Properties of particleboard made from Salacca (Salacca sp) frond

R Widyorini*, K B Aji, D N Anisa and G K Dewi
Departement of Forest Product Technology Forestry Faculty Universitas Gadjah Mada Jl. Agro no. 1, Bulaksumur, Yogyakarta 55281, Indonesia

*Corresponding author’s e-mail address: rwdyorini@ugm.ac.id.

Abstract. Salacca frond is a potential agricultural waste material that is not fully utilized yet. This study aimed to investigate the properties of particleboard made from salacca frond. The single-layer and three-layer particleboards were manufactured at three kinds of particle size. The particle size of the core layer was passed through a 10 mesh screen and retained on a 20 mesh screen (-10 +20 mesh). Two different particle sizes of face layer were passed through a 20 mesh screen and retained on a 40 mesh screen (-20 +40 mesh) and passed through a 40 mesh screen and retained on a 60 mesh screen (-40 +60 mesh). The target density of particleboard was set at 0.8 g/cm$^3$ to be pressed at a temperature of 180°C for 10 minutes. Citric acid was used as a bonding agent with 20 wt% based on the dry weight of particles. Physical and mechanical properties tests were performed according to the Japanese Industrial Standard (JIS) A 5908 for particleboard. The result showed that the single-layer particleboards had higher mechanical properties compared to three-layer particleboards. The highest properties of single-layer particleboard were achieved with the particle size of salacca frond of -40 +60 mesh. The properties of the board met the requirement of the JIS A 5908 type 13 standard. Based on this result, it showed that salacca frond has potential as a material for manufacturing particleboard.

1. Introduction
Indonesia has a large agricultural area and various types of agricultural land. Statistics Indonesia stated that the agricultural area in 2017 reached 37,132,382 Ha and the growth was 1.06% from 2016 [1]. Those areas were planted dominantly by oil-palm, sugar-cane, coconut, paddy rice, cassava, and fruit-plant [2]. One of the fruit plants that was widely cultivated is salacca (Salacca sp.). The productive area of salacca plantation in Indonesia was 27.231 Ha with 38,327,088 clumps in 2017. The annual growth area was 5-10% in 2015-2017 [3]. Salacca plant has an intensive plant maintenance that required its frond pruning every 2-4 months for optimizing fruit production. The waste was abundant and it can be a problematic environmental issue if the waste is not managed and utilized properly.

Salacca frond waste had been studied as raw material for particleboard and natural fiber resource due to its high lignocellulose content [4-7]. The citric acid based-particleboard with particles passed through 10 mesh, 20% adhesive content and be pressed at 180°C for 10 min has high mechanical properties that met the requirement of Japanese Industrial Standard (JIS) 5908. The physical properties (thickness swelling) of the board did not meet the standard, and the surface roughness of the particleboard was rather higher than the surface roughness of commercial particleboard (3.67-5.46) [8]. High quality of particleboard was characterized by high mechanical properties, low thickness...
swelling, and low surface roughness [9]. There are some efforts on improving the particleboard properties i.e. layering and fining the particles.

Layering is usually applied on particleboard manufacturing in the industrial scale. The layer is consisting usually of two faces layer with one core layer (three-layer particleboard) and the face layer was usually consisted of finer particles [10]. The finer particle produces a smoother surface than coarse particle [11], but the use of finer particles needs to be considered due to its effect on other properties like mechanical and physical properties. Fine particle produces higher internal bonding strength, but lower static bending strength (modulus of rupture and modulus of elasticity) than coarse particle [12]. This research aimed to investigate the properties of particleboard made from salacca frond with layering and particle size treatment.

2. Materials and Methods

2.1. Material
Salacca (Salacca sp.) frond were used as raw material and collected from Sleman District, Yogyakarta, Indonesia. The thorn was removed from the frond before it was ground in the knife ring flaker. The particles were then screened in 10 mesh, 20 mesh, 40 mesh, and 60 mesh screens. Salacca frond particles that passed through 10 mesh-retained in 20 mesh (-10 mesh +20 mesh) were used for the core layer, meanwhile the particles that passed through 20 mesh-retained in 40 mesh (-20 mesh +40 mesh) and passed through 40 mesh-retained in 60 mesh screen (-40 mesh +60 mesh) were used as the face layer. All the particles were air-dried (the MC was around 12%).

Citric acid (anhydrous) was used as adhesives and purchased from Weifang Ensign Industry Co. Ltd., without further purification. The adhesives were applied in a solution. Citric acid was dissolved in distilled water at a concentration of 59-60 wt%.

2.2. Manufacture of particleboard
The citric acid solution was sprayed onto salacca frond particles at 20% adhesive content based on the dry particle weight. The sprayed particles were then oven-dried at 80°C overnight (the moisture content was 4-6%) before it was hand-formed into a mat using a forming box with 25 cm x 25 cm size. The mat was hot-pressed at 180 °C for 10 min at 3 MPa specific pressure. The particleboard was made in three layers at different particle sizes as stated before. The face: core: face ratio was conducted at 1:1:1. The single-layer particleboard with different particle sizes was also made as the comparison. The target dimension was 25 cm x 25 cm x 1 cm and the target density were 0.8 g/cm³. The particleboards were then conditioned at room condition (the moisture content and the relative humidity was 26-29°C and ±77%, respectively) for one week before the board testing.

2.3. Evaluation of board properties
Japanese industrial standard (JIS) A 5908 for particleboard was applied for the board properties evaluation [13]. Physical and mechanical properties were tested. The density (D), moisture content (MC), thickness swelling (TS), water absorption (WA), and surface roughness (SR) of the particleboards were tested to find out the physical properties, meanwhile the internal bonding strength (IBS) and static bending strength (modulus of rupture and modulus of elasticity) were tested to determine the mechanical properties. The D (g/cm³) value was measured by dividing the sample weight and its volume. The MC (%) value was tested by dividing the weight change of the sample after oven-dried with its initial weight. The TS and WA (%) values were measured by dividing the thickness and the weight changes of a 5 cm x 5 cm sample after an immersion for 24 hours at room temperature with its initial thickness and weight. The SR (µm) value was measured at six random points on both surfaces of the board using SRG 400 (Bosworth Instrument, Cleveland, OH, USA). The mechanical properties were tested using Universal Testing Machine (UTM) Instron 3360 series (USA). The IBS value was tested using a 2 mm/min tension loading speed in a 5 cm x 5 cm sample. The static bending strength (modulus of rupture and modulus of elasticity) was tested by conducting
The static three-point on a 20 cm x 5 cm sample with a 10 mm/min load. The IBS, modulus of rupture (MOR) and modulus of elasticity (MOE) values were corrected to its value at target density by using regression. Those tests were conducted in triplicate with calculating the average and standard deviation.

3. Results and Discussions

All the board was manufactured without delamination. The density and moisture content values were ranged from 0.70-0.79 g/cm³ and 7.57-7.59%, respectively. The density did not meet the target density. Widening the dimension of the board during hot-press was the reason behind the phenomenon. The two lowest densities were obtained by the three-layer particleboard, and the three highest densities were obtained by the single-layer particleboard. Single-layer particleboard might have better compactness of inter-particles due to the same particle size for the whole board, so the density was higher than the three-layer particleboard. The board moisture content met the requirement of JIS A 5908 (5-13%) [13].

The thickness swelling, water absorption, and surface roughness are shown in Table 1. All the TS values met the requirement of JIS A 5908 (max. 12%) [13], except the single-layer particleboard with particle size of (-10 mesh +20 mesh). All the WA values met the requirement of the FAO standard (20-75%) [14]. The SR values in this research did not meet the SR value of commercial particleboard standard (3.67-5.46 µm) [8], but it had a value range around the SR value of commercial particleboard made from rubberwood (8.2 µm) [15]. Further treatment will be needed to improve the SR value.

Layering improved the physical properties of particleboard (decreasing the TS and SR values) by comparing it with a single-layer board with the particle size of (-10 mesh +20 mesh) (the particle size of core layer), but the WA values increased. The WA values of the three-layer particleboard were higher 12-28% than the single-layer particleboard and it increased due to the finer particle on the face layer. Finer particle has a larger contact area among particles compared to coarse particles [12], so it required more adhesive content for good bonding. The contact area that was not covered by the adhesives will bond with OH-groups from water, so the WA value was high.

The single-layer particleboard with fine particle size (-40 mesh +60 mesh) had the TS, WA and SR values lower than the three-layer particleboard, even with the same particle size on the face layer. As told before, the single-layer particleboard might have better compactness than the three-layer particleboard so the density was higher. High compactness and high density of the board might prevent water from entering onto particleboard. High density produced low surface roughness [16].

Table 1. The thickness swelling (TS), water absorption (WA) and surface roughness (SR) of the particleboards made from salacca frond

| Particleboard types | Particle size  | TS (%)    | WA (%)    | SR (µm)  |
|---------------------|---------------|-----------|-----------|----------|
|                     | -10 mesh +20 mesh | 12.41 ± 1.13 | 48.96 ± 2.07 | 9.17 ± 0.5 |
| Single-layer        | -20 mesh +40 mesh  | 11.32 ± 0.49 | 53.94 ± 1.13 | 8.05 ± 0.3 |
|                     | -40 mesh +60 mesh  | 7.23 ± 0.67  | 48.25 ± 1.04 | 5.91 ± 0.5 |
| Face particle size  |               |           |           |          |
|                     | Single-layer    |           |           |          |
|                     | -20 mesh +40 mesh  | 9.51 ± 0.61  | 60.62 ± 3.66 | 8.27 ± 0.20 |
| Three-layer         | -40 mesh +60 mesh  | 8.01 ± 0.48  | 61.53 ± 3.47 | 7.06 ± 0.11 |

The IBS value of three-layer particleboard was 50% lower than the single-layer particleboard (Figure 1). This result might be caused by the low bonding strength of the inter-layers. Further research is needed to improve the bonding strength of the inter-layers. The IBS value was increased along with the use of finer particles. A particle of (-40 mesh +60 mesh) produces higher IBS values than other particle sizes in the single-layer and three-layer particleboards. All the particleboard in this research has high IBS value because it could meet the requirement of JIS A 5908 type 18 (min. 3 MPa) [13].
Figure 1. The internal bonding strength (IBS) values of particleboard.

The MOR and MOE values of the three-layer particleboard tend to be lower than the MOR and MOE values of the single-layer particleboard (Figure 2). The MOR values of the three-layer particleboard at both particle size in the face layer were the same as the MOR value of single-layer particleboard with (-10 mesh +20 mesh). It was expected that the finer particle in the face layer did not affect the MOR value of particleboard made from salacca frond.

The MOR and MOE values tend to increase along with the use of the finer particle in the single-layer particleboard, but different trends were found in the three-layer particleboard. The three-layer particleboard with different particle sizes had similar MOR value, but the MOE value tends to decrease in the use of the finer particle. All the MOR and MOE value in this research met the requirement of JIS A 5908 type 8 (min. 8 MPa for MOR values and min 2 GPa for MOE values), even the MOE value of single-layer particleboard met the JIS A 5908 type 18 (min. 3 GPa) [13].

Figure 2. The static bending strength of particleboard made from salacca frond, a) modulus of rupture (MOR) and b) modulus of elasticity (MOE).

4. Conclusion
All the particleboard from salacca frond has a good physical and mechanical properties which met the requirement of JIS A 5908 for particleboard. The single-layer particleboard has higher mechanical properties compared to the three-layer particleboard. Finer particle has higher mechanical and physical properties in the single-layer particleboard. The best properties of particleboard were achieved by the single-layer particleboard with the particle size of salacca frond was -40 +60 mesh.
References

[1] Statistics Indonesia 2018 Agricultural Statistics 2018 Ministry of Agriculture, Republic of Indonesia Statistics Indonesia Jakarta

[2] NL Agency 2012 Indonesia-Market Opportunities for Bioenergy Ministry of Foreign Affairs Netherlands

[3] Statistics Indonesia 2018 Statistics of Annual Fruit and Vegetable Plants 2017 Statistics Indonesia Jakarta

[4] Darmanto S, Rochardjo H S B, Jamasri and Widyorini R 2017 Effects of alkali and steaming on mechanical properties of snake fruit (Salacca) fiber AIP Conference Proceedings 1788 DOI 10.1063/1.4968313

[5] Darmanto S, Rochardjo H S B, Jamasri and Widyorini R 2018 Effect on sonification treatment on fibrillating snake fruit (Sallaca) frond fiber AIP Conference Proceedings 1931 DOI 10.1063/1.5024123.

[6] Widyorini R, Umemura K, Septiano A, Soraya D K, Dewi G K and Nugroho W D 2018 Manufacture and properties of citric acid-bonded composite board made from Salacca frond: effect of maltodextrin addition, pressing temperature, and pressing method BioResources 13 8662-8676

[7] Widyorini R, Umemura K, Soraya D K, Dewi G K and Nugroho W D 2019 Effect of citric acid content and extractives treatment on the manufacturing process and properties of citric-acid-bonded salacca frond particleboard BioResources 14 4171-4180

[8] Hirizoglu S and Suzuki S V 2007 Evaluation of surface roughness of commercially manufactured particleboard and medium density fiberboard in Japan J. Mater. Process Technol. 184 436-440

[9] Pan Z, Zheng Y., Zhang R and Jenkins, B M 2007 Physical properties of thin particleboard made from saline eucalyptus Ind. Crop Prod. 26 185-194

[10] Berglund L and Rowell R M 2005 Wood Composites, In : R.M. Rowell, Ed., Handbook of Wood Chemistry and Wood Composites CRC Press Boca Raton Florida

[11] McNulty P, and Grace P M. Agricultural Mechanization and Automation vol. II. EOLSS Publisher, Co. Ltd. Oxford United Kingdom

[12] Widyorini R, Umemura K, Isnan R, Putra D R, Awaludin A and Prayitno T A 2016 Manufacture and properties of citric acid-bonded particleboard made from bamboo materials. Eur. J. Wood Wood Prod.74 57–65.

[13] JIS A 5908 2015 JIS for Particleboard Japanese Industrial Standard Tokyo

[14] FAO 1966 Plywood and Other Wood Based Panels Food and Agriculture Organization Rome.

[15] Hiziroglu S, Jarusombuti S. and Fueangvivat V 2004 Surface characteristics of wood composites manufactured in Thailand. Build. Environ. 39 1359-1364.

[16] Nemli G, Ozturk I and Aydin I 2005 Some of the parameters influencing surface roughness of particleboard. Build. Environ. 40 1337–1340.

Acknowledgments
This research was supported by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, under the recognition of final task (RTA) 2019 scheme.