JOURNAL

by Mirna Lubis

UNS UNIVERSITAS SEBELAS MARET

ALCHEMY Jurnal Penelitian Kimia

Laman resmi: https://jurnal.uns.ac.id/alchemy

ISSN 1412-4092
EISSN 2443-4183
ALCHEMY JURNAL PENELITIAN KIMIA

Effect of Adhesive-Particle Ratio on the Characteristics of Particleboard Made from Oil Palm Empty Fruit Bunches

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DOI: xxx

Received..., Accepted, Published xxx

Keywords:

avocado seed filler; oil palm bunches; matrix; mechanical property; particleboard

ABSTRACT. Indonesia's forest conservation efforts have become a development priority that is urgently needed to maintain the balance of the ecosystem, as well developed to conserve the judicious use of wood. The need for the wood increases with increasing development, but its dwindling availability makes it difficult for the industry to process it. Efforts to reduce this impact are by finding environmentally friendly solutions, namely by utilizing waste into new products. Therefore, this study is focused on oil palm empty fruit bunches to be reprocessed into particleboard. The matrix is polyvinyl acetate as a composite reinforcement, and dibutyl phthalate is added to make the adhesive flexible. The variables were the adhesive/particle ratio (0.8, 1.1, 1.2, 1.4, and 1.6) and the percentage of avocado seed filler (0.4, 0.8, 1.2, 1.6, and 2%). The resulting composites were then tested for modulus of rupture, moisture content, modulus of elasticity, thickness swelling, density, and tensile strength. The results indicated that particle board with an adhesive/particle ratio of 1.6 and a filler percentage of 2% avocado seeds could improve some of the characteristics of particleboard, namely modulus of rupture, thickness swelling, moisture content, and density required by SNI 03-2105-2006.

INTRODUCTION

The volume of timber production is increasing along with rapid urbanization and industrialization. Based on Statista Research Department, Indonesia produced 1.87–2.58 million cubic meters in the range of 2016–2020 (Statista Research Development, 2023). Data for the period 2013 to 2020 indicates that there is significant fluctuation in timber production levels, with little or sustained increase in all categories of processed wood, such as sawn wood, plywood and veneer, laminated timber, veneer, wood chip, and wood pulp. However, materials obtained from forest wood result in diminishing forest resources. The diminishing wood production causes the demand for wood to be greater than what is available, so that alternative wood is sought that has better quality than wood (Atoyebi *et al.,* 2018). One way to overcome the need for wood is to utilize plant waste. Manufacture of artificial boards in the form of particle boards is one way to utilize plant waste that is not used economically. The use of natural particles or fibers as a new engineered material for making particleboard is important to prevent forest area from decreasing (Owodunni *et al*., 2020).

Particleboard is a board made of wood particles and glued together with adhesive. In general, the manufacture of particleboard uses materials containing hemicellulose, cellulose, and lignin. The mechanical and physical quality of particleboard is still low because of the large particle size, the mixture of filler as additional reinforcement, and the adhesive content used (Lestari and Mora, 2018). Adhesion is defined as the state or bonding condition in which two surfaces become one because of the bonding force between the surfaces. This force is a bond known in molecular theory in the form of valence/ionic bonding force and an interlocking force between the adhesive and the material (Prayitno, 1996). Adhesive is one of the main ingredients that is very important in the industry. The craft industry is included in the creative industry that produces decorative items for home decoration or fashion. The glues commonly used in the craft industry are synthetic adhesives called yellow glue, white glue, and polyvinyl acetate (PVAc).

Particleboard has several advantages compared to wood, such as knot-free, not easily broken, and not easy to crack. Making particleboard is based on economic considerations, namely utilizing waste from various types of plants (Nasution and Mora, 2018). Some lignocellulosic materials that can be physically and chemically modified into particleboards are castor seed meal, coconut shell, empty fruit bunch fiber, rice husks (Widyorini *et al*., 2018), coconut coir (Hasan *et al*., 2020), oil palm stems (Hashim *et al*., 2020), bagasse (Oliveira *at al*., 2016), corn stalks (Soleimani *et al*., 2017), palm fronds (Santoso *et al*., 2017), salak fronds (Juliana *et al*., 2012), and sorghum (Sutiawan *et al*., 2022). In addition, the application of filler composite materials is an effective way to manage agro-industrial waste or natural fibers effectively (Azevedo *et al*., 2022).

Oil palm empty fruit bunch (OPEFB) is a potential lignocellulosic material with a fiber content of up to 72.67%, which has the potential to be used as a panel product, such as particleboard. Previous research succeeded using OPEFB to make exotic particleboard (Lubis *et al*., 2018). OPEFB prepared with 700 kgm^{-3} in density with 14% urea formaldehyde had the best composition of elastic modules and modulus of rupture of particle board according to EN 312-3 standard (Wahab *et al*., 2015). However, OPEFB board has a weakness because the larger fiber size causes cavities between the particles. The existence of these cavities causes the strength of the board to decrease, making it easier to break the board. The pressing temperature and urea formaldehyde content could improve the situation (Saad *et al*., 2018). Another method that is very suitable for improving the physical characteristics of particleboard from OPEFB in the form of moisture content and density, as well as mechanical properties in the form of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) is the addition of additional resin (Ridzuan *et al*., 2002). Increasing the proportion of filler decreases the shrinkage and residual stress (Aruniit *et al*., 2011). In addition, particleboard from OPEFB and mahogany filler was found in 15:50 ratio (Sunardi *et al*., 2020). The addition of additional finer sized avocado seeds is expected to fill the empty spaces between the empty palm oil bunches and make the particle board denser. Avocados have a spherical seed with a diameter of 2.5–5 cm which is the part that develops from the ovule and acts as regenerating component. Seeds are a food source for humans and animals. Avocado seeds contain alkaloids, flavonoids, steroids, terpenoids, saponins, and tannins (Kopon *et al*., 2020). Other benefits are as medicine, fiber (cotton), drinks (coffee and chocolate), and a source of oil (Esau, 1977). In addition, it is expected to increase the value of the physical and mechanical characteristics of the resulting OPEFB particleboard. Thus, the objective of this study is to analyze the influence of the adhesive/particle ratio on the physical and mechanical characteristics of particleboard using avocado seed as a filler.

RESEARCH METHODS

OPEFB was cut into small pieces with a size of 1 cm. Then the OPEFB was soaked for two hours to remove the water, oil, and dirt content. Then the OPEFB was dried in the sun and then the OPEFB was sieved using a sieve machine. The adhesive was weighed as needed, in this study the ratio of adhesive/particle used was 1.6, 1.4: 1.2; 1.1, and 0.8. The polyvinyl acetate adhesive was mixed into the particles until thoroughly mixed. Particles and adhesive mixture was put into a pressed sheet measuring 20 × 20 × 1 cm and then compacted. The bottom and top of the mold are covered (Wulandari *et al*., 2020) with aluminum plates. Hot pressing was done on the left and right by placing a square iron with a side length of 1 cm. Hot press was done using a hot press machine with a time of approximately 15 minutes. The hot sheet was left for ± 10 minutes. Drying was carried out at room temperature for approximately seven days (Ginting *et al*, 2016).

RESULT AND DISCUSSION

Particleboard Density

Density is a physical property that shows the ratio between the sizes of an object's mass and the volume of the object (Alamsjah *et al*., 2017). The density value is calculated by comparing the mass with the volume of the composite board. The composite board density values produced in this study is displayed in Figure 1.

Based on Figure 1, it appears that the physical property of particleboard for all filler contents of avocado seeds shows a density of 0.3–0.6 g/cm^3. It appears in Figure 1, the density value of particleboard increases as the increase in the ratio of adhesive/particle and the percentage of avocado seed filler. This is in accordance with previous research that the resulting particleboard has the density value related to the ratio of the adhesive used (Hasan *et al*., 2020). The more adhesive used in the manufacture of particleboard, the greater the density value of the resulting particleboard. Likewise, the higher the percentage of avocado seed filler, the higher the density of the resulting particleboard. In accordance with previous study, with the addition of filler, the density value will increase (Sunardi *et al*., 2017). Avocado seed has a higher economic value to be used as a filler in the particleboard manufacturing.

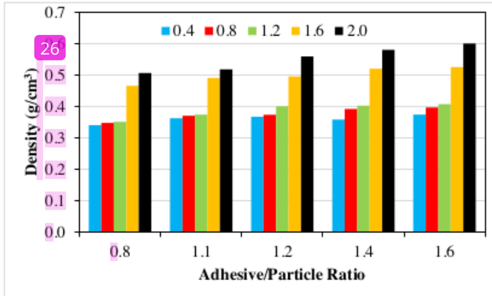

Figure 1. The result of the particleboard density test with various adhesive/particle ratios.

However, it is important to note that the suitability and performance of avocado seeds as a filler would depend on various factors, including their availability, chemical and physical properties, cost-effectiveness, and the specific requirements of the particle board manufacturing process. Avocado seeds are typically discarded as waste after consuming the fruit, so finding a productive use for them could be environmentally beneficial.

In Figure 1 it can be seen that the lowest density of particleboard is obtained with 0.4% avocado seed filler and an adhesive/particle ratio of 0.8, which is 0.34 g/cm^3. The highest percentage value of avocado seed filler is found in 2% avocado seed filler and 1.6 adhesive/particle ratio, namely 0.6 g/cm^3. SNI 03-2105-2006 and JIS A 5908:2003 standards for testing particleboard require that a good density of particleboard is 0.4–0.9 g/cm^3, which is included in particleboard with medium density. The board complies with SNI 03-2105-2006 and JIS A 5908:2003 standards, namely 0.4–0.9 g cm^{-3}.

Particleboard Moisture Content

Particleboard moisture content is a significant factor affecting the dimensional stability, strength, and overall performance of particleboard. Moisture content indicates the water content present in the particleboard expressed in percent its dry weight. It is typically determined by the amount of moisture in the wood particles and the water content introduced during the adhesive mixing and curing process. Data from particleboard moisture testing results are presented in Figure 2.

Based on Figure 2, it can be seen that the average results of the particleboard moisture content tests that have been carried out are in the range of 10.10%–19.84%. JIS A 5908-2003 requires the water content value of particleboard to be in the range of 5%–13%, whereas according to the SNI 03-2105-2006 it should not be more than 14%.

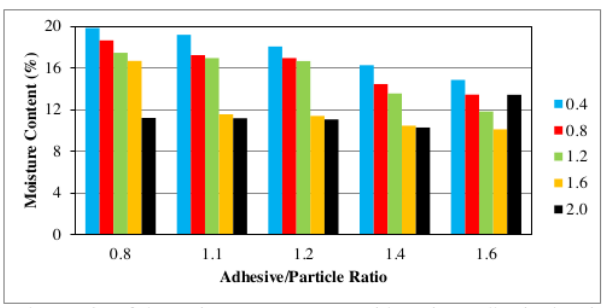

Figure 2. The results of the moisture content test with various adhesive/particle ratios.

Based on Figure 2, the highest particleboard moisture content is found in 0.8% avocado seed filler with a water content value of 19.84% while the lowest water content value in 1.6% avocado seed filler with a moisture content value of 10.1%. In Figure 2 the highest particleboard moisture content is found in the adhesive/particle ratio of 0.8 with a particle board moisture content value of 19.84%. Meanwhile, the lowest moisture content of particleboard, namely 10.1%, is obtained at an adhesive/particle ratio of 1.6 and complies with JIS A 5908-2003 regulation, namely in the range of 5%–13% moisture content. As the adhesive content increases, the particleboard moisture content tends to decrease (Aprilia *et al*., 2019). It can be explained that a higher adhesive composition allows a wider distribution of adhesive, so that the bonds between particles become stronger, water molecules are difficult to enter, and can reduce the moisture content of particleboard. Using a higher adhesive-to-particle ratio means adding a greater amount of adhesive to the wood particles.

Thickness Swelling

Thickness swelling refers to the increase in thickness that occurs when particleboard absorbs water after 24 hours of soaking. More water absorption causes thicker swelling that will negatively impact overall performance and lower dimensional stability. The results of testing the thickness swelling value by soaking the particleboard for 24 hours in water can be seen in Figure 3.

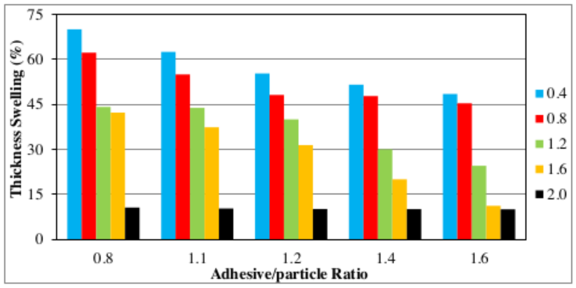

Figure 3. The results of the particleboard thickness swelling with various adhesive/particle ratios.

Based on Figure 3, the highest thickness swelling of 70% is obtained with 0.4% avocado seed filler, while the lowest thickness swelling is 10% with 0.4% avocado seed filler. In Figure 3, it can be seen the results of testing the thickness of particleboard soaked in cold water at 25ºC for 24 hours. The highest thickness swelling value is 70% with an adhesive/particle ratio of 0.8, while the lowest thickness swelling value is 10% with an adhesive/particle ratio of 1.6 and complies with JIS A 5908-2003 and SNI 03-2105-2006 regulations that require swelling maximum 12%.

Insufficient adhesive can result in weak or incomplete bonding between the particles, leading to reduced strength and integrity of the particleboard. On the other hand, excessive adhesive can clog the void spaces between the particles, reducing the permeability of the panel. This can hinder the movement of moisture within the board and decrease the overall moisture resistance. With a high adhesive-to-particle ratio, it becomes more challenging for the adhesive to fully penetrate the wood particles, reducing the overall strength and integrity of the board. Particleboard is susceptible to moisture absorption, and an excess of adhesive can exacerbate this issue. Higher water absorption leads to increased swelling, warping, and decreased dimensional stability.

Several things that affect the thickness of the particleboard are the densities of the particleboard and the original wood. The low density of particleboard makes it easier for water to enter into the cracks of the board, thereby facilitating swelling of the board (Maftuhatin *et al*., 2017). A low density wood board will cause a high thickness swelling when the particleboard is immersed in water because of the internal pressure it creates.

Modulus of Elasticity

The MOE describes a measure of the particleboard's resistance to deformation or bending that occurs up to the elastic limit. The higher the MOE of the particleboard, the more elastic it will be. The MOE test results are presented in Figure 4.

Based on Figure 4, it appears that the greatest MOE value was found in 2% avocado seed filler with an MOE value of 10,837.4 kgf/cm^2 while the lowest MOE value was found in 0.4% avocado seed filler with an MOE value of 4,947.1 kgf/cm^2. In Figure 4 it can be seen that the highest MOE of 10,837.4 kgf/cm^2 is found at an adhesive/particle ratio of 1.6 while the lowest MOE is 4.947.1 kgf/cm^2 found at an adhesive/particle ratio of 0.8. This is in accordance with previous research that the MOE value can be affected by the type and composition of board adhesive used and the adhesion among the particles [7]. According to SNI 03-2105-2006 regulation, the MOE value is required at least 20,400 kgf/cm^2. Therefore, the resulting particleboard has a low MOE value and does not meet SNI 03-2105-2006 standards. Particleboard from non-wood materials has low flexural strength because the raw material has low strength (Anggita *et al*., 2019).

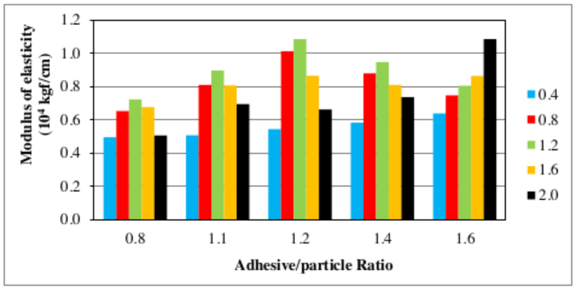

Figure 4. The results of particleboard MOE with various adhesive/particle ratios.

The amount of adhesive and raw materials used in the particleboard manufacturing determines its static bending strength. The adhesive-to-particle ratio can have an effect on the MOE of particleboard, but the relationship is not straightforward. MOE describes a value of the rigidity or stiffness of a material and reflects its ability to withstand deformation under applied loads. The adhesive-to-particle ratio affects the bonding quality between the wood particles. An appropriate adhesive-to-particle ratio ensures adequate resin penetration and bonding between the particles, resulting in stronger interparticle bonds. Stronger bonds contribute to an increased MOE as they provide better load transfer between particles.

In this study, the wood particles are aligned in a specific orientation. The composition of the adhesive can affect its ability to hold the particles in place during pressing and curing. Proper particle alignment leads to improved load distribution and enhances the MOE. The adhesive properties can vary with the adhesive-to-particle ratio.

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Modulus of Rupture of Particleboard

The modulus of rupture is the property of the particleboard to withold loads from a perpendicular direction until the board breaks. The values of the MOR test are presented in Figure 5.

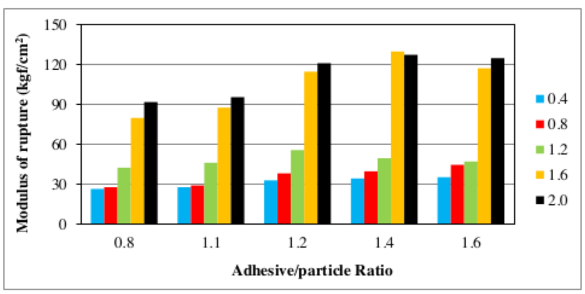

Figure 5. MOR test results for particleboard with various adhesive/particle ratios.

Figure 5 shows that the lowest MOR value of 26.5 kgf/cm^2 is obtained at an adhesive/particle ratio of 0.8, while the highest MOR of 129.84 kgf/cm^2 is obtained at a ratio of 1.4 and the percentage of avocado seed filler is 1.6%. In Figure 5 the lowest MOR value is found in 0.4% avocado seed filler, namely 26.5 kgf/cm^2, while the largest MOR is found in 1.6% avocado seed filler, namely 129.84 kgf/cm^2 and meets SNI Standard 03-2105-2006 which required a particleboard MOR of at least 82 kgf/cm^2. This is because of the strong particle bond between the palm particle and the adhesive. The mixture of adhesive and empty palm oil bunches was not evenly mixed in the empty palm fruit bunches. The more adhesive that is mixed on the particleboard, the more difficult the particleboard will be to break. The strength of particleboard can be determined from the bond strength of each particle making up the board (Haygree and Bowyer, 1982). The proportion of a large mixture of wood particles in non-wood particleboards can increase the MOR value of the resulting boards (Trisatya and Sulastiningsih, 2019). Chemicals in raw materials interfere with adhesion, such as oil, extractives, lignin, and silica which reduce the fracture toughness of the board (Ramadan and Sayed, 2012).

The adhesive-to-particle ratio can significantly impact the MOR of particleboard. The MOR measures the material's ability to withstand applied stress or load before fracturing. The adhesive-to-particle ratio directly affects the bonding strength between the wood particles. An appropriate ratio ensures adequate resin penetration and bonding, resulting in stronger interparticle bonds. Stronger bonds contribute to increased load transfer and enhanced resistance to fracture, leading to a higher MOR.

The adhesive/particle ratio can influence the properties of the adhesive to hold the bunch particles in place during pressing and curing. Proper particle alignment and distribution are crucial for achieving uniform stress distribution. An optimized ratio helps ensure better particle alignment, which improves the load-carrying capacity and ultimately increases the MOR.

Tensile Strength Test

The next test is a tensile strength test that the test object is subjected to a tensile load until the particle board breaks, so that the tensile test values can be seen in Figure 6.

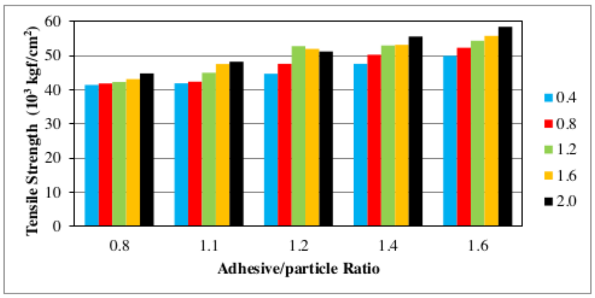

Figure 6. Tensile strength test results with various adhesive/particle ratios.

Based on Figure 6, it can be seen that the lowest tensile test was found at an adhesive/particle ratio of 0.8, which was 41.406 kgf/cm^2, while the highest tensile test was found at an adhesive/particle ratio of 1.6 with a tensile strength value of 58.454 kgf/cm^2. In Figure 6 the lowest tensile test value is found in 0.4% avocado seed filler, namely 41.406 kgf/cm^2, while the highest tensile test value is found in 2.0% avocado filler, namely 58.454 kgf/cm^2. This is because of the less optimal pressing time resulting in low particle density and low particle binding capacity, causing the particleboard reinforcement material to shift.

The adhesive-to-particle ratio can have an impact on the tensile strength of particleboard, although the relationship is not as straightforward as in the case of MOR. The tensile strength measures a material's ability to resist stretching or pulling forces. The adhesive-to-particle ratio plays a crucial role in determining the bonding quality between the wood particles. An appropriate ratio ensures proper resin penetration and bonding, leading to stronger interparticle bonds. Stronger binding enhances the tensile strength of the particleboard as it provides better load transfer and resistance to separation or determination between the particles.

The adhesive-to-particle ratio can influence the alignment of wood particles during the manufacturing process. Proper particle alignment is crucial for achieving uniform stress distribution and load transfer within the particleboard. Optimal alignment enhances the tensile strength of the board.

The type of adhesive used and its properties can vary with the adhesive-to-particle ratio. Different adhesives have different strengths, viscosities, and curing characteristics. These adhesive properties affected by this ratio can affect the bond strength between the particles and as a result it influences the tensile strength value of the particleboard. The adhesive-to-particle ratio and tensile strength are very important to observe given the complex nature of the relationship.

CONCLUSION

Particleboard with the highest density of 0.6 g/cm^3 was produced with an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seed and met the JIS A 5908:2003 and SNI 03-2105-2006 regulations. The lowest moisture content was obtained on particleboard with an adhesive/particle ratio of 0.8:1 and a filler percentage of 0.4% avocado seeds. All results of testing for moisture content comply with JIS A 5908:2003 regulation, namely moisture content with a percentage of 5%–13% and SNI 03-2105-2006 that requires a maximum moisture content of 14%. The smallest thickness swelling was produced on particle board with an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seeds, namely 10%. The thickness swelling test results comply with JIS A 5908:2003 and SNI 03-2105-2006 regulations that require a maximum thickness swelling value of 12%. The highest MOE values were obtained for particleboard with an adhesive/particle ratio of 1.2:1 and 1.6:1, which was 10,837.4 kgf/cm^2. However, MOE test results do not meet SNI 03-2105-2006 regulation. The highest MOR percentage of 129.84 kgf/cm^2 was produced on particleboard with an adhesive/particle ratio of 1.6:1 and a filler percentage of avocado seeds of 2.0% and met the SNI 03-2105-2006 regulations that required a minimum particleboard MOR value of 82 kgf/cm^2. The highest tensile strength value of 58,45 kgf/cm^2 was produced for particles with an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seed filler. Based on the research results that have been obtained, the best particleboard with polyvinyl acetate adhesive is produced at an adhesive/particle ratio of 1.6:1 and the percentage of avocado seed filler is 2%.

ACKNOWLEDGEMENTS

The authors thank to Process Technology Laboratory and all parties who assisted in discussions, data collection, and data analysis of this research.

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