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Properties of oriented strand board made from Betung bamboo (*Dendrocalamus asper* (Schultes.f) Backer ex Heyne)

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Abstract Bamboo has gained increasing attention as an alternative raw material for use in the manufacture of composite boards. Three-layer OSBs were made using Betung bamboo (*Dendrocalamus asper* (Schultes.f) Backer ex Heyne) strands to evaluate the effects of strand length and pre-treatment techniques on the physical, mechanical, and durability properties. Three different strand lengths, namely 50, 60, and 70 mm, were prepared. Prior to the manufacture into OSB, the strands were immersed in cold water for 24 h and in 6% acetic anhydrides solution for 48 h. The OSBs were fabricated using 5% MDI resin based on the strand dry weight. The results indicated that MOR and MOE values in perpendicular to the grain direction were much influenced by strand length. The dimensional stability of OSB was slightly improved by immersing the strands in acetic anhydride solution. Immersing strands in cold water and acetic anhydride solution improved the resistance of OSB against subterranean termite (Macrotermes gylvus) attack under the adopted experimental condition. All OSB parameters manufactured in this experiment were better than the minimum requirement of CSA 0437.0 (Grade O–2) standard.

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Introduction

Bamboo is abundantly available in many countries, and it is a very promising alternative as a substitution material for wood due to its very fast growth rate, short rotation age, high tensile strength, and traditional usage as building material by human kind.

Researches regarding the utilization of bamboo as raw material for composite products have been carried out by many researchers. Researches on particleboard, fiberboard, and MDF made from bamboo have been carried out (Sakuno and Han 2003; Xu et al. 2001; Matsumoto et al. 2001; Kawai et al. 2001; Zang 2001; Zang et al. 1997). Chen (1985) reported that bamboo can be manufactured to bamboo plywood as a structural material. Nugroho and Ando (2000) have developed a bamboo zephyr board. Several studies on OSB made from bamboo were done by Lee et al. (1996) and Sumardi et al. (2006). It was concluded that the mat-formed panel products could be effectively manufactured in an industrial scale using bamboo.

Betung bamboo most commonly grows in tropical regions such as Indonesia, Malaysia, Thailand, Vietnam, and so forth. Betung bamboo is among the bamboo species with a big potential to be used for board manufacturing due to its big culm size. It can grow as high as 30 m with diameters of about 20 cm at the bottom part (Dransfield and Widjaya 1995). But, bamboo is very susceptible to termite and borers attack. Hence, the composite prepared from bamboo as raw material belongs to nondurable materials.

It is well established that acetylation provides significant improvement in wood dimensional stability and protection against decay fungi (Hill et al. 2006; Papadopoulous and Hill 2002; Papadopoulos and Traboulay 2002). Since it does not use any hazardous chemical substances, acetylation can be catagorized as environmentally friendly technique to improve woody materials durability.

Hence, in order to complete the information regarding the feasibility of using bamboo as a raw material for OSB manufacturing, particularly in tropical regions, research addressing the properties of OSB made from Betung bamboo is urgently needed. The objectives of this research were to evaluate the effect of strand length variation and pre-treatment techniques of strands on the physical, mechanical, and durability properties of OSB made from Betung bamboo.

Materials and methods

Materials

Four-year-old Betung bamboo was collected from Cikereteg, Bogor district, West Java, Indonesia. The strands were produced by using wood planer. Three different strand lengths (l) were prepared, namely 50, 60, and 70 mm. The width (*w*) and the thickness (*t*) of the strand were 20 mm, and 0.60–0.80 mm, respectively. Firstly, bamboo was converted into bamboo lath with 20 mm width. Long strands were produced by using wood planer with a thickness of around 0.60–0.80 mm. The strands were then cut into 50, 60, and 70 mm length. No sieve analysis was carried out. The strands produced were then manually selected. Thirty strands from each length were randomly selected for aspect ratio measurement. Methane di-Isocyanate (MDI, Type H3 M) adhesive and acetic anhydride obtained from commercial market (from PT. Polychemie Asia Pasific, Jakarta and PT Frisconina, Bogor) were used as adhesive and strand pre-treatment chemical, respectively.

Treatments of strand

Pre-treatment of strands was done using two different techniques, namely (1) immersion in cold water and (2) immersion in acetic anhydride solution. After immersing the strands in cold water for 24 h, the strands were dried in an oven at 75–80°C for several days to reach the moisture content (MC) of 7%. The strands were dried in an oven at 75–80°C to reach the MC of 3% before immersion in 6% acetic anhydride solution for 48 h. After that, the wet strands were dried in an oven at 110–120°C for 24 h. Then, they were washed in water to remove excess of acetic anhydride and acetic acid by-products. Finally, they were re-dried in an oven at 75–80°C to reach the MC of 7%. For comparison, untreated strands were also prepared.

Manufacturing of OSB

Three-layer OSBs were produced with the dimensions of 30 by 30 by 1.0 cm^3 and the target density of 0.7 g/cm^3. Commercial MDI adhesive was used to bond the strands to OSB with a spreading rate of 5% based on oven dry weight of the strand. Rotary drum blender was used for mixing strand and adhesive. The OSB layers were hand formed with face and back layers aligned perpendicular to the core layer. The weight ratio of the face-to-core-to-back layers was set at 1:2:1. The board was hot pressed at 160°C, 25 kg/cm^2 pressure for 6 min. After that, the board was conditioned for 10 days in a room adjusted at 25–30°C and 60–65% R.H. No sanding was applied. Four boards were prepared for each treatment condition. The board target thickness was 10 mm. The average additional thickness swelling of OSB due to the release of residual compressive stresses imparted to the board during the pressing of the mat in the hot press and the moisture absorbed during conditioning was 5.75%.

Methods

Determination of physical, mechanical, and durability properties of OSB made from Betung bamboo

Two series of experiments were conducted, namely (1) The effect of strand length on physical and mechanical properties of OSB prepared from Betung bamboo strand and (2) The effect of pre-treatment techniques on physical, mechanical, and durability properties of OSB prepared from Betung bamboo strand.

The board parameters measured were air-dry density, MC, water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB).

The mechanical properties (MOE, MOR and IB) were tested by using universal testing machine (UTM Instron) equipped with a load cell with a capacity of 10,000 N. The dimensions of the specimen in bending test were 185 by 50 by 9 mm^3. Evaluation of MOE and MOR were done both in lengthwise and crosswise direction of the panel. While for IB test, the dimensions of the specimen were 50 by 50 $\times$ 9 mm^3. Evaluation of MOE, MOR, and IB were done at 28°C and 60% R.H. The crosshead speed was adjusted to 10.0 mm/min.

The dimensions of the specimen for evaluation of air-dry density and MC of board were 100 by 100 by 9 mm^3. The specimens were immediately weighed and dried in an oven at 103 $\pm$ 2°C until they reached constant weight. For water absorption and thickness swelling tests, the dimensions of the specimen were 50 by 50 by 9 mm^3. The specimens were immediately weighed, and average thickness was determined by taking several measurements at specific locations. After 2 and 24 h of submersion, specimens were dripped and wiped cleaning off any surface water. The weight and thickness of specimens were measured. All the parameters measured compared to CSA 0437.0 (Grade O–2) standard (SBA 2004).

The resistance of OSB made from Betung bamboo against subterranean termite (Macrotermes gilvus) attack

The resistance of OSB against subterranean termite (*Macrotermes gilvus*) attack was determined through grave yard test. The test was conducted in the arboretum of Faculty of Forestry, Bogor Agricultural University, Indonesia. The test was performed using specimens with the dimensions 200 $\times$ 50 $\times$ 13 mm^3 in length, width, and thickness, respectively. The specimens were dried in an oven at 103 $\pm$ 2°C to obtain oven dry weight. The specimens were then buried leaving 50 mm of board length above the ground and with a space of 600 mm between each sample. After 3 months, the specimens were taken out of the ground, and then they were cleaned and dried in an oven at 103 $\pm$ 2°C to obtain oven dry weight. The weight loss percentage and the extent of damage of samples were determined.

Data analysis

For physical and mechanical properties, all multiple comparisons were subjected to an analysis of variance (ANOVA). Highly significant ($\alpha \leq 0.01$) and significant ($\alpha \leq 0.05$) differences between mean values of the untreated and treated specimens were determined using Duncan's multiple range tests.

Results and discussion

The effect of strand length on physical and mechanical properties of OSB prepared from Betung bamboo

There are many factors affecting the final board properties. Among the major factors are wood species and its density, strand quality, strand size, aspect ratio of the strand, strand orientation, resin type, layer structure, pressing parameter, board moisture content, and board density. The size and shape of particles significantly influence both physical and mechanical properties of particleboard (Kelly 1977). Hence, in this experiment, the effect of strand length on the physical and mechanical properties of OSB made from Betung bamboo was examined. Table 1 shows the mean, minimum, and maximum values for strand length and width. The mean aspect ratio was 3.54, 2.98, 2.61, for 70, 60, 50 mm strand length, respectively.

The mean values of air-dry density, MC, WA, TS, MOR, MOE, IB of OSB prepared from Betung bamboo strands with various strand lengths are presented in Table 2. The mean values of air-dry density and MC of the specimens ranged between 0.70 and 0.71 kg/m^3 and 5.35 and 5.75%, respectively. OSB prepared with various strand lengths showed similar values of air-dry density and MC. Furthermore, the mean value of WA of specimens after immersing in water for 2 and 24 h ranged between 13.63 and 16.44% and 46.03 and 48.49%, respectively. OSB prepared with various strand lengths showed similar values of WA. The mean value of TS of specimens after immersing in water for 2 and 24 ranged between 4.30 and 6.25% and 12.92 and 14.94%, respectively. Similar to WA parameter, there is no significant difference of TS value prepared with various strand lengths. However, the values of TS obtained in this experiment did not exceed the OSB minimum property requirement of CSA 0437.0 (Grade O–2) standard (SBA 2004).

The mean values of MOR both in parallel and perpendicular to the grain direction ranged between 565 and 581 kg/cm^2 and 324 and 417 kg/cm^2, respectively. The mean values of MOE both in parallel and perpendicular to the grain direction ranged between 80,958 and 90,627 kg/cm^2 and 19,649 and 34,915 kg/cm^2, respectively. The mean values of IB of specimens ranged between 5.41 and 7.28 kg/cm^2.

It is clear that increasing the strand length resulted in increasing values of MOR and MOE in perpendicular to the grain direction linearly. However, specimens prepared with strands of 60 and 70 mm length showed similar values of MOE in perpendicular to the grain parameter. The mechanical properties of particle board

Table 1 Dimension of Betung bamboo strands

Strand length (mm)	Parameter	Mean	Minimum	Maximum
50	L (mm)	50.0 (1.61)	47.0	53.0
	W (mm)	19.2 (1.33)	17.0	22.0
	Aspect ratio	2.61 (0.23)	2.23	3.06
60	L (mm)	59.3 (1.14)	57.0	63.0
	W(mm)	20.0 (1.38)	17.0	22.0
	Aspect ratio	2.98 (0.23)	2.64	3.47
70	L (mm)	69.0 (1.10)	66.0	71.0
	W (mm)	19.5 (1.22)	17.0	22.0
	Aspect ratio	3.54 (0.20)	3.09	4.00

Determined by measuring 30 strands from each strand length classification and selected randomly

L length, *W* width

Values in parentheses are standard deviation

Table 2 Effect of strand length on physical and mechanical properties of OSB prepared from Betung bamboo strands

Strand length	Physical and mechanical properties										
	Moisture content (%)	Air-dry density ($kg.m^{-3}$)	Water absorption (%)		Thickness swelling (%)		Modulus of rupture ($kg.cm^{-2}$)		Modulus of elasticity ($kg.cm^{-2}$)		Internal bond ($kg.cm^{-2}$)
			2H	24H	2H	24H	‖	⊥	‖	⊥	
50 mm	5.45 (0.12)	0.71 (0.02)	16.44 (2.18)	48.49 (3.84)	4.67 (1.21)	13.43 (1.10)	565 (47.11)	324[b] (31.99)	80,958 (9,213)	19,649[b] (2,113)	5.41 (1.06)
60 mm	5.75 (0.20)	0.70 (0.02)	14.18 (4.15)	46.03 (8.09)	6.25 (1.07)	14.94 (2.24)	579 (81.06)	383[ab] (54.62)	83,050 (12,435)	31,432[a] (3,307)	7.01 (0.52)
70 mm	5.35 (0.10)	0.70 (0.02)	13.63 (2.42)	47.80 (2.96)	4.30 (0.78)	12.92 (1.18)	581 (30.88)	417[a] (55.21)	90,627 (13,785)	34,915[a] (3,290)	7.28 (1.28)
CSA 0437.0 (Grade O-2) standard	–	–	–	–	–	≤15	296	126	56,084	15,296	3.52

P: 0.01

Homogeneity group: Same letters in each column indicate that there is no significant difference between the samples according to the Duncan's multiple range test

‖ Parallel to the grain direction

⊥ Perpendicular to the grain direction

Values in parentheses are standard deviation

were much improved by using longer and thinner particles or strands. The MOR and MOE values increase with increasing particle length (L) or decreasing particle width (*W*) and thickness (*T*) (Kawai and Sasaki 1986; Kawai et al. 2001; Zhang et al. 1998). On the other hand, there is no significant difference of MOR and MOE values in parallel to the grain direction of OSB prepared from three different strand lengths (i.e., 50, 60, and 70 mm). However, the MOR and MOE values of OSB tend to increase with increasing strand length (Table 2). Sumardi (2008) has evaluated the effect of strand length ranging from 20 to 80 mm on some properties of three-layer OSB made from moso bamboo (*Phyllostachys pubescens)*. It was proven that the MOR increased greatly among strand lengths of 20–40 mm and increased slightly beyond this range. Youngquist (1999) suggested that in order to obtain OSB with excellent bending properties, the value of aspect ratio had to be at least 3. According to Schuler et al. (2001) and Kuklewski et al. (1985), strand aspect ratio of two is enough to produce OSB with superior properties.

All the mechanical parameters of OSB prepared in this experiment were much higher than the minimum property requirement according to CSA 0437.0 (Grade O–2) standard (SBA 2004).

The effect of pre-treatment techniques of the strands on physical, mechanical, and durability properties of OSB prepared from Betung bamboo

In order to improve OSB properties especially its dimensional stability and durability, the effect of immersion of strands in cold water and acetic anhydride solution on physical, mechanical, and durability properties of OSB made from bamboo strands was evaluated in this experiment. The strand length used in this experiment was 7 mm. The mean values of air-dry density, MC, WA, TS, MOR, MOE, IB of OSB prepared from Betung bamboo strands using various pre-treatment techniques of strands are presented in Table 3.

The mean values of air-dry density and MC of the specimens ranged between 0.68 and 0.70 kg/m^{-3} and 5.10 and 5.76%, respectively (Table 3). OSB prepared using various pre-treatment techniques of strands showed similar values of air-dry density and MC. The mean value of WA of specimens after immersion in water for 2 and 24 h ranged between 11.15 and 13.63% and 35.59 and 47.80%, respectively. Pre-treatment of bamboo strands in cold water for 24 h and in 6% acetyc anhydride solution for 48 h resulted in lower water absorption of specimen. Furthermore, the average value of TS of specimens after immersion in water for 2 and 24 ranged between 3.66 and 6.33% and 10.73 and 22.24%, respectively. Pre-treatment of strands in 6% acetic anhydride solution for 48 h followed by drying in an oven at 110–120°C for 24 h showed significant improvement in thickness swelling value of specimen. Immersing the strands in cold water dissolved some bamboo extractives resulting in better adhesion between the strands and the adhesive achieved and restricted water absorption of specimen to some extent. Due to chemically bonded acyl groups occupying a certain space within the cell wall, this volume is thereby denied to water molecules, and as a consequence, the water absorption and thickness swelling of the acetylated wood are reduced. These results are confirmed with those obtained by Papadopoulus and Traboulay (2002) regarding acetylated fir strands.

Table 3 Effect of pre-treatment techniques on physical, mechanical, and durability properties of OSB prepared from Betung bamboo

Pre-treatment of Strands	Physical properties						Mechanical properties					Durability	
	Moisture content (%)	Air-dry density ($kg.m^{-3}$)	Water absorption (%)		Thickness swelling (%)		Modulus of rupture ($kg.cm^{-2}$)		Modulus of elasticity ($kg.cm^{-2}$)		Internal bond ($kg.cm^{-2}$)	Weight loss (%)	Degree of resistance
			2H	24H	2H	24H	‖	⊥	‖	⊥			
Control	5.35 (0.04)	0.70 (0.02)	13.63 (2.42)	47.80^{b} (2.96)	4.30 (0.58)	12.92^{b} (0.68)	581 (31)	417 (65)	93,927 (14,118)	34,915 (3,290)	7.28 (2.18)	13.53	Not resistant
Cold Water	5.54 (0.44)	0.70 (0.03)	11.15 (1.81)	37.12^{a} (2.22)	4.31 (1.12)	14.45^{b} (1.24)	655 (134)	492 (74)	108,694 (11,213)	36,817 (4,965)	9.34 (1.46)	6.73	Medium
Acetic Anhydride Solution	5.10 (0.13)	0.70 (0.02)	11.69 (1.44)	35.59^{a} (3.30)	3.66 (0.54)	10.40^{a} (1.44)	709 (37)	438 (18)	112,960 (10,427)	33,276 (3,000)	9.61 (1.19)	6.54	Medium
CSA 0437.0 (Grade O-2) standard	–	–	–	–	–	≤15	296	126	56,084	15,296	3.52	–	–

P: 0.01

Strand length; 70 mm, Homogeneity group; Same letters in each column indicate that there is no significant difference between the samples according to the Duncan's multiple range test

‖ Parallel to the grain direction, ⊥ Perpendicular to the grain direction

Values in parentheses are standard deviation

The mean values of MOR of specimens both in parallel and perpendicular to the grain direction ranged between 534 and 709 kg/cm^2 and 370 and 492 kg/cm^2, respectively. The mean values of MOE of specimens both in parallel and perpendicular to the grain direction ranged between 90,627 and 112,960 kg/cm^2 and 31,144 and 33,276 kg/cm^2, respectively. The mean values of IB of specimens ranged between 7.01 and 9.61 kg/cm^2.

Subterranean termite utilizes wood both as a shelter and food source. After being buried in soil for 3 months, the weight loss of the samples ranged between 6.54 and 13.53%. Pre-treatment of strands in cold water and acetic anhydride solution improved the durability of OSB up to one level from being not resistant (control) and moderate resistant against *Macrotermes gylvus* attack under the adopted experimental condition. At the same location of the termite test, Iswanto (2008) evaluated the resistance of OSB prepared from Sentang wood (*Melia excelsa* Jack) with or without immersion in cold water prior to the manufacture. It was reported that the weight loss values of samples were 7.50 and 5.50% for control and cold water immersed treatment, respectively.

All the mechanical parameters of OSB prepared from this experiment were much higher than the minimum property requirement according to CSA 0437.0 (Grade O–2) standard (SBA 2004).

Conclusion

1. The values of MOE and MOR in the perpendicular direction were significantly affected by strand length. OSB prepared from strands with 70 mm strand length had better values compared to 60 and 50 mm strand length.
2. The dimensional stability of OSB was slightly improved by immersing the strands in acetic anhydride solution.
3. Immersing strands in cold water and acetic anhydride solution improved the resistance of OSB against subterranean termite (*Macrotermes gylvus*) attacked under the adopted experimental condition.

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