	51.8 (5.0)
	30	53.6 (6.6)	56.6 (3.7)	58.2 (3.1)

Each value was the average of three speciments.
Values in parentheses are standard deviations.

Table 4. Summarized ANOVA of mechanical properties of bamboo strandboard.

Properties	F calculated		
	Strand length (A)	Specific pressure (B)	Interaction (AB)
MOR	31.91**	0.27 ns	0.05 ns
MOE	4.48 *	2.83 ns	20.07**
Internal bond	13.13**	15.37**	2.36 ns
Screw holding power	3.14 ns	0.08 ns	3.05 ns

ns not significant
* significant
** highly significant

MOE values of bamboo strandboards varied from 67.5 10^3 kgf/cm^2 or 6,626 MPa to 106.2 10^3 kgf/cm^2 or 10,418 MPa with an average of 92.3 10^3 kgf/cm^2 or 9,055 MPa. The bamboo strandboards produced in this study had MOE values meet the Japanese Industrial Standard requirement for type 24-10 particleboard. ANOVA in Table 4 showed that the MOE of bamboo strandboard was not only affected by the strand length but also affected by the interaction between strand length and specific pressure. Therefore one can not generalize about the strand length effect without taking into account its interaction. Previous study [19] showed that uni-directionally orientation bamboo strandboard of moso bamboo with 80 mm strand-length glued with 6% resin content of MDI had MOE value of 10.5 GPa, whereas those oriented strandboards had MOE value of 9.6 GPa. Other investigators [17] reported that MOE of oriented strandboard made from mixture of wood strands comprising 60% *Calophyllum inophyllum* and 40% *Paulownia coreana* glued with 4.5% phenol formaldehyde was 3.9 GPa. Febrianto *et al.* [15] reported that oriented strand board prepared from steam-treated bamboo strands bonded with commercial MDI adhesive had MOE value ranged from 4,828 to 10,215 MPa. Other study conducted by Laemlaksakul [21] reported that MOE of bamboo particleboard made from bamboo waste of *Dendrocalamus asper* backer (bamboo chips) glued with 13% UF was affected by density of particleboard. This finding was in agreement with the previous finding [14].

The bonding quality of any composite products is very important. To determine the bonding quality of bamboo strandboard, the internal bond strength test was carried out. The internal bond strength (IB) of bamboo strandboards varied from 4.62 kgf/cm^2 or 0.45 MPa to 7.22 kgf/cm^2 or 0.71 MPa with an average of 5.63 kg/cm^2 or 0.55 MPa. The data on IB were subjected to analysis of variance. The result showed that the IB of bamboo strandboard was strongly affected by strand length and specific pressure (Table 4). The lowest value of IB was obtained from bamboo strandboard produced from 100 mm strand-length and 25 kg/cm^2 specific pressure while the highest IB was obtained from bamboo strandboard produced from 150 mm strand-length and 30 kg/cm^2 specific pressure. The possible reason being that the bamboo strandboard with longer strand has more uniform distribution through the thickness of the boards hence resulting in higher IB. The bamboo strandboards produced in this study had IB values meet the Japanese Industrial Standard requirement for type 24-10 particleboard since the values are not less than 0.3 MPa. The IB of bamboo strandboard (UNID) made of 80 mm strand-length of moso bamboo and glued with 6% MDI was 0.48 MPa [19]. Other researcher [21] reported the IB of particleboard from bamboo waste of *Dendrocalamus asper* Backer (bamboo chips) bonded with 13% UF resin were 0.19MPa, 0.20 MPa, and 0.17 MPa for particleboard with the density of 600 kg/m^3, 700 kg/m^3, and 800 kg/m^3, respectively.

The screw holding power (SHP) of bamboo strandboards varied from 51.8 kgf or 508 N to 64.8 kgf or 635 N with an average of 56.5 kgf or 554 N. The bamboo strandboards produced in this study had SHP values meet the Japanese Industrial Standard requirement for type 24-10 particleboard since the values are not less than 500 N. The results of ANVA (Table 4) showed that the SHP of bamboo strandboards were not affected by both strand length and specific pressure. Nevertheless, it was observed in Table 3 that the SHP increased with increase in strand length. The possible reason being that the bamboo strandboard with longer strand has more uniform distribution through the thickness of the boards hence resulting in higher SHP.

4. Conclusion

The study concluded that Andong bamboo (*Gigantochloa pseudoarundinacea*) strands could be used as raw material for strandboard production. Strand length and specific pressure showed significant effect on some physical and mechanical properties of bamboo strandboard. The results of the current study indicated that the produced strandboards made from Andong bamboo strands glued with 7% phenol formaldehyde adhesive at various treatment combinations meet the Japanese Industrial Standard requirement for type 24-10 particleboard.

References

[1] Widjaja E A 2012 *The utilization of bamboo: At present and for the future*. in Gintings et al. (Editors). In *Proceedings of International Seminar Strategies and Challenges on Bamboo and Potential Non Timber Forest Products (NTFP) Management and Utilization* pp 79–85.

[2] Lee A W C and Liu Y 2003 Selected Physical Properties of Commercial Bamboo Flooring. *Forest Products Journal* **53**(6) pp 23–26.

[3] Sulastiningsih I M, Nurwati and Santoso A 2005 Pengaruh Lapisan Kayu terhadap Sifat Bambu Lamina. *Jurnal Penelitian Hasil Hutan* **23**(1) pp 15–22.

[4] Rittironk S and Elnieiri M 2008 *Investigating Laminated Bamboo Lumber as an Alternate to Wood Lumber in Residential Construction in the United States* (Changsa, China: Proceedings of First International Conference on Modern Bamboo Structures (ICBS-2007)) October, 28–30 pp 83–96

[5] Correal J and Lopez L 2008 *Mechanical Properties of Colombian Glued Laminated Bamboo in Xiao et al (Editors). Modern Bamboo Structures.* (Changsa, China: Proceedings of First International Conference on Modern Bamboo Structures (ICBS-2007)) October, 28–30 pp 121–127

[6] Sulastiningsih I M and Nurwati 2009 Physical and Mechanical Properties of Laminated Bamboo Board *J. Trop. For. Sci.* **21**(3) pp 246-251

[7] Correal J and Ramirez F 2010 Adhesive Bond Performance in Glue Line Shear and Bending for Glued Laminated Guadua Bamboo. *J. Trop. For. Sci.* **22**(4) 433–439

[8] Mahdavi M, Clouston P L and Arwade S R 2011 Development of Laminated Bamboo Lumber: Review of Processing, Performance, and Economical Considerations. *Journal of Materials in Civil Engineering* **23**(7) pp 1036–42
[9] Sulastiningsih I M and Santoso A 2012 Pengaruh Jenis Bambu, Waktu Kempa dan Perlakuan Pendahuluan Bilah Bambu terhadap Sifat Papan Bambu Lamina. *Jurnal Penelitian Hasil Hutan* **30**(3) pp 198–206
[10] Sulastiningsih I M, Santoso A and Krisdianto 2016 Karakteristik balok bambu lamina susun tegak dari bambu Andong (*Gigantochloa pseudoarundinacea* (Steud.) Widjaja). *Jurnal Penelitian Hasil Hutan* **34**(3) pp 167–177
[11] Japanese Industrial Standard 2016 *Particleboards* (JIS A 5908:2015). (Tokyo: Japanese Standards Association)
[12] Dransfield S and Widjaya E A 1995 *Plant Resources of South East Asia No 7 Bamboos*. (Leiden: Backhuys Publishers)
[13] Maloney T M 1993 *Modern Particleboard and Dry Process Fibreboard Manufacturing*. (San Fransisco: Miller Freeman Publications, Inc)
[14] Hiziroglu S 2009 Properties of Strandboard Panels Manufactured from Eastern Redcedar. *Materials* **2** 926-933
[15] Febrianto F, Jang J-H, Lee S-H, Santoso I A, Hidayat W, Kwon J-H., and Kim N-H 2015 Effect of Bamboo Species and Resin Content on Properties of Oriented Strand Board Prepared from Steam-treated Bamboo Strands. *BioResources* **10**(2) pp 2642–55.
[16] Sumardi I and Suzuki S 2014 Dimensional stability and mechanical properties of strand-board made from bamboo. *BioResources* **9**(1) pp 1159–67
[17] Oh Y S and Kim J M 2015 Properties of oriented strandboard bonded with phenol-urea-formaldehyde resin. *J Trop For Sci* **27**(2) pp 22–26
[18] Febrianto F, Sahroni, Hidayat W, Bakar E S, Kwon G-J, Kwon J-H, Hong S-I and Kim N-H 2012 Properties of oriented strand board made from Betung bamboo (*Dendrocalamus asper* (Schultes.f) Backer ex heyne). *Wood Sci Technol* **46** pp 53–62
[19] Sumardi I, Suzuki S and Rahmawati N 2015 Effect of board type on some properties of bamboo strandboard. *J Math Fund Sci* **47**(1) pp 51–59
[20] Sulastiningsih I M, Indrawan D A, Balfas J, Santoso A and Iskandar M I 2017 Sifat fisis dan mekanis papan untai berarah dari bamboo tali (Gigantochloa apus (J.A. & J.H. Schultes) Kurz). *Jurnal Penelitian Hasil Hutan* **35**(3) pp 197–209
[21] Laemlaksakul V 2010 Physical and mechanical properties of particleboard from bamboo waste. World Academy of Science, Engineering and Technology *International Journal of Chemical, Moleculer, Nuclear, Materials and Metallurgical Engineering* **4** pp 4