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The Effect of Pressing Temperature and Time on the Quality of Particle Board Made from *Jatropha* Fruit Hulls Treated in Acidic Condition

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Abstract

The high of pH of *jatropha* fruit hulls causes the negative properties of particleboard made from this material. Adjusting the particle acidity and pressing conditions (temperature and time) is among the technical modifications available to improve this particleboard's properties. Particle acidity has been adjusted in a previous research project, and immersing the particles in acetic acid was found to be the best treatment in this preliminary research. In order to improve the particleboard's properties, an experiment was conducted to determine the best pressing temperature and time. The objective of the research was to evaluate the influence of pressing temperature and time on the physical and mechanical properties of the board. *Jatropha* fruit hulls were immersed in 1% acetic acid solution for 24 hours. UF resin was used as the adhesive in the amount of 10%. The pressing temperatures and times used in this research were 110 °C, 120 °C, and 130 °C for 8 and 10 minutes, respectively. The particleboards were tested to determine their physical and mechanical properties according to JIS A 5908-2003. The result showed that pressing at 130 °C for 10 minutes resulted in the best physical and mechanical properties. Increasing the pressing temperature at a constant time or increasing the pressing time at a constant temperature caused the particleboard to exhibit decreased water absorption. The thickness swelling and modulus of elasticity (MOE) of the particleboard did not fulfil JIS A 5908-2003.

Abstrak

Pengaruh Suhu dan Waktu Pengempaan terhadap Kualitas Papan Partikel yang Terbuat dari Kulit Buah Jarak yang Diberi Perlakuan Asam. Tingginya pH kulit buah jarak berpengaruh negatif terhadap sifat papan partikel yang dihasilkan. Penyesuaian keasaman partikel dan kondisi pengempaan (suhu dan waktu kempa) merupakan teknik modifikasi untuk memperbaiki sifat papan partikel. Penyesuaian keasaman partikel telah dilakukan pada penelitian sebelumnya dimana perlakuan perendaman partikel dalam larutan asam asetat merupakan perlakuan yang terbaik. Dalam rangka memperbaiki sifat yang masih rendah perlu dilakukan percobaan untuk menentukan suhu dan waktu yang terbaik. Tujuan penelitian ini untuk mengevaluasi pengaruh suhu dan waktu pengempaan terhadap sifat fisis dan mekanis papan. Kulit buah jarak direndam dalam larutan asam asetat 1% selama 24 jam. Kadar perekat UF yang digunakan sebesar 10%. Suhu dan waktu pengempaan yang diupergunakan dalam penelitian ini masing-masing adalah 110 °C, 120 °C, and 130 °C selama 8 dan 10 menit. Pengujian sifat fisis dan mekanis papan partikel mengacu pada standar JIS A 5908-2003. Hasil penelitian menunjukkan bahwa suhu 130 °C selama 10 menit menghasilkan sifat fisis dan mekanis yang terbaik. Peningkatan suhu pengempaan pada waktu yang sama atau peningkatan waktu pengempaan pada suhu yang sama menyebabkan terjadinya penurunan daya serap air. Pengembangan tebal dan modulus elastisitas (MOE) papan partikel belum memenuhi standar A 5908-2003.

Keywords: jatropha fruit hulls, particleboard, pressing temperature and time

1. Introduction

Jatropha fruit hulls are a low-acidity waste created via biodiesel production. Preliminary research has shown the pH of *jatropha* fruit hulls to be around 10. Other

research has shown the pH of *jatropha* fruit hulls to be around 8.1 [1]. The high pH of *jatropha* fruit hulls causes curing problems when urea formaldehyde resin is used. In the previous research, the utilization of *jatropha* fruit hulls as material in particleboard

manufacturing while using urea formaldehyde resin yielded poor board properties in terms of thickness swelling, water absorption, modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB). Low acidity caused problems in resin bonding strength [2]. The acidity also influenced the resin curing rate of formaldehyde resin, especially urea formaldehyde (UF) resin [3]. Furthermore, Kamal *et al.* [4] stated that material acidity is one of the factors to be considered in particleboard manufacturing using UF as *acid-curing resin* and PF as *alkaline-curing resin*.

The optimum polymerization rate for creating good bonding strength can be achieved by (1) adjusting the time and temperature of pressing and (2) adjusting the material buffer of the alkaline or acid [5]. In the previous research, the improvement of the physical and mechanical properties of particleboard has been achieved via particle pretreatment to reduce of its pH and buffering capacity so as to make it compatible with urea formaldehyde resin. The result showed that among particle pretreatments (i.e., immersion in cold water, hot water, or acetic acid solution), particle immersion in 1% acetic acid solution was the best treatment to improve the physical and mechanical properties of particleboard, although some properties did not meet the standard when this was done.

According to Paridah *et al.* [5], the polymerization rate of resin depends on material acidity, which will influence the temperature and time chosen for particleboard manufacturing. Furthermore Wang [6] reported that adjusting the temperature and time of pressing could be conducted through two mechanisms: increasing pressing time at a constant temperature and increasing temperature at a constant pressing time. Xing *et al.* [7] stated that pH differences in the materials caused curing time differences in the hot pressing process. A mix of acid wood fiber and urea formaldehyde resin will require a relatively short curing

time, while long pressing time will cause over-curing and result in a low bonding strength. In order to determine the best pressing temperature and time, a research project on the effect of temperature and time on the particleboard manufacturing process was conducted. The objective of this research was to evaluate the influence of pressing temperature and time on the physical and mechanical properties of the board.

2. Methods

Materials. The jatropha fruit hulls, a biodiesel waste, were collected from the biodiesel industry. The acetic acid solution (CH₃COOH-98%) and commercial urea formaldehyde resin (UA-140 for particleboard manufacturing) were supplied by PT, Palmolite Adhesive Indonesia Probolinggo, East Java.

Particle treatment. 98% acetic acid solution was dissolved in aquadest to obtain 1% acetic acid solution. The jatropha fruit hulls were immersed in 1% acetic acid solution for 24 hours. Following this, the jatropha fruit hulls were dried until they reached 3-4% moisture content. After this treatment, the pH value of the jatropha fruit hulls was 5.9.

Particleboard manufacturing. The particleboard manufacturing conditions are shown in Table 1.

Manufacturing process. Single-layer particleboard with a size of 300 x 300 x 10 mm³ and a target density of 0.7 g/cm³ was produced. Urea formaldehyde was used as the binder for particleboard manufacturing, with 10% resin content and 63% solid content. A rotary drum blender was used for mixing the particles and adhesive. After the mat was hot-pressed (Table 1), the board was conditioned for one week at an adjusted room temperature in the range of 25~30 °C and 60~65% humidity. Three boards were prepared for each treatment.

Table 1. Particleboard Manufacturing Conditions

No	Information	Condition
1	Size of board	300 x 300 x 10 mm ³
2	Density target	0.7 g/cm ³
3	Adhesive	Urea formaldehyde (UA-140) Resin content: 10% Resin solid content: 63%
4	Jatropha fruit hulls	Moisture content: 3-4% Treatment: immersion in acetic acid solution for 24 hours
5	Hot pressing	Temperature: 110, 120, 130 °C Time: 8, 10 min Pressure: 2.44 N/mm ²
6	Pressing schedule	One-step pressing schedule

Determination of physical and mechanical properties.

Prior to physical and mechanical tests, specimens were conditioned for 7 days in a room with an adjusted temperature of 25~30 °C. The board parameters measured were air-dry density, moisture content (MC), water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE) in bending, and internal bond (IB). The dimensions of the specimens used for evaluating the air-dry density and MC of boards were 100 x 100 mm². The specimens were weighed immediately after being dried in an oven at 103±2 °C until they reached a constant weight. For the WA and TS tests, the dimensions of the specimens were 50 x 50 mm². The specimens were also weighed immediately. The average thickness was determined by taking several measurements at specific locations. After 24 hours of submersion in water, the specimens were dripped and wiped to eliminate any surface water, and then, the weight and thickness of the specimens were measured. Their mechanical properties (MOE, MOR, and IB) were tested by using a universal testing machine (UTM) equipped with a load cell with a capacity of 10,000 N. The dimensions of the specimens used in the bending tests were 200 x 50 mm², while the dimensions of those used for the IB test were 50 x 50 mm². The evaluations of the MOE, MOR, and IB parameters were performed at 28 °C and 60% R.H. The crosshead speed was adjusted to 10.00 mm/min.

Data analysis. Two factors of a completely randomized design in three replicates were used in this experiment. Data analysis was conducted using SPSS software. Significant difference ($\alpha < 0.05$ or $\alpha < 0.01$) between the mean values of temperature, time, and the interaction of both were determined using Duncan's multiple range tests (DMRTs).

3. Results and Discussions

Physical properties. The physical properties of the particleboard that were evaluated included density, moisture content (MC), water absorption (WA), and thickness swelling (TS).

Density and moisture content. The density value of the particleboard varied between 0.59 and 0.69 g/cm³ (Figure 1). The density obtained in this experiment was lower than the target density of 0.70 g/cm³ because of the springback of the board after pressing and swelling during board conditioning. Several factors influence the board density, including wood density, pressing pressure, particle quantity in mat, resin content, and other additives [8]. Statistical analysis showed that the analysis of variance for pressing temperature, time, and the interaction of both were not significantly different and thus did not affect the density value (Tabel 2). The density value in this research project fulfilled JIS A

5908 [9]. This standard required a density value between 0.4 and 0.9 g/cm³.

The MC value of the particleboard varied between 8.44 and 11.49% (Figure 2). The existence of MC in particleboard was influenced by board density and particle porosity. Lower density caused water vapor to be more accessible to the board. *Jatropha* fruit hulls have high porosity, which allow them to easily absorb water when immersed in water and to easily release water when dried. The trend in Figure 2 shows that increasing the pressing temperature and time caused a decrease in the MC of the particleboard. A similar case was also reported by Winandy and Krzysik [11]. Statistical analysis showed that the analysis of variance for pressing time was significantly different and thus affected MC, while the temperature and the interaction of temperature and time were not significantly different and thus did not affect the MC value (Tabel 2). The MC value in this research project fulfilled JIS A 5908 [9]. This standard required an MC value between 5 and 13%.

Water absorption and thickness swelling. The WA value of the particleboard varied between 76.31 and 120.45% (Figure 3). Increased pressing temperature at a constant time and increased pressing time at a constant temperature caused decreased the WA of the particle board. The WA that resulted from this experiment was still high. Furthermore, Winandy and Krzysik [11] reported

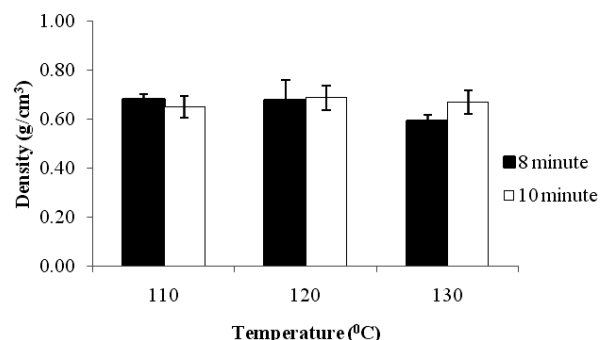


Figure 1. Density of Particleboard

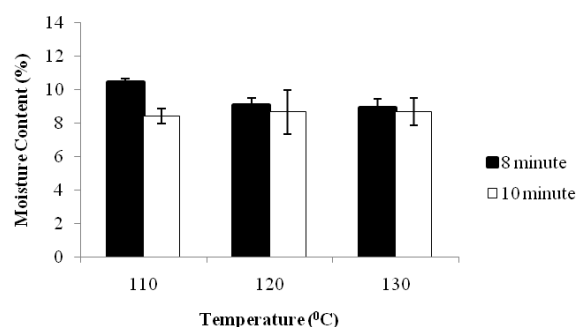


Figure 2. Moisture Content of Particleboard

Table 2. Variance Analysis of the Physical Properties of Particleboard

Source	Density		MC		WA		TS	
	F	Sig	F	Sig	F	Sig	F	Sig
Temperature	1.53	Ns	1.51	ns	18.01	**	12.35	**
Time	0.78	Ns	6.80	*	10.05	**	37.92	**
Temperature x Time	1.79	Ns	2.89	ns	1.07	Ns	0.95	Ns

that increasing pressing temperature and time does not inhibit the ability of MDF to absorb water. The interior use of urea formaldehyde resin [12] has a role in increasing WA. Statistical analysis showed that the analysis of variance for pressing temperature and time had a high significant difference and thus affected WA, while the interaction of temperature and time was not significantly different and thus did not affect the WA value (Tabel 2). Duncan’s multiple range test analysis showed that the WA at 120 and 130 °C temperatures had a significant difference from that at a 110 °C temperature, while that at a 120 °C temperature was not significantly different from that at 130 °C.

The TS value of the particleboard varied between 23.84 and 41.28% (Figure 4). Jatropha fruit hulls with a high pH (pH:10) will cause curing problems in urea formaldehyde resin and result in low bonding strength and other negative board properties. Previous research showed that immersing particles in weak acid on the treated board resulted in a TS that was 3 times lower than that of the untreated board [18]. In this research, increasing the pressing temperature at a constant time and increasing the pressing time at a constant temperature both caused a decrease in particleboard TS. A temperature of 130 °C for 10 minutes were the best conditions in which to produce a board with a low TS. The WA value in this research project was very high, but the TS had a lower value than WA. Another research project conducted by Winandy and Krzysik [11] reported that the TS of medium-density fiberboard (MDF) could be retained even if moisture was absorbed into board. It is possible that the absorbed water occupies in void space that is not directly associated with the fibers.

The TS of the board had a negative correlation with internal bond (IB). The coefficient correlation value between TS and IB was 0.6 (Figure 5). This means that TS and IB have a strong, moderate correlation. The higher value of IB resulted in the lower TS. The TS value at 120 °C was slightly lower than that at 130 °C because the IB value for 130 °C was slightly lower than that at 120 °C. The statistical analysis and Duncan’s multiple range test analysis for thickness swelling were similar to those for WA. The TS value in this research did not fulfill JIS A 5908 [9]. This standard requires a thickness swelling value less than 12%.

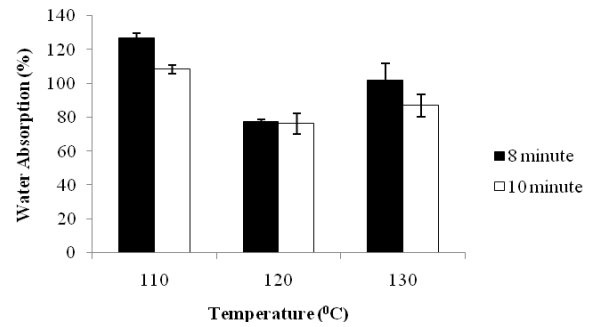


Figure 3. Water Absorption of the Particleboard

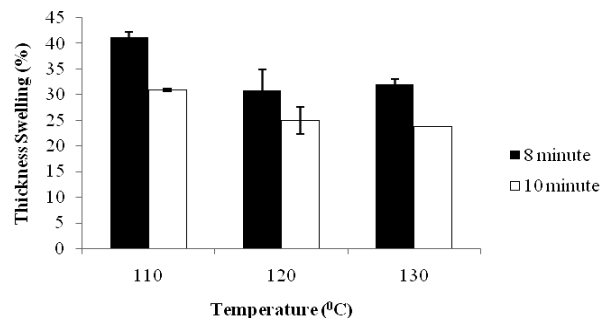


Figure 4. Thickness Swelling of the Particleboard

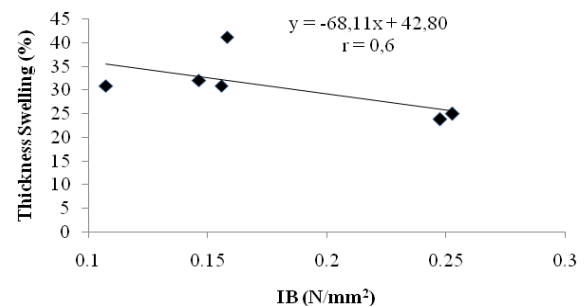


Figure 5. Correlation between Thickness Swelling and Internal Bond

Mechanical properties. The evaluation of the mechanical properties of the particleboard included modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB).

Modulus of elasticity and modulus of rupture. The MOE value of the particleboard varied between 452.89 and 1006.52 N/mm² (Figure 6). Increased pressing temperature at a constant time and increased pressing time at a constant temperature increased the MOE of the particleboard. According to Malanit *et al.* [13], a higher pressing temperature increased the adhesive bonding rate, which will enhance strength. A lower temperature during the hot pressing process resulted in the low strength because the resin did not cure. Also, when very high temperature was used, the resin would be over-cured. Both of these conditions will reduce the bonding strength in adhesive bond. Furthermore, Maloney [14] stated that the MOE value was influenced by the type and content of the resin, adhesive bonding strength, and fiber length. Research conducted by Agustina [15] reported that variations in urea formaldehyde adhesive content (10, 12, 14%) do not significantly affect the improvement of the MOE value of particleboard made from untreated jatropa fruit hulls. The low MOE value was presumably due to jatropa fruit hulls being classified as short to medium fibers and having a high pH. Statistical analysis showed that the analyses of variance for pressing temperature, time, and the interaction of temperature and time had significant differences and thus affected MOE (Table 2). Duncan's multiple range test analysis showed that the MOE at 120 and 130 °C was significantly difference from that at 110 °C, while the MOE at 120 °C was not significantly different from that at 130 °C. A pressing temperature of 120 °C for 10 minutes or of 130 °C for 10 minutes had significant differences as compared to other treatments, while between that of 120 °C for 10 minutes and 130 °C for 10 minutes, there was no significant difference. The MOE value in this research did not fulfill JIS A 5908 [9]. This standard requires an MOE value greater than 2000 N/mm².

The MOR value of particleboard varied between 5.31 and 10.65 N/mm² (Figure 7). The trend of the MOR curve was similar with that of the MOE curve: increased pressing temperature at a constant time and increased time at a constant temperature increased of MOE of particleboard. Research conducted by Maloney [14] discovered that one of the factors that influences MOR is particle geometry. Particle geometry has relationships with particle size, slenderness ratio, and aspect ratio (Table 4). A higher slenderness ratio will improve particle orientation, which will increase the strength and

require less adhesive per unit of surface area. In addition to the slenderness ratio, a good board orientation will be achieved if the aspect ratio is greater than 3 [14]. Statistical analysis showed that various pressing times were significantly different and thus affected MOR, while various temperatures and interactions of temperature and time were not significantly different and thus did not affect the MOR value (Table 3). Pressing at 130 °C for 10 minutes resulted in a MOR value that fulfilled JIS A 5908 [9]. This standard requires a MOR value greater than 8 N/mm².

Internal bond (IB). The IB value of the particleboard varied between 0.15 and 0.25 N/mm² (Figure 8). Increased pressing temperature at a constant time and increased pressing time at a constant temperature increased the IB of the particleboard. According to Nemli [16], increased pressing temperature, time, pressure, and adhesive ratio caused a significant improvement in board

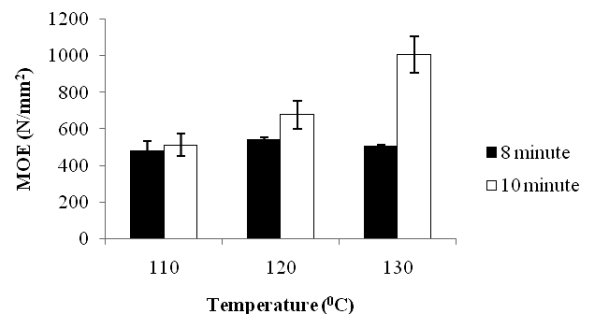


Figure 6. Modulus of Elasticity of the Particleboard

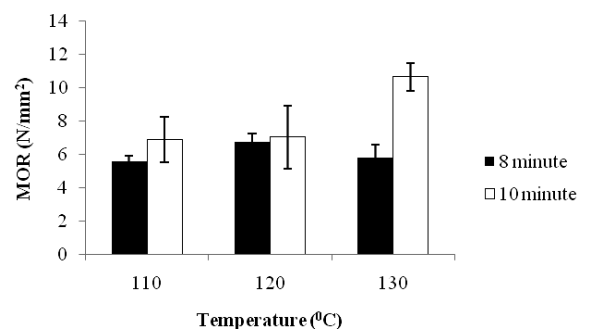


Figure 7. Modulus of Rupture of the Particleboard

Table 3. Variance Analysis of the Mechanical Properties of the Particleboard

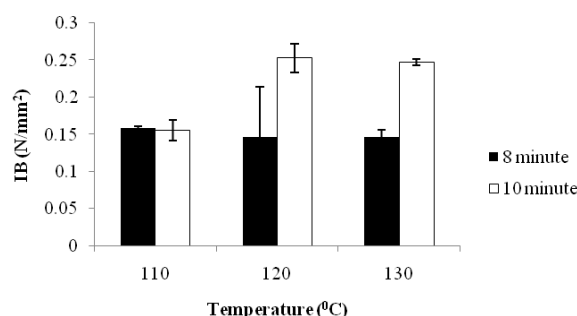
Source	MOE		MOR		IB	
	F	Sig	F	Sig	F	Sig
Temperature	6.14	*	0.49	Ns	11.11	**
Time	27.93	**	7.01	*	203.54	**
Temperature X Time	7.45	**	1.88	Ns	55.56	**

Note: ns (not significant), * (significant on $\alpha=5\%$), ** (significant on $\alpha=1\%$)

Table 4. Size and Slenderness Ratio of Jatropha Fruit Hulls⁽ⁿ⁾

Parameter	Average	Min	Max
Length (mm)	27.46 ± 1.41	24	30
Width (mm)	1.51 ± 0.14	1.15	1.84
Thickness (mm)	0.34 ± 0.13	0.1	0.70
Slenderness Ratio (SR)	92.35 ± 33.58	41.43	260
Aspect Ratio (AR)	4.96 ± 1.97	16.57	2.20

n: 100 Jatropha fruit hulls

**Figure 8. Internal Bond of the Particleboard**

strength and IB. This may have been due to their relationships with resin curing, the reduced wettability of the particle surface, the limitation of diffusion, and/or the spreading of the adhesive within the particles and over the particle surface [16]. Furthermore, Heinemann *et al.* [17] reported the difference in internal bond for particleboards using 10% UF at five pressing temperatures. There are two approaches to explaining this phenomenon. Firstly, temperature will influence the adhesion ability of UF resin to wood materials. Pressing temperature will influence water flow in wood, which causes the diffusion of adhesive molecules into the voids of the wood. The low temperature causes low adhesive diffusion into the wood, so it will decrease the mechanical bonding strength (mechanical interlocking). Secondly, the chemical exchange of the substrate surface is an effect of temperature, e.g., the melting of lignin or the degradation of hydrogen bonds, which have an important role in bond strength. At low temperatures, the mobility of the reactive OH- group of the polymeric molecules will be reduced. Moreover, less stable methyl ether bridges do not convert into stable methylene bridges, which results in low bond strength.

Statistical analysis showed that the analysis of variance for pressing temperature, time, and the interaction of both of these have significant differences and thus affect IB (Table 3). Duncan's multiple range test analysis showed that the IBs at 120 and 130 °C had significant

differences from that at 110 °C, while the IB at 120 °C was not significantly different from that at 130 °C. The IB values at 120 °C for 10 minutes and 130 °C for 10 minutes had significant differences with those of other treatments, while there was no significant difference between the IB at 120 °C for 10 minutes and that at 130 °C for 10 minutes. Overall, the IB values in this research fulfilled JIS A 5908 [9]. This standard requires an IB value greater than 0.15 N/mm².

4. Conclusions

In particleboard manufacturing, pressing temperature and time were important factors that influenced board quality. Accidity's effect on the particles was one of the reasons to explore pressing temperature and time in order to determine the best pressing conditions. In this research, pressing at 130 °C for 10 minutes resulted in the best physical and mechanical properties for the board. For the best treatment, hot pressing at 130 °C for 10 minutes resulted in density, MC, MOR, and IB values that fulfilled JIS A 5908 (2003), but some properties, such as TS and MOE, did not fulfill this standard. Suggestions for future research include mixing jatropha fruit hulls and other lignocellulosic materials in several ratios.

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