Characteristics of Particleboards Made from Agricultural Wastes

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Abstract. The growth of particleboard production is parallel with the growth of world population. Yet, supply on wood chips as raw material for particleboard facing the shortage. Indonesia as a tropical country has various source of renewable resources, including agricultural residuals and non-wood forest product. This research was conducted to investigate the properties of particleboard made from core and rattan bark, from corn stalk and wood waste. Particles with moisture content less than 5% were mixed with adhesive. Phenol formaldehyde (PF) 10% was used as the adhesive. Mixed particles were then hot pressed for 10 minutes at 150°C with 25 Kgf/cm². Targeted density of the board was 0.7 g/cm³. Prior to testing, boards were conditioned for seven days at room temperature. Testing was conducted for physical and mechanical properties as well as the surface roughness. Standard for physical and mechanical properties referred to the JIS A 5908-2003. Results show that the particleboard from corn stalk had the lowest thickness swelling which was 16.7%. The highest modulus of rupture was given by particleboard from wood waste which was 21.69 MPa.

1. Introduction

Wood-based panels includes particleboard are getting more important since they can substitute solid wood for furniture and construction sectors. Particleboard is still the most excellent wood-based products due to its advantage, such as evenly distributed mechanical properties in all part of the board. Furthermore, particleboard can be produced from less-desired wood and several lignocellulosic non-wood materials such as bamboo and certain type of agricultural wastes, such as wheat straw, rice straw, sorghum stalks, coir, corn cob and corn stalks. The various raw materials for particleboards results in high yield production compare to those of solid wood. Specific application of particleboard is quite extensive such as buildings, automotive interiors, packaging and furniture [1]. All those applications are broadly used in Indonesia.

Data from FAOSTAT mentioned that in 2017, particleboard production in Indonesia was 125,000 m³. This makes Indonesia in 48 of world rank on particleboard production which was 0.1% of world share. In addition, during the last three years, the global production of particleboard is escalated. In 2017, the worldwide production of particleboard was approximately 95.5 million m² [2]. Demand on particleboard forecasted to rose due to the increase on necessity in furniture and building materials. The high demand on both interior and exterior housing parts as a result of high rate on population is increasing, especially in Indonesia which populated with approximately 266,8 million people in 2018.

Therefore, the objectives of this research were to investigate the suitability of several agricultural wastes as raw material for particleboard as well as the properties of particleboard.

2. Material and method

Material used for this research were core and skin of rattan waste, corn stalk, coir and wood waste. Rattan waste was supplied by PT. Rimba Makmur Utama (RMU), Katingan. Corn stalk and wood
waste were obtained from traditional farm in Dramaga, Bogor. Phenol formaldehyde as adhesive was purchased from PT. PAI Probolinggo.

2.1 Particle Preparation
Raw materials were manually chopped using ring flaker machine to obtain small size particle. Particle were sun-dried to reduce the moisture content. Following step was sieving the particle to retain 4-14 mesh. Particle at this stage has moisture content above 25%, thus oven dried process should be carried out. Oven drying was successfully reduce the moisture content particle into less than 5%, so that the particle can be processed into particleboard. Dry particle and adhesive were weighing according to formula. Formula calculation depends on targeted density of the particleboard.

2.2 Particleboard Production
Targeted density of particleboards was 0.7 g/cm$^3$ board and the board dimension was 30 cm x 30 cm x 1 cm. The phenol formaldehyde (PF) content was 10%. Particle and adhesive were mixed using drum mixer and spray gun. Afterwards, the mixture of particle and adhesive was spread in a 30 x 30 wood-square mould. Hot pressing was conducted for 10 minutes at temperature 150°C with pressure 25 kgf/cm$^2$. The particleboard was conditioned for 7 days at room temperature prior to physical and mechanical testing.

2.3 Particleboard Testing
2.3.1 Physical Properties. Testing for physical properties includes particleboard density, moisture content, thickness swelling and water absorption after 24 hours immersion.
- Particleboard density
  Density was calculated according to the following equation:

  \[ D = \frac{m}{v} \]  

  \[ D = \text{density (g/cm}^3\text{)} \]
  \[ m = \text{mass (g)} \]
  \[ v = \text{volume (cm}^3\text{)} \]

- Moisture content
  Dimension of test specimen for moisture content was 5 x 5 cm. The equation for moisture content is as follows:

  \[ mc = \frac{w2-w1}{w2} \times 100 \]  

  \[ mc = \text{Moisture content (%)} \]
  \[ w1 = \text{initial weight of the samples (g)} \]
  \[ w2 = \text{weight after oven (g)} \]

- Thickness swelling and water absorption
  Basically, the investigation on thickness swelling is based on the dimensional change of the test specimen (5 x 5 cm). The test specimen was immersed in water for 24 hours.

  \[ TS = \frac{T0-T1}{T1} \times 100 \]  

  \[ TS = \text{Thickness Swelling (%)} \]
  \[ T0 = \text{Wet thickness after water immersion (mm)} \]
  \[ T1 = \text{Dried Thickness (mm)} \]
• Water absorption was calculated with the following equation:

\[ wa = \frac{w_2 - w_1}{w_1} \times 100 \]

\[ wa = \text{water absorption (\%)} \]
\[ w_1 = \text{Weight at dry condition (g)} \]
\[ w_2 = \text{Weight after immersion (g)} \]

2.3.2 Mechanical Properties. Mechanical properties that were tested were flexural strength (modulus of rupture/MOR and modulus of elasticity/ MOE), internal bond and screw withdrawal. Flexural strength was tested using three points static bending test using Shimadzu Universal Testing Machine (UTM) 50 kN load cell. Internal bond and screw withdrawal were also tested using the same machine with different cross head.

2.3.3 Surface Roughness. Mitutoyo surface roughness tester type SJ-210 was used to test the average of surface roughness (Ra) of the particleboard. Measuring speed and pin top angle were 0.02 in/s and 90°.

3. Results and discussion

3.1 Physical Properties

3.1.1 Density and moisture content. The density of particleboard was ranged between 0.78 – 0.73 g/cm³, this result indicates that all the particleboard reached the targeted density (0.7 g/cm³). Particleboard made from wood waste has the highest density (0.78 g/cm³). Figure shows that all the particleboards have density that fulfil the Japan Industrial Standard (JIS) A 5908:2003 [3]. The standard requires the density of particleboard between 0.4-0.9 g/cm³. Density of particleboard is greatly affected by the density of raw materials. The graph shows that particleboard made from wood particles has the highest density compare to four other boards that made from non-wood materials. Those different value of board density as a result that wood particle has higher density compare to those corn, coir and rattan.

![Figure 1. Density and moisture content of particleboard.](image_url)

Moisture content of particleboard was 7.27-11.22%. The acceptable range of moisture content based on JIS A 5908:2003 is between 5-13%. Thus, all the particleboards have acceptable moisture content based on the standard. Particleboard from corn stalk had the highest moisture content (11.2%).
this was due to the characteristics of corn stalk that comprises by a pithy core and the long fibres at its outer layer [4]. Those components remarkably hydrophilic that easily absorbs moisture. Moisture content of raw materials is not totally released during the hot pressing therefore the moisture content of raw materials directly affected the moisture content of particleboard. Furthermore, liquid adhesive such as phenol formaldehyde contains water that can increase the moisture content of particleboard around 4-6% [5].

3.1.2. Thickness Swelling and Water Absorption. JIS standard mentioned that acceptable range of thickness swelling for particleboard is maximum 12%. The graph in Figure 2 shows that the best thickness swelling was performed by particleboard from corn stalk with the thickness swelling 16.7%, while the unsatisfied percentage of thickness swelling given by particleboard using coir which was 37.10%. Therefore, all the boards far above the standard value.

![Figure 2. Thickness swelling and water absorption of particleboard.](image)

Several factors that might be contributed to this condition are percentage of adhesive and the insufficient time for transformation of hydrophilic component of the fibres into hydrophobic products. it means that the addition on pressing time predicted to increase the thickness swelling properties [6]. Water absorption value is inline with thickness swelling percentage. As it is seen from the graph, the higher percentage of thickness swelling also the more particleboard absorbs water. There is no certain value on JIS regarding the percentage of water absorption for particleboard. The application of water repellent such as wax or paraffin may decrease the water uptake which leads to better thickness swelling properties.

3.2. Mechanical properties

3.2.1. Flexural Strength. The results test for MOR of all the particleboards are depicted in Figure 3. MOR values were around 10.1-21.7 MPa. The lowest MOR performed by particleboard from corn stalk and the highest given by particleboard from wood particles. JIS standard categorized particleboards into three types according to its value of MOR, type 8 with minimum MOR value 8 MPa, type 13 and 18. The result suggests that only particleboard made with corn stalk was classified in type 8. Another four particleboard are categorized as particleboard type 18.
Figure 3. Flexural strength value of particleboard.

Particleboard made from rattan core has MOR value that slightly different from particleboard made from wood. The low value of MOR on particleboard using corn stalk was caused by the small surface contact between particle and adhesive. Furthermore, corn particle is very light compared to the other materials. Beside percentage of adhesive, particle geometry and particle density has major impact on MOE and MOR of particleboard [7]. Regarding adhesive percentage, the more adhesive gives the higher MOR, yet increase the production cost. High amount of adhesive increases the bond contact among individual particles which led to a superior MOR [8].

3.2.2. Internal Bond. Internal bond values of particleboards were 0.35-1.46 MPa. Particleboard from wood particles gave the topmost value while particleboard from rattan core was the lowest. Since JIS A 5908:2003 required 0.15 MPa as the minimum value of internal bond for particleboard type 8 thus all particleboards satisfy the standard. Distribution of adhesive on particle significantly influenced internal bond properties.

Figure 4. Internal Bond and Screw Withdrawal value of Particleboard

Internal bond of panels is the most depictive mechanical properties for characterising particleboard, both for internal and external laboratories purposes. Using the result from internal bond testing, particleboard can be promptly assessed for suitability for edge machining, among other properties [9]. According to those insight, particleboard made from wood waste particle has an early sign for superior mechanical properties.
3.2.3. Screw Withdrawal. The highest screw withdrawal value on this research was 403.5 N obtained from particleboard made from coir. Since the JIS require minimum 300 N for screw withdrawal, particleboard with coir give the only screw withdrawal value that meet the JIS standard. Particleboard made from wood waste particle was slightly under the standard which was 295.3 N, the lowest value was given by particleboard made from rattan skin which was 158.6 N. The high value of screw withdrawal is influenced type of particle as its raw materials [10].

3.2.4. Surface Roughness. The average surface roughness of particleboard in this research was ranged 3.34-6.09 μm. Particleboard from wood had the smoothest surface while particleboard from rattan had the roughest. According to Hiziroglu and Suzuki, acceptable range of average surface roughness for particleboard was 3.67-5.56 μm [11]. Therefore, only particleboard from wood particles and rattan skin were acceptable according to the reference.

![Figure 5. Roughness average of particleboards.](image)

Surface quality of particleboard and other wood-based products play a major role on finishing and bonding characteristics. Data of surface characteristics on this research can be useful to estimate amount of finishing material that will be used. There are several ways to evaluate the surface characteristics, stylus method which is used in this research is argued as the simplest way yet provide reliable data. [12]. The better characteristics of surface roughness on particleboard from wood were also due to the better interaction of wood particles with PF as adhesive. Another finding reported that particleboard from non-wood materials (wheat straw) with urea formaldehyde resin as adhesive gives superior surface roughness [13]. Thus, surface roughness value also determined by the suitability of particles type with the adhesive.

4. Conclusion

Agricultural wastes that was used in this research were suitable as raw material for particleboard. All the boards were meet the targeted density which was 0.7 g/cm³. The highest moisture content was performed by particleboard made from corn stalk (11.2%) and the lowest was particleboard made from wood (7.27%). Thickness swelling of all particleboards had not meet the standard, yet, the best was 16% given by particleboard made from corn stalk. The highest thickness swelling was 37.10% given particleboard using coir, consequence with water absorption value which around 70%. Modulus of rupture (MOR) and internal bond (IB) of particleboard satisfied the standard of JIS A 5908-2003. Particleboard from corn stalk hasd the roughest surface with roughness average value approximately 8.19 μm, yet it had better physical properties among others.
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