The influence of particle soaking in acetic acid and NaOH solutions on the quality of sandwich particleboard from raru wood and belangke bamboo

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Abstract. As a composite product, particleboard has disadvantages related to low dimensional stability. The research purpose was to analyze the effect of immersion in acetic acid and NaOH solution on the quality of the particleboard sandwich. Sandwich particleboard (SPb) was made in a size of 25 cm length and 25 cm width. The target thickness and density are 1 cm and 0.75 g/cm³, respectively. The adhesive used was isocyanate adhesive with a content of 7%. First, the particles, which were in the form of wood shavings and bamboo strands, were soaked in a solution of acetic acid and NaOH at various concentrations (0, 1, 2, and 3%). The moisture content of the particles to be made SPb was set at 7%. After evenly mixing the particles (wood shavings and bamboo strands) and the adhesive, the sheet was created. The board sheets were made into three layers, namely 40% face layer in the form of a bamboo strand, 20% core layer in the form of wood shavings, and 40% back layer in the form of the bamboo strand. The next stage was the hot pressing process at 160 °C for 5 min and 30 kg/cm² pressure. The following process was conditioning the board for seven days. Testing of quality refers to the standard JIS A5908 (2003). The results showed that the immersion of Raru wood particles in acetic acid and NaOH at various concentrations (0, 1, 2, and 3%) significantly affected the value of density, water absorption, thickness swelling, modulus of elasticity, modulus of rupture, and internal bond. Except for the moisture content on the AA3 and NA2 boards and the internal bond value on the untreated (control) board, all of the panel properties in this study met the standard.
1. Introduction

Particleboard is a composite board made of lignocellulose material in wood or non-wood by using a thermosetting or thermoplastic adhesive and maturing through hot pressing [1]. One of the local wood species that grows in North Sumatra is Raru (*Cotylelobium melanoxylon*). According to [2], this wood grows in the Central Tapanuli and North Tapanuli areas. Raru belongs to the strong class II-III and can be used as a building material for furniture and others.

In addition to wood, bamboo is a non-wood lignocellulose material that can be utilized as a raw material for particleboard. According to [3], the nature of bamboo stems that are strong, ductile, straight, stiff, and light makes bamboo used for various building construction. Other than that, several studies related to the use of bamboo have been carried out by [4–6]. The Belangke bamboo (*Gigantochloa pruriens*) is a species of bamboo that grows in North Sumatra. Belangke bamboo has a fiber length more significant than other types of bamboo, so it is suitable for pulp and cellulose nanofibers material [7]. Belangke bamboo is rated as strength class III based on its specific gravity [8]. The research on particle treatment in acid and the base solution was conducted to analyze the effect of immersion of particles in a solution of acetic acid and NaOH at concentrations of 1, 2, and 3% on SPb properties.

2. Materials and methods

2.1. Materials

The materials utilized include Raru wood sawdust (*Cotylelobium melanoxylon*), belangke bamboo (*Gigantochloa pruriens*), 100% acetic acid, and 40% NaOH are the chemicals utilized. Isocyanate is applied as the adhesive, which has a 7 percent content and a 98 percent solid composition.

2.2. Methods

2.2.1. Raw materials preparation

Raru wood was shaved using a planer machine. The Raru particles have 11.45 mm length, 13.71 mm width, and 0.62 mm thickness. Then a bamboo strand with 25 cm length, 25 mm width, and 0.1 mm thickness was made. Sawdust of Raru wood and belangke bamboo strands were soaked in acetic acid solutions at 1, 2, and 3% concentrations and NaOH solutions at 1, 2, and 3% concentrations. As a comparison, a board without immersion treatment (control) was prepared.

2.2.2. Board making

The board was made of 25 x 25 cm$^2$ with 1 cm thickness and 0.75 g/cm$^3$ target density. The layer ratio consists of a face (40%) of the bamboo strand, core (20%) of Raru particles, back (40%) of the bamboo strand. The particles are mixed with the adhesive until evenly distributed. The bamboo strand is smeared with adhesive on only one surface area and then formed into a sheet using a mold 25 x 25 cm$^2$. Furthermore, the sheet is placed on two press plates and compressed at 160 °C for 5 minutes and 30 kg/cm$^2$ pressure.

The boards were left indoors at room temperature for 14 days to homogenize the moisture content and reduce residual stresses caused by compression. After conditioning, the panels were cut into several sizes to test their physical and mechanical properties. Cutting and testing of the test sample board refers to the standard of JIS A 5908-2003. The board testing parameters consist of physical properties, which include density, moisture content (MC), water absorption (WA), and thickness swelling (TS), as well as mechanical properties consisting of Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and internal bonds (IB).

2.2.3. Data analysis

Completely Randomized Design (CRD) was chosen to analyze the effect of treatment on panel properties. The linear model used is the treatment of immersion in 1, 2, and 3% acetic acid; 1, 2, and
3% NaOH with three replications. The number of boards obtained in this study was 21 boards.

3. Result and discussion

3.1. Physical properties

3.1.1. Density

Figure 1. Density of particleboard

According to Figure 1, the panel density value ranges from 0.68 to 0.75 g/cm$^3$. The highest density is found on the AA3 board, and the lowest is found on the AA2 board. Most of the panel density values obtained did not meet the target density of 0.75 g/cm$^3$. This could be due to the presence of spring back to relieve the pressure experienced by the board during compression time. A similar condition was reported by [6,9,10]. The possibility of particle loss during the sheet-making process and board compression is reported by [11]. Density is influenced by several factors: wood species, compression pressure, number of particles, adhesive content, and additives [12]. The statistical analysis showed that the immersion treatment on the particles did not significantly affect the 95% confidence interval on the density of the board.

3.1.2. Moisture content

Figure 2. The moisture content of particleboard

The board's moisture content ranged from 4.65 to 5.42 percent, with the NA3 board having the highest value and the NA2 board having the lowest. The trend in Figure 2 shows that the treatment of particle immersion in acetic acid solution at several concentrations appears to slightly reduce the moisture
content when compared to the untreated board. According to [13], hemicellulose hydrolysis caused by chemical modification using weak acids impacts increasing porosity. Increasing the substrate’s porosity will improve the adhesive's penetration ability so that the adhesion and distribution of the resulting adhesive will be better. Good adhesive penetration in the substrate cavity will cause a decrease in access to water and moisture movement so that the MC and WA values of the resulting board are low. Most of the particleboard produced in this study has met the JIS A 5908-2003 standard which requires the board moisture content to be 5-13% [14].

3.1.3. Water absorption

![Figure 3. Water absorption of particleboard](image)

The water absorption value of the board ranged from 34.13 - 63.27%. The AA3 board yielded the lowest value, while the NA2 board yielded the highest. In general, Figure 3 shows that the board treated with particles immersed in an acid solution had a lower water absorption value than the control and treatment in NaOH solution. As explained in the water content parameter, according to [13], the acid treatment caused hemicellulose hydrolysis, which increases porosity; the effect that occurs makes it easier to penetrate the adhesive, thereby reducing the accessibility of water and moisture. Because the size of the water molecule is smaller than the acetyl group, acetate wood can still absorb water through capillary action on the cell wall [15]. Still, the resulting expansion does not exceed the elastic limit of the cell wall.

3.1.4. Thickness swelling

![Figure 4. Thickness swelling of particleboard.](image)
The thickness swelling of the board ranged from 3.9 - 9.12%. The AA1 board yielded the lowest value, while the AA2 board yielded the highest. Refers to Figure 4 generally shows that the immersion treatment in both acetic acid and NaOH solutions resulted in a panel having a lower thickness expansion value than the control panel. The immersion treatment impacts the reduction of extractive substances, one of the inhibiting factors in the gluing process. The decrease in extractive substances causes the wettability of the particles to increase so that the bonding bond becomes better [16]. The isocyanate adhesive response looks better on boards treated with acetic acid immersion. Acidic conditions could degrade wood chemical components such as hemicellulose degradation was able to reduce the hydroxyl groups in the board [17].

Statistical analysis showed that the particle immersion treatment was significantly different at the 95% confidence interval for the development of the thickness of the board. Overall, the panel produced in this study has met the standard, which requires a maximum thickness expansion value of 12% [14].

3.2. Mechanical properties

3.2.1. Modulus of elasticity and modulus of rupture. Based on Figure 5 below, the MOE value of the panel ranges from 53,522.34 – 95,730.87 kg/cm², the lowest value was generated by the control, while the highest value was in the NA3 board. In this study, all treatments significantly increased the MOE value of the board when compared to the control board. The immersion treatment can reduce extractive substances, so the particles' wettability increases and results in better bonding [16]. According to [1], the MOE value is affected by the level and type of adhesive, adhesive bonding strength, and length of the fiber.

![Figure 5. MOE of particleboard](image)

Based on Figure 5, the MOR value of the board ranges from 442.67 – 825.39 kg/cm². The lowest value is obtained on the control board and the highest value on the AA1 type board. The trend in Figure 5 shows that in the treatment of particle immersion in acetic acid solution, the higher the concentration of acetic acid resulted in a decrease in the MOR value of the board. Acids that have high concentrations will hydrolyze the chemical components of wood, so it causes decreasing in wood strength in treatments with higher acid concentrations. Several studies have shown such conditions, including [6,17–20].

3.2.2. Internal bond. The internal bond of the board ranges from 1.46 – 3.80 kg/cm². The lowest value is obtained on the control board and the highest value on the AA3. The immersion treatment in acetic acid or NaOH solution seems to improve the internal bond value of the board. According to [21], the internal bonding strength of chemically modified wood particles with formaldehyde and isocyanate-based adhesives indicates that these modifications do not affect bond efficiency with isocyanate
adhesives. The NaOH immersion treatment on lignocellulose materials could change the chemical and physical structure of the fiber surface [22]. Rough fiber surface topography will produce better mechanical interlocking with the matrix [23].

![Figure 6. Internal bond of the particleboard](image)

4. Conclusion

Physical properties, including density, moisture content, water absorption, and thickness swelling, ranged from 0.68-0.75 g/cm³ respectively; 4.65-5.42%; 34.13-63.27%; and 3.9-9.12%. Meanwhile, the parameters of the board's mechanical properties, which include MOE, MOR, and IB, each ranged from 53,522.34-95,730.87 kg/cm²; 442.67-825.39 kg/cm²; and 1.46-3.80 kg/cm². In this study, the particle immersion treatment gave a significantly different effect on the 95% confidence interval on the physical and mechanical properties of the board. Treatment in an acid solution improved the physical and mechanical properties of the board, especially the dimensional stability of the particleboard sandwich. Based on the value, the AA3 board and AA1 board are the best boards. Most of the panels produced have complied standard of JIS A 5908 (2003).

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