Surface modification of eco-friendly particleboard made from sorghum bagasse and citric acid sucrose adhesive

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Abstract. Eco-friendly particleboard made from sweet sorghum bagasse bonded with citric acid and sucrose was developed and met the minimum requirement of JIS standard. The surface roughness of particleboard which is important for coating with thin overlays, however did not measure yet. Therefore, the effect of particle size composition in surface modification of particleboard on the physical and mechanical properties of the panel was investigated. Sorghum bagasse has been used as raw materials in the manufacturing of three-layer particleboard. The composition of coarse particle (core layer) and fine particle (face and back layers) in the fabrication of particleboard was varied into four compositions such as A (0 (face): 100 (core): 0 (back)), B (12.75:75:12.75), C (25:50:25), D (37.5:25:37.5). Particleboard was bonded with 20 wt% of citric acid-sucrose (CAS) adhesive based on dry weight of particle and hot-pressing at 15 MPa and 200°C for 10 minutes. Dimension and target density of particleboards were 30 x 30 x 0.9 and 0.8 g/cm³, respectively. The physical and mechanical properties of the particleboard were evaluated according to JIS A 5908-2003. The Moisture Content (MC), Thickness Swelling (TS), Water Absorption (WA), Internal Bonding (IB) strength, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) values of the particleboard satisfied the requirements for the type 8 JIS A 5908-2003 standard. The particleboard made of composition C had lowest value of surface roughness. The addition of fine particle ratio on the surface layer lowered the WA and TS of the particleboard and slightly increased the IB strength. Further, the MOE and MOR of the particleboard was not affected by increasing fine particles on the surface layer. This study suggests that particle size composition remarkably affects the physical and internal bonding strength of particleboard, while it has less interference to the mechanical properties.

1. Introduction
Particleboard production in Europe has increased from 2016 to 2017. Particleboard production in 2016 amounted to 36.61 thousand m³ and increased to 36.80 thousand m³ in 2017 and is predicted to increase to 37.02 thousand m³ in 2018 [1]. However, the increase of particleboard production was not accompanied by the availability of raw materials from natural forests caused by deforestation in the world forests [2]. MoEF data [2] states in Indonesia from 2015 to 2016 there has been deforestation of 0.63 million ha. The future particleboard raw material requirements cannot potentially be [3]. As a result, other lignocellulose materials have an important role as an alternative raw material in the manufacture of particleboards. Another raw material of lignocellulose is sorghum (Sorghum bicolor (L.) Moench).
Sorghum has potential to be used as raw material for particleboard. The total area of sorghum of the world in 2020 is 40.81 million ha [4] and according to Pabendon et al. [5] the average of sorghum stem biomass is 23.06 tonnes/ha, while the average sorghum bagasse biomass is 4.89 tonnes/ha.

Iswanto et al. [6] and Khazaeeian et al., [7] successfully utilized sorghum bagasse for raw material particleboards using synthetic adhesives. The results of the study showed that the mechanical properties of the particleboard satisfied the requirements of JIS (Japanese Industrial Standard) and EN (European Norm). However, particleboards using synthetic adhesives have poor dimensional stability and commonly release formaldehyde emission. To overcome these problems, particleboard from sorghum bagasse was developed using citric acid (CA) and citric-sucrose (CAS) adhesive [8,9]. CA has been used as a natural cross-linker that promotes ester-type cross-linking [10]. In fact, a combination of CA with polysaccharides can be used as bio-based wood adhesives that produce durable and eco-friendly wood-based panels [11,12]. Particleboards bonded with CAS adhesive has a good quality showing a thickness swelling, modulus of elasticity, modulus of rupture, internal bond, and screw holding that satisfied JIS A 5908-2003 type 18 standards [9].

Sorghum bagasse particleboard bonded with CAS adhesive is still rough on the surface. The roughness of the surface increases the risk of fine defects on the particleboard surface. Fine defects on the board surface can reduced product grade, finishing and bonding qualities [13]. The effort to overcome this limited product particleboard by making a three-layer particle board with a smooth surface [13]. This study aims to evaluate the various layer compositions three-layer sorghum bagasse particleboards (TLSB-particleboard) bonded with CAS adhesives.

2. Materials dan Methods

2.1. Materials

The particle sorghum species super 1 were planted in research field at the Biotechnology Research Center on Indonesia Institute of Sciences (LIPI). The particles were milled, then sieved to size of 4-14 mesh for core and -60 mesh for face and back layers. The particle were dried at 80°C for 12 hours to keep moisture content less than 10%. CA and sucrosa of extra purity grade was purchased from MERCK (Jakarta, Indonesia). CA and sucrosa (CAS) was dissolved in distilled water with a final concentration of 59 wt.% and used as adhesive [8].

2.2. Methods

2.2.1. Particleboard manufactured

Particleboards with size of 30 × 30 × 0.9 cm and target density of 0.8 g/cm³ were manufactured according to Kusumah et al. [8], Kusumah et al. [3] and Kusumah et al. [9]. Around 20 wt.% of adhesive content based on dry weight particle, pressure of 15 MPa, pressing temperature of 200°C, pressing time of 10 min, and CA:sucrose ratios (10/90 wt.%) were used to prepare the panel. Based on the various layer compositions such as surface (face and back) and core layer, the TLSB-particleboard panels were classified into 4 types (Table 1). The particles were sprayed with CAS adhesive using a spray gun (Meiji, Japan) and then were pre-dried at 80°C for 12 hours [8]. Subsequently, the particles were hand-formed into a mat by using a forming box of 30 x 30 cm, followed by hot-pressing into TLSB-particleboard with a distance bar of 9 mm to control the thickness.

| Table 1. Various layer compositions |
|------------------------------------|
| Type of TLSB-particleboard | face:core:back (wt.%) |
| A  | 0:100:0 |
| B  | 12.5:75:12.5 |
| C  | 25:50:25 |
| D  | 37.5:25:37.5 |
2.2.2. Physical and mechanical testing
The TLSB-particleboard were conditioning for 1 week at a room temperature of 20°C at 60% of relative humidity (RH). The TLSB-particleboard properties were evaluated according to the Japanese Industrial Standard for Particleboards (JIS A 5908-2003) [14]. The Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bonding (IB) strength, Thickness Swelling (TS), Water Absorption (WA) after water immersion for 24 hours and screw holding (SH) power, were tested. The specimens of 20 x 5 cm were prepared for each board in the bending properties test. The three point bending test was conducted over an effective span of 150 mm at a cross-head speed of 10 mm/min using a universal testing machine (UTM, Shimadzu, Japan). Specimens sized 5 x 5 cm were prepared for each board in IB tests, and two specimens of the same size of each board were prepared for TS and WA tests after 24 hours water immersion at 20°C. The specimens of 10 x 5 cm from each board were prepared for the SH test. Two positions in the tested pieces were vertically screwed, and then the screws pulled out with a cross-head speed of 2 mm/min. The sample 5 x 5 cm were tested for their surface roughness using portable surface roughness tester (Mitutoyo, Japan), which average roughness (Ra) was used to evaluate roughness characteristics of TLSB-particleboard. Each experiment was performed in three replications, and the average values and standard deviations were calculated.

2.3. Data analysis
Data were analyzed using Microsoft Excel and IBM SPSS Statistics (Statistical Product and Service Solution ver. 23, United States). A simple completely randomized design with a single factor was used for data analysis. The factor analysis of variance tests of various layer compositions (face:core:back) (0:100:0, 12.5:75:12.5, 25:50:25 and 37.5:25:37.5) on physical and mechanical properties were evaluated. Duncan’s multiple range test was used for further analysis if the significance value of glue spread levels was significantly different at p-value <0.05.

3. Results and Discussion
3.1. Density and moisture content
The density and MC of TLSB-particleboard was 0.72-0.73 g/cm³ and 6.24%-6.62%, respectively, that was shown in Figure 1. The analysis of variance (ANOVA) shows that the density and MC were not significantly affected by various layer compositions (Table 2). The MC of TLSB-particleboard in this study was lower than the MC of particleboard bonded with synthetic adhesive (2.92-11.06) [6]. This is because the CAS adhesive resistant to water on the bio-composite products [15]. In addition, the formation of ester linkages from the reaction of –COOH of CA and –OH of sucrose or wood could improve the water resistancy of particleboard. The MC of resulting TLSB-particleboard was less than 13% which satisfied JIS A 5908-2003 standard.

![Figure 1. Density and MC of TLSB-particleboard](image)
Properties Sign Significant
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Density 0.959$^{\text{ns}}$
Moisture content (MC) 0.751$^{\text{ns}}$
Water absorption (WA) 0.020$^{**}$
Thickness swelling (TS) 0.000$^{**}$

Note: ns: not significant at 95% confidence interval; **: significantly different at 95% confidence interval

3.2. Water absorption and thickness swelling
Incorporation of fine particles remarkably affected the physical properties of particleboard. The WA and TS values decreased gradually as the fine particles ratio on the surface layer increased. As shown by ANOVA at p-value <0.05 (Table 2), the A type TLSB-particleboard had greater WA and TS than B, C, and D type TLSB-particleboard (Figure 2). These results indicated that the addition of fine particles on the surface layer effectively decreased the WA and TS values. The particleboards made from fine particles has greater water resistance, indicating that the adhesive system has excellent bonding performance. It is probably due to the larger surface contact area of fine particles than that of coarse particles [16]. Tabarsa et al. [13] states the combination of particle size and particle cavities on the particleboard will be reduced so the value of WA and TS decreases. Smaller particle size would fill the pores between coarse particles in the core of the particleboard [17]. The WA value of TLSB-particleboard was lower than that of the WA of particleboard bonded with CA [8].The TS value of all the TLSB-particleboard satisfied JIS A 5908 (2003) standard (> 12 %).

3.3. Modulus of Elasticity and Modulus of Rupture
The value of MOE and MOR was in the range of 1883-2263 MPa and 6.84-10.92 MPa, respectively (Figure 3). The MOE and MOR A types of TLSB-particleboard was higher than the MOE and MOR B, C, and D types of TLSB-particleboard as revealed by ANOVA at p-value <0.05 (Table 3). Tabarsa et al. [13] reported that the use of fine particles decrease MOE and MOR particleboard due to low adhesion between particles. The MOE and MOR value of TLSB-particleboard was inferior than the MOE and MOR of particleboard teak wood [18]. The type 8 JIS A 5908-2003 met MOE and MOR value of 2000 MPa and 8 MPa, respectively. The A and C particleboard of TLSB-particleboard was satisfied type 8 JIS A 5908-2003, while type B and D of TLSB-particleboard were not.
Figure 3. MOE and MOR of TLSB-particleboard.

Table 3. Analysis of variance (ANOVA) of various layer compositions on the mechanical properties of TLSB-particleboard.

| Properties               | Significant |
|--------------------------|-------------|
| Modulus of elasticity (MOE) | 0.046**     |
| Modulus of rupture (MOR)  | 0.000**     |
| Internal bond (IB)       | 0.153ns     |
| Screw holding (SH)       | 0.709n      |
| Surface roughness        | 0.023ns     |

*Note: ns: not significant at 95% confidence interval; **: significantly different at 95% confidence interval

3.4. Internal bond and screw holding

The IB strength values of the TLSB-particleboard gained slightly as the fine particles ratio increased. As depicted in figure 4, the IB strength values of the A, B to C increased, and then decreased for D type TLSB-particleboard. According to ANOVA results, the IB values of the A to D types of TLSB-particleboard were not statistically different at p-value > 0.05 (Table 3). Previous research [15] stated that fine particles might provide a larger contact areas and resulting a stronger bonding. The IB values of TLSB-particleboard were 0.16-0.30 MPa, which complied with the JIS A 5908-2003 standard (≤0.15 MPa). Besides, the IB values of TLSB-particleboard were comparable to particleboards teak wood bonded with CAS (0.2-0.3 MPa) [18].

The SH values of TLSB-particleboard were also investigated. The value was in the range of 129.23-169.86 N (Figure 4). Those SH values were about 50% lower than that of the particleboard bonded with CA (348 N) [3]. In addition, the SH of TLSB-particleboard was not satisfied the type 8 requirement of JIS A 5908-2003 (≥300 N). This result indicates that the addition of fine particle does not affect the SH of TLSB-particleboard as reveals by ANOVA at p-value >0.05 (Table 3). However, the addition fine particles slightly decreased the SH value of TLSB-particleboard.
The average Ra value for TLSB-particleboard were 1.58-3.01 µm (Figure 5). The A types of TLSB-particleboard has the highest Ra values than B, C, and D types of TLSB-particleboard as confirmed by ANOVA at p-value <0.05 (Table 2). Increasing the fine particles ratio on the surface layer would cause smoother surface TLSB-particleboard. Particleboard made from fine particles had a smoother surface compared to that of coarse particles [15].

4. Conclusion
The MC, TS, IB strength, MOE and MOR values of TLSB-particleboard satisfied the requirements for the type 8 JIS A 5908 (2003) standard. The addition of fine particles ratio on surface layer affected the value of WA and TS of TLSB-particleboard and slightly increased IB value of TLSB-particleboard. Meanwhile, the MOE and MOR TLBS-particleboard were not affected by increasing fine particles on the surface layer. The increasing of fine particles composition on surface layer improve the smoothness of the TLSB-particleboard.
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