Conference Paper

The Effects of Extractives Substances for Bonding Performance of Three Natural Binder on Nipa Fronds Particleboard

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Abstract

Nipa (*Nypa Fruticans* Wurmb) is a non-wood material that potential as a raw material of the composite board. One of the disadvantages of the nipa fronds is it contains very high extractives and inorganic substances. The presence of high content of extractives in raw material of particleboard potentially be an obstacle in the process of gluing the composite board. The existing of extractive substances on the surface of the composite board raw materials contributes to make the bonding process is not going well. On the other side, the utilization of natural binder for non–wood composite is still limited. Maltodextrin, sucrose, and citric acid is a potential natural binding agent for composite products. This research focused to investigate the effects of extractive substances for bonding performance of three natural binders (maltodextrin, sucrose, and citric acid) for nipa fronds particleboard. The particles screened passed through aperture sizes of 10 mesh and treated with three condition (un–extraction, hot water extraction, and n–hexane extraction) were used as materials in this research. The addition of natural binder of 10 % air dried particles was done and pressing temperature was set at 180 °C under a pressure of 3.6 MPa during 10 min. Physical and mechanical properties were done according to JIS A 5908 : 2003. The most optimum particleboards on this research was a citric acid bonded particleboard with hot water extraction which produces particleboard with characteristics i.e. density 0.84 g · cm^{-3}, moisture content 7.44 %; thickness swelling 1.12 %; water absorption 21.83 %; surface roughness 7.57 μm; internal bonding strength 0.49 MPa; modulus of rupture 10.42 MPa, and modulus of elasticity 3.65 GPa. All of the properties meet the 5908 : 2003.

Keywords: Citric acid, Extractives substance, Maltodextrin, Nipa frond, Particleboard, Sucrose

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1. Introduction

The results of the research conducted by Kruse and Frühwald stated that the particleboard from nipa fronds generally has a satisfactory characteristic for the purposes of furniture [1]. Roliadi et al. and Indrawan et al. also expressed the nipa fronds has better potential than the coconut husk as raw material composite board [2, 3]. Widyorini's research also proved that nipa fronds can be used as raw material of particleboard bonding with citric acid with the optimal quality particleboard obtained at 180 °C pressed temperature and 10 % of resin content [4]. It showed that the value of thickness swelling is 2.4 %, the water absorption is 41 %, internal bonding strength at 0.2 MPa, modulus of rupture (MoR) at 5.5 MPa, and modulus of elasticity (MoE) at 1.6 GPa. The results show that the MoR and MoE were still not meet the standards of JIS A 5908 : 2003 (at least 8 MPa for MoR and 2 GPa for MoE) [4, 5]. Nipa frond has a weakness as a raw material of particleboard that contains very high extractive substances and inorganic substances. According to Indrawan et al., the content of hot water extractive reaches 16.10 %, whereas the inorganic content ranged from 11.8 % to 13.80 % [1–3]. The extractive substances on the raw material of particleboard potential to become as obstacle in the gluing process. They are known have a negative influence on the quality of binding of the particleboard using synthetic adhesives [6, 7], as well as the natural adhesive like starch [8].

The synthetic wood binder based on formaldehyde compound has been used for a long time and has been known to have excellent performance, good working properties, and are economically adequate. However, these adhesives are carcinogenic to humans, it can cause irritation of the eyes and throat, respiratory disorders, and have a nature as non–renewable and non-biodegradable materials [9]. Many researches have been focusing on the reduction of the synthetic adhesives in wood-based materials production. With steadily increasing of environmental and healthy awareness, natural binders from renewable resources regained attraction as alternative bonding agents. Many studies on natural binder using bio-resources have been conducted to develop an eco–friendly bio–composites, such as citric acid [4, 10], citric acid with sucrose [11, 12], tannin with sucrose [13], also sucrose and starch [14]. Maltodextrin, sucrose, and citric acid have a potential to be developed as a natural binder for replace the synthetic adhesives based on formaldehyde [10, 11, 13–15]. Citric acid has been known to act as a natural binder that can provide excellent strength bonding [4, 10]. Sucrose also has been known to have the ability for bonding lignocellulosic material and may serve as an additive agent on the citric acid based binder [11, 12]. Maltodextrin is a product derived from starch by acid hydrolysis that has a better bonding properties than starch for carton board packaging and can be made as an extender for formaldehyde based adhesives [15, 16]. Citric acid has also been studied as a cross–linking agent for wood and starch [18]. Studies have shown that when citric acid is used as a cross–linking agent, the carboxyl groups from citric acid reacts with the hydroxyl groups from wood and reduces the hygroscopicity of wood as well as the tendency of wood to swell or shrink [19].

The study of the maltodextrin, sucrose, and citric acid as natural binders and how the extractive substances effect the bonding properties of the particleboard from nipa frond is not yet known, so the research on it is important in order to minimize the failure of the gluing process. The objectives of this study are to determine how the removal of these extractives by solvent extraction would improve the bonding performance by comparing the bonding strength of the un-extracted, hot water extracted, and n-hexane extracted nipa frond particle using maltodextrin, sucrose, and citric acid as binder.

2. Materials and Methods

2.1. Board materials

Nipa fronds particles were collected from Jatimalang Beach, Purworejo, Middle Java Province, and were used as the board material of this experiment. The particles were screened and those which passed through aperture sizes of 10 mesh were used as materials in this research. According to the mesh analysis of particle size, about 69 % of the particles used is between 10 mesh to 40 mesh, 6 % between 40 mesh to 60 mesh, 4 % between 60 mesh to 100 mesh, and 3 % passed through 100 mesh. All particles were air–dried to a moisture content of around 12 %. The nipa frond particles were extracted successively with a hot water at 100 °C for 3 h and n–hexane at ambient temperature for 48 h. All extracted particles were air-dried to a moisture content approximately 12 %.

2.2. Preparation of adhesive solution

Maltodextrin DE 10–15 from Zhuceng Dongxiao Biotechnology Co. Ltd. (China), sucrose from PT. Multi Kimia Raya Nusantara (Indonesia), and citric acid anhydrous from PT. Budi Starch & Sweetener (Indonesia), were used without further purification. Maltodextrin, sucrose, and citric acid were dissolved in distillated water with the solution concentration was adjusted variated to 50 % for maltodextrin and sucrose, and 60 % for citric acid (wt%).

2.3. Board manufacturing

The solution was used as an adhesive and sprayed onto the particles at 10 % and 20 % resin content based on the weight of air–dried particles. The sprayed particles were then oven-dried for 20 h at 80 °C to reduce the moisture content. The moisture content of the mat was 2 % to 5 %. The particles were hand–formed into a mat using a forming box followed by hot pressing into particleboards with a distance bar of 10 mm to control the board thickness. The boards were pressed at 200 °C for 10 min under a pressure of 3.6 MPa. The target density was 1 g · cm^{-3} with board size of 250 mm × 250 mm and three particleboard panels were prepared for each experimental variable. Prior to the evaluation of the physical and mechanical properties, all boards were conditioned at ambient conditions for approximately 2 wk.

2.4. Board evaluation

The particleboards were evaluated according to the Japanese Industrial Standard for Particleboards [5]. The tests were carried out to determine the density, moisture content, thickness swelling and water absorption, surface roughness, modulus of rupture, modulus of elasticity, and internal bond strength. Static three-point bending tests were conducted on a 200 mm × 50 mm × 10 mm specimen. The effective span and loading speed were 150 mm and 10 mm · min^{-1}, respectively. The density, moisture content, thickness swelling, water absorption, and internal bond strength test was performed on a 50 mm × 50 mm × 10 mm specimen cut from each board. The thickness swelling and water absorption tests after water immersion for 24 h at 20 °C. The surface roughness was measured using portable surface roughness tester (SRG-4000), where average roughness (Ra) was used to evaluate roughness characteristics of the particleboards and eight measurements were randomly taken from both surfaces of the 200 mm × 50 mm × 10 mm specimen. Each experiment was performed in triplicate, the average value and standard deviation were also been calculated.

3. Result and Discussion

3.1. Density and moisture content

All of particleboards in this research could be manufactured without any delamination, with the moisture content of particleboards ranged from 4.75 to 7.44 for all condition process. The boards density ranged from 0.77 g · cm^{-3} to 0.87 g · cm^{-3}, besides the manufacture condition. The boards bonded with citric acid were darker in color than boards bonded with sucrose and maltodextrin. The extraction treatment does not make a different color of the boards with same binder (Fig.1). The different color of the board with different binder might be attributed of the binder and other modification of chemical components during process. The darker color was also found at boards made from particles with citric acid, as also appeared in the acacia bark and wood molding [10, 11].

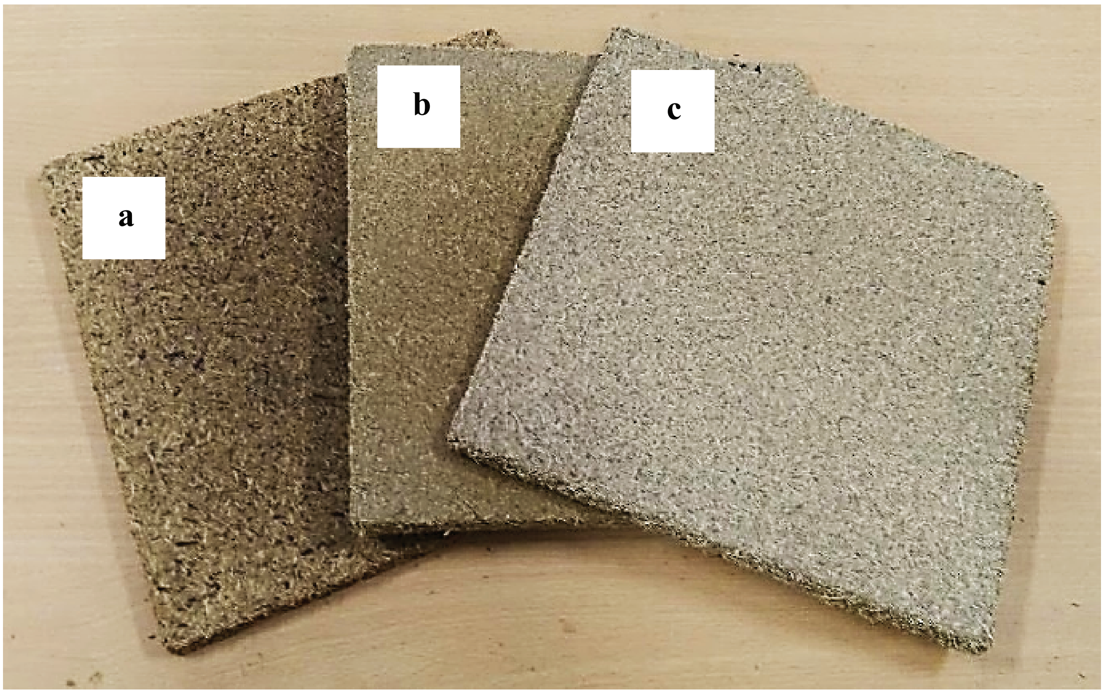

Figure 1: The particleboard from nipa frond bonded with (a) citric acid, (b) sucrose and (c) maltodextrin and hot water extraction treatment.

Fig. 2 shows the results of density and moisture content of the particleboards with various natural binder compositions and extraction treatment. The density was not significantly different by statistical analysis and meet the JIS A 5908 : 2003 for medium density particleboard about 0.6 g · cm^{-3} to 0.9 g · cm^{-3} [5]. This result indicates that the type of adhesive and extraction treatment has not been affecting to the density of particleboar

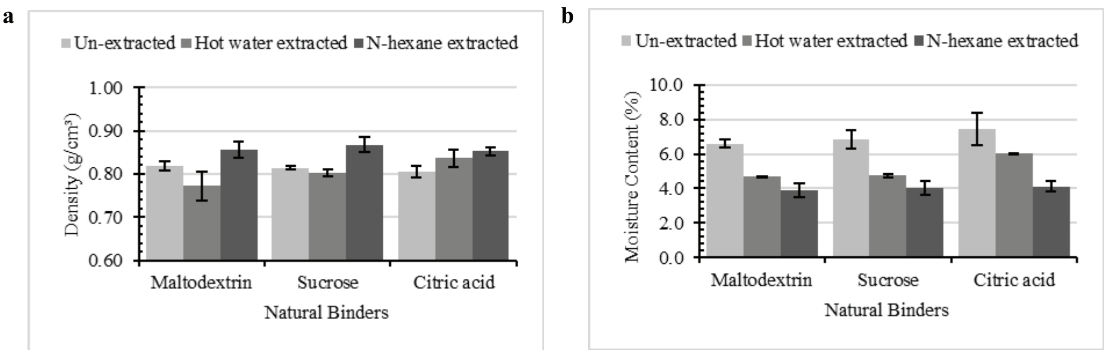

Figure 2: Density (a) and moisture content (b) of particleboard at various natural binder compositions and extraction treatments. The vertical bar represents standard deviation.

Moisture content value was not significantly different by statistical analysis that affect by the type of binders and significantly different that affect by the extraction treatment. All of particleboard made on this research have meet the JIS 5908 : 2003 standards that required the moisture content about 5 % to 13 % [5].

3.2. Thickness swelling and water absorption

The thickness swelling and water absorption of the bonded particleboards ranged from 4.19 % to 250.31 % and 21.83 % to 352.180 %, respectively. Fig. 3 shows the results of thickness swelling and water absorption (immersion at 20 ˚C for 24 h) of the particleboards with various of natural binders and extraction treatment.

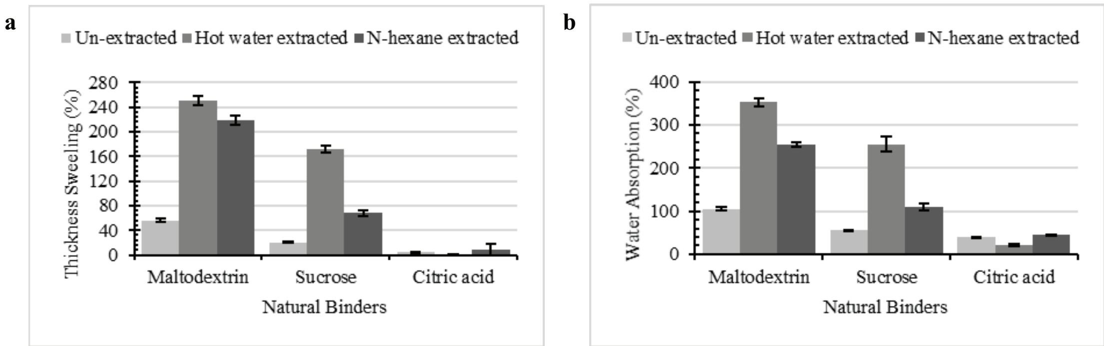

Figure 3: Thickness swelling (**a**) and water absorption (**b**) of particleboard at various natural binder compositions and extraction treatments. The vertical bar represents standard deviation.

It is obvious from Figure 3a and 3b that the citric acid bonded particleboards have a superior dimensional stability compared to maltodextrin and sucrose bonded particleboard. The optimum thickness swelling and water absorption on this research value were 1.12 % and 21.83 % with citric acid binder and hot water extraction treatment. The results clearly showed that most of the particleboards with added citric acid meet the requirements of JIS 5908 : 2003 (thickness swelling max 12 %) on the various extraction treatment. It showed that nipa frond particleboards bonded using citric acid had high performance on dimensional stability, as also found on citric acid bonded from softwood [10] and hardwood [12]. This is supposedly due to the ester-linked bonds ester linkages between carboxyl groups from citric acid with hydroxyl groups from nipa frond that were formed [10–12].

On the maltodextrin and sucrose bonded particleboard, the dimensional stability was extremely low. On the sucrose bonded particleboard, it can be attributed of the sucrose that more easily dissolves in water as shown by its solubility [12] and when sucrose is heated at a high (rises up to 160 ˚C), it converts to caramel, which contains many water-soluble substances [11]. Maltodextrin was a glucose polymers with an average chain length of 5 glucose to 10 glucose units or molecule and had soluble in water compared to insoluble starch. This attribute supposed to make the dimensional stability of maltodextrin bonded particleboard low.

The extraction treatment significantly increased the value of thickness swelling and water absorption on the maltodextrin and sucrose bonded particleboard. Sheshmani deducted the hot water extraction removed a greater quantity of materials, a portion of the cell wall and some inorganic materials, and when subjected to soaking, the hydrophilic properties of lignocellulosic materials and the capillary action induced an uptake of water and thus increased the thickness swelling and water absorption values [20]. Lamaming found the same results that is when the hot water extraction treatment in the old and waste oil palm trunks particle increases thickness swelling and water absorption values twice when compared to the un-extracted particleboard [8]. The n-hexane extraction treatment has better value of thickness swelling and water absorption, but still has low dimensional stability of particleboard. Sakuno and Moredo found different results, where the n-hexane extraction treatment in teak lamina board has better characteristic compared to un-extracted treatment [6].

3.3. Surface roughness and internal bonding

The average value of the surface roughness particleboards ranges from 7.18 μm to 13.49 μm (Fig. 4a). The surface roughness values for the manufactured boards in this study does not meet the standards of surface roughness of commercially manufactured particleboard in Japan ranged in value from 3.67 μm to 5.46 μm [21]. The results showed that the type of binder significantly affects the surface roughness of particleboard from nipa fronds. Some of the factors that affect to the surface roughness of particleboard i.e. compacted surface layer, good hardening of the adhesive, and the effectiveness of the evaporation of water [22]. On this research, the compacted of surface layer supposed to be affected to the value of the surface roughness. Widyorini found the addition of citric acid on the bamboo particleboard resulted in better contact among particles, hence better adhesion occurred, and producing smooth surface [23].

Figure 4b shows the internal bonding properties of the nipa frond particleboards bonded with maltodextrin, sucrose and citric acid, and the extraction treatment. The highest internal bonding strength was achieved on the citric acid binder and hot water extraction treatment, with the internal bonding strength of 0.49 MPa which met the requirement of JIS A 5908 : 2003 type 18 [5]. Internal bonding of maltodextrin bonded particleboard on all extraction treatment not meet the JIS A 5908 : 2003 [5]. Sucrose

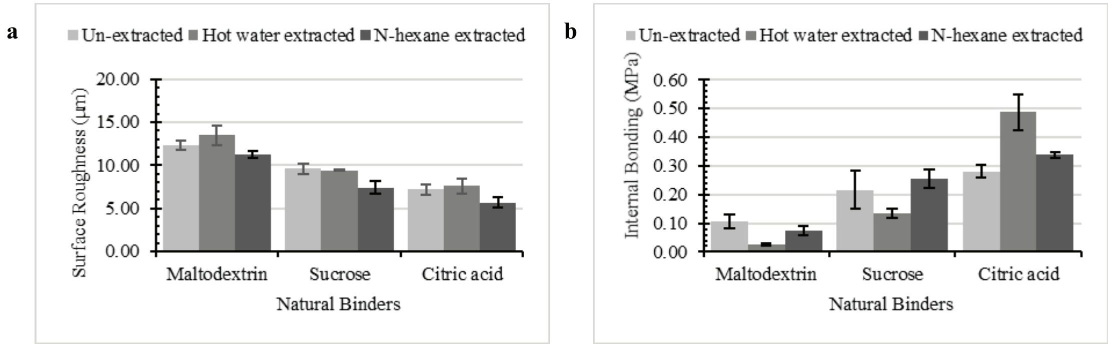

Figure 4: Surface roughness (a) and internal bonding (b) of particleboard at at various natural binder compositions and extraction treatments. The vertical bar represents standard deviation.

bonded particleboard gives better results than maltodextrin and has met the JIS A 5908: 2003 type 8 [5]. The hot water extraction treatment on the maltodextrin and sucrose bonded particleboard decreases the internal bonding strength of particleboard significantly. Lamaming found the same results, where the hot water extraction decreased the internal bonding up to twice compared to the un-extracted particleboard [8]. On the citric acid bonded particleboard, the hot water extraction treatment can improve significantly the internal bonding of particleboard up to two times.

On the other side, the n-hexane extraction treatment has a different affect to the internal bonding of nipa frond particleboard. On the maltodextrin and sucrose bonded particleboard not give a significantly different by statistical analysis, but on the citric acid bonded particleboard, it gives a significant effect. Sakuno and Moredo was found different result were the hexane extraction treatment on apitong (*Dipterocarpus* spp.), teak (*Tectona grandis* Lf.), karin (*Pterocapus indicus* Wild) and bubinga (*Guibourtia tessmannii* Benn.) wood block bonded with aqueous polymer isocyanate (API) had better dry and wet strength than their un-extracted counterpart [6].

3.4. Modulus of rupture and modulus of elasticity

Fig. 5 presents the modulus of rupture (MoR) and modulus of elasticity (MoE) of the particleboards from nipa frond bonded with maltodextrin, sucrose, and citric acid on the various extraction treatment. This result revealed that the MoR and MoE significantly affect by type of binder and extraction treatments. The highest MoR and MoE value of 10.41 MPa and 3.65 GPa was determined for the board made with the citric acid bonded and hot water extraction treatments, which met JIS A 5908 : 2003 type 13 [5]. It showed nipa frond particleboards with hot water extraction treatment and bonded using citric acid had high performance on bending properties.

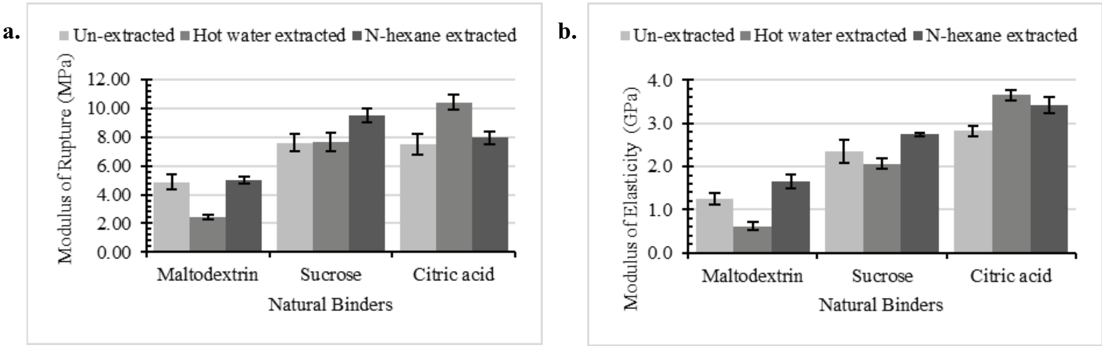

Figure 5: Modulus of rupture (a) and modulus of elasticity (b) of particleboard at at various natural binder compositions and extraction treatments. The vertical bar represents standard deviation.

On the boards that applied maltodextrin and sucrose as binder, the hot water extraction treatment had negative effect to the bending properties of particleboard. The same result was also found on old and waste oil palm trunks particleboard bonded with starch 20 % and indicated that sugar played a major role in improving the properties of boards and suggests that sugar contributed to the bond formation in the boards [8]. On the n–hexane extraction treatment, maltodextrin and sucrose bonded particleboard was not significantly different of bending properties compared to the un–extracted treatment. This result comes contrast to the bending properties of apitong wood block that was significantly improve when extracted by hexane [6].

4. Conclusions

In this research, optimum conditions were achieved at the citric acid bonded particleboards with hot water extraction treatment. The properties of the particleboard at the optimum condition were as follows: density 0.84 g · cm^{-3}; moisture content 7.44 %; thickness swelling 1.12 %; water absorption 21.83 %; surface roughness 7.57 μm; internal bonding strength of 0.49 MPa; modulus of rupture 10.42 MPa; and modulus of elasticity 3.65 GPa. The modulus of rupture, modulus of elasticity, internal bonding, and thickness swelling of the board manufactured under the optimum condition were comparable to or higher than the requirement of the type 8 of JIS A 5908:2003. The thickness swelling 1.12 % indicates the board exhibited good water resistance and the internal bonding strength was over 0.49 MPa indicates that the adhesive system had excellent bond performance. The hot water extraction treatment on the maltodextrin and sucrose bonded particleboard has the physical and mechanical properties decrease significantly. On citric acid bonded particleboard, the value increased by the hot water extraction treatment. The n-hexane extraction treatment has a different affect to physical and mechanical properties of nipa frond particleboard defend on the type of binders. Based on the result of this research, the extractives substances affect the quality of nipa frond particleboard and its influence depend on the type of binders that is used.

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