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Particleboard characterization using sawdust from sengon wood, mahogany wood, bayur wood, and rice husk ash as composite fillers

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Abstract. Banten Province, Indonesia, has abundant natural resources. Waste from processing natural resources has not been utilized maximally. Several types of wood and plants used in this study were sengon (*albizia Chinensis*), bayur (*pterspermum javanicum*), mahogany (*Swietenia mahogany*) and rice husk ash as filler. The reference particleboard characteristics used are Indonesian Standard, SNI 03-2105-2006. The characteristics observed were pore diameter, hardness, impact toughness, flexural strength, and thickness development. The particleboard composition is 50% filler, 15% oil palm empty fruit bunches, 20% polyvinyl acetate adhesive, and 15% epoxy resin. The length of fiber used is 5 mm. This research shows that particleboard with mahogany filler has optimum characteristics, namely pore diameter 2.0288 mm, hardness 43 N/mm², flexural strength 641.65 N/mm², toughness 3.54 kJ/m², and thickness swelling 1.20%.

1. Introduction

The area of forest and water conservation in Banten Province is 24.03 million hectares. Production of teak wood is 17,033.71 m³ and the other wood is 13,711.34 m³-processed wood products in the form of sawn wood 39,311.37 m³ and plywood 196,894 m³ [1]. The effect of a high production rate is environmental problems. Sawdust from these wood products must be utilized to reduce pollution. For this reason, wood waste can be used as a filler in particleboard composites, such as sengon [2], iroko [3], oak [4], acacia [5], pine [6] and the others wood [7]–[9]. On the other hand, wood can also be used as a material for biogas products [10]. The other material that can be used as filler includes the orange peel [11], sycamore leaf [9], rice husk [12], water hyacinth petiole [13], palm kernel cake [14], sago [15] and mango shell [16]. Fibers that are often used for reinforcement in composite include pineapple fiber, sisal [17], areca nut [18], coconut [19], bamboo [20], jute [21], oil palm empty fruit bunches [22], and cellulose material [23].

The quality of particleboard is influenced by the characteristics of the matrix, filler, and fiber used. The particle size used in composites has a significant effect on the particleboard produced. Terciu et al. used oak wood particles as fillers in the manufacture of composites of various sizes, namely 1-2mm,



0.4-1mm, and 0.2-0.4mm. Particle size causes changes in the value of the composite density, tensile strength, elongation when it breaks, and energy absorbed. Research conducted shows that oak wood particles with a size of 0.4-1 mm can absorb maximum energy. The long shape of oak wood particles also increases fracture resistance when compared to spherical or rectangular particles [4]. Coconut shell particle size of 0.25 mm can provide the optimum properties, like tensile strength, flexural strength, impact strength, and hardness compared to larger particle sizes [24]. The particle size of pine bark with 50 mesh was obtained density, moisture content, modulus of rupture, and bonding strength corresponded to SNI 03-2105-2006 standards for medium density particleboard type 8 [25]. The rice straw with mesh 50 provides a density of 0.76 gr/cm³. Smaller rice straw particles will increase density, but the thickness swelling is decreased [26]. The same phenomenon also occurs in acacia wood [5]. The smaller the particle size tends to hold the water and the bond between the particles will be more durable [27]. The sengon wood powder, which is used as particleboard, also has the same phenomenon. Smaller particle size increases the density, modulus of elasticity, and hardness of the particleboard surface, but the impact strength and thickness swelling are decreases [2]. Combining particle size of sengon wood will affect the quality of particleboard. From this research, a 40-60-80 mesh filler combination provides the particleboard characteristics met the SNI standard 03-2105-2006 [28]. Areca nut fiber used as reinforcement in particleboard shows that the smaller the fiber size, the modulus of rupture and screw bonding increases [29].

The pre-treatment of the fiber significantly affects the quality of particleboard. From studies show that the longer pre-treatment of fiber or filler in a solution will reduce its strength. The alkali treatment of sisal and bagasse fibers decreases tensile strength, tensile modulus, and water absorption, but the flexural strength, impact, and hardness increases [30]. Fibers treated with 10% KOH for 36 hours at 30°C can provide a bond between the matrix and the fiber better than those without treatment [18]. The more extended immersion of fiber in the alkali solution will increase water absorption [31]. Oil palm empty fruit bunched fiber immersed in 5% NaOH solution for 2 hours provides the optimum particleboard quality compared to the untreated fiber or immersed for more than 2 hours. Immersing fiber for more than 2 hours can damage the cellulose content [32]. The higher fiber immersion temperature can cause water absorption, and thickness swelling of the particleboard will increase [33].

The composition and ratio of the constituent elements in the composite have a significant effect. The ratio of sawdust and polyethylene terephthalate (PET) is very influential on the quality of wood-plastic composite [33]. Rice straw with a composition of 80, 85, and 90%vol produces particleboard that meets SNI 03-2105-2006, such as density, modulus of rupture, and modulus of elasticity [34]. The composition of wood particles and sycamore leaves on a composite can reduce mechanical properties if the number of sycamore leaves is higher [9]. The addition of black rice husk ash can reduce its tensile strength and elongation, but the modulus of elasticity will increase. From this research, it is known that the ratio between filler and matrix 95/5 gives the best performance particleboard[35]. The composition of rice straw and polypropylene (60/40) produce the particleboard with a density of 0.76 gram/cm³[26]. The maximum content of the polystyrene-based resin matrix is 30% can produce particleboards with the best performance when mixed with bamboo fiber [20]. The addition of rice husk ash will decrease the density and flexural strength, compression stress, and hardness, but the water absorption and modulus of elasticity will increase [31]. The particleboard characteristics are affected by density and particle size, and distribution of filler and binder. From this research, it is known that the content of mango shell particle 40-50% has optimum characteristics[16]. The composition of jute fiber and glass fiber (50/50) produces optimum tensile strength, flexibility, and toughness [21]. Composites with a composition ratio of resin, sisal, and bagasse (60/20/20) provide optimum performance [30]. Particleboard has maximum values and complies with SNI 03-2105-2006 if the composition between matrix and oil palm empty fruit bunch fiber 50:50 [36]. The oil palm empty fruit bunch fiber can be used as a particle reinforcement with sengon wood powder as filler. This study shows that the composition of 15% oil palm fruit bunches provides excellent mechanical properties [37]. Tensile strength, flexural, and impact decreases with the increasing volume of coconut filler fraction. This study states that the 40% volume fraction, coconut shell particle reinforced epoxy produced, has the most optimum value [24].

The type of adhesive is a crucial factor in composite characteristics. The composition and characteristics of the adhesive determine the bonding strength between filler, fiber, and matrix. Cellulose in the form of cellulose nanofibers by 1% to urea-formaldehyde can improve the fracture toughness of composites, reduce thickness swelling, and increase internal bonding and flexural strength [7]. The adhesive content will produce different types of particleboard. In general, the 11% binder content met is the minimum requirement for modulus of rupture and modulus of elasticity in particleboard recommended by US Standard ANSI/A208.1[38]. Adding nano-TiO₂ and nano-SiO₂ to polyvinyl acetate can improve the quality of the joints on the particleboard [39].

The gap between the previous research and the topic discussed in this paper is degradable property. This property is due to fillers and fibers used are a natural material. The matrix also used still allows degraded because the resin used has a slight percentage. Particleboard refers to SNI 03-2105-2006. Another purpose of this study is to use wood waste, thereby reducing environmental pollution.

2. Method

Particleboard samples in this research were made consist of palm oil empty bunches fibers with 5 mm length (15%), polyvinyl acetate (20%), epoxy resin (15%), and filler (50%). Fillers used in this sample had mesh 40 from any wood in Indonesia, especially Banten Province. The wood particles used were sengon wood, mahogany wood, and bayur wood obtained from a sawmill in Pandeglang. The sample's initial shape is a beam with a size of 15 x 70 x 50 mm. A single punch made the samples of the cold press using a hydraulic press machine with 30 bar.

2.1. Material

The material used as a constituent of particleboard is wood and rice husk ash as filler, oil palm empty fruit bunches as reinforcement, epoxy resin, and polyvinyl acetate adhesive as a matrix. Particleboard composition using volume fraction, which is 15% fiber, 50% filler, 20% polyvinyl acetate, and 15% epoxy resin. The parameters for determining the volume fraction are:

$$V_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f} \dots \dots (1)$$

Where V is the volume fraction, ρ is the density of material, and W is the weight of fibers. Alphabet m and f indicate matrix and fiber.



Figure 1. Filler from wood (a) sengon, (b) mahogany, (c) bayur, and (d) rice husk ash

2.2. Preparation of Filler

Sawdust is obtained from sawmills in Pandeglang, Banten. The sawdust is dried in the sun and then sieved with mesh 40. Figure 1 shows that the sawdust used in this research from sengon wood, bayur wood, mahogany wood, and rice husk ash. The density of sengon wood is 250 kg/m³[40], mahogany 800 kg/m³[41], bayur 530 kg/m³[42] and density of rice husk ash is 90-150 kg/m³[43].

2.3. Preparation of Fiber

The fiber used is the base of oil palm empty fruit bunches. The fiber is cleaned and dried to decompose the fiber. The length of the fiber used is 5 mm. Initial treatment on the fiber is immersing in a 5% NaOH

solution for 2 hours. After 2 hours, the fibers are cleaned with pure water to eliminate the NaOH solution's effects and dry in the sun for 24 hours.



Figure 2. Fiber separation of oil palm empty fruit bunches

2.4. Preparation of Specimens

The mixing process between fillers, fiber, and the matrix is carried out with an electric mixer for 20 minutes at speed 700 rpm for getting a homogeneous mixture. After that, the mixture is allowed to stand for 10 minutes before the compacting process. Compacting was carried out by a single punch of cold press with 30 bar pressure and a holding time of 120 minutes. From this beam-shaped sample, specimens are then made according to refer to testing standards. Hardness test (ISO 2039-1 Standard), bending strength (ASTM D 790), impact toughness (ISO 179-1), pore diameters with surface area analyzer, a microstructure using a scanning electron microscope, and thickness swelling with SNI 03-2105-2006.

3. Result and Discussion

The quality of particleboard is determined when the particleboard is in contact with external conditions. The properties that will be discussed in this paper are pore diameter, hardness, bending strength, impact toughness, and thickness swelling.

3.1. Pore Diameter

Surface area analyzer (SAA) can be used to determine the surface area, pore volume in the nano-scale. By using SAA, the required sample is only 0.01-0.1 grams. From the SAA test obtained the data, as shown in Figure 3. From Fig. 3, it is known that the particleboard with mahogany filler has the smallest pore diameter. This condition shows that the particleboard has the lowest porosity or the highest density. Porosity will affect the properties of particleboard, such as hardness, toughness, flexural, and thickness swelling.

The mahogany wood has the highest density compared to the other fillers. This density causes the mahogany filler to be distributed and mixed evenly on the sample so that the composite constituents can be compressed easily. If the wood density is low, it isn't easy to mix the constituent materials homogeneously. This condition can cause the composite to have higher porosity. From this condition, it can be said that the density of wood will significantly affect the resulting particleboard's porosity. The higher the density of wood, the smaller the porosity of particle boards. The smaller the porosity, the higher the particleboard density. This result is in line with research conducted by Maharani et al [27].

Pore diameter needs to be known because it will be closely related to density, hardness, tensile strength, impact toughness, and thickness swelling. That is why the characterization of pore diameter is placed at the beginning of this discussion.

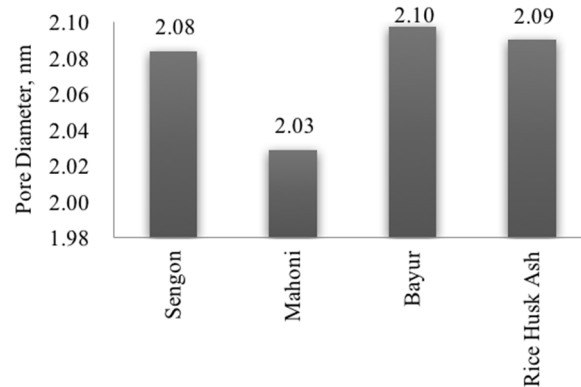


Figure 3. Pore diameter

3.2. Hardness

Hardness testing is carried out to determine how strong the particle board is when other materials scratch it. Because in its application, particleboard will come into contact with other objects. The hardness testing is done by the ball indentation method or equal to Rockwell hardness type H. The value acquired is called ball indentation hardness (N/mm^2). Composite with mahogany filler has the highest hardness, which is $43 N/mm^2$. This surface hardness correlates directly with porosity formed during the manufacturing process. The filler distribution pattern in the composite will affect the mechanical properties of the particleboard. The homogeneous distribution of fillers can provide higher hardness and strength than the distribution of fillers that are not uniformly and lumpy. This filler distribution can be studied from hardness at any point in the material surface. If the hardness at any point has the same value, it is said that filler distribution is uniform.

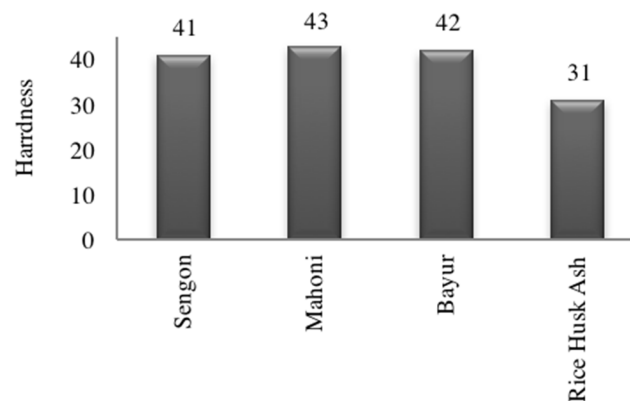


Figure 4. Correlation between filler type and hardness

A homogeneous bonding between filler and matrix can improve the mechanical properties of the composite. Force subjected to the surface area will be continued and retained by the constituent elements of particleboard simultaneously. Particleboard with rice husk ash filler has the lowest hardness. The filler distribution causes this condition [31]. The formation of filler lumps in certain parts causes different hardness. When indenter presses on the surface of filler lump, the more profound deformation will occur. Whereas if the indenter presses the matrix area, the surface will be less deformation.

Unequal distribution of filler is caused during the mixing processes between constituent material. The density of rice husk ash is the main factor that causes the rice husk ash to clot so that there is no strong bond between the fiber, filler, and matrix. The effect is the clumping of rice husk ash cannot bind fiber properly. This binding can be seen from the phenomenon of pull out on particleboard using rice husk ash as filler.

3.3. Bending Strength

Bending strength is one of the fundamental properties that particle board must possess. When used, the particleboard will have a long span. The particleboard must be able to withstand the applied load. Large deflection due to force acting on the particleboard can interfere with the stability of other objects that are placed. Bending testing is carried out using the 3 points bending method (ASTM D790). Specimen with size 100x14x5mm is subjected to loading to the center. The loading speed of 2.5 mm/min towards the bottom of the specimen. The filler type influences the bending strength of the composite. The highest bending strength occurs in composites with rice husk ash filler, which is 1,160.61 N/mm². This strength is caused by composites that are dominated by the matrix. The bending strength of composites is inversely proportional to its hardness. This composite tends to be brittle, characterized by high pore diameter and low deformation in the type of rice husk ash as filler [31].

Particleboard with rice husk ash filler has a unique behavior, that is high bending strength, but hardness, toughness, porosity, and thickness swelling is low. of mechanical and physical properties. The temporary hypothesis is the force subjected to composite held by matrix and its fiber. The bonding between matrix and fiber is appropriately, so this composite can withstand the external force that subjected.

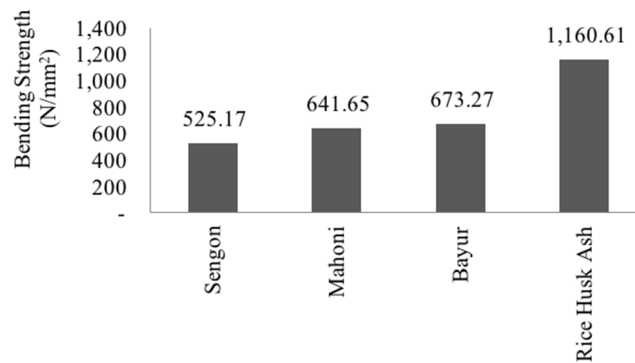


Figure 5. Correlation between filler type and bending strength

3.4. Impact Toughness

Impact tests are carried out to determine the particleboard's toughness when it falls, or there is a collision with another object. That's the reason why this test needs to be done. Impact testing was conducted in the Polymer Technology Centre, LIPI. The standard used is ISO 179-1, which sample has a size 80 x 10 x 5 mm. The sample is placed horizontally on the instrument and then given the pendulum's impact with an energy of 2 joules and a speed of 2.9 m/sec².

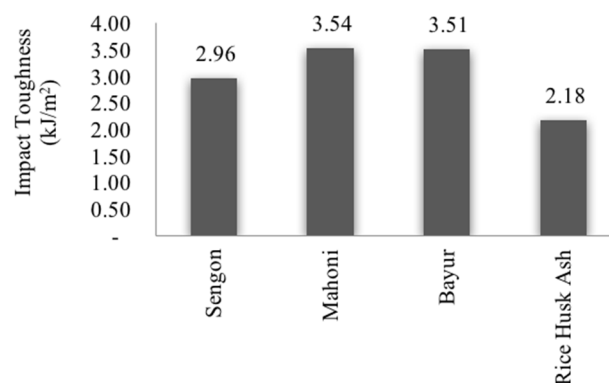


Figure 6. Correlation between filler type and impact toughness

From this experiment, it is known that the highest impact strength occurs in particleboard with mahogany wood filler, which is 3,54 kJ/m², followed by bayur, sengon, and rice husk ash filler 3.51 kJ/m², 2,96 kJ/m² and 2,18 kJ/m², respectively. Fig. 6 shows that the type of filler influences the impact strength of the particleboard significantly. Composite with mahogany filler has high impact strength caused by mahogany wood particles mixed with matrix and fiber homogeneously. When a fast loading is given to the specimen, the force will be distributed evenly to the particleboard directly so that each constituent material will receive loading. This condition can be caused by the bonding between the composite materials that formed adequately.

The toughness of particleboard with rice husk ash filler has the lowest value. From the previous discussion that porosity is high, and elongation is low. This low elongation shows that this material tends to brittle so that particleboard characteristics are natural to break when the load exceeds its strength. The toughness of particleboard with rice husk ash and sengon wood filler has toughness under the existing particleboard.

3.5. Thickness Swelling

Thickness swelling testing is carried out to determine the performance of the particleboard when in contact with water. Usually, the particle board exposed to water will expand due to the release of bonds between the composite components. It is known that the particle board on the market is very quickly damaged/destroyed when exposed to water. While the particleboard developed in this study aims to improve the thickness swelling characteristics for the better, this composite still has biodegradable properties.

Thickness swelling is a physical property that can be seen directly. The particleboard, when in contact with water, will cause dimensional changes. Thickness swelling is strongly influenced by filler type characteristics—the higher percentage of thickness swelling, the worse particleboard performance. Composite with low density tend to have high porosity. This low density is why water quickly enters the pores of particleboard so that that water will break the bond between filler, fiber, and matrix.

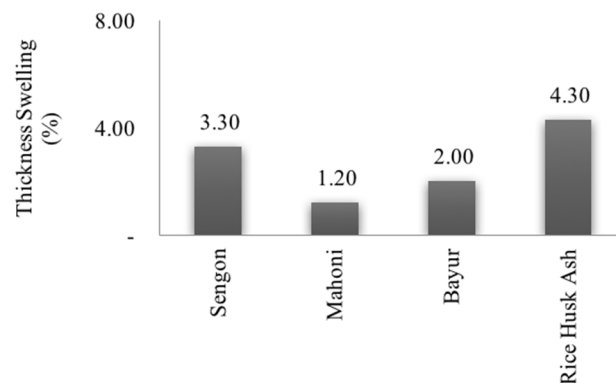


Figure 7. Correlation between filler type and thickness swelling

Figure 7 shows that particleboard with mahogany filler has the lowest thickness swelling, which is 1.20%. This thickness swelling is lower than the other filler and the existing particleboard in the market. The lowest thickness swelling is due to the smallest pore diameter. Particleboard with minimal porosity will make the water trying to enter the pores. This minimal porosity causes the percentage of thickness swelling to be smaller. On the other hand, composite with rice husk ash filler will be very different, and thickness swelling is very high, which is 4.30%.

Thick development is closely related to porosity and filler characteristics when in contact with water. The higher the pore diameter, the more water comes in contact with the surface of the material. This phenomenon will cause the development of thicker particle board with husk ash filler to be higher. This condition is in line with research conducted by Baharuddin et.al [5].

3.6. Microstructure

Microstructure observation using a scanning electron microscope can answer the phenomenon of particleboard characteristics. From Figure 8, it can be seen that the sengon and rice husk ash filler have high porosity. The figure also shows that the bond between matrix, filler, and fiber does not occur ideally. Perfect binding occurs on particleboard with mahogany and bayur filler. This perfect binding is related to why the hardness, toughness, porosity, and thickness swelling are better than other fillers directly.

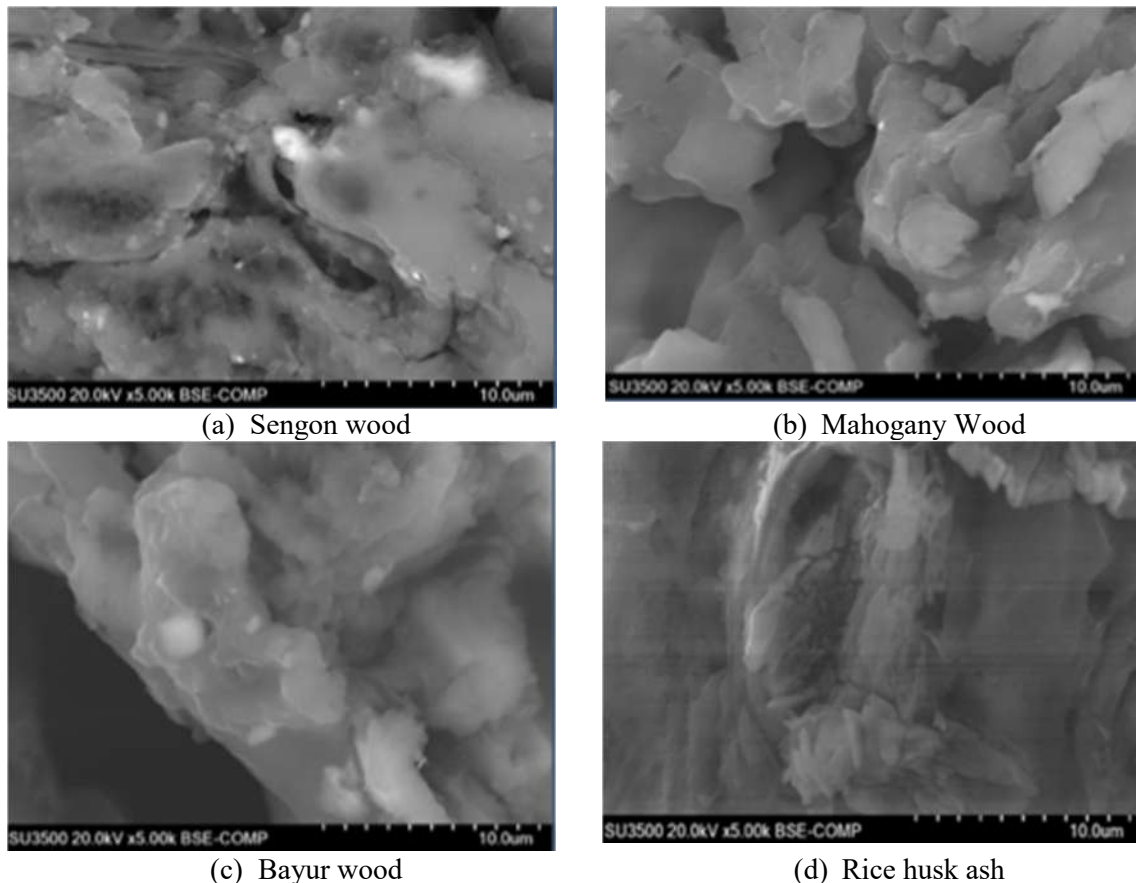


Figure 8. Correlation between filler type and thickness swelling

4. Conclusion

The utilization of wood waste is one way to reduce environmental problems and look for alternative materials to replace logs as furniture materials and other household needs. From this research, it is known that this type of filler significantly affects particle properties. The density of wood sawdust is in line with hardness and toughness, but inversely proportional to pore diameter and swelling thickness. Particleboard with Mahogany filler has excellent properties and meets Indonesian standards, SNI 03-2105-2006. The characteristics obtained are pore diameter 2.0288 nm, hardness 43 N/mm², bending strength 641.65 N/mm², toughness 3.54 kJ/m², and swelling thickness of 1.20%.

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