Effect of Acetic Acid and Acetic Anhydride Ratio to Physical and Mechanical Properties of Particleboard

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Abstract. In general, particleboard has a weakness in terms of low dimensional stability. This study aims to analyse the effect of immersing wood shavings in a mixture of acetic acid (AAc) and acetic anhydride (AAn) solution at several ratios to properties of particleboard. Wood shavings were immersed in an AAc/AAn solutions for 24 hours with a concentration of AAc 3% and AAn 2% with a mixture ratio of AAc / AAn consisting of 100/0, 80/20, 70/30. The boards made with a thickness and density target of 10 mm and 0.75 g/cm³, respectively. The pressing was carried out at 130°C, pressure 30 kg/cm² and the time was 10 minutes. Testing of board properties refers to the JIS A 5908 (2003). The results show that acetylation treatment on wood shavings reduces the thickness swelling value. It was an indication that there had been an improvement in dimensional stability. An increase in the proportion of AAn resulted in a decrease of thickness swelling, water absorption, and moisture content of particleboards. On the internal bond, increasing the AAn proportion in the AAc/AAn solution further decreases the value of an internal bond, however overall internal bond value of board in this research meets the standard.

1. Introduction

Timber demand for the industry continues to increase, while the supply of timber from natural forests is insufficient. An alternative to solve that problem is the utilization of wood waste from sawmills as a raw material in particleboard manufacturing. Particleboard is a composite product made of wood particles or other lignocellulosic material, which is bound with synthetic adhesives or other binder and is then subjected to a hot pressing process [1].

According to [2] particleboard has a weakness in terms of low dimensional stability. Several studies had been carried out to improve the dimensional stability of particleboard through particle pre-treatment. Immersion of particles in a 1% acetic acid solution for 24 hours has succeeded in improving some of the...
physical and mechanical properties of particleboards from jatropha fruit hulls [3]. Immersing strand in acetic anhydride solution caused a decrease of moisture content, thickness swelling and water absorption of oriented strand board (OSB) [4]. Furthermore [5,6] reported that in jatropha fruit hulls and wood-shaving particleboard, particle immersing in 1% acetic acid solution had higher dimension stabilization and mechanical properties compared to control boards. Based on the description, the purpose of this study is to analyse the effect of the mixture ratio of AAc and AAn to enhance of particleboard quality.

2. Materials and methods

2.1. Materials

Wood shavings waste from sawing a small industry in Medan, North Sumatra. Furthermore, were a solution of acetic acid (AAc) and acetic anhydride (AAn) as a treatment material for wood shavings particles and adhesive in this case of urea-formaldehyde as a binder.

2.2. Methods

2.2.1. Materials preparation. Wood shavings were immersed in a mixture of acetic acid solution at a concentration of 3% and acetic anhydride with a concentration of 2% with a composition of 100/0, 80/20, and 70/30 (% v/v). The immersion process was carried out for 24 hours at room temperature conditions.

2.2.2. Manufacturing of particleboard. Wood shavings were mixed with UF adhesive using a rotary blending machine. Particles that have been mixed with the adhesive were even put into a mold measuring 25 cm by 25 cm to be made into sheets. The formed sheet was then compressed using a hot press machine which had been set at 130°C, pressure 30 kg/cm² for 10 minutes. Boards that had been made were conditioned for 7 days at a place with room temperature conditions.

2.2.3. Cutting of sample. After conditioning process, the next step was cutting of board into a test sample with size for density and moisture content test of 10 cm by 10 cm, water absorption and thickness swelling test of 5 cm by 5 cm, bending test of 20 cm by 5 cm, and internal bond test of 5 cm by 5 cm. All the sample size refers to JIS A 5908 (2003).

2.2.4. Particleboard test. The parameters tested for particleboard in this study consisted of density, moisture content, water absorption, thickness development, modulus of elasticity, modulus of rupture and internal bond. All tests carried out refer to JIS A 5908 2003.

3. Results and discussion

3.1. The physical properties of particleboard

3.1.1. Density and moisture content. The density value of particleboard in this study ranged between 0.53 to 0.56 g/cm³. The density and moisture content value of particleboard were presented in Fig 1.
Overall, the density of particleboard results in this research still below the density target (0.75 g/cm³). A similar case had been reported by [5,6,7]. It was presumed by a spring back of particleboard after the conditioning process. The average of spring back value for each treatment was 18.37%; 31.57%; 32.63%; 29.27% respectively for untreated, 100/0, 80/20 and 70/30. According to [8] Several factors influence the value of particleboard density include wood type, pressure press, particle number, amount of adhesive and additives. Density value is very dependent on the density of wood as raw material and the amount of pressure applied in manufacturing [2]. The relationship between density and spring back value of particleboard was presented in Fig 2.

All density of particleboard produced in this research was classified in a lower density. According to [1] that low-density particleboard, which is particleboard that has a density of less than 0.59 g/cm³. Overall the density value of particleboard in this research had fulfilled of JIS A 5908 (2003) which requires particleboard density values of 0.4 to 0.9 g/cm³.

The moisture content of particleboard produced in this study ranged between 4.05 to 4.60 %. The highest moisture content value was achieved on untreated board (control), while the lowest value was obtained on board using the treatment of 70/30 AAc/AAn ratio (Fig 1). Trends in the results of this study indicate that immersing particles in a mixture of acetic acid and acetic anhydride at various ratios appears to reduce of moisture content of particleboard. The higher of acetic anhydride proportion resulted in the
lower moisture content. It was due to that acetic anhydride bonded to the OH group in wood thereby reducing the hygroscopic properties of wood, whereas acetic acid only functions as an accelerator in the acetylation process. Replacing some hydroxyl groups from cell wall polymers with acetyl group bonds reduces the hygroscopic properties of wood.

3.1.2. Water absorption. Water absorption value of particleboard for 2 and 24 hours soaking in water at room temperature was ranged between of 82.87 to 87.86%, and 94.77 to 99.54%. The water absorption value of particleboard is presented in Fig 3.

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

Based on Fig 3, similar conditions with moisture content value that untreated board resulted in the highest value of water absorption. While the lowest value produced from particleboard using treatment of 70/30 AAc/AAn ratio. Several factors causing the low water absorption value after acetylation treatment are the dissolution of some extractive substances, degradation of hemicellulose, and better adhesion processes. Acid treatment can degrade wood polysaccharides especially hemicellulose [9]. According to [10] hemicellulose is an amorphous polysaccharide fraction that is easily degraded and is polyhydroxy. Therefore, degraded and partial dissolution of hemicellulose along with starch will reduce the abundance of hydroxyl groups in boards that can bind water. This causing of water absorption value of the untreated board is higher than the board treated with acetylation. The acetylation treatment can dissolve some extractive substances from wood shavings. This results in better adhesive penetration into wood shavings. Good adhesive penetration will cause limited accessibility of water and vapor movements, as a result, the moisture content and water absorption of the board are low.

3.1.3. Thickness swelling. Thickness swelling value of particleboard for 2 and 24 hours soaking in water at room temperature ranged between of 14.81 to 18.73% and 18.47 to 25.33%. The thickness swelling value of particleboard was presented in Fig 4.
Figure 4. Thickness swelling of particleboard

Similar to water absorption value, the highest thickness swelling values for 2 hours and 24 hours were produced by untreated particleboard. While the lowest value produced from particleboard using treatment of 70/30 AAc/AAn ratio. The thickness swelling value in this study was still high because the adhesive used as urea-formaldehyde (UF) which is a non-waterproof adhesive. Even though the acetylation treatment had been given, water can still be absorbed by particleboard. Similar to research conducted by [3] about acetylation of oriented strand board. Acetylated wood can still absorb water through capillary action in cell walls. It is due to the water molecule is smaller than the acetyl group, some swelling occurs in acetylated wood but the swelling does not exceed the elastic limits of the cell wall. All the particleboard resulted from this research didn’t fulfill JIS A 5908 (2003) which requires a maximum thickness swelling value of 12%.

3.2. Mechanical properties of particleboard

3.2.1. Modulus of elasticity (MOE) and Modulus of Rupture (MOR). Modulus of elasticity and Modulus of Rupture value of particleboard ranged between 14.81 to 18.73% and 18.47 to 25.33% respectively. Modulus of elasticity and Modulus of Rupture value of particleboard was presented in Fig 5.

Figure 5. Modulus of elasticity and Modulus of Rupture of particleboard
The modulus of elasticity of particleboard produced in this study was low. It was caused by particle geometry. Based on the particle geometry, the wood shavings used in this study had a slenderness ratio (SR) of 16.38. The slenderness ratio value produced in this study did not meet of ideal value as suggested by [1] which is equal to 150. Besides density, adhesive content and particle geometry are the main characteristics that determine the MOE value [2]. In this study, the MOE value of all particleboards did not meet JIS A 5908 (2003) which required a minimum MOE value of 20,400 kg/cm².

Furthermore, the highest MOR value was achieved on boards produced from particleboard using treatment of 100/0 AAc/AAn ratio, while the lowest MOR values were obtained on boards with a 70/30 ratio. Overall, the MOR value of boards resulted is low, it was due to the acetylated wood causes of wood has more hydrophobic characteristic so that the adhesive is difficult to penetrate the wood. According to [11], a slight decrease in some strength properties occurs as a result of acetylation treatment. In this study, the MOR values of all particleboards produced did not meet JIS A 5908 (2003) which required a minimum MOR value of 82 kg/cm² (JSA, 2003).

3.2.2. Internal bond (IB). The internal bond value of particleboard in this study ranged between of 1.51 to 4.41 g/cm³. The internal bond value of particleboard was presented in Fig 6.

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

Based on Fig 6, trends show that the internal bond value of particleboard decreases with the increasing proportion of AAn in the acid solution mixture. The lower internal bond value of treated particleboard was caused by a decrease in pH due to acetylation. Changes in wood particle acidity will influence the time and temperature parameters of the press in the particleboard manufacturing process. According to [12] differences in pH cause differences in the time of adhesive curing during hot pressing, if not adjusted it will result in a decrease of internal bond value. Pressing time and temperature as one of the main parameters determining the success of the gluing process. In the pressing of the board, there are two phenomena related to the condition of adhesive curing namely, the first, if the press temperature is too low will result in adhesive not curing, and second, for temperatures that are too high will result in adhesive being over curing at the same time pressing conditions. Long a pressing condition will result in a lower IB [13]. According to [2], the internal bond of particleboard is affected by mixing, forming and good compressing. In this study, all particleboards did not fulfill JIS A 5908 (2003) which required an IB value of 1.5 kg/cm².

4. Conclusion
The acetylation treatment related to the immersion of wood shavings in a mixture of acetic acid and acetic anhydride solutions able to reduce thickness swelling value even though the overall thickness swelling value of the board produced did not meet JIS A 5908 (2003). The greater proportion of acetic anhydride in
a mixture of acetic acid and acetic anhydride solutions resulted in a decrease of mechanical properties, in this case, modulus of rupture, modulus of elasticity, and internal bonds.

References
[1] Maloney T M 1993 Modern Particleboard and Dry-Process Fiberboard Manufacturing (USA: Miller Freeman Inc. San Francisco)
[2] Bowyer J L, Shmulsky and Haygreen J G 2003 Forest Products and Wood Science – An Introduction Fourth edition (USA: Iowa State University Pr.)
[3] Iswanto A H, Febrianto F, Hadi Y S, Ruhendi S, Hermawan D and Fatriasari W 2018 Effect of Particle Pre-Treatment on Properties of Jatropha Fruit Hulls Particleboard J Korean Wood Sci Technol 46(2) 155-165
[4] Iswanto A H, Widya F, Andi D Y, Ahmad Z, Fauzi F 2013 Physical and Mechanical Properties of Oriented Strand Board Prepared from Acetylated Wood Strands J Ilmu dan Teknologi Kayu Tropis 11(2) 184-191
[5] Iswanto A H, Febrianto F, Hadi Y S, Ruhendi S and Hermawan D 2018 IOP Conf Ser: Earth Environ Sci 126 012015
[6] Iswanto A H, Supriyanto, Fatriasari W and Susilowati A 2018 IOP Conf Ser: Earth and Environ Sci 126 012016
[7] Iswanto A H, Aritonang W, Azhar I, Supriyanto and Fatriasari W 2017 The physical, mechanical and durability properties of sorghum bagasse particleboard by layering surface treatment J Indian Acad Wood Sci 14(1) 1–8
[8] Kelly M W 1977 General Technical Report FPL-10-US Department of Agriculture Forest Service and Forest Products Laboratory University of Wisconsin Critical Literature Review of Relationship Between Processing Parameter and Physical Properties of particleboard
[9] Fengel, D and Wegener, G 1984 Wood: Chemistry, Ultrastructure, Reactions (Berlin and New York: Walter de Gruyter)
[10] Sjostrom E 1991 Wood Chemistry, Fundamentals, and Applications (New York: Academic Press)
[11] Rowell R M 2007 Chemical Modification of Wood Handbook of Engineering Biopolymers Homopolymers, Blends and Composites (Munich: Carl Hanser Verlag)
[12] Paridah M T, Chin A M E and Zaidon A 2001 Bonding Properties of Azadirachta excelsa J Tropical Forest Products 7 161-171
[13] Wang D and Sun X S 2002 Low density particleboard from wheat straw and corn pith Industrial Crops and Products, 15(1) 43-50

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