Properties of Oriented Strand Boards Made from Two Indonesian Bamboo Species at Different Pressure Levels and Strand Lengths

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This study aimed to evaluate the effect of bamboo species, specific pressure, and strand length on the properties of oriented strand boards (OSBs). Laboratory scale OSBs were made from two Indonesian bamboo species [tali (*Gigantochloa apus*) and andong (*Gigantochloa pseudoarundinacea*)] with three different strand lengths (75, 100, and 150 mm). For each bamboo species and strand length, OSBs were fabricated by bonding bamboo strands with 7% phenol formaldehyde resin and 0.5% wax emulsion based on their oven-dry weight. The layer structure of the face, core, and back of the three-layer cross-oriented board were 25%, 50%, and 25%, respectively. A specific pressure of 25 or 30 kg/cm^2 was applied for 6 min at 160 °C. The targeted OSB density was 0.75 g/cm^3. The results showed that OSBs from andong bamboo had better dimensional stability and bending strength than those from tali bamboo. The bending strength of bamboo-based OSBs increased with increased bamboo strand length. A strong interaction was found between bamboo species, specific pressure, and strand length on the mechanical properties of OSBs. The properties of all bamboo-based OSBs produced in this study conform with the requirements of the Japanese Industrial Standard JIS A 5908 (2015) and British Standard BS EN 300 (2006).

DOI: 10.15376/biores.19.2.2863-2882

Keywords: Oriented strand board; Tali bamboo; Andong bamboo; Strand length; Specific pressure; Phenol formaldehyde; Physical and mechanical properties

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INTRODUCTION

Bamboo is a significant non-timber forest product in Indonesia, acknowledged for its versatility as a plant. Because of its rapid growth rate in diverse soil types and desirable properties, bamboo possesses the potential to serve as a substitute for furniture and housing materials (Dransfield and Widjaja 1995). Tali bamboo (*Gigantochloa apus* (JA & JH Schultes) Kurz) and andong bamboo (*Gigantochloa pseudoarundinacea* (Steud) Widjaja) are two species grown abundantly in Indonesia (Widjaja 2012). Andong bamboo has average air-dry density and flexural strength values of 600 kg/m^3 and 63.98 MPa, respectively, whilst tali bamboo's air-dry density and flexural strength values are 670 kg/m^3 and 76.9 MPa, respectively (Nugroho *et al.* 2021). Both bamboo species have drawn attention as a potential replacement for conventional wood-based materials due to their outstanding physical and mechanical performances (Abdullah *et al.* 2017; Sulastiningsih *et al.* 2017; Sulastiningsih *et al.* 2019). However, bamboo is prone to swelling and shrinkage and has a high diameter variation along its length (Kelkar *et al.* 2023), which can hinder its utilization. Making bamboo into composite panels such as OSB can overcome those disadvantages, thus increasing the potential of bamboo utilization as a replacement for wood.

Oriented strand board (OSB) emerges as a viable alternative among the array of bamboo-based products that can be developed from tali and andong bamboos. The OSB comprises several layers of strands and adhesive mixture that are further compressed to generate a compact composite product. The strands are intentionally arranged perpendicularly between layers, allowing the panel to exhibit excellent screw-holding and resistance to deflection, delamination, and warping (Rahman *et al.* 2021).

According to Thoemen *et al*. (2010), OSB is a multi-layered panel made from wood strands with predetermined dimension (typically, 15 to 25 mm wide, 75 to 150 mm long, and 0.3 to 0.7 mm thick), which are bonded together with a binder (often water resistant) under pressure and heat. The strands in the outer layers are aligned parallel to the long board edge and the production line. On the other hand, the strands in the core layer are often smaller and can be randomly oriented, generally at right angles to the strands of the face layers. The APA (2009) states that OSB is manufactured in a cross-oriented pattern similar to plywood to create a strong, stiff structural panel. OSB is composed of thin rectangular-shaped wood strands arranged in layers at right angles to one another, which are laid up into mats that form a panel. OSB is bonded with fully waterproof adhesives.

General steps in manufacturing bamboo-based OSB are quite similar to those in wood-based OSB production. The sequential procedures include converting bamboo materials into strands with random or targeted size, drying the bamboo strands, mixing the bamboo strands with prepared adhesive mixture, forming layers of strands and adhesive mixture in the prepared mold, piling up to 3 layers (front face, core, and back face) while also arranging their strands direction so that they are perpendicular between layers, and finally, compressing all layers to a full board with specific targeted density (Barbirato *et al.* 2022; Maulana *et al*. 2020, 2023). Therefore, the OSB properties are potentially governed by the properties of the materials being used, such as the strand length, and various technical factors applied during its processing, such as the specific pressure applied during production.

The impact of strand length and the pressure level used on OSB's quality has been intensively investigated for OSB production from wood materials (Beck *et al*. 2009; Damitrascu *et al.* 2020; Gündüz *et al*. 2011; Akrami *et al*. 2014; Ciobanu *et al*. 2014; Hamzaçebi 2016; Salem *et al*. 2018; Lunguleasa *et al*. 2020, 2021; Furugi and Yapici 2021; Rahman *et al*. 2021; Zhuang *et al.* 2022a). Several studies have also investigated the separated or simultaneous effect of various bamboo strand lengths and pressure levels applied on the properties of bamboo-based strand board (Sumardi *et al.* 2008; Febrianto *et al.* 2012; Iswanto *et al*. 2019; Sulastiningsih *et al*. 2017, 2019). Utilizing longer strands in strand board production positively affects the longitudinal properties of the board, resulting in improved modulus of rupture (MOR) and modulus of elasticity (MOE) values for the panels (Suzuki and Takeda 2000; Sumardi *et al.* 2008; Beck *et al.* 2009; Febrianto *et al.* 2012; Sulastiningsih et al. 2017, 2019; Iswanto *et al*. 2019). These findings emphasize the importance of strand length as a critical variable that possibly can enhance OSB's performance and long-term resilience, including bamboo-based OSB. Incorporating longer strands tends to enhance the overall strength and structural performance of OSB panels, making them more suitable for demanding applications, such as construction/structural material.

The interaction between the strand lengths and pressure levels significantly increases the MOE values of bamboo strand boards (Sulastiningsih *et al*. 2019). Different compression ratios during bamboo-OSB manufacture also affected the panels' mechanical properties (Maulana *et al.* 2020). Those studies reveal that the pressure conditions applied affect the compaction and bonding of the bamboo strands, resulting in the final bamboo strand board panels' variation of internal structure and mechanical properties. Employing appropriate pressure is critical, as it assists in achieving rapid curing of the adhesive and providing mat compaction through lignocellulose plasticization (Ciobanu *et al*. 2014).

Comprehending the impact of specific pressure and strand length on the characteristics of bamboo-based OSB is imperative for optimizing the manufacturing process and customizing the boards for specific applications. Up to now, no studies have examined the simultaneous effect of applying different specific pressures and strand lengths on the properties of OSB prepared from tali and andong bamboo. Thus, this study aimed to explore and quantify the influence of specific pressure and strand length on several physical and mechanical properties of OSB derived from these two bamboo species. The outcomes of this research will contribute to the advancement of manufacturing techniques and sustainable utilization of both bamboo species for construction practices. By gaining a deeper understanding of how the specific pressure and strand length affect OSB properties, optimizing the production process and facilitating the design of bamboo-based OSB for diverse engineering applications will be possible.

EXPERIMENTAL

Materials

The main materials used were 3-year-old tali bamboo (*Gigantochloa apus* (J.A. & J.H. Schultes) Kurz) with average diameter, thickness, and length of 8.1 cm, 9.5 mm, and 6 m, respectively, and 4 m-long each of bottom, middle, and top parts of 4-year-old andong bamboo (*Gigantochloa pseudoarundinacea* (Steud.) Widjaja). The bottom part of andong bamboo had an average diameter and thickness of 10.4 cm and 14.2 mm, respectively, while the middle part had an average diameter and thickness of 9.8 cm and 10.3 mm, respectively. Its top part had an average diameter of 8.7 cm and a thickness of 7.4 mm. Only the top parts of andong bamboo were converted into bamboo strands. The bamboo culms were collected from Sukabumi District, West Java, Indonesia. The adhesive used was liquid phenol formaldehyde (43% solid content, viscosity of 1.2 poise, pH 11) bought from PT. Palmolite Adhesive Industry, Probolinggo, Indonesia). Other chemicals used were wax as the additive and paraformaldehyde as the hardener.

Methods

Strands preparation

Depending on the internode length, the bamboo culms were cross-cut into 30- to 40-cm-long without the nodes and further split into 2.5 cm wide bamboo strips. The outer skin of bamboo strips was removed. The strips were then manually sliced using a sharp knife, to prepare strands with 0.6 to 0.8 mm thickness. The long strands were cut into targeted lengths. The targeted dimensions of the bamboo strands were 75 mm (C1), 100 mm (C2), and 150 mm (C3) in length, and 25 mm in width. The bamboo strands were air-dried at room temperature for one week until they reached MC of ±15%, followed by oven-drying at 80 °C for 72 hours or until they reached ± 4% moisture content (MC).

Determination of aspect ratio, slenderness ratio and density of bamboo strands

According to Maloney (1993), the strand geometry plays a fundamental role in determining the properties and characteristics of the board. Similarly, Marra (1992) asserted that the particle geometry of the particles significantly influences the strength and performance of wood composites. The strand length is not the sole determining factor; the interplay between strand length and strand thickness, often known as the slenderness ratio, is also crucial (Beck *et al.* 2009; Sackey and Smith 2009).

Thirty strands from each bamboo species and each length were randomly selected for aspect ratio and slenderness ratio measurements. The aspect ratio was calculated as the length ratio to the strand width, while the slenderness ratio was calculated as the length ratio to the strand thickness (Maloney 1993). The strands length, width, and thickness were measured using a digital caliper with a precision of 0.01 mm. The bamboo strand density was calculated by dividing its mass by its volume. All these measurements were carried out at ±12% MC. Figure 1 presents the samples of bamboo strands.

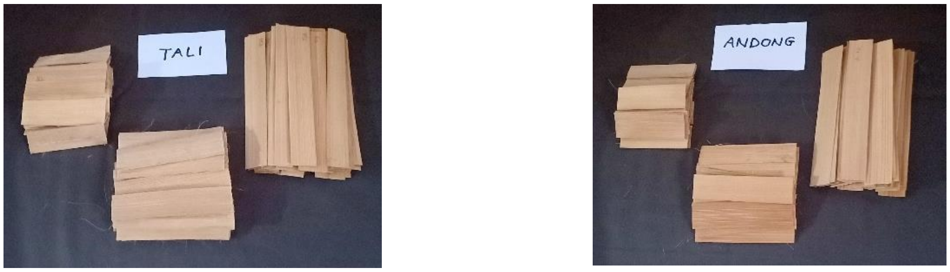

Fig. 1. Samples of bamboo strands

Determination of compression ratio of bamboo OSB

The effect of furnish species on particleboard properties is primarily related to the wood density (in this case, is bamboo density) and the necessity of compressing the wood or bamboo to obtain satisfactory particleboard or OSB. Generally, a conventional particleboard with a density lower than the density of the wood or bamboo furnish will be unsatisfactory. The compaction of the mat to an average density higher than the density of the furnish will allow better surface contact between the component particles of the mat. This results in better adhesive utilization because more adhesive-coated particles will be in intimate contact with other wood particles instead of voids (Kelly 1977). The compression ratio is an essential parameter for determining the quality of the particleboard or OSB. The compression ratio of bamboo OSB is calculated by dividing the OSB density by the density of the raw material.

OSB manufacturing

According to Maloney (1993), the strand geometry plays a fundamental role in determining the properties and characteristics of the board. The laboratory scale 3-layer OSBs, sizing 30 cm x 30 cm x 1.2 cm (length x width x thickness), were prepared from each bamboo species and each strand length. The layer structure of the face, core, and back of the 3-layer cross-oriented boards were 25%, 50%, and 25%, respectively. The targeted density for fabricated bamboo OSBs was 0.75 g/cm^3. The adhesive used was commercial liquid phenol-formaldehyde (PF) with 7% resin content (resin solid) based on the oven-dry weight of the strands. Paraformaldehyde with 1% of the PF weight and 0.5% wax emulsion based on the oven-dry weight of the bamboo strands were added as a hardener and additive, respectively. All chemicals were homogenously mixed and then applied to a specified quantity of bamboo strands using a pressurized spray gun in a rotary drum blender. Afterward, mat formation was manually performed using the resinated bamboo strands and with the mat's face and back layers cross-oriented to the core layer. The hand-formed mats were hot pressed at 160 °C for 6 min at a specific pressure of 25 or 30 kg/cm^2. The produced boards were further conditioned at room temperature (RH ±75%, 30 °C) for two weeks prior to testing. Figure 2 presents the general scheme of OSB manufacture and properties tests carried out in the study. Approximately three (3) boards were prepared for each treatment combination. Figure 3 illustrates the samples of bamboo OSBs manufactured in this study.

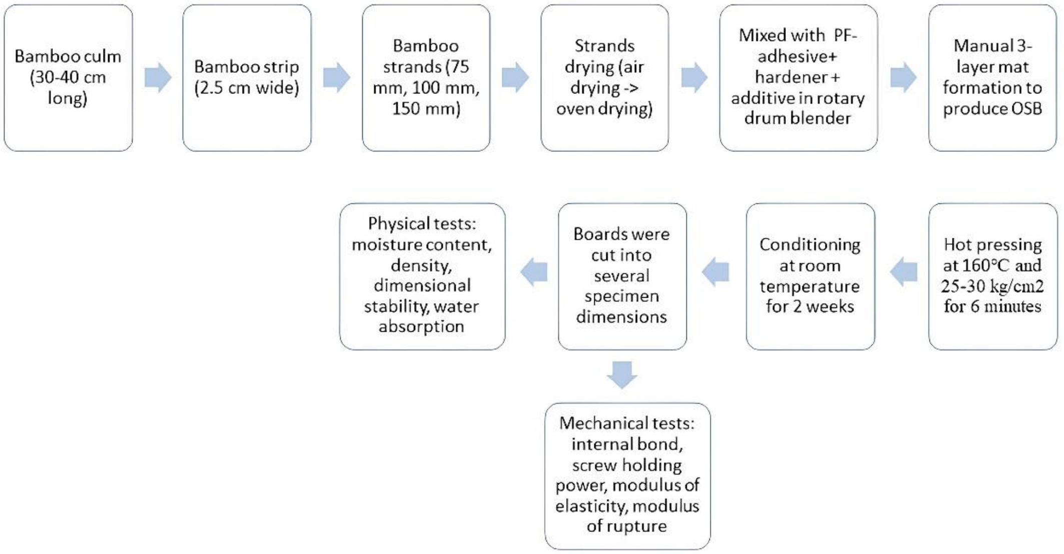

Fig. 2. General scheme of OSB manufacture and properties tests

Fig. 3. Samples of manufactured-bamboo OSB

Determination of physical and mechanical properties of bamboo OSB

Each board was cut to yield the targeted specimen's dimension for determining the board's properties. The specimens for physical and mechanical property tests were conditioned at room temperature (RH ±75%, 30 °C) for two weeks before testing. All tests for evaluating the properties of bamboo OSBs were performed in accordance with the Japanese Industrial Standard JIS A 5908 (2015). The air-dry density and moisture content tests were performed using specimens of 100 mm (width) x 100 mm (length) x 12 mm (thickness). The initial weight and dimension of the specimens were recorded. Afterward, all specimens were oven-dried at 103 ± 2 °C until they reached constant weight. To support the discussion of this particular aspect, the average compression ratio of the produced boards was also determined and calculated as the ratio of the average board density to the raw material density.

The dimensional stability parameters investigated were thickness swelling (TS), width expansion (WE), and water absorption (WA). Each specimen dimension was 50 mm x 50 mm x 12 mm. The specimens were immersed in cold water for 24 h. The initial weight, width, and thickness were measured before and after the immersion.

The mechanical properties, comprising bending strength (MOR) and modulus of elasticity (MOE), internal bond strength (IB), and screw holding power (SHP), were tested using a universal testing machine (Model LLOYD EZ 20; AMETEK Lloyd Instruments Ltd., Fareham Hampshire, UK). The specimen's dimension of the bending strength test was 230 mm x 50 m x 12 mm. Specimens for MOR and MOE were determined in both parallel and perpendicular to the surface grain direction. The specimen's dimension of the IB test was 50 mm x 50 mm x 12 mm. The specimen's dimension for the screw-holding power test was 75 mm x 50 mm x 12 mm. All properties tested were compared to those of JIS A 5908 (2015) and BS EN 300 (2006).

Data analysis

All data obtained from various testing results of bamboo OSB were averaged and tabulated. The effects of bamboo species, specific pressure, and length of bamboo strands on OSB's physical and mechanical properties were investigated using a 3-factorial analysis of variance (ANOVA) with a completely randomized design (CRD). The main factors were consecutively: (i) bamboo species (A), tali bamboo (A1), and andong bamboo (A2); (ii) specific pressure (B), 25 kg/cm^2 (B1) and 30 kg/cm^2 (B2); and (iii) strand lengths (C), 75 mm (C1), 100 mm (C2), and 150 mm (C3). Approximately three replications were prepared for each treatment combination (R). Following a significant ANOVA result, Tukey's honestly significant difference (HSD) range test was employed (Ott 1994). The ANOVA and Tukey tests were conducted using the SAS program (SAS Institute Inc., 6th Edition, Cary, NC, USA).

RESULTS AND DISCUSSION

Density of Bamboo Strands

The density of the wood raw material is the most important species variable governing board properties. The density has been the important factor in determining which species are used for manufacture of particleboard. Oriented strand board (OSB) is a type of particleboard with particles in the form of strands. Generally, the lower-density woods will produce particleboards within the desired density ranges, usually with strength properties superior to the higher-density species. The reason for this lies in the fact that the lower density woods can be compressed into medium density particleboards with the assurance that sufficient interparticle contact area is developed during the pressing operation to achieve good bonding (Maloney 1993). This statement also applies to bamboo. Table 1 shows the average values of bamboo strands density of each bamboo species and strand length. The average density of tali and andong bamboo strands were 0.62 g/cm^3 (620 kg/m^3) and 0.56 g/cm^3 (560 kg/m^3), respectively. These values of bamboo strand density were lower than the bamboo culm density, where the densities of tali and andong bamboo culms were 670 kg/m^3 and 600 kg/m^3, respectively (Nugroho *et al.* 2021). This result is possibly due to the presence of outer and inner skins of bamboo culms during the culm density measurement.

Table 1. Density of Bamboo Strands

Targeted Length of Bamboo Strands (mm)	Description	Density of Bamboo Strands (g/cm^3)	
		Tali bamboo	Andong bamboo
75	Average	0.62	0.56
	SD	0.05	0.04
	Min.	0.52	0.50
	Max	0.71	0.68
100	Average	0.62	0.56
	SD	0.05	0.06
	Min.	0.52	0.50
	Max.	0.70	0.69
150	Average	0.62	0.56
	SD	0.05	0.05
	Min.	0.51	0.50
	Max.	0.70	0.70

S.D.- Standard deviation

Bamboo Strand Geometry

Table 2 shows the average values of the lengths, widths, thickness, slenderness ratios, and aspect ratios of bamboo strands. The slenderness ratio and aspect ratio ranges of tali bamboo were 96.0 to 182.0 and 3.02 to 5.89, respectively. Those values for andong bamboo ranged from 92.3 to 192.3 and 3.00 to 6.12, respectively. Bamboo strands at 150 mm length (C3) showed a higher slenderness ratio and aspect ratio than the strands at 100 mm length (C2) and 75 mm length (C1). All bamboo strands fulfilled the aspect ratio requirement to provide good orientation in OSB fabrication because the values were not less than three. Based on the result of the slenderness ratio, the OSB prepared from tali and andong bamboo might have resulted in good MOR values. Kelly (1977), Zhuang *et al.* (2022a), and Arabi *et al.* (2023) mentioned an increase in the slenderness ratio might lead to a MOR increase in composite panels.

Table 2. Geometry of Tali and Andong Bamboo Strands

Species	Targeted Length (mm)	Description	Parameter				
			Length (mm)	Width (mm)	Thickness (mm)	Slenderness Ratio	Aspect Ratio
Tali	75	Average	74.2	24.62	0.79	96.05	3.02
		SD	0.75	0.64	0.11	12.84	0.09
		Min.	72.4	23.13	0.62	73.42	2.84
		Max.	75.0	25.53	1.00	120.68	3.24
	100	Average	100.0	25.3	0.82	123.29	3.96
		SD	2.27	0.68	0.07	13.04	0.16
		Min.	92.9	23.9	0.59	105.53	3.65
		Max.	104.4	26.1	0.93	171.85	4.26
	150	Average	147.1	25.0	0.81	181.98	5.89
		SD	0.16	0.67	0.07	15.34	0.19
		Min.	145.0	23.7	0.68	158.92	5.65
		Max.	150.2	25.9	0.92	215.16	6.23
Andong	75	Average	74.5	25.0	0.81	92.32	3.00
		SD	0.76	0.90	0.06	6.24	0.13
		Min.	72.3	22.9	0.67	80.04	2.79
		Max.	76.0	26.5	0.92	107.85	3.31
	100	Average	99.72	25.07	0.81	124.45	3.98
		SD	0.48	0.82	0.09	16.01	0.14
		Min.	98.85	22.82	0.60	107.16	3.79
		Max.	100.67	26.34	0.93	165.98	4.34
	150	Average	152.55	25.0	0.81	192.33	6.12
		SD	1.04	1.29	0.12	34.24	0.32
		Min.	150.0	22.3	0.55	166.66	5.69
		Max.	153.80	26.69	0.91	277.13	6.86

S.D.- Standard deviation

Physical Properties

MC analysis

Table 3 shows the average data of several physical properties of the manufactured OSBs in this study. The average MC of OSB fabricated from andong and tali bamboo ranged from 9.4% to 10.3% (Table 3). Andong-bamboo-based OSB manufactured with 75 mm strand length and at a specific pressure of 25 kg/cm^2 had the lowest MC. The overall MC values of OSB produced were less than the maximum MC allowed for the OSB products according to JIS A 5908 (2015) (maximum MC of 13%) and BS EN 300 (2006) (maximum MC of 12%). Therefore, the OSB in this study met the requirements of both standards. Nevertheless, ANOVA results (Table 4) revealed that all three factors (bamboo species, strand length, and specific pressure) or their interactions had no significant effect on the OSB's MC.

Density

The average density of the manufactured OSBs ranged from 0.74 to 0.77 g/cm^3 (Table 3), classifying the boards as medium-density (Maloney 1993). The highest density occurred for the OSB fabricated from tali bamboo, using a specific pressure of 25 kg/cm^2 and 75 mm-long strands. Nevertheless, ANOVA results disclosed that neither bamboo species, specific pressure, strand length, nor their interactions significantly affected the OSB density (Table 4).

Table 3. Physical Properties of the OSB Fabricated from Andong and Tali Bamboo by Using Different Pressure and Strand Lengths

Treatment Combination (ABC)	Physical Properties				
	MC (%)	Density (g/cm³)	Dimensional Stability		WA (%)
			TS (%)	WE (%)	
A1B1C1	9.8 (0.2)	0.77 (0.01)	3.50 ab (0,40)	0.55 a (0,03)	27.43 ab (3.00)
A1B1C2	10 (0.4)	0.76 (0.01)	4.69 a (0.89)	0.53 ab (0.07)	30.90 ab (1.32)
A1B1C3	9.8 (0.2)	0.75 (0.01)	4.76 a (0.61)	0.54 ab (0.08)	28.73 ab (3.57)
A1B2C1	9.7 (0.2)	0.76 (0.03)	4.79 a (0.40)	0.47 abc (0.01)	35.80 a (3.78)
A1B2C2	10.3 (0.8)	0.74 (0.02)	3.62 ab (0.42)	0.55 a (0.05)	32.90 ab (2.08)
A1B2C3	9.5 (0.2)	0.75 (0.01)	3.55 ab (0.37)	0.54 ab (0.01)	33.37 ab (2.80)
A2B1C1	9.4 (0.2)	0.76 (0.01)	3.46 ab (0.28)	0.45 abc (0.02)	25.14 b (3.00)
A2B1C2	10.1 (0.3)	0.76 (0.01)	4.36 a (0.71)	0.56 a (0.03)	30.83 ab (4.66)
A2B1C3	10.1 (0.1)	0.75 (0.02)	3.99 a (0.30)	0.49 ab (0.03)	31.30 ab (2.48)
A2B2C1	10 (0.4)	0.75 (0.003)	4.28 a (0.37)	0.34 c (0.08)	33.50 ab (2.81)
A2B2C2	9.8 (0.4)	0.75 (0.02)	3.48 ab (0.40)	0.43 abc (0.06)	28.70 ab (3.59)
A2B2C3	9.9 (0.1)	0.76 (0.02)	2.53 b (0.33)	0.41 bc (0.02)	25.47 b (4.27)

Notes: A= bamboo species (A1 = tali bamboo, A2 = andong bamboo), B = specific pressure (B1 = 25 kg/cm^2, B2 = 30 kg/cm^2), C = strand length (C1 = 75 mm, C2 = 100 mm, and C3 = 150 mm); Values in parentheses are standard deviations; MC = moisture content, TS = thickness swelling, WE = wide expansion, WA = water absorption; Values in the same column followed with the same letters are not significantly different (according to Tukey's test)

Density is indeed an important variable that governs composite board properties. However, the compression ratio, or the ratio of the board density to the raw material density, must also be considered. According to Kelly (1977), Maloney (1993), and Maulana *et al.* (2020), a compression ratio in the range of 1.2 to 1.3 resulted in a good-quality composite. In this study, the average density values of tali and andong bamboo strands and the produced OSBs were 0.62, 0.56, and 0.75 g/cm^3, respectively. Further calculation showed that the average compression ratio scores of tali and andong-bamboo-based OSBs were 1.21 and 1.34, respectively. Therefore, the manufactured OSBs in this study satisfied the requirement of high-quality medium-density boards.

Dimensional stability

Dimensional stability is crucial in determining the quality of solid wood, panel, or composite products. This study used two parameters, thickness swelling (TS) and width expansion (WE), to understand the dimensional stability phenomenon of the bamboo-based

OSB. This study showed that bamboo-based OSB's average thickness swelling (TS) ranged from 2.53% to 4.79% (Table 3). The TS values of bamboo-based OSB in this study conform with JIS A 5908 (2015) with a maximum TS tolerance of 20% and BS EN 300 (2006) with a maximum TS tolerance of 25% (Type OSB/1), 20% (Type OSB/2), 15% (Type OSB/3) and 12% (Type OSB/4).

A low TS value indicates a high dimensional stability of a panel or composite product. The lowest TS value, 2.53%, was obtained for andong-bamboo-based OSB fabricated at a specific pressure of 30 kg/cm^2 and 150 mm long strands. In contrast, tali bamboo-based OSB manufactured at a particular pressure of 30 kg/cm^2 and 75-mm-long strands had the highest TS value (4.79%) after 24-h immersion. Due to their low TS values, the bamboo-based OSB produced in this study exhibited superior dimensional stability compared to OSB products reported in several previous studies. Specifically, the bamboo-OSB bonded with MDI showed a TS value range of 8.65% to 14.94% (Febrianto *et al.* 2012, 2015; Davinsy *et al.* 2019). In contrast, the eastern red cedar-based strand board bonded with 8% liquid phenol-formaldehyde had a TS value range of 15.2% to 18.4% (Hiziroglu 2009). TS value of *Pinus maritinus*-based OSB bonded with water solution of a procyanidin tannin extract was 10% (Pichelin *et al.* 2002). The mixture of *Calophyllum inophyllum* and *Paulownia coreana*-based OSB bonded with a mixture of synthesized phenol-formaldehyde and phenol-urea-formaldehyde exhibited a TS value range of 24.5% to 31.1% (Oh and Kim 2015). Differences in the strand types, adhesive, and variation in the manufacturing process applied during each OSB type production potentially contribute to these comparison results.

Table 4. Summarized Results of Analysis of Variance on Physical Properties of OSB from Tali and Andong Bamboo

Sources of Variation	F Calculated				
	MC (%)	Density (g/cm^3)	TS (%)	WE (%)	WA (%)
Bamboo species (A)	0.16 ns	0.00 ns	8.21 *	27.41 **	4.80 *
Pressure level (B)	0.21 ns	2.66 ns	6.51 *	16.58 **	5.65 *
Strand length (C)	2.22 ns	0.29 ns	1.68 ns	5.42 *	0.37 ns
A*B	0.16 ns	0.17 ns	0.29 ns	8.46 *	5.12 *
A*C	1.89 ns	0.55 ns	1.73 ns	1.59 ns	0.02 ns
B*C	1.38 ns	0.43 ns	20.78 **	1.16 ns	7.23 *
A*B*C	3.34 ns	0.11 ns	0.37 ns	1.27 ns	1.98 ns

Notes: MC = moisture content; TS = thickness swelling; WE = width expansion; WA = water absorption; ** = highly significant (F-calculated > F-table at 99% confidence level); * = significant (F-calculated > F-table at 95% confidence level); ns = non-significant (F-calculated < F-table at 95% confidence level)

The manufactured OSB's average width expansion (WE) ranged from 0.34% to 0.56% (Table 3). The lowest WE value was observed for andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 and strand length of 75 mm. Contrastingly, andong bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 specific pressure and strand length of 100 mm had the highest WE.

The ANOVA results revealed that bamboo species, specific pressure, and the interaction between specific pressure and strand length significantly affected the bamboo-based OSB's TS value (Table 4). In contrast, the OSB's WE was influenced considerably by bamboo species, specific pressure, and their interaction (Table 4). Subsequent Tukey's tests (Table 3) showed tali bamboo-based OSB had a higher TS and WE than andong bamboo-based OSB. All OSB manufactured at a specific pressure of 25 kg/cm^2 also had higher WE than OSB manufactured at a specific pressure of 30 kg/cm^2.

The effect of bamboo's strand length on the OSB's TS and WE varied, depending on the bamboo species and the specific pressure being applied. The TS of tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 tended to increase as the strand length increased. When a specific pressure of 30 kg/cm^2 was applied, the TS of both tali and andong bamboo-OSBs tended to decrease as the strand length increased. Andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 with a strand length of 75 mm and 150 mm had the lowest WE (0.34%) and the lowest TS (2.53%), respectively (Table 3). Thus, among other OSBs produced in this study, both andong-bamboo OSBs allegedly exhibited the most stable dimension. High pressure could cause the adhesive to spread evenly and cure rapidly within and between layers, thus enhancing the internal bonding between strands.

Water absorption

The OSB's average water absorption (WA) ranged from 25.2% to 35.8% (Table 3). The lowest WA value occurred for andong bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 with a strand length of 75 mm. The result obtained was very similar to the WA of andong bamboo-based strand board bonded with phenol-formaldehyde, which ranged from 22.8% to 29.6% (Sulastiningsih *et al.* 2019); or the WA of moso bamboo-based OSB bonded with MDI (which was 23.6%) at the targeted density of 0.73 g/cm^3 (Sumardi and Suzuki 2014). The comparable result with the andong-bamboo strand board reported by Sulastiningsih *et. al.* (2019) could be due to having the same manufacturing process and strand length or type used but with different strand orientation arrangement between OSB produced in this study and strand board in the previous study. The average density of andong-bamboo OSB in this study (0.75 g/cm^3) was closely similar to that of moso-bamboo OSB (Sumardi and Suzuki 2014). A previous study reported that density did affect the water absorption of wood-composite products, *i.e.*, particleboard (Esteves *et al*. 2023).

The WA values of bamboo-OSB manufactured in this study were also lower than those of OSBs manufactured from the mixture of 60% *Calophyllum inophyllum* and 40% *Paulownia coreana* strands (varied from 47.2% to 54.8%) and glued with self-synthesized phenol-formaldehyde and phenol-urea-formaldehyde (Oh and Kim 2015). The bamboo OSB in this study had a higher density than the OSB from a previous study (Oh and Kim 2015). It has been reported that composite boards with higher density absorbed water less than those with lower density (Esteves *et al.* 2023).

The ANOVA results showed the bamboo species, specific pressure, and the interaction between specific pressure and strand length significantly affected the OSB's WA (Table 4). Subsequent Tukey's tests (Table 3) revealed that tali bamboo-based OSB had a higher WA value than andong bamboo-based OSB. All OSB manufactured at a specific pressure of 25 kg/cm^2 had smaller WA values than those manufactured at a specific pressure of 30 kg/cm^2. Increasing the strand length of bamboo also tended to change the OSB' WA values with the magnitudes depending on bamboo species and specific pressure.

Mechanical Properties

The internal bond strength

The internal bond strength (IB) or tensile strength perpendicular to the board surface is a crucial property determining the bonding quality of the composite board. The average IB values of the manufactured OSB ranged from 0.53 to 0.79 MPa (Table 5). This result was similar to those obtained for betung bamboo-based OSB (Febrianto *et al.* 2012) and andong bamboo-based strand board (Sulastiningsih *et al.* 2019). The comparable results from this study with andong-bamboo strand board from a previous study (Sulastiningsih *et.al.* 2019) are possibly due to differences in the strand orientation arrangement but with similar other technical parameters for the manufacturing process. The density of bamboo-OSB from this study was closely similar to betung-bamboo OSB from the previous study (Febrianto *et al.* 2012). This fact could be the reason behind their similarity in IB values. Further, the density of composite boards, such as particle boards, has been reported to significantly affect the board's IB (Esteves *et al.* 2023).

The IB values of all bamboo-based OSB in this study were higher than those of OSB made from black spruce and trembling aspen (Zhuang *et al.* 2022a). The highest IB value occurred for tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 and strand length of 100 mm. All IB values of bamboo-based OSB in this study met the requirements of JIS A 5908 (2015) for type 24-10 (OSB type) particleboard (minimum IB of 0.3 MPa and BS EN 300 (2006) for Type OSB/1 (minimum IB of 0.28 MPa) Type OSB/4 (minimum IB of 0.45 MPa).

The ANOVA results showed a significant effect of pressure levels (B); interaction between bamboo species and strand length (A*C), interaction between bamboo species and specific pressure (A*B), and interaction of all three main factors (A*B*C) on the IB values of OSBs in this study (Table 6). Subsequent Tukey's tests (Table 5) indicated that tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 had higher IB values than OSB manufactured at a specific pressure of 30 kg/cm^2. Increasing the strand length of bamboo also tended to change IB values, with the magnitudes depending on bamboo species and specific pressure.

The screw-holding power

The average screw-holding power (SHP) values of the manufactured OSB ranged from 524 to 875 N (Table 5). The highest SHP value (875 N) occurred for tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 and strand length of 150 mm. The lowest SHP occurred for andong bamboo-based OSB (524 N) manufactured under the same processing pressure and strand length. These results indicate that tali bamboo-based OSB had the best ability among other OSB compositions investigated in this study in maintaining the screw position and resisting it from being pulled out under external force. All SHP values of the manufactured OSB in this study also met the Japanese Industrial Standard (JIS A 5908 2015) requirement (500 N) for type 24-10 (OSB type) particleboard.

Nevertheless, the SHP values of bamboo-based OSB in this study were lower than those reported in a previous study by Hidayat *et al.* (2013). This situation is possibly due to the use of low-density wood raw materials, *i.e.*, *Paraserianthes falcataria* (0.36 g/cm^3), *Maesopsis eminii* (0.41 g/cm^3), and *Acacia mangium* (0.46 g/cm^3) in the OSB manufacture, which resulted in higher compression ratio to meet the targeted OSB density (0.70 g/cm^3). The higher compression ratio will result in better adhesive utilization because more adhesive-coated particles will be in intimate contact with other wood particles instead of voids (Kelly 1977).

Table 5. The Mechanical Properties of the OSB Fabricated from Andong and Tali Bamboo at Various Pressure Levels and Strand Lengths

Treatment Combination (ABC)	Mechanical Properties					
	IB (MPa)	SHP (N)	MOR-PR (MPa)	MOE-PR (MPa)	MOR-PP (MPa)	MOE-PP (MPa)
A1B1C1	0.76 ab (0,03)	655.1 bc (85,5)	43.4 g (0,6)	5393 fg (153)	29.8 bcd (1.04)	1963 d (309)
A1B1C2	0.79 a (0.06)	677.3 bc (52.7)	49.8 efg (5.1)	6552 ef (839)	29.9 bcd (3.22)	2298 cd (257)
A1B1C3	0.73 abc (0.02)	874.8 a (66)	58.2 cde (2.4)	7858 de (665)	32.4 bc (2,55)	2860 abc (143)
A1B2C1	0.66 abcd (0.06)	744.0 ab (52.7)	46.1 fg (1)	7909 cde (149)	30.5 bcd (2.16)	2026 d (268)
A1B2C2	0.60 cd (0.05)	558.3 c (37.7)	60.4 bcde (4.5)	8798 bcd (537)	29.9 bcd (5)	2368 bcd (337)
A1B2C3	0.53 d (0.02)	557.2 c (65.2)	71.0 ab (4.8)	9838 ab (441)	37. 9 ab (4.11)	3323 a (310)
A2B1C1	0.62 bcd (0.05)	570.1 c (36.2)	46.3 fg (2.2)	5138 g (254)	33.7 abc (2.49)	3066 ab (151)
A2B1C2	0.60 cd (0.06)	555.7 c (37.7)	61.6 bcd (2.7)	7819 de (549)	23.4 d (3.13)	2211 cd (174)
A2B1C3	0.62 bcd (0.09)	524.3 c (22.3)	58.6 cde (5.3)	8954 bcd (323)	33.7 abc (2.92)	2486 bcd (203)
A2B2C1	0.63 bcd (0.06)	543.9 c (35.4)	54.4 def (2.3)	8492 bcd (87)	28.7 cd (1.98)	1968,0 d (128)
A2B2C2	0.71 abc (0.02)	617.2 bc (77.1)	66.8 abc (3.7)	9308 abc (720)	42.2 a (1.49)	3358 a (297)
A2B2C3	0.73 abc (0.06)	647.2 bc (19.6)	72.6 a (4.9)	10370 a (244)	34.7 abc (3.96)	3347 a (212)

Notes: A = bamboo species (A1 = tali bamboo, A2 = andong bamboo), B = specific pressure (B1 = 25 kg/cm^2, B2 = 30 kg/cm^2), C = strand length (C1 = 75 mm, C2 = 100 mm, and C3 = 150 mm); Values in parentheses are standard deviations; Each value was the average of 3 replications; IB = internal bond strength; SHP = screw-holding power; MOR-PR = modulus of rupture parallel to the surface; MOE-PR = modulus of elasticity parallel to the surface; MOR-PP = MOR perpendicular to the surface; MOE-PP = MOE perpendicular to the surface; Values followed with the same letter within the same column were not significantly different (according to Tukey's tests)

The ANOVA results showed that bamboo species (A); interaction between bamboo species and specific pressure (A*B); interaction between bamboo species and strand length (A*C); interaction between specific pressure and strand length (B*C); and interaction of all three factors (A*B*C) significantly affected the SHP values of bamboo-based OSB in this study (Table 6). Subsequent Tukey's tests (Table 5) showed that tali bamboo-based OSB had higher SHP values than andong bamboo-based OSB. Tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 also had higher SHP than those manufactured at a specific pressure of 30 kg/cm^2. However, andong bamboo-based OSB gave contradicting results. Similar to the IB case above, increasing the bamboo's strand length caused varying trend changes in the SHP values, with values depending on bamboo species and the applied pressure. The results obtained from this study were different from previous research findings, in which SHP was influenced more by processing parameters than the types or basic properties of the materials used in OSB or plywood manufacture (Erdil *et al.* 2002). Research on the manufacture of corn straw fiber brick has also demonstrated that the brick's surface and side-screw holding were significantly affected by the corn straw mass and processing parameter, *i.e*., cold press time (Gao *et al.* 2018).

The MOE

Table 5 shows that the average values of MOE, parallel and perpendicular to the OSB surface grain, were 5,140 to 10,400 MPa and 1,970 to 3,360 MPa, respectively. The highest values of MOE parallel (10,400 MPa) and perpendicular to the surface grain (3,360 MPa) occurred for andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 and bamboo's strand length of 100 to 150 mm. All MOE values of bamboo-based OSB in this study met JIS A 5908 (2015) requirements for type 24-10 (OSB type) particleboard (4000 and 1300 MPa) and BS EN 300 (2006) requirements for Type OSB/1 (2500 and 1200 MPa) to Type OSB/4 (4800 MPa and 1900 MPa).

The values of MOE parallel to the surface grain of bamboo OSBs in this study were comparable to those of OSBs prepared from four different Canadian wood species (balsam fir, trembling aspen, black spruce, and jack pine) (Zhuang *et al.* 2022b). However, their values were higher than those of OSB prepared from the mixture of *Calophyllum inophyllum*'s and *Paulownia coreana'*s strands that were glued with synthesized phenol-formaldehyde and phenol-urea-formaldehyde (Oh and Kim 2015), OSB prepared from CCB treated fast-growing tree species strands (Hidayat 2013), OSB prepared from steam-treated bamboo strands (Febrianto *et al*. 2015), and OSB prepared from resinous and broad-leaved fast-growing species (Lunguleasa *et al*. 2021). These differences may be due to different processing parameters used during the OSB manufacture from each previous study mentioned above.

The ANOVA results showed the bamboo species (A), pressure levels (B), strand length (C), and the interaction between pressure levels and strand length (B*C) significantly affected both MOE parallel and perpendicular to the surface grain of OSB in this study (Table 6).

Table 6. Summarized Results of Analysis of Variance on Mechanical Properties of OSB from Tali and Andong Bamboo

Sources of Variation	F Calculated					
	IB	SHP	MOE-PR	MOR-PR	MOE-PP	MOR-PP
Bamboo species (A)	2 .11 ns	33.84 **	15.32 **	18.39 **	10.83 **	1.02 ns
Pressure level (B)	6.85 **	3.29 ns	185.76**	53.09 **	9.63 **	12.32 **
Strand length (C)	0.54 ns	2.61 ns	84.14 **	71.76 **	28.84 **	6.02 **
A*B	48.25 **	23.41 **	0.26 ns	0.03 ns	0.42 ns	2.04 ns
A*C	5.16 *	4.07 *	2.09 ns	3.76 *	7.50 **	1.19 ns
B*C	0.01 ns	4.56 *	5.93*	3.70 *	22.60 **	10.96 **
A*B*C	3.25 *	21.21 **	2.50 ns	1.62 ns	16.76 **	15.68 **

Notes: IB = internal bond strength; SHP = screw-holding power; MOR-PR = modulus of rupture parallel to the OSB surface; MOE-PR = modulus of elasticity parallel to the surface; MOR-PP = MOR perpendicular to the surface; MOE-PP = MOE perpendicular to the surface; **= highly/very significant (F Calculated > F Table at 99% confidence level); **= significant (F Calculated > F Table at 95% confidence level); ns = non-significant (F Calculated < F Table at 95% confidence level)

The MOE perpendicular to the OSB surface grain was also significantly affected by the interaction between bamboo species and strand length (A*C) and the interaction of all three main factors (A*B*C). Subsequent Tukey's tests (Table 5) indicated that the MOE parallel and perpendicular to the surface grain' values of tali bamboo-based OSB tended to be lower than those of andong bamboo-based OSB. All values of MOE parallel and perpendicular to the surface grain of OSB manufactured at a specific pressure of 25 kg/cm^2 were lower than those OSBs manufactured at a specific pressure of 30 kg/cm^2. Higher pressure may compress the fibers better than the low pressure, rendering the fiber bond more compact and stronger. Increasing the strand length of bamboo also increased the MOE parallel and perpendicular to surface grain values. These results agreed with previous studies (Suzuki and Takeda 2000; Sumardi *et al.* 2008; Beck *et al.* 2009; Febrianto *et al.* 2012).

The MOR

The average values of MOR, parallel and perpendicular to the OSB surface grain direction, were 43.4 to 72.6 MPa and 23.4 to 42.2 MPa, respectively (Table 5). The highest MOR parallel to the surface grain,72.6 MPa, was obtained for andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 and strand length of 150 mm. On the other hand, the highest MOR perpendicular to the surface grain, 42.2 MPa, occurred for andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 and strand length of 100 mm. These results could be due to their strand's slenderness ratios, which were higher than others. A study on the production of particleboards from poplar (*Populous alba*) has revealed that particles with higher slenderness ratio tended to improve the boards' MOE and MOR than those with lower slenderness ratio (Arabi *et al.* 2011).

The values of MOR parallel to the surface grain of bamboo-based OSB in this study were higher than those of OSB, as reported in previous studies (Suzuki and Takeda 2000; Sumardi *et al*. 2008; Hidayat *et al*. 2013; Febrianto *et al*. 2015; Sulastiningsih *et al*. 2017; Iswanto *et al*. 2019; Lunguleasa *et al.* 2021; Zhuang *et al*. 2022a). All MOR values of bamboo-based OSB in this study met the JIS A 5908 (2015) requirements for type 24-10 (OSB type) particleboard (24 and 10 MPa). They also met the BS EN 300 (2006) requirements for Type OSB/1 (18 MPa and 9 MPa) to Type OSB/4 (28 MPa and 15 MPa).

The ANOVA results (Table 6) showed that the pressure levels (B), strand length (C), and the interaction between pressure levels and strand length (B*C) significantly affected both MOR parallel and perpendicular to the surface grain of OSB in this study. The MOR parallel to the surface grain of OSB was also significantly affected by the bamboo species (A) and the interactions between bamboo species and strand length (A*C). On the other hand, the MOR perpendicular to the surface grain of OSB was significantly affected by the interaction between bamboo species, pressure levels, and strand length (A*B*C). Tukey's tests (Table 5) revealed that the MOR parallel and perpendicular to the surface grain of tali bamboo-based OSB tended to be lower than those of andong bamboo-based OSB. The possible reason is that tali bamboo-based OSB had a lower compression ratio (1.21) than andong bamboo-based OSB (1.31). The increasing compression ratio resulted in a more sufficient interparticle contact area, better adhesive utilization, and good bonding. The MOR parallel and perpendicular to the surface grain of OSB manufactured at a specific pressure of 25 kg/cm^2 were lower than those from OSB manufactured at a specific pressure of 30 kg/cm^2. Higher pressure may cause more compact fiber bonds, resulting in stronger OSB, which can withstand heavy loading strain. Similar to the previous MOE case above, increasing the strand length of bamboo also increased the values of MOR parallel and perpendicular to the surface grain of OSB in this study. The results obtained from this investigation contradict a recent study by Zhuang *et al.* (2022a). Those authors found the strand length only positively affected the parallel strength properties of OSB made from black spruce and trembling aspen, but not the perpendicular version.

CONCLUSIONS

1. All oriented strand boards (OSBs) prepared from tali and andong bamboos with three strand length variations (75, 100, and 150 mm) and compressed at two pressure levels (25 and 30 kg/cm^2) met the category of medium-density board.
2. The bamboo species, pressure levels, and strand length affected the thickness swelling, width expansion (WE), and water absorption (WA) of bamboo-based OSB in this study.
3. Andong bamboo-based OSB manufactured at a specific pressure of 30 kg/cm^2 and strand length of 150 mm had the most stable dimension and the highest of both modulus of elasticity (MOE) and modulus of rupture (MOR)-parallel-to-surface grain. The OSB manufactured from the same bamboo species and at the same pressure level but with a strand length of 100 mm exhibited the highest MOE and MOR-perpendicular to-surface grain.
4. Tali bamboo-based OSB manufactured at a specific pressure of 25 kg/cm^2 and strand length of 100 mm had the highest internal bond strength (IB). The OSB manufactured from the same bamboo species and at the same pressure level but with a strand length of 150 mm exhibited the highest screw-holding power (SHP).
5. Tali bamboo-based OSB tended to have higher water absorption, internal bonding, and screw-holding power but lower dimensional stability (indicated by thickness swelling and width expansion values) and bending strengths (indicated by MOE and MOR values) than that of andong bamboo-based OSB.
6. Increasing the bamboo strand length also increased the MOE and MOR parallel and perpendicular to surface grain OSB values. However, the best OSB was obtained from andong bamboo with a strand length of 150 mm and a specific pressure of 30 kg/cm^2.

ACKNOWLEDGMENTS

The authors convey their gratitude to the Ministry of Environment and Forestry of Indonesia for providing the grants and required facilities for the study.

REFERENCES CITED

Abdullah, A. H. D., Karlina, N., Rahmatiya, W., Mudaim, S., Patimah, and Fajrin, A. R. (2017). "Physical and mechanical properties of five Indonesian bamboos," *IOP Conference Series: Earth and Environmental Science* 60, article ID 012014. DOI: 10.1088/1755-1315/60/1/012014

Akrami, A., Barbu, M. C., and Frühwald, A. (2014). "European hardwoods for reducing dependence on pine for oriented strand board," *International Wood Products Journal* 5(3), 133-135. DOI: 10.1179/2042645314Y.0000000073

Arabi, M., Faezipour, M., Layeghi, M., and Enayati, A.A. (2011). "Interaction analysis between slenderness ratio and resin content on mechanical properties of particleboard," *Journal of Forestry Research* 22(3), 461-464 DOI 10.1007/s11676-011-0188-2

Arabi, M., Haftkhani, A.R., and Pourbaba, R. (2023). "Investigating the effect of particle slenderness ratio on optimizing the mechanical properties of particleboard using the response surface method," *BioResources* 18(2), 2800-2814. DOI: 10.15376/biores. 18.2.2900-2814

Barbirato, G. A., Gauss, C., Júnior, W. E. L., Martins, R., and Fiorelli, J. (2022). "Optimization of castor oil polyurethane resin content of OSB panel made of *Dendrocalamus asper* bamboo," *Ciencia Florestal* 32(1), 187-205. DOI: 10.5902/1980509846908

Beck, K., Cloutier, A., Salenikovich, A., and Beauregard, R. (2009). "Effect of strand geometry and wood species on strandboard mechanical properties," *Wood and Fiber Science* 41(3), 267-278.

BS EN 300 (2006). "Oriented stand boards (OSB) - Definitions, classification and specifications," British Standards Institution, London, UK.

Ciobanu, V. D., Zeleniuc, O., Dumitrascu, A. E., Lepadatescu, B., and Iancu, B. (2014). "The influence of speed and press factor on oriented strand board performance in continuous press," *BioResources* 9(4), 6805-6816. DOI:10.15376/biores.9.4.6805-6816

Damitrascu, A. E., Lunguleasa, A., Salca, E. A., and Ciobanu, V. D. (2020). "Evaluation of selected properties of oriented strand boards made from fast growing wood species," *BioResources* 15(1), 199-210. DOI: 10.15376/biores.15.1.199-210

Davinsy, R., Satria, E. D., Maulana, M. I., Nawawi, D. S., Sari, R. K., Maulana, S., Hidayat, W., and Febrianto, F. (2019). "Sifat fisis dan mekanis oriented strand board hibrida bambu pada berbagai shelling ratio [Physical and mechanical properties of hybrid bamboo oriented strand board at various shelling ratios]," *Jurnal Ilmu Teknologi Kayu Tropis* 17(2), 152-159.

Dransfield, S., and Widjaya, E. A. (1995). *Plant Resources of South East Asia No 7: Bamboos*, Backhuys Publishers, Leiden, Netherlands.

Erdil, Y. Z., Zhang, J., and Eckelman, C. A. (2002). "Holding strength of screws in plywood and oriented strandboard," *Forest Products Journal* 52(6), 55-62.

Esteves, B., Aires, P., Sen, U., Gomes, M. d. G., Guiné, R. P. F., Domingos, I., Ferreira, J., Viana, H., and Cruz-Lopes, L. P. (2023). "Particleboard production from *Paulownia tomentosa* (Thunb.) Steud. grown in Portugal," *Polymers* 15(5), 4-6. DOI: 10.3390/polym15051158

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), 2642-2655. DOI: 10.15376/biores.10.2.2642-2655

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 Science and Technology* 46, 53-62. DOI: 10.1007/s00226-010-0385-8

Furugi, A., and Yapici, F. (2021). "Optimization of production parameters in oriented strand board (OSB) manufacturing by using Taguchi method," *Drvna Industrija* 72(4), 347-352. DOI: 10.5552/drvind.2021.2033

Gao, Y., Wang, M., Ma, C., Jia, W., Lu, Z., and Long, C. (2018). "Single and multi-factor analysis on screw-holding power of corn straw fiber brick," *Construction and Building Materials* 181, 579-587. DOI: 10.1016/j.conbuildmat.2018.06.069

Gündüz, G., Yapici, F., Özçifçi, A., and Kalaycıoğlu, H. (2011). "The effects of adhesive ratio and pressure time on some properties of oriented strand board," *BioResources* 6(2), 2118-2124.

Hamzaçebi, C. (2016). "Optimization of process parameters in oriented strand board manufacturing by Taguchi method," *BioResources* 11(3), 5987-5993. DOI: 10.15376/biores.11.3.5987-5993

Hidayat, W., Sya'bani, M. I., Purwawangsa, H., Iswanto, A. H., and Febrianto, F. (2013). "Effect of wood species and layer structure on physical and mechanical propreties of strand board," *Jurnal Ilmu dan Teknologi Kayu Tropis* 9(2), 123-140.

Hiziroglu, S. (2009). "Properties of strandboard panels manufactured from eastern redcedar," *Materials* 2(3), 926-933. DOI: 10.3390/ma2030926

Iswanto, A. H., Idris, M., and Sucipto, T. (2019). "Effect of bamboo strand length on oriented strand board," *IOP Conference Series: Earth and Environmental Science* 260, article ID 012039. DOI: 10.1088/1755-1315/260/1/012039

JIS A 5908:2015 (2016). "Particleboards," Japanese Standards Association, Tokyo, Japan.

Kelkar, B. U. Shukla, S. R., Nagraik, P., and Paul, B. N. (2023). "Structural bamboo composites: A review of processing, factors affecting properties and recent advances," *Advances in Bamboo Science* 3, article 100026. DOI: 10.1016/j.bamboo.2023.100026

Kelly, M. W. (1977). *Critical Literature Review of Relationship Between Processing Parameters and Physical Properties of Particleboard* (General Technical Report: FPL-10), U.S. Department of Agricuture, Forest Service, Forest Products Laboratory, Madison, WI, USA.

Lunguleasa, A., Dumitrascu, A. E., and Ciobanu, V. D. (2020). "Comparative studies on two types of OSB boards obtained from mixed resinous and fast-growing hard wood," *Applied Science (Switzerland)* 10(19), article 6634. DOI: 10.3390/APP10196634

Lunguleasa, A., Dumitrascu, A. E., Spirchez, C., and Ciobanu, V. D. (2021). "Influence of the strand characteristics on the properties of oriented strand boards obtained from resinous and broad- leaved fast-growing species," *Applied Science (Switzerland)* 11(4), article 1784. DOI:10.3390/app11041784

Maloney, T. M. (1993). *Modern Particleboard and Dry Process Fibreboard Manufacturing*, Miller Freeman Publications, Inc., San Francisco, CA, USA.

Marra, A. A. (1992). *Technology of Wood Bonding: Priciples in Practice*, Van Nostrand Reinhold, New York, NY, USA.

Maulana, S., Sumardi, I., Wistara, N. J., Kim, N. H., and Febrianto, F. (2020). "Effects of compression ratio on physical and mechanical properties of bamboo oriented strand board," *IOP Conference Series: Materials Science and Engineering* 935(1). DOI: 10.1088/1757-899X/935/1/012063

Maulana, S., Taher, T., Rianjanu, A., Febrina, M., Agustina, S., Murda, R. A., Hidayat, W., and Bindar, Y. (2023). "Physical and mechanical properties of bamboo oriented strand board prepared from alkali-immersed strands," *Science and Technology Indonesia* 8(1), 1-8. DOI: 10.26554/sti.2023.8.1.1-8

Nugroho, N., Kartini, and Bahtiar, E. T. (2021). "Cross-species bamboo grading based on flexural properties," *IOP Conference Series: Earth and Environmental Science* 891(1), article ID 012008. DOI:10.1088/1755-1315/891/1/012008

Oh, Y. S., and Kim, J. M. (2015). "Properties of oriented strandboard bonded with phenol-urea-formaldehyde resin," *Journal of Tropical Forest Science* 27(2), 222-226.

Ott, R. L. (1994). *An Introduction to Statistical Methods and Data Analysis*, Duxbury Press., Belmont, CA, USA.

Pichelin, P., Pizzi, A., Frühwald, A. and Triboulot, P. (2002). "Exterior OSB preparation technology at high moisture content. Part 2: Transfer mechanisms and pressing parameters," *Holz als Roh- und Werkstoff* 60, 9-17, Springer-Verlag. DOI 10.1007/s00107-001-0270-0

Rahman, W. M. N. W. A., Tamat, N. S. M., Yunus, N. Y. M., and Kasim, J. (2021). "Size effect of core strands on the major physical and mechanical properties of oriented strand boards from fast growing tropical species," in: *Engineered Wood Products for Construction,* M. Gong (Ed.), InTechOpen, London, UK, pp. 1-13. DOI: 10.5772/intechopen.99953

Sackey, E. K., and Smith, G. D. (2009). "Empirical distribution models for slenderness and aspect ratios of core particles of particulate wood composites," *Wood and Fiber Science* 41(3), 255-266.

Salem, M. Z. M., Böhim, M., Sedivka, P., Nasser, R. A., Ali, H. M., and Albo Elgat, W. A. A. (2018). "Some physico-mechanical characteristics of uncoated OSB ECO-products made from Scots pine (*Pinus sylvestris* L.) and bonded with pMDI resin," *BioResources* 13(1), 1814-1828. DOI: 10.15376/biores.13.1.1814-1828

Sulastiningsih, I. M., Indrawan, D. A., Balfas, J., Santoso, A., and Iskandar, M. I. (2017). "Sifat fisis dan mekanis papan untai berarah dari bambu tali (*Gigantochloa apus* (J.A. & J.H. Schultes) Kurz) [Physical and mechanical properties of oriented strand board made of tali bamboo (Gigantochloa apus (J.A. & J.H. Schultes) Kurz)]," *Jurnal Penelitian Hasil Hutan* 35(3), 197-209. DOI: 10.20886/jphh.2017.35.3.197-209

Sulastiningsih, I. M., Indrawan, D. A., and Trisatya, D. R. (2019). "Some important properties of strandboard manufactured from andong bamboo (*Gigantochloa pseudoarundinacea*)," *IOP Conference Series Materials Science & Engineering* 593, article ID 012002. DOI: 10.1088/1757-899X/593/1/012002

Sumardi, I., and Suzuki, S. (2014). "Dimensional stability and mechanical properties of strand-board made from bamboo," *BioResources* 9(1), 1159-1167. DOI: 10.15376/biores.9.1.1159-1167

Sumardi, I., Kojima, Y., and Suzuki, S. (2008). "Effects of strand length and layer structure on some properties of strandboard made from bamboo," *Journal of Wood Science* 54(2), 128-133. DOI: 10.1007/s10086-007-0927-3

Sumardi, I., Suzuki, S., and Rahmawati, N. (2015). "Effect of board type on some properties of bamboo strandboard," *Journal of Mathematical and Fundamental Science* 47(1), 51-59. DOI: 10.5614/j.math.fund.sci.2015.47.1.4

Suzuki, S., and Takeda, K. (2000). "Production and properties of Japanese oriented strand board I: Effect of strand length and orientation on strength properties of Sugi oriented strand board," *Journal of Wood Science* 46(4), 289-295. DOI: 10.1007/BF00766219

Thoemen, H., Irle, M., and Sernek, M. (2010). "*Wood-Based Panels - An Introduction for Specialists*," ISBN 978-1-902316-82-6, Brunel University Press, London, UB8 3PH. England

Widjaja, E. A. (2012). "The utilization of bamboo: At present and for the future," in: *Proceedings of International Seminar Strategies and Challenges on Bamboo and Potential Non-Timber Forest Products (NTFP) Management and Utilization*, A. N. Gintings, and N. Wijayanto (Eds.), Ministry of Forestry, Forestry Research and Development Agency, Centre for Forest Productivity Improvement Research and Development, Bogor, Indonesia, pp. 79-85.

Zhuang, B., Cloutier, A., and Koubaa, A. (2022a). "Effects of strands geometry on the physical and mechanical properties of oriented strand boards (OSBs) made from black spruce and trembling aspen," *BioResources* 17(3), 3929–3943. DOI: 10.15376/biores.17.3.3929-3943

Zhuang, B., Cloutier, A., and Koubaa, A. (2022b). "Physical and mechanical properties of oriented strand board made from eastern Canadian softwood species," *Forests* 13(4), 1-11. DOI: 10.3390/f13040523

Article submitted: September 8, 2023; Peer review completed: November 4, 2023; Revised version received and accepted: March 10, 2024; Published: March 20, 2024.
DOI: 10.15376/biores.19.2.2863-2882