Effect of Bamboo Species and Resin Content on Properties of Oriented Strand Board Prepared from Steam-treated Bamboo Strands

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The objective of this research was to evaluate the effect of bamboo species and resin content on the physical and mechanical properties of oriented strand boards (OSBs) prepared from steam-treated bamboo strands. The strands from three species of Indonesian bamboo, namely Andong (*Gigantochloa verticillata*), Betung (*Dendrocalamus asper*), and Ampel (*Bambusa vulgaris*), were steamed at 126 °C for 1 h at a pressure of 0.14 MPa. Three-layered OSBs with the core layer oriented perpendicularly to the face layers were prepared by bonding them together with 3 to 5% methylene diphenyldiisocyanate (MDI) resin based on oven-dried strands and with the addition of 1% paraffin. The strand compositions for the face, core, and back layers were 25%, 50%, and 25%, respectively. The slenderness ratios and aspect ratios of the strands ranged from 71.02 to 76.60 and from 2.96 to 3.02, respectively. The physical and mechanical properties of the OSBs fabricated from Andong and Betung were better than those from Ampel, and the properties of all OSBs were improved by increasing their resin content. OSBs from Betung with 3 to 5% resin content and those from Andong and Ampel with 4 to 5% resin content showed strength retention of more than 50%, which means they can be used for exterior structural applications. Except for OSBs fabricated from Ampel with 3% resin content, the properties of all OSBs prepared in this study were higher than the minimum values required by the CSA O437.0 (grade O-1) standard (2011).

Keywords: Oriented strand board; Bamboo; Steam-treated strand; Resin content

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INTRODUCTION

Bamboo is abundant in Indonesia and plays an important role in the livelihood of the Indonesian rural community, particularly as housing components. Moreover, use of bamboo as an industrial raw material is well established in construction products, stairs, fences, containers, furniture, musical instruments, and handicraft products. Bamboo has also been used as a traditional building material because it causes less damage during earthquakes than materials such as stone and mortar. In recent years, bamboo has attracted increasing interest as an alternative material for wood because of its very fast growth rate, short rotation cycle, ease of cultivation, excellent mechanical properties, medium to high density, ease of processing, and established use in various products. Moreover, because of the decreasing quantity and deteriorating quality of forest resources, global interest in bamboo utilization has considerably increased.

Among the 143 species of bamboo in Indonesia, only 32 species are used for distinct purposes (Wijaya 2001; Wijaya *et al.* 2004). Each species of bamboo has its own characteristics, resulting in a different usage (Nuryatin 2012). However, some of the disadvantages of bamboo utilization are its susceptibility to attack by termites and borers and the limited diameter of its stem.

The successful commercialization of bamboo plywood and flooring in recent years has stimulated research into bamboo for structural applications such as oriented strand board (OSB), which are structural panels suitable for a wide range of construction and industrial applications. An OSB is a matted panel made of strands that are sliced in the longitudinal direction from fast-growing round wood logs with small diameters and bonded with an exterior-type binder under heat and pressure (Structural Board Association 2005). A large number of studies on bamboo OSB have been conducted, showing that they can be effectively manufactured at an industrial scale (Lee *et al*. 1996; Sumardi *et al*. 2008; Febrianto *et al*. 2012; Sumardi and Suzuki 2013).

In our previous publication (Febrianto *et al*. 2012), we reported that Betung bamboo (*Dendrocalamus asper*) shows great promise for use as a raw material for OSB because of its excellent physical and mechanical properties. Moreover, pretreatments such as cold-water extraction and partial acetylation resulted in a significant improvement in the performance of these OSBs.

In this study, bamboo strands were treated by steam to improve the OSB properties. Secondly, the respective effects of bamboo species and resin content on OSB were also investigated. Steam treatment is commonly used to facilitate the bending of bamboo into desired shapes. It can also improve bamboo's resistance to insect attack (Liese 1985). During steam treatment, free sugars in woody materials can be converted into furan intermediates, which can be further converted into furan resins. This phenomenon is known to improve both the mechanical properties and the dimensional stabilization of the resulting boards (Rowell *et al.* 2002; Iswanto *et al*. 2010).

EXPERIMENTAL

Materials

For the present study, 3- to 4-year-old Andong (*Gigantochloa verticillata*), Betung (*Dendrocalamus asper*), and Ampel (*Bambusa vulgaris*) bamboos were collected from the Bogor District, West Java, Indonesia. Twenty-five bolts of bamboo were used for each species. Their average basic densities were found to be 0.61, 0.57, and 0.50 g/cm^3, respectively. Strands were manually produced using a sharp knife. The target length, width, and thickness of the strands were 70, 20, and 0.80 mm, respectively. Methylene diphenyldiisocyanate (MDI, Type H3M) adhesive and paraffin were purchased from PT. Polychemie Asia Pacific (Jakarta, Indonesia).

Methods

Steam treatment and OSB preparation

The strands were steamed at 126 °C for 1 h at a pressure of 0.14 MPa. The strands were then air-dried for 1 week and oven-dried at 75 to 80 °C for 3 days to achieve a moisture content (MC) of 7%. Three-layered OSBs with a size of 300 mm × 300 mm × 10 mm (length x width x thickness) were prepared. The strand compositions for the face, core, and back were 25%, 50% and 25%, respectively. The target density of bamboo OSB was set to 0.7 g/cm^3. Commercial MDI adhesive with a solids content of 98% was used to bond the strands with concentrations of 3%, 4%, and 5% based on the oven-dry weight of the strands. A rotary drum blender was used to mix strands and adhesive. Paraffin at a concentration of 1% (based on the oven-dry weight of strands) was added to the strands and adhesive mixture prior to mat formation. The mats were manually formed with face and back layers were aligned perpendicular to the core layer. The mat-form was hot-pressed at 160 °C for 6 min at a pressure of 2.5 MPa to fabricate the OSBs. Boards were then conditioned for two weeks in a room adjusted to a temperature of 25 to 30 °C and 60 to 65% relative humidity (RH). The duration of the conditioning process was determined by weighing specimens regularly until no further weight changes detected. Three boards were prepared for each treatment.

Determination of slenderness and aspect ratios of strands

The slenderness ratios and aspect ratios were calculated as the ratios of length to thickness and of length to width of the strands, respectively (Maloney 1993). To determine the slenderness and aspect ratios of the strands, 100 strands from each species were randomly selected. A caliper with a precision of 0.01 mm was used to measure the length, width, and thickness of the strands.

Determination of physical and mechanical properties of OSB

Prior to the physical and mechanical property tests, the specimens were conditioned at 25 to 30 °C and 60 to 65% RH for 2 weeks. The physical and mechanical properties of OSB were measured according to JIS A 5908 (2003) standard. For the water absorption (WA) and thickness swelling (TS) tests, the dimensions of each specimen were 50 mm × 50 mm ×10 mm. These specimens were weighed, and their average thicknesses were determined by taking four measurements at specific locations. After 24 h of immersion, the specimens were dripped and wiped clean of any surface water. The weights and thicknesses of the specimens were measured again.

The mechanical properties, *i.e.*, the modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond strength (IB), were tested using a universal testing machine (Model 4482, Instron, USA) equipped with a load cell with a capacity of 10 kN. The dimensions of the specimen used in the bending test were 185 mm × 50 mm ×10 mm. MOE and MOR were evaluated in both parallel and perpendicular directions of the panel. For the IB test, the dimensions of the specimen were 50 mm × 50 mm × 10 mm. The crosshead speed was set to 10 mm/min. The specimen dimensions for the air-dry density and MC tests were 100 mm × 100 mm ×10 mm. The conditioned specimens were weighed and dried in an oven at 103 ± 2 °C until they achieved their respective final constant weights. All parameters measured were compared to those of the CSA O437.0 (2011) (grade O-1) standard for OSB panels.

Data analysis

To assess physical and mechanical properties, all multiple comparisons were subjected to an analysis of variance (ANOVA). Significant ($\alpha \leq 0.05$) differences between the mean values of the untreated and treated specimens were determined using Duncan's multiple range tests. All statistics were performed on IBM SPSS Statistics Version 21.

RESULTS AND DISCUSSION

Strand Geometry

Strand geometry is a key parameter affecting both bamboo board properties and the manufacturing process (Suchsland and Woodsoon 1987). It has a definite relationship with the compression ratio; thus, it will influence the density of the composite board. Table 1 summarizes the mean values of the lengths, widths, thicknesses, slenderness ratios, and aspect ratios of the strands. Most of the slenderness ratios ranged from 60 to 100 (Fig. 1). This indicates that the strands had medium-to-high slenderness ratios. Figure 2 shows that all strands produced had aspect ratios of more than 2. Strands having aspect ratios higher than 1 can be easily oriented during the mat-forming process (Maloney 1993). According to Shuler and Kelly (1976) and Kuklewski *et al.* (1985), a strand aspect ratio of 2 is enough to produce an OSB with excellent properties.

Table 1. Strand Geometry of Betung, Andong, and Ampel Bamboo Strands

Species	Description	Parameter				
		Length (mm)	Width (mm)	Thickness (mm)	Slenderness ratio	Aspect ratio
Betung	Average	64.02	21.69	0.92	73.75	2.97
	SD	2.4	0.18	0.02	19.01	0.29
	Min.	55.30	17.00	0.50	38.37	2.40
	Max.	74.70	26.50	1.60	128.80	4.31
Andong	Average	65.52	22.23	0.91	76.60	2.96
	SD	1.30	1.31	0.24	19.47	0.18
	Min.	60.00	18.80	0.50	31.50	2.58
	Max.	70.00	25.40	2.00	128.80	3.51
Ampel	Average	62.74	20.92	0.90	71.02	3.02
	SD	1.60	1.82	0.30	19.25	0.28
	Min.	53.20	16.00	0.50	32.00	2.49
	Max.	67.50	25.40	2.00	127.20	3.84

Notes: n = 100; SD= standard deviation

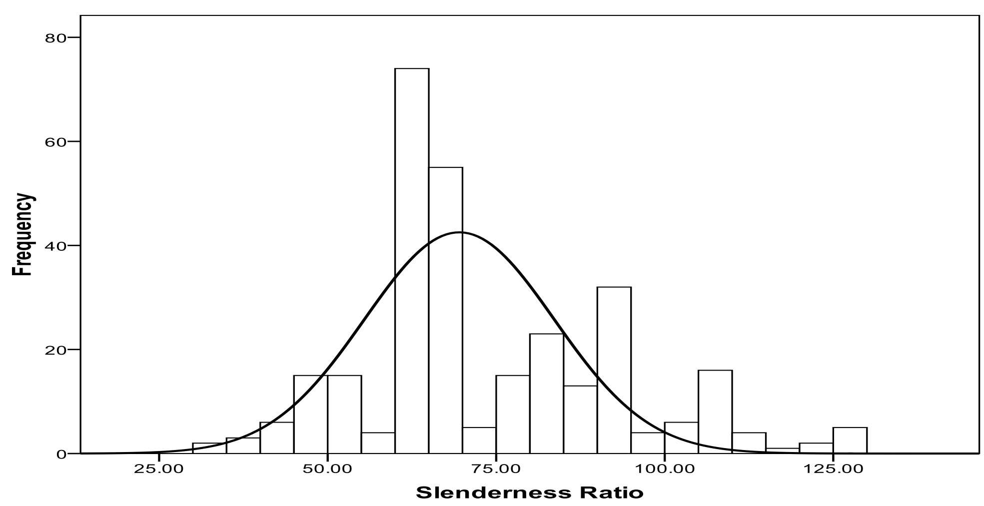

Fig. 1. Slenderness ratio distribution of bamboo strands

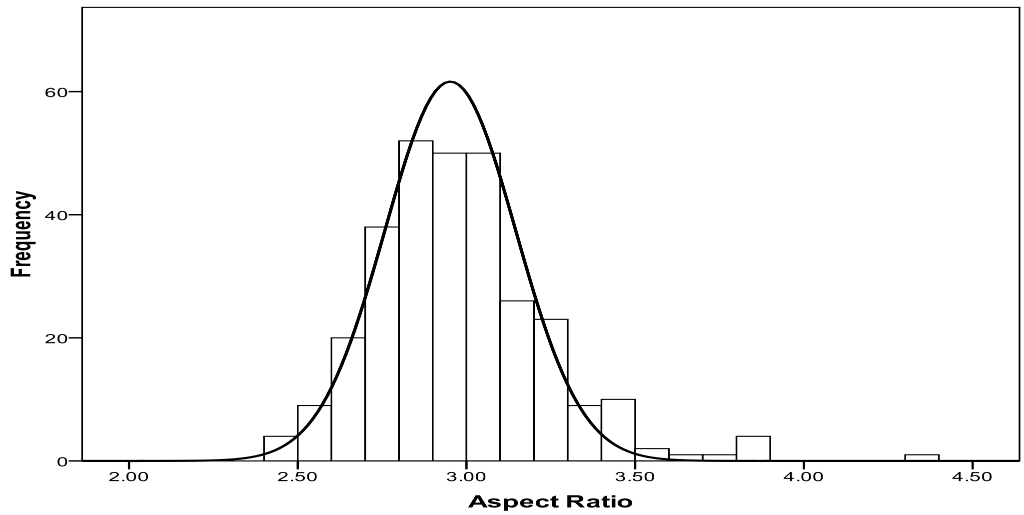

Fig. 2. Aspect ratio distribution of bamboo strands

Physical and Mechanical Properties of OSB

Many factors, such as wood species, density, quality, geometry, strand orientation, resin type and content, layer structure, pressing parameters, board MC, density, and pretreatment affect the final board properties. Bamboo properties are also affected by their structure; they comprise vascular bundles. Nuryatin (2012) reported that the MOR of solid bamboo is greatly affected by the patterns in its vascular bundles. In this experiment, therefore, the respective effects of a bamboo species and resin content on the physical and mechanical properties of its OSB, derived from steamed pretreated bamboo strands, were investigated.

Physical properties of OSB

The density of an OSB is an important physical property because it has a significant influence on the resulting strength of the OSB. In this study, OSBs with minor variations in density were successfully manufactured, with mean values ranging from 0.74 to 0.79 g/cm^3 (Fig. 3). The lowest and the highest values of density were observed for OSB from Ampel strands with 5% resin content and for OSB from Betung strands with 5% resin content, respectively. However, statistical analysis showed there was no significant difference in the air-dried density values measured for bamboo species and resin contents adopted in this experiment.

To produce satisfactory contact between strands in the board, it is usually necessary to compress the board to a density of 1.2 to 1.6 times that of the strands' initial densities (Bowyer *et al*. 2003). The ratio between board density and wood density is called the compression ratio.

The compression ratios of the OSBs in this study were between 1.2 and 1.58; the lowest and highest compression ratios were achieved by OSBs from Andong and Ampel with 3% resin content, respectively. Maloney (1993) pointed out that a compression ratio of 1.3 is a good guideline for determining the minimum board density for a medium-density board.

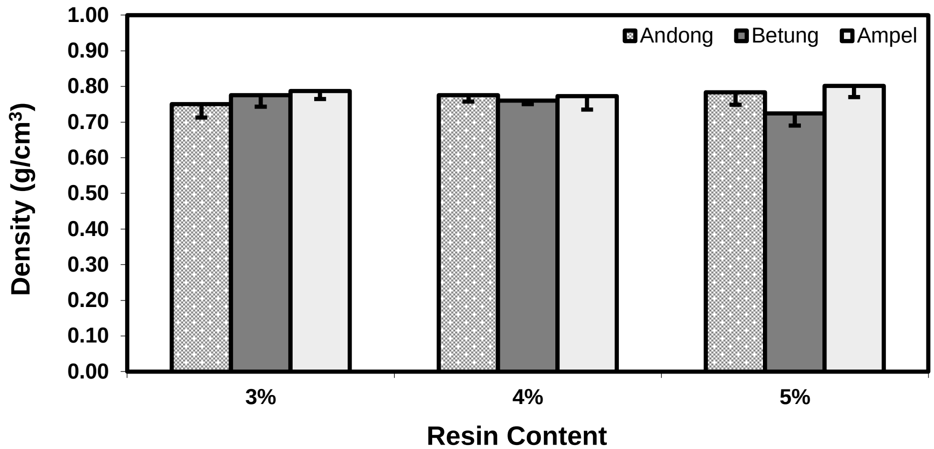

Fig. 3. Densities of OSBs from three bamboo species with various resin contents

Dimensional stability is an important property of wood composites and can be indicated by the WA and TS parameters. Figures 4 and 5 show the mean values of WA and TS, respectively, in OSBs made from three different bamboo species. The mean values of WA and TS varied from 19.34% to 36.95% and from 8.65% to 14.14%, respectively. The lowest and the highest values of WA were achieved for OSB from Andong strands with 5% resin content and for OSB from Ampel strands with 3% resin content, respectively. On the other hand, the lowest and the highest values of TS were found for OSB prepared from Betung strands with 5% resin content and for OSB from Ampel strands with 3% resin content, respectively.

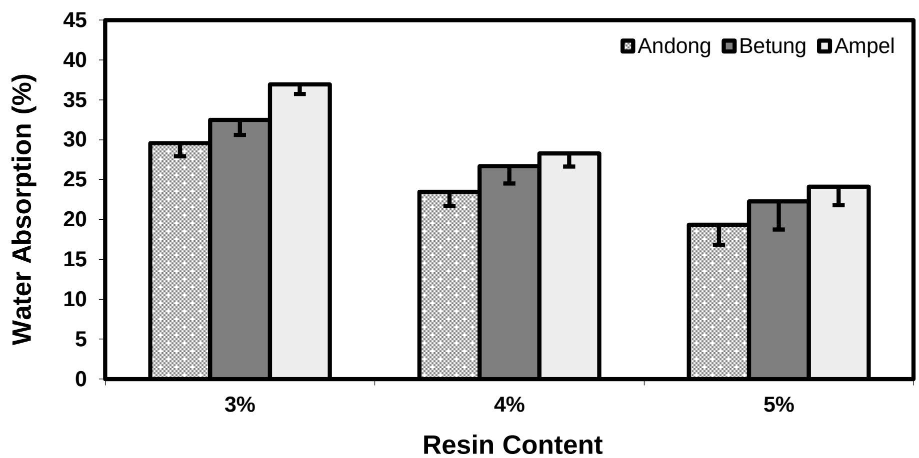

Fig. 4. Water absorption of OSBs from three bamboo species with various resin contents

The results of this study showed that WA was significantly influenced by the bamboo species. It is clear that at lower resin content (*i.e.*, 3%), OSBs from Ampel strands tended to absorb more water and showed higher WA values compared to OSBs from Betung and Andong strands. The cause of high WA on OSBs prepared from lower density strands is the higher compression ratio compared with OSBs from other bamboo species; when soaked in water, the Ampel OSB will absorb more water than the other types of bamboo OSBs because of their hygroscopic nature. However, at higher resin contents (*i.e.*, 5%), the WA values of OSBs from Andong, Betung, and Ampel strands tended to be similar.

Resins are essential additives in the manufacture of OSBs because they bond strands to each other. In this study, OSBs bonded with 3% resin content had the highest TS value, and the value decreased when the resin content was raised to 4% and 5% (Fig. 5). This indicates that when strands are mixed with higher amounts of resin, better water-proof properties are established. The resin penetrated into the bamboo cell walls and filled the lumen or some parts of the capillaries. Penetration of resin reduces the diameters of the capillaries or the total void age, which results in a reduced water uptake. Water uptakes in these OSBs were almost equivalent to those reported for OSBs from softwood and hardwood (Zhang *et al.* 2007; Febrianto *et al.* 2009; Gündüz *et al.* 2011; Ciobanu *et al.* 2014). The values of TS obtained in this experiment did not exceed the OSB minimum property requirement according to the CSA O437.0 (grade O-1) standard.

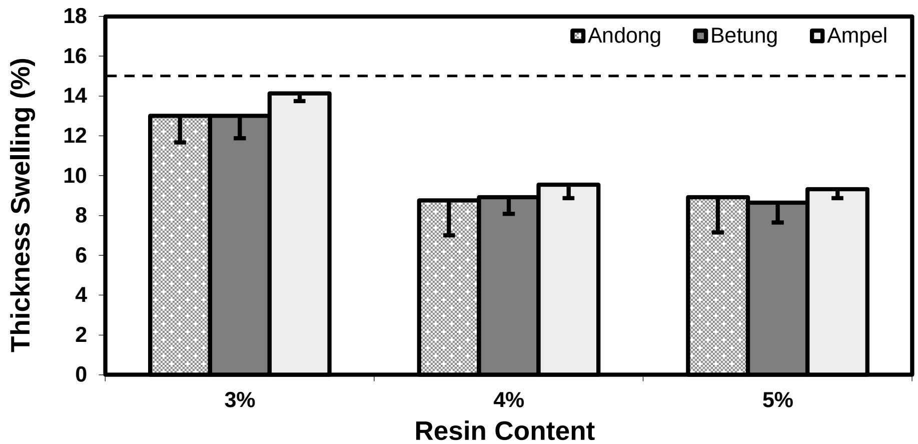

Fig. 5. Thickness swelling of OSBs from three bamboo species with various resin contents. Dashed line: CSA O437.0 standard (grade O-1 OSB) for TS (= 15%)

Mechanical properties of OSB

The bending strength (*i.e.*, MOR and MOE) of OSBs was measured in both the dry and wet states. MOR is an important property for determining suitability of particleboards for structural components (Kelly 1977). Figure 6 shows the dry-state MOR of OSBs in parallel (prl) and perpendicular (pn) directions with respect to the surface grain. The mean values of MOR parallel and perpendicular to the surface grain ranged between 21 and 65 N/mm^2 and between 11 and 43 N/mm^2, respectively. The lowest and highest values of the MOR parallel and perpendicular to the surface grain were obtained for OSB from Ampel with 3% resin content and for OSB from Betung with 5% resin content, respectively. Statistical analysis revealed that the dry-state MOR, both parallel and perpendicular to the OSB surface grain, was greatly affected by resin content and species. In general, higher resin content results in higher MOR values (Ayrilmis and Kara 2013). The present results are in agreement with previous studies. The dry-state MOR of OSBs with 3% resin content increased with increasing resin content to 4% and 5%. However, OSBs bonded with 4% and 5% resin content tended to have similar values of dry-state MOR parallel to the surface grain. OSBs manufactured from Andong and Betung with the same resin content showed higher values of MOR both parallel and perpendicular to the surface grain as compared with the OSB from Ampel. Thus, it could be concluded that in terms of the MOR parameter, the respective performances of OSBs from Betung and Andong were superior to those of the OSB from Ampel. Furthermore, the dry-state MOR values with 4% and 5% were superior compared to OSB from palm strand (Hegazy *et al.* 2015).

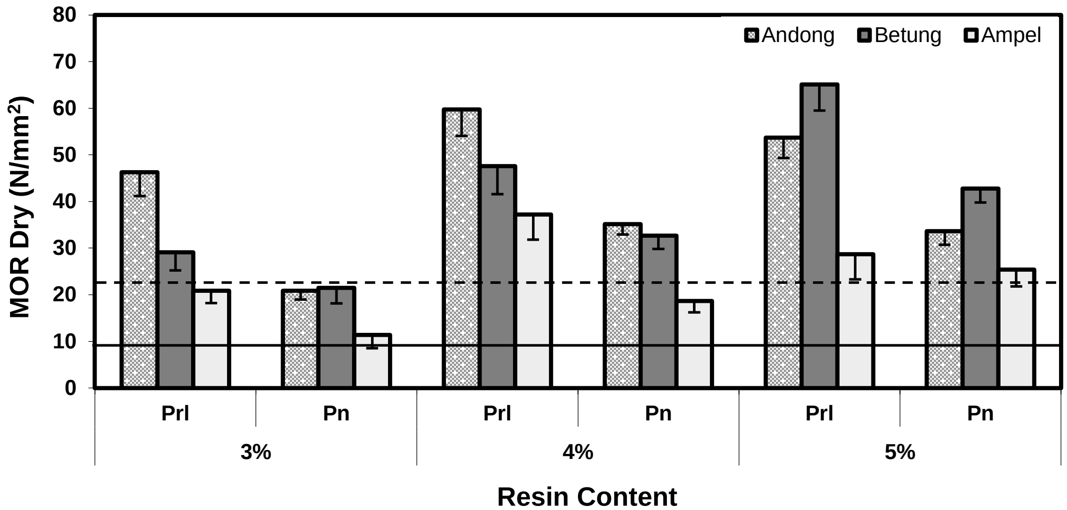

Fig. 6. Dry-state MOR parallel (prl) and perpendicular (pn) to the surface grain. Solid line: CSA O437.0 standard (grade O-1 OSB) for MOR perpendicular (= 9.42 N/mm^2); dashed line: CSA O437.0 standard (grade O-1 OSB) for MOR parallel (= 22.96 N/mm^2)

The mean values of wet-state MOR parallel and perpendicular to the surface grain ranged from 9 to 51 N/mm^2 and 11 to 32 N/mm^2, respectively (Fig. 7). The lowest and highest values of wet-state MOR parallel to the surface grain were observed for OSB from Ampel with 3% resin content and for OSB from Andong with 4% resin content, respectively. The lowest and highest values of wet-state MOR perpendicular to the surface grain were achieved for OSB from Ampel with 3% resin content and for OSB from Betung with 5% resin content, respectively.

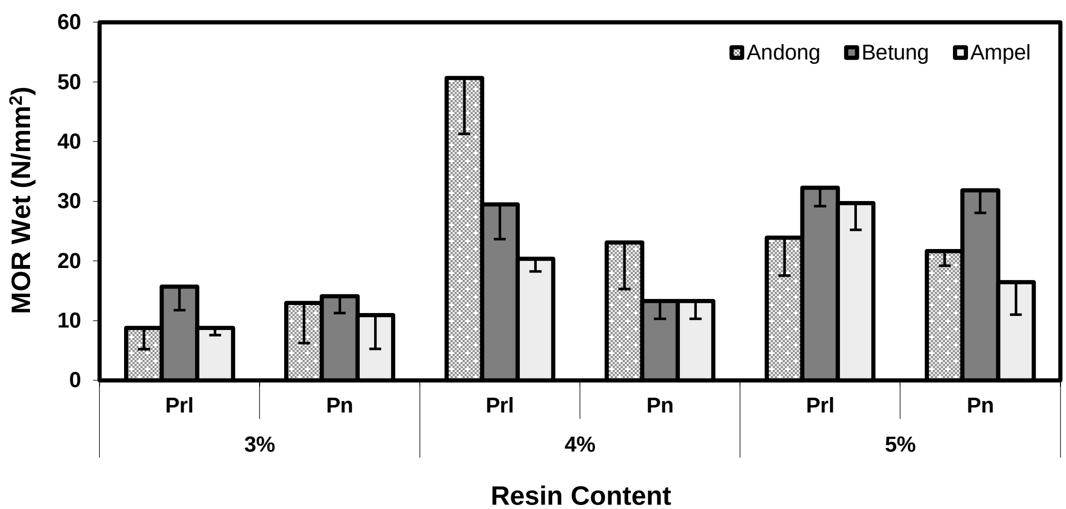

Fig. 7. Wet-state MOR parallel (prl) and perpendicular (pn) to the surface grain

The MOE is an important property because it is a measure of the stiffness, or resistance to bending, when a material is stressed (Kelly 1977). Figure 8 shows dry-state MOE parallel and perpendicular to the surface grain of OSBs from the three bamboo species with various resin contents. The mean values of dry-state MOE parallel and perpendicular direction to the surface grain ranged from 4,828 to 10,215 N/mm^2 and 1,267 to 3,496 N/mm^2, respectively. The lowest and highest values of dry-state MOE parallel to the surface grain were achieved for OSB from Ampel with 3% resin content and OSB from Andong with 5% resin content, respectively. The lowest and highest values of dry-state MOE perpendicular to the surface grain were measured for OSB from Ampel with 3% resin content and for OSB prepared from Betung with 4% resin content, respectively.

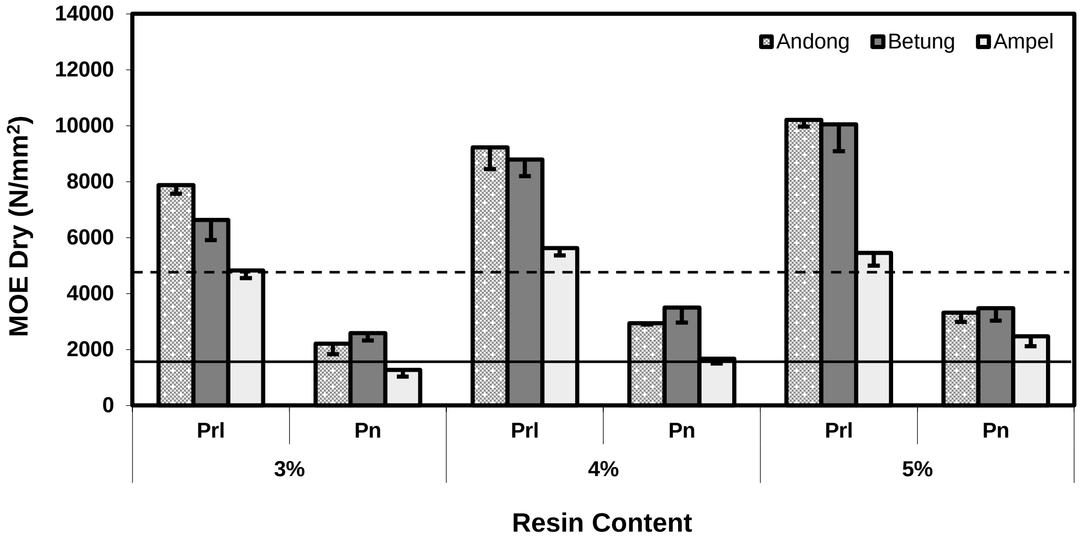

Fig. 8. Dry-state MOE parallel (prl) and perpendicular (pn) to the surface grain. Solid line: CSA O437.0 standard (grade O-1 OSB) for MOE perpendicular (= 1276 N/mm^2); dashed line: CSA O437.0 standard (grade O-1 OSB) for MOE parallel (= 4416 N/mm^2)

The values of dry-state MOE parallel and perpendicular to the surface grain were also significantly affected by resin content and species of bamboo tested. In particular, the measured MOE values increased with increasing resin content. The OSB obtained from Ampel strands bonded with 4% and 5% resin content showed similar values of MOE parallel to the surface grain. Furthermore, for the same resin content, the values of MOE parallel and perpendicular to the surface grain of OSBs from Betung and Andong were significantly higher than those of OSB from Ampel. MOR and MOE values of OSBs made from Betung, Andong, and Ampel strands were much higher than the minimum property values required by the CSA O437.0 (2011) (grade O-1) standard. Only MOE perpendicular to the grain of Ampel OSB with 3% resin content had lower values than the minimum requirement.

The mean values of wet-state MOE parallel and perpendicular to the surface grain were 1,701 to 6,222 N/mm^2 and 1,012 to 2,612 N/mm^2, respectively (Fig. 9). The lowest and highest values of wet-state MOE parallel to the surface grain were achieved for OSB from Andong with 3% resin content and from OSB from Betung with 5% resin content, respectively. The lowest and highest values of wet-state MOE perpendicular to the surface grain were achieved for OSB from Ampel with 3% resin content and OSB from Betung with 5% resin content, respectively.

Strength retention is defined as the ratio of the MOR or MOE in the wet state to MOR or MOE in the dry state. The higher the strength retention value, the more suitable the board is for exterior structural application (Massijaya and Okuma 1996). The strength retention of the OSBs varied between 26.85% and 94.38%. Betung OSBs with 3%, 4%, and 5% resin content and Andong and Ampel OSBs with 4% and 5% resin content had strength retentions above 50%. Thus, these OSBs can be used for exterior applications. Although the MOR and MOE values of Andong OSB with 3% resin content indicated excellent performance in the dry state, their strength retentions were frequently below 50%. Thus, this type of OSB can only be used for interior applications.

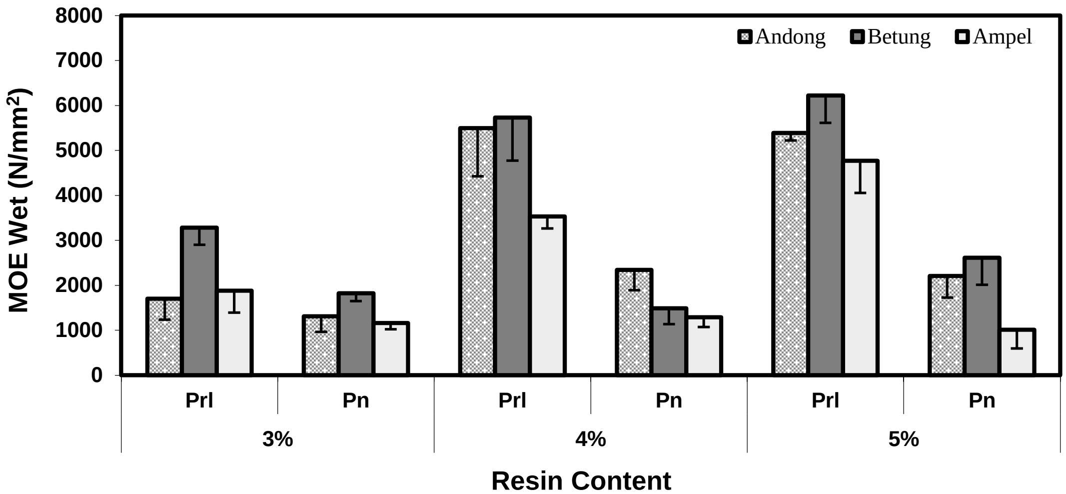

Fig. 9. Wet-state MOE parallel (prl) and perpendicular (pn) to the surface grain with various resin contents

The IB or tensile strength perpendicular to the board surface is a widely determined property in all particleboard studies (Kelly 1977). Figure 10 shows the IB of OSBs from three bamboo species with various resin contents. The mean values of the IB parameter ranged between 0.34 and 0.57 N/mm^2. The lowest and highest values of IB were found for Andong OSBs with 3% and 5% resin contents, respectively. The values were comparable to the IB values of OSB made from moso bamboo (*Phyllostachys pubescens*) with 6% of MDI resin content (Sumardi and Suzuki 2014). Statistical analysis showed that IB value was significantly influenced by resin content.

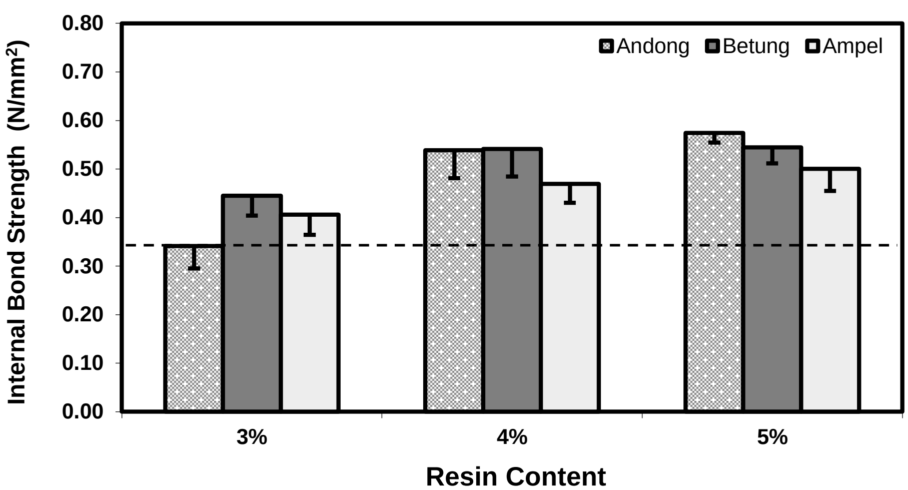

Fig. 10. IB values of OSBs from three bamboo species with various resin contents. Dashed line: CSA O437.0 standard (grade O-1 OSB) for IB (=0.34 N/mm^2)

It is common in particleboard and OSB products that increasing the resin content results in an increase in the IB value (Kelly 1977). It is interesting to note that at lower resin content (*i.e.*, 3%), the IB values of OSBs from Ampel were lower compared with OSBs from other bamboo species. This occurs because Ampel bamboo has the lowest density, so at the same OSB density, the Ampel bamboo strands have the highest surface areas and resin cannot completely distribute throughout its surface, which results in the lowest IB strength. However, at higher resin content (*i.e.*, 4 to 5%), the IB values of OSBs from the three bamboo species were almost equivalent. Similar results have been reported by Iswanto *et al.* (2010), Febrianto *et al.* (2009), Hermawan *et al.* (2007), and Zhou (2004) for OSBs prepared from wood strands. All the values for the IB strengths of OSBs obtained in this experiment met the requirements of the CSA O437.0 (grade O-1) standard.

The properties of bamboo as a raw material have a significant effect on the mechanical properties of OSBs. Previous studies have reported that for strand-based structural composites such as OSB, the panel strength largely depends on the mechanical properties of individual strands (Rowell and Banks 1987; Lee and Wu 2003). The higher bending strength values of the Betung and Andong OSBs compared to Ampel OSB are due to the different typical anatomical features and fiber morphology of such species. The vascular bundle size (radial/tangential ratio) and fiber length are correlated positively with the MOE and stress at the proportional limit for solid bamboo (Latif *et al.* 1990; Nuryatin 2012). Liese (1998) reported that the genera of *Bambusa*, *Gigantochloa*, and *Dendrocalamus* each have vascular bundle types III and IV. Fatriasari and Hermiati (2006) reported that the fiber lengths of Betung and Andong are higher than those of Ampel. Furthermore, it is a common phenomenon that higher resin content resulted in higher values of MOE, MOR, and IB strength of OSB. Similar results have been reported for OSBs made from wood strands (Avramidis and Smith 1989; Zhou 2004; Hermawan *et al.* 2007; Febrianto *et al.* 2009; Gündüz *et al.* 2011).

CONCLUSIONS

1. The physical and mechanical properties of OSBs from Betung and Andong strands are much superior to those of OSB from Ampel strands.
2. Higher resin content in the range of 3 to 5% resulted in better physical and mechanical properties for OSBs. OSBs from Betung strands bonded with 3 to 5% MDI resin, and OSBs from Andong and Ampel strands bonded with 4 to 5% MDI resin, have strength retention above 50%. These types of OSBs can be used for exterior applications.
3. The MOR and MOE values of OSB prepared from Andong strands bonded with 3% MDI resin showed excellent performance in the dry state, but some of them had strength retention below 50%. This type of OSB can only be used for interior applications.
4. All the physical and mechanical properties of OSB from Betung and Andong strands bonded with 3%, 4%, and 5% resin content and those of OSB from Ampel strands bonded with 4% and 5% resin contents met the requirements of the CSA O437.0 (grade O-1) standard.

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