Effect of number of recycling time on physical and mechanical properties of binderless particleboards from jatropha press cake

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Abstract. In this study, the binderless particleboards from jatropha press cake were recycled five times. The effects of number of recycling times on physical and mechanical properties of the particleboards were investigated. This information is important to determine how many times the recycling process is carried out so that the physical and mechanical properties will still meet the standards. The mechanical properties of the produced particleboard (modulus of rupture/MOR and modulus of elasticity/MOE) tended to decrease linearly with the increasing number of recycling process up to the 5th recycle. The produced particleboard had a density of the target of 0.9 g/cm³ with the condition of pressing temperature of 180 °C and the pressing press of 200 kgf/cm² for 10 min. Thickness swelling, water absorbance, modulus of elasticity, modulus of rupture and internal bonding of the produced particleboard did not meet the standard of Japanese Industrial Standard (JIS) A 5908. Therefore, the protein which serves as a natural adhesive has not maximally functioned in the binding with the particles of the jatropha press cake.

Keywords: binderless particleboard, jatropha, castor, recycle.

1. Introduction
The particleboard is the result of hot pressing from a mixture of wood particles or other lignocellulosic materials with organic adhesives and other materials [1]. The particleboard is used widely for home furnishing, flooring, home construction, cabinet, stairs, bookshelf, and so forth [2]. Particleboard is a composite material consisting woody material that is adhesive-bonded together. The process to make wood composites usually consists of gluing fiber pieces together with a binder, forming them into a mat, and pressing them into the final product. The binder is typically a thermosetting or heat-curing resin often made from toxic formaldehydes. These toxins will continue to be used unless the supply of petrochemicals is interrupted or a new adhesive system is developed from renewable resources [3]. The problems that are often experienced by the particleboard industry are the emissions from the synthetic adhesives used so that it can cause the environmental pollution and the health problems [4]. The existences of these problems encourage the use of natural adhesives for the particleboards (usually known as binderless particleboard).

The ability to bind fibers that exist in binderless particleboards comes from reactions between chemical components (such as proteins) which are caused by hot pressing. Kurniati et al. conducted a research on the use of castor press cake as the raw material for the binderless particleboard [5]. Proteins contained in castor cake played a role as a natural adhesive on the produced particleboard.
The press cake of jatropha (Jatropha curcas) has the potential to be used as the raw material for the binderless particleboard, because it contains high protein (35%) and enough fiber (18%) [7]. Recycling after the service life is an added value considering the environmental problems especially the problem of rapidly up landfills. Recycling process also require extensive grinding as well as high-temperature mixing which could cause degradation in the properties of constituents and subsequently the composite material.

In this study, the particleboard was fabricated without the use of synthetic adhesive, but it utilized the protein contained in the jatropha seed cake as an adhesive. The recycling process of the binderless particleboard is intended as the attempt to reuse the produced particleboard to be more environmentally friendly.

This study was focused on the attempt of the utilization of the jatropha press cake to become binderless particleboards and to recycle them. The physical and mechanical properties of produced particleboards were analyzed by several analyses, such as modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding (IB), thickness swelling (TS) and water absorption (WA).

2. Materials and Methods
Jatropha press cake used was supplied by PT JEDO Indonesia. Proximate analysis was carried out to determine moisture (AOAC 1995, 950.46), crude fat (SNI 01-2891-1992), ash (AOAC 1995, 923.03), crude protein (AOAC 1995, 991.20), crude fiber (Indonesian Standard/SNI 01-2891-1992). Meanwhile, lignin and cellulose contents were obtained according to the method of ADF-NDF (Acid Detergent Fiber-Neutral Detergent Fiber).

The dried jatropha press cake was grinded to 50 mesh. Before the press cake being pressed it was steamed with the target condition of water content of ±15 wt% for 25 min. The binderless particleboard from jatropha press cake was made by using the mold with dimensions of 10 cm x 10 cm x 0.5 cm and a target density around 0.9 kg/cm². The pressing condition was a temperature of 180 °C and a pressure of 200 kgf/cm² for 10 minutes. The manufactured binderless particleboards were then recycled five times with three replications for each formulation. In recycling process, the materials were ground into size of 50 mesh using grinder and after drying they were processed again in the same procedure as condition of un-recycled process. The recycling was performed to look at the ability of the adhesion protein which is increasingly degraded due to the compression and recycling processes. Hereinafter pressed particleboards were conditioned in the room temperature for 10 days. The cutting and testing of tested samples were conducted referring to the standard of JIS A 5908 [8]. The physical and mechanical properties such as moisture content, thickness swelling (TS), water absorption (WA), modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB) were also evaluated referring to the standard of JIS A 5908 [8]. The MOE, MOR, and IB were conducted by Instron 3369 testing machine. The TS and WA of all samples were measured after soaking in distilled water for 2 and 24 hours (h).

3. Results and Discussion
Visually, the color of binderless boards was dark-brown. The jatropha press cake was rich in proteins (18.1%) and fibers (38.6%). Jatropha press cake has lignin and cellulose contents of 23.2% and 23.0% respectively.

3.1. Moisture Content
Figure 1 shows moisture content of binderless particleboard from jatropha press cake and its recycled-particleboard. The moisture content of initial material (jatropha press cake) was 15%. This moisture
content was always higher than that of the produced particleboard (4.3-6.76%). The decrease of the moisture content after the binderless particleboard production process might be caused by the water evaporation process due to the pressing at high temperature. The moisture content increased with increasing number of recycling process.

The initial moisture content can influence the protein activation as the natural adhesive due to heating and pressure for the manufacture of the particleboard. According to Lestari and Kartika [7], the water can increase the movement of chain of the protein polypeptide in the press cake of jatropha so that it facilitates the interaction of protein with other polymers. The initial moisture content can function as plasticizer and can reduce the protein exothermic temperature [9].

Based on the standard of JIS A 5908 [8], the moisture content of binderless particleboard from jatropha press cake produced met the requirement as the particle board product. Figure 1 shows the increase of moisture content during the recycling process until the 3rd process (R3), then it tended to be constant in the 4th (R4) and 5th (R5) recycling processes. This was presumably because there were significant amounts of protein which were diminishing after the board was recycled so that the lignocellulosic material was easily binding with water. Increasing the initial moisture content deteriorated both bending strength (MOE) and water resistance which would be explained later.

![Figure 1. Moisture content of binderless particleboard from jatropha press cake and its recycled particleboard](image)

3.2. Density

Density becomes one of the important factors which greatly affects the properties of the resulting binderless particleboard and becomes the basis for use of a product [10]. The density of the binderless particleboard from the jatropha press cake had the lowest value of 0.89 g/cm³ and the highest of 1.02 g/cm³ (Figure 2). Based on the density values and its standard deviations obtained, the density of particleboards tends to be constant with increasing the number of recycling time. Overall, the density of particleboard produced was above the target density.

The density of the particleboard depends on the mixing of particle, the initial moisture content of the material at the time of being compressed, the chemical reaction, the temperature and the pressure of compression given to the board [11]. The adhesion mechanism by protein occurs mechanically (mechanical interlock), namely the process by which the entry of the protein into the pores of the substrate surface [12]. The protein will work as an adhesive at the temperature and the pressure of compression used in this research, so as to produce a high-density-particleboard.
3.3. Thickness Swelling

Thickness swelling behavior of binderless particleboard from jatropha press cake exposed to the number of recycling times is presented in Figure 3. It is well known that a major part of the thickness swelling is caused by the absorption of water by the composite material. Thickness swelling is brought about by the swelling of the individual fibers as well as penetration of water into the interface between the two phases and the subsequent damages to this area caused by the absorbed water.

As shown in Figure 3, for all formulation, thickness swelling decreased linearly as water absorption decreased. However, the dependence of thickness swelling on water absorption was not the same for all particleboards. After third recycling, the additional absorbed water slightly caused thickness swelling.

Measurement of thickness swelling was conducted to find out the adhesion resistance and the quality of particleboard toward the environmental humidity. The measurement of thickness swelling was conducted for 2 hours and 24 hours, with the lowest and highest values in the immersion test condition of 2 and 24 hours are 7.26 %; 9.67 % and 21 %; 23.95 %, respectively (Figure 3). The lowest value obtained on the particleboard was recycled of 3 times (R3), while the highest value was on the board which was 5th recycled (R5). During the compression process, the compactness was decreased between particles in the recycling process as a result of decreased levels of protein. Based on the data obtained the thickness development did not meet the standard of JIS A 5908 [8] which requires the maximum value of thickness swelling of 12 %.
Figure 3. Thickness swelling of the binderless particleboard from the jatropha press cake and its recycled-particleboard

3.4. Water Absorption
Water absorption is important property in the durability of such composite and board. The absorbed water affects many properties such as dimensional stability, natural durability and mechanical and physical properties. The products can have better durability if water absorption (WA) is limited. The WA of the binderless particleboards produced ranged from 15.17 % to 19.5 % for 2 h and from 68.24 % to 69.82 % for 24 h immersion in water as shown in Figure 4.

The water absorption of the panels decreased with increasing number of times recycled. Maximum WA for the original particleboard was 85% for 2 h and 85% for 24 h immersion in water. This was reduced to 32% for 2 h and 36% for 24 h immersion in water after five times recycling. Although the recycled particleboard of 5 had the structure which is more fragile, however the resulting board absorbs less water, this is related to the change in the chemical structure on the particle which makes the particle condition can not bind with water. Recycling cycles reduced water absorption. Maximum water absorption for the original binderless particleboard was 68.24%. This was reduced to 15.17% after five times recycling.

Figure 4. Water absorption of the binderless particleboard from the jatropha press cake and its recycled-particleboard
3.5. Mechanical Property
In mechanics, the flexural modulus (MOE) measures the tendency of the material to bend. Hence the material’s aspect ratio is an important consideration for attaining a high flexural modulus.

The modulus of elasticity is the indicator value for the stiffness of material. The lowest and highest values of MOE of particleboards were 47.38 MPa and 484.04 MPa, respectively (Figure 5). The value of MOE was declined in line with the number of times recycled, allegedly due to the effect of diminishing amount of protein during the recycling process.

The lower value of MOE of the binderless particleboard of jatropha seed cake showed the bonding power and the elasticity of protein was less than the maximum. The elasticity of the particleboard is influenced by the increasing the interaction between the protein to the surface of the fiber [7]. The hot temperature given for the hot compression process could change the structure of protein, so that it could bind with the fibers on jatropha seed cake. The value of MOE produced did not meet the standard of JIS A 5908 [8] which requires the value of MOE at minimum of 2000 MPa.

![Figure 5. Modulus of elasticity of the binderless particleboard from the jatropha press cake and its recycled-particleboard.](image)

The effect of number of times cycled on the modulus of rupture (MOR) of binderless particleboards is shown in Figure 6. The lowest and highest average values of MOR of board were of 0.12 MPa and 2.68 MPa, respectively (Figure 6). With increasing the number of recycling time, the MOR of particleboard was decreased. The value of MOR of the particleboard of jatropha seed cake did not meet the standard of JIS A 5908 [8] which requires a minimum value of 8 MPa.
Internal bonding strength (IB) shows the strength of the bond between particles in per unit of area in each sheet of the particleboard. The bonding strength property produced on board will be more perfect by increasing the adhesive used in the manufacture of particleboard [10]. The lowest and highest average values on the particleboards were of 0.02 MPa and 0.37 MPa, respectively (Figure 7), the values were on the 5th recycle board and the 1st recycle board, respectively.

The strength of the particleboard in recycling process was disrupted due to the reduced amount of protein contained in jatropha seed cake during the thermal compression process. The particleboard produced became increasingly fragile because of the reduced adhesive in particleboard. The value of bonding strength produced did not meet the standard of JIS A 5908 [8] which requires a minimum value of 0.15 MPa.
4. Conclusion
In this study, the binderless particleboard from jatropha seed cake was recycled five times. The physical and mechanical properties of the recycled particleboards did not meet the standard of JIS A 5908. The protein contained in jatropha seed cake has not reached the maximum value as the natural adhesive in the binding with the particles of the jatropha press cake.

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