Effects of compression ratio on physical and mechanical properties of bamboo oriented strand board

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Abstract. The objective of this study was to evaluate the physical and mechanical properties of a bamboo-oriented strand board (BOSB) under various compression ratios. The raw material of BOSB was betung (Dendrocalamus asper) strand that steamed and followed by rinsing with a 1% NaOH solution. BOSB with the dimensions of 30 x 30 x 0.9 cm³ were manufactured with a compression ratio of five levels i.e. 1.15; 1.25; 1.35; 1.44; and 1.54. Three layers of BOSB were made with a shelling ratio of 50:50. Phenol formaldehyde (PF) adhesive (SC=43%) was added with 8% concentration, while paraffin was used as much as 1% of the dry weight of the oven strand. Strand geometry evaluation was carried out on 100 strands randomly. The physical and mechanical properties were evaluated according to JIS A 5908-2003. The results showed that relatively homogeneity strand geometry in this research was suitable to manufacture of BOSB. Increasing in BOSB compression ratio up to 1.54 increased mechanical properties. However, the increase of the BOSB compression ratio was decreased the dimensional stability. The optimum BOSB compression ratio was 1.35.

1. Introduction
Composite products such as Oriented Strand Board (OSB) are widely developed. Generally, the raw material of OSB is wood. However, wood supply decreases both quality and quantity. Therefore, OSB alternative material search efforts need to be conducted. One of the potential alternative materials for the OSB raw material is bamboo. It’s supported by Adrin et al. [2] and Chaowana [5] that reported that Bamboo has a match to be used as raw material for biocomposite products, particularly OSB.

Research on bamboo as a raw material of the oriented strand board has been done much. OSB products made of bamboo are called bamboo-oriented strand boards (BOSB). Previous research showed that BOSB had a better mechanical property compared to OSB [1,7]. However, BOSB is still using a relatively expensive, such as MDI. The cheaper adhesives such as PF could be applied, but high concentration was required. Therefore, modifications to the strand were applied to solve this problem [1].
Some research showed that modifications to the strand were successfully carried out to improved BOSB quality. The heat modification in the strand proved to improve BOSB dimensional stability and mechanical properties [1,6,18]. The chemical modifications in the strand after the steam process were done to removed extractive substance on the surface and improved the quality of BOSB [4]. However, the resulting BOSB still has a very high difference in parallel and perpendicular strength. Besides, physical modification i.e. by shelling ratio adjustment successfully carried out to regulated the parallel and perpendicular BOSB strength [7,16].

A series of studies have been conducted indicating that modifications to the raw materials in the form of strand have been done successfully improving the quality of BOSB. Another factor that needs to get attention in the manufacture of BOSB was a comparison between the density of board and raw materials. This comparison value was called the compression ratio. The strength of composite products such as BOSB increased with an increase in compression ratios [15]. However, increased compression ratios require more raw materials. It had been reported that the optimum compression ratio on the particle board was 1.3 [15]. However, there were no scientific reports of the optimum compression ratio value on BOSB. Therefore, the purpose of the study was to evaluate the physical and mechanical properties of BOSB at various compression ratios.

2. Materials and Methods

2.1. Materials
The main material used in this research was ±4 years betung bamboo (Dendrocalamus asper) 0.52 g/cm$^3$ densities from Sukabumi, West Java, paraffin, PF adhesive (SC=43%). The main equipment used in this research were digital balance, caliper, autoclaves, teflon, rotary blenders, oven, spray guns, hot press, dan Universal Testing Machine (UTM).

2.2. Methods
2.2.1. Strand treatment
Culms of bamboo with no nodes and bark converted into strand with target dimension 70 x 25 x 0.5 mm$^3$. Strand was given the steam modification treatment at a temperature of 126°C, pressure 1.4 kg/cm$^2$ for 1 hour and followed by rinsing using a 1% NaOH solution [4]. The modified strand was air-dried to a moisture content of ±15%. Strand was oven dried at 60-80°C for ±36 hours until a moisture content of <5% reached. The strand was measured by 100 samples taken at random to determine strand geometry both the strand aspect ratio (AR) and slenderness ratio (SR) [15].

2.2.2. BOSB manufacturing
BOSB was made with a dimension 30 x 30 x 0.9 cm$^3$ compression ratio of 1.15; 1.25; 1.35; 1.44; and 1.54. PF adhesive used with a concentration of 8% of the dry weight of the oven strand. BOSB structure was made of three layers with a shelling ratio of 50:50. Paraffin was added as much as 1% of the dry weight of the oven strand. The layers of BOSB was pressed for 9 minutes at a temperature of 135°C with a specific pressure of 25 kg/cm$^2$. The board was conditioned for ±2 weeks to eliminate residual tension.

2.2.3. Physical and mechanical properties evaluations
Physical and mechanical properties evaluations of BOSB were carried out according to JIS A 5908-2003 standard [13]. Physical properties evaluation include density, Moisture Content (MC), Water Absorption (WA), Thickness Swelling (TS). Mechanical properties evaluation includes Modulus of Elasticity (MOEs) and Modulus of Rupture (MOR) in parallel and perpendicular to the grain, and internal bonding (IB).

2.2.4. Data analysis
The experimental design used in the study was a simple completely randomized design with a single factor: compression ratio (five levels i.e. 1.15; 1.25; 1.35; 1.44; and 1.54). Each treatment was carried out in four replications. The physical and mechanical properties data obtained in this research were
analyzed statistically by using analysis of variance (ANOVA). The value of TS, MOE, MOR, and IB was compared to the OSB commercial standard CSA 0437.0 (Grade O-1) [19].

3. Results and Discussions

3.1. Strand geometry
The value of SR and AR was determined in this study to ensure that the strand size used in this study did not become a research factor. The strand geometry distribution is presented in Figure 1. The value of SR and AR obtained from the results of this research in succession was 114.28 and 3.03. This indicated that the strand was suitable for use as a BOSB raw material. The SR value above 60 was classified into a high SR value. To produce a composite with good mechanical properties required a minimum AR value of 3 [14]. High SR and AR values allowed composite boards to have high strength.

![Figure 1. (a) Distribution of SR and (b) AR values](image)

3.2. Physical properties of BOSB
The resulting BOSB density values were range from 0.60-0.81 g/cm³ (Figure 2a) and achieved a specified compression ratio. The results of the statistical analysis (α=0.05) indicated that the compression ratio provides a significant effect on the OSB density. The compression ratio relies heavily on the board density and the raw material density used. A high-density value of a board with the same raw material resulted in a higher value compression ratio. This caused the compactness of the board to increase. The results showed that the value of a BOSB MC ranged from 11.15-11.92% (Figure 2b). The value indicated that the whole MC of BOSB was uniform. It was supported by statistical analysis results (α = 0.05) which indicated that the compression ratio does not give a significant influence on the MC BOSB.

![Figure 2. (a) The value of density and (b) MC BOSB](image)
The WA values gained from the study ranged from 22.72-25.73% (Figure 3a). The results of the statistical analysis ($\alpha=0.05$) indicated that the compression ratio gives a significant effect on the WA of BOSB. Duncan's test results stated that the WA BOSB value of the compression ratio of 1.15 was the lowest WA value and differs from other BOSB. The value of TS obtained was approximately 5.6-9.60% (Figure 3b). The entire BOSB had met to the OSB commercial standard CSA 0437 (Grade O-1) [20]. The results of the statistical analysis ($\alpha = 0.05$) indicated that the compression ratio provides a significant effect on the value of TS. Duncan's test results stated that the TS BOSB value with the compression ratio of 1.15 differs from other BOSB.

![Figure 3. The value of WA (a) and TS (b) BOSB](image)

The research showed that increased compression ratios decreased dimensional stability. This was supported by increasing the value of both TS and WA by increasing the compression ratio. Higher compression rate values indicated that in one board there were more cell walls because more materials were needed. This caused BOSB with a higher compression ratio to have lower dimensional stability. This phenomenon in line with some previous reports showing increased compression ratios led to an increased value of TS [8,9,11].

### 3.3. Mechanical properties of BOSB

The value of parallel and perpendicular MOE BOSB was ranging from 4611-8101 MPa and 1529-2619 MPa, respectively (Figures 4a and 4b). The entire value of MOE BOSB had met the commercial standard CSA 0437 (Grade O-1). The results of the statistical analysis ($\alpha=0.05$) indicated that the compression ratio gave a significant effect on the value of MOE both parallel and perpendicular to the grain. The highest value of parallel and perpendicular MOE occurred in BOSB with a compression ratio of 1.54. It was also supported by Duncan's advanced test results stating that BOSB with the 1.54 compression ratio was different from other BOSB.

![Figure 4. (a) The value of MOE BOSB parallel and (b) perpendicular to the grain](image)
The value of parallel and perpendicular MOR BOSB was ranging from 24-46 MPa dan 18-22 MPa (Figures 5a and 5b). The entire MOR values perpendicular and parallel to the grain had met the standard set CSA 0437 (Grade O-1). The results of the statistical analysis ($\alpha=0.05$) indicated that the compression ratio provides a significant effect on both parallel and perpendicular MOR values. Duncan's test results stated that BOSB with the 1.54 compression ratio had a distinct MOR value with other MOR OSB.

![Figure 5. (a) The value of MOR BOSB parallel and (b) perpendicular to the grain](image)

The research showed that an increased compression ratio leads to an increased value of MOE and MOR BOSB. This phenomenon was in line with some research suggesting that high compression ratios produced high mechanical properties of composite boards [3,10,12,21,22]. The high compression ratio value indicated that the board was more compact. This was very supportive in the event of press voltage and pull at the time of testing MOE and MOR. Therefore, increasing the compression ratio increased MOE and MOR.

The average IB value of BOSB produced ranges from 0.30-0.34 MPa (Figure 6). The results of the statistical analysis ($\alpha=0.05$) indicated that the compression ratio provides a significant effect on the IB value. Duncan's test results stated that BOSB made with the compression ratio of 1.54 differs significantly from other BOSB. Research showed that an increase in compression ratios increases the IB value. High compression ratio values indicated a high compact board. This greatly affected the BOSB's mechanical properties including the IB value. This phenomenon was similar to previous research that increased IB was found with increasing compression ratios [3,10,12,21].

![Figure 6. The value of IB BOSB](image)

The research showed that IB values that had met the standard were BOSB made with a compression ratio of 1.35; 1.44; and 1.54. In other words, BOSB with a compression ratio of 1.35; 1.44; and 1.54 had met the entire OSB commercial standards. However, it should be noted that the higher the value of the
compression ratio, the higher the raw material requirements. Therefore, the optimum compression ratio in BOSB manufacturing from betung was 1.35.

4. Conclusions

The results showed that the increase in BOSB compression ratio up to the 1.5 level increased the mechanical properties, but decreased the dimensional stability. Optimum compression ratio in BOSB manufacturing was 1.35.

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