Particleboard from kemenyan wood and belangke bamboo: effect of particle pre-treatment in acidic solution

A H Iswanto¹,³*, R Tanfiz¹, R Hartono¹, F Oktaviani², A R Putra², T Sucipto¹,³, L Hakim¹,³, I Azhar¹,³, H Manurung¹,³, A Darwis⁴, Samsuri³,², A Zaitunah³,⁵, H Arinah³,⁵, A Susilowati¹,³, D Elfati³,⁶, D Rangkuti³,⁶, O K Syahputra³,⁵, M M Harahap³,⁷, M Ulfa³,⁷ and R Rambey³,⁷

¹Department of Forest Products, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia  
²Magister Student, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia  
³JATI-Sumatran Forestry Analysis Study Center, Jl. Tridharma Ujung No.1, Kampus USU, Medan, North Sumatra 20155, Indonesia  
⁴School of Life Sciences and Technology, Institut Teknologi Bandung, Gedung Labtex XI, Jalan Ganesha 10, Bandung 40132, West Java, Indonesia  
⁵Department of Forest Management, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia  
⁶Department of Silviculture, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia  
⁷Department of Forest Conservation, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia  
*E-mail: apri@usu.ac.id

Abstract. Dimensional stability is a significant problem in particleboard. This study aims to analyze the effect of immersing particles in an acid solution on particleboard's physical and mechanical properties made of kemenyan (Styrax sumatrana) wood and belangke (Gigantochloa pruriens) bamboo. The particles were immersed in each acid solution for 24 h, and then dried to reach 9% water content. The particleboard was made with a 25x25 cm² with a target thickness and density of 1 cm and 0.70 g/cm³, respectively. After being made into sheets, the next step is hot pressing using a hot press machine that has set the temperature, time, and pressure at 160 °C, 5 min, and 30 kg/cm², respectively. The results showed that immersion in the acid solution can stabilize the dimensions of the resulting particleboard but does not reduce the strength of the board. Several board properties have met the standards, such as density, thickness swelling, modulus of rupture, and internal bond.

1. Introduction
Dimensional stability is a significant problem in particleboard. The hydrophilic character of the lignocellulose-containing material is the reason why particleboard can still absorb water even though it has used a water-resistant type of adhesive. Several previous studies have shown that particleboard has a relatively high thickness swelling value [1-5,6].
One of the efforts to overcome this problem is through the pretreatment of particles in an acid solution. According to [7], one of the chemical modification techniques of materials containing lignocellulose is reacting the hydroxyl group with acetic anhydride. This technique is known as acetylation. In principle, acetylation is a reaction for the formation of esters from acetic anhydride with hydroxyl functional groups in wood. This reaction causes a reduction in the primary hydroxyl group that absorbs water so that the fiber is more hydrophobic [9]. Several studies related to acetylation have been conducted previously, including [1,10-12].

![Figure 1](image.png)

Figure 1. The reaction of an anhydride with wood, [8]

Based on this description, this research focuses on improving the particleboard's dimensional stability through pretreatment of the particles in an acid solution. The type of acid solution used here is acetic acid and citric acid. These two acids are weak acids that are not expected to damage the cellulose components of the particles.

2. Materials and Methods

2.1. Materials

The raw materials used in this study were Kemenyan (*S. sumatrana*) wood, Belangke (*G. pruriens*) bamboo, acetic acid (AA) at 1% (v/v) concentration, citric acid (CA) at 2% (v/v) concentration, a mixture of acetic acid and citric acid (AAC) at 1% (v/v) concentration, and isocyanate adhesives at 7% level.

2.2. Methods

2.2.1. Particle Treatment. The particles were immersed in each of the predetermined solutions for 24 hours. After that, the particles are drained and air-dried before the drying stage in the oven. The particles were oven-dried to reach 9% moisture content.

2.2.2. Board Making. The particleboard was made with a 25x25 cm² with a target thickness and density of 1 cm and 0.70 g/cm³, respectively.

- **Adhesive application.** An amount of adhesive according to the specified level is sprayed on the particles until evenly distributed.

- **Mat forming.** The particles sprayed with adhesive are then put into a mold measuring 25x25 cm² and then pressed so that the sheet becomes denser.

- **Board pressing.** The compression process was carried out using a hot press machine that had been set at 160 °C, 5 minutes, and 30 kg/cm² of temperature, time, and pressure, respectively.

- **Conditioning.** This step is the final stage in the manufacture of the board. Board conditioning was carried out for 14 days in a room with temperature and pressure according to room conditions. It aims to release the residual stress that occurs due to the compression process.

- **Board cutting.** According to [12], the boards were made into several sizes of test samples.

2.2.3. Physical and Mechanical Properties Test of Particleboard. The board test refers to [12]. The test includes two parameters: (1) physical properties consisting of density, moisture content, water absorption, and thickness swelling. (2) Testing of mechanical properties consisting of internal bond (IB), Modulus of Elasticity (MOE), and Modulus of Rupture (MOR)
2.2.4. Data Analysis. The experimental design model used a two-factor factorial Completely Randomized Design (CRD). The first factor is the type of lignocellulosic material (Kemenyan wood and Belangke Bamboo), and the second factor is the type of acid solution (AA, CA, and AAC). The number of replications for each treatment was three replications.

3. Results and Discussion

3.1. Physical Properties

The test results on the physical properties of particleboard are presented in Table 1.

| Treatment | Density (g/cm³) | MC (%) | WA (%) | TS (%) |
|-----------|----------------|--------|--------|--------|
|           | KW | BB | KW | BB | KW | BB | KW | BB | KW | BB |
| Untreated | Avg | 0.59 | 0.61 | 4.11 | 5.32 | 82.80 | 60.30 | 15.70 | 16.90 |
|           | StDev | 0.04 | 0.03 | 0.15 | 0.07 | 0.04 | 0.04 | 0.03 | 0.01 |
| AA | Avg | 0.57 | 0.60 | 2.79 | 4.54 | 56.20 | 50.20 | 15.10 | 15.90 |
|       | StDev | 0.01 | 0.07 | 0.11 | 0.36 | 0.11 | 0.09 | 0.02 | 0.02 |
| CA | Avg | 0.58 | 0.57 | 3.13 | 4.59 | 78.20 | 55.00 | 11.70 | 13.00 |
|       | StDev | 0.05 | 0.05 | 0.43 | 0.66 | 0.05 | 0.09 | 0.01 | 0.02 |
| AAC | Avg | 0.52 | 0.60 | 3.65 | 3.17 | 61.00 | 47.50 | 14.50 | 15.50 |
|       | StDev | 0.02 | 0.03 | 0.50 | 0.54 | 0.13 | 0.02 | 0.02 | 0.03 |

Note: KW (Kemenyan wood), BB (Belangke Bamboo)

3.1.1. Density. Overall, the particleboard made of belangke bamboo has a higher density value than the kemenyan wood board. Similar conditions also occur on boards without immersion treatment. The density of the panels produced in this study has not yet reached the set target of 0.7 g/cm³. This condition is thought to be due to the high spring back of the board. The average spring back value from the results of this study is about 24%.

Furthermore, [14] stated that the density value is influenced by several factors such as wood type, amount of raw material, compression pressure, adhesive content, additives, and other additives. The board density produced in this study is in the medium category. According to [15] stated that medium density particleboard has a density value ranging from 0.4 to 0.9 g/cm³. The results analysis of variance (ANOVA) showed that the interaction between the type of lignocellulosic material and the acid solution did not significantly affect the 95% confidence interval on board density.

3.1.2. Moisture Content (MC). Untreated bamboo produced the highest moisture content, while Kemenyan wood with AAC treatment had the lowest moisture content. The treatment of particleboard immersion in a solution of acetic and citric acid can reduce the value of the water content of the resulting board. The acidic functional groups can bind to the hydroxyl groups of the wood, thereby reducing the hygroscopic nature of the wood. According to [12], the treatment of wood immersion in an acid solution could reduce extractive substances, degrade hemicellulose and starch. This condition results in a decrease in the hygroscopic properties of wood. Replacing some of the hydroxyl groups of wood cell wall polymers with acetyl acid groups can reduce the hygroscopic properties of wood.

Reducing the hygroscopic nature of wood can lower the water binding capacity so that the water content becomes low. According to [16], acid significantly reduces the OH group on the particleboard. Due to the reduced ester bond, the particleboard is more hydrophobic with better water resistance and dimensional stability. The reduction of starch and sugar through immersion could make the adhesive easier to enter and form a particle bond with a stronger adhesive [17]. The analysis of variance (ANOVA) showed that the interaction of the two factors had a significantly different effect on the moisture content of the particleboard at a 95% confidence interval.
3.1.3. Water Absorption (WA). Untreated kemenyan wood produced the highest water absorption value, while the lowest value was produced by bamboo with AAC treatment. The immersion treatment in an acid solution resulted in extractive degradation and several other chemical components such as cellulose, hemicellulose [18]. The analysis of variance (ANOVA) showed that the interaction of the two factors have a significantly different effect on the 95% confidence interval on the water absorption value.

3.1.4. Thickness Swelling (TS). Untreated bamboo produced the highest thickness swelling value, while kemenyan wood with CA treatment had the lowest thickness swelling value. Acetylated wood can still absorb water through capillary action in the cell walls. This happens because the water molecule is smaller than the acetyl group. Some swelling occurs in acetylated wood. Still, the swelling does not exceed the elastic limit of the cell wall.

Acid treatment can degrade the chemical properties of wood to dissolve extractive substances on particleboard. Hemicellulose is a cell wall component that is also susceptible to acid treatment. Hemicellulose is non-crystalline, so that it expands easily and is easily hydrolyzed by acid, and is soluble in alkali [18]. Hemicellulose degradation causes a decrease in OH groups in hemicellulose polymers. This can reduce the hygroscopic nature of the wood so that the water holding capacity decreases and the thickness swelling decreases. The analysis of variance (ANOVA) showed that the interaction of the two factors did not have a significantly different effect on the 95% confidence interval on the thickness swelling value.

3.2. Mechanical Properties
The test results on the mechanical properties of particleboard are presented in Table 2.

Table 2. Mechanical properties of particleboard.

| Treatment | MOE (kg/cm²) | MOR (kg/cm²) | IB (kg/cm²) |
|-----------|--------------|--------------|-------------|
|           | KW           | BB           | KW          | BB          |             |
| Untreated | Avg          | 15,596       | 12,180      | 119.78      | 52.54       | 2.11        | 1.64        |
|           | StDev        | 1,965        | 2,256       | 22.00       | 13.00       | 0.16        | 0.20        |
| AA        | Avg          | 16,238       | 13,065      | 125.99      | 82.86       | 1.88        | 1.55        |
|           | StDev        | 2,524        | 2,026       | 17.00       | 8.00        | 0.19        | 0.14        |
| CA        | Avg          | 16,312       | 15,320      | 128.30      | 66.26       | 1.53        | 1.53        |
|           | StDev        | 1,501        | 1,416       | 19.00       | 19.00       | 0.05        | 0.16        |
| AAC       | Avg          | 17,718       | 12,802      | 136.63      | 68.86       | 2.02        | 1.35        |
|           | StDev        | 2,776        | 1,183       | 20.00       | 15.00       | 0.20        | 0.16        |

Note: KW (Kemenyan wood), BB (Belangke Bamboo)

3.2.1. Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). Kemenyan wood with AAC treatment produced the highest MOE value, while bamboo without treatment produced the lowest value. The acid treatment had no negative effect on MOE in this study. This is presumably because the acid used in the treatment is a weak acid with a deficient concentration. In general, acid treatment will cause a decrease in the mechanical properties of the board. Kemenyan particle with AAC treatment produced the highest MOE value, while bamboo without treatment produced the lowest value. In this study, acid treatment did not have a negative effect on MOE. This is presumably because the acid used in the treatment is a type of weak acid with a very low concentration. In general, acid treatment will cause a decrease in the mechanical properties of the board. Acid could hydrolyze polysaccharides, cellulose, and hemicellulose in wood [18]. The high acid content can reduce the value of the strength and durability of wood. The analysis of variance (ANOVA) showed that the interaction of the two factors did not have a significantly different effect on the 95% confidence interval on the MOE value.

Kemenyan wood with AAC treatment produced the highest MOR value, while bamboo without treatment had the lowest value. This condition is similar to MOE in that acid treatment does not decrease the strength of the board. The analysis of variance (ANOVA) showed that the interaction of the two
factors did not have a significantly different effect on the 95% confidence interval on the MOR value of the board.

3.2.2. Internal Bonding (IB). Kemenyan wood with AAC treatment produced the highest IB value, while bamboo with AAC treatment had the lowest value. In general, the acid treatment causes a decrease in the IB value. This is caused by two things, namely extractive substances and the pH or acidity of the particles. The treatment of immersion in liquid can dissolve extractive substances so that the gluing process will take place correctly. Furthermore, the increase in acid concentration causes an increase in the acidity of the particles used. Although isocyanate adhesives are acid-tolerant adhesives, there are limitations where this adhesive cannot work optimally in strong acid conditions. In this study, the acidity (pH) of the particles was about 4.5. The analysis of variance (ANOVA) showed that the interaction of the two factors did not have a significantly different effect on the 95% confidence interval on the IB value of the board.

4. Conclusion
The treatment of immersing kemenyan wood particles and bamboo belangke in an acid solution can improve the value of water absorption and increase the thickness of the resulting board. This indicates an improvement in the dimensional stability of the board. In this study, the treatment of immersion in an acid solution did not have a negative effect on the strength of the wood because the type of acid used is a weak acid with a low concentration.

Acknowledgment
The author would like to thank the Universitas Sumatera Utara, which has funded this research through the "TALENTRA" Penelitian Dasar scheme in 2021 (Number 368/UN5.2.3.1/PPM/SPP-TALENTRA USU/2021, date June 18, 2021)

References
[1] Iswanto A H, Febriana R, Azhar I, Madyaratri E W, Wirjosentono B, Darwis A and Hartono R 2019 IOP Conf. Ser.: Earth Environ. Sci. 454 012042
[2] Iswanto A H, Oktaviani F, Tarigan W F and Nuryawan A 2021 IOP Conf. Ser.: Earth Environ. Sci. 713 012047
[3] Iswanto A H, Simarmata J, Fatriasari W, Sucipto T, Azhar I and Hartono R 2017 J. Korean Wood Sci. Technol. 45 787
[4] Iswanto A H, Idris M and Sucipto T 2019 IOP Conf. Ser.: Earth Environ. Sci. 260 012039
[5] Iswanto A H, Munthe R, Darwis A, Azhar I, Susilowati A, Prabuningrum D S and Fatriasari W 2019 Korean J. Mat. Res. 29 277
[6] Hartono R, Iswanto A H, Sucipto T and Lubis K M 2018 IOP Conf. Ser.: Earth Environ. Sci. 166 012006
[7] Rowell R M 1975 Proc Am Wood Preservers’ Assoc 71 41
[8] Hill C A S 2006 Wood Modification: Chemical, Thermal and Other Processes (John Wiley & Sons Ltd: England)
[9] Rowell R M 2007 Chemical Modification of Wood. Handbook of Engineering Biopolymers Homopolymers, Blends and Composites (Carl Hanser Verlag: Munich)
[10] Iswanto A H, Febrianto F, Hadi Y S, Ruhendi S, Hermawan D and Fatriasari W 2018 J. Korean Wood Sci. Technol. 46 155
[11] Febrianto F, Sahroni, Hidayat W, Bakar E S, Kwon G J, Kwon J H and Kim N H 2012 Wood Sci. Technol. 46 53
[12] Febrianto F, Endriadilla D R and Nawawi D S 2016 J. Ilmu Teknologi Kayu Tropis 14 23
[13] J S A 2003 Japanese Industrial Standar JIS A 5908 for Particleboard (Japanese Standard Association: Japan)
[14] Kelly M W 1977 Critical Literature Review of Relationship Between Processing Parameter and
Physical Properties of Particleboard (Wisconsin University USA)

[15] Maloney T M 1993 Modern Particleboard and Dry Process Fiberboard Manufacturing (Miller Freeman Publication: San Fransico)

[16] Umemura K, Suguhara O and Kawai S 2014 J. Wood Sci. 61 40

[17] Iswanto A H, Coto Z and Effendi K 2008 J. Perennial 4 6

[18] Fengel D and Wegener G 1984 Wood, Chemistry, Ultrastructure, Reactions (Walter de Grugter: USA)