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

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ABSTRACT. Conservation efforts in Indonesian forests have become a development priority crucial for maintaining ecosystem balance, coupled with the endeavor to preserve the judicious use of wood. The demand for wood increases with its development, but its diminishing availability poses challenges for the industry. Efforts to reduce this impact involve finding environmentally friendly solutions, namely by utilizing waste to create new products. Therefore, this study focuses on reprocessing oil palm fruit bunches into particleboard using polyvinyl acetate and dibutyl phthalate as adhesives. The variables studied include the adhesive/particle ratio and the percentage of avocado seed filler. The resulting composite was tested for modulus of rupture, moisture content, modulus of elasticity, thickness swelling, density, and tensile strength. These results show that particleboard with an adhesive/particle ratio of 1.6 and 2% avocado seeds can enhance modulus of rupture, thickness swelling, moisture content, and density under the SNI 03-2105-2006 standard.

INTRODUCTION

The increase in wood production in Indonesia aligns with rapid urbanization and industrialization. Data shows production in the range of 1.87 – 2.58 million cubic meters between 2016 and 2020 (Statista Research Development, 2023), with significant fluctuations in the production of various wood categories from 2013 to 2020. Despite these fluctuations, the demand for wood remains high, surpassing the availability supply, prompting the continuous search for alternative high-quality wood sources (Atoyebi *et al.*, 2018). This paper suggests the use of plant waste to form particleboards to address this need, preventing further depletion of forest resources (Owodunni *et al.*, 2020). Particleboard is a composite material made from wood particles bonded together with adhesive. Some challenges in particleboard manufacturing include low mechanical and physical quality attributed to factors such as large particle size, the inclusion of filler for reinforcement, and adhesive content (Lestari and Mora, 2018). The importance of adhesion in the industry, particularly in the craft sector, is that synthetic adhesives like yellow glue, white glue, and polyvinyl acetate (PVAc) are commonly used on two surfaces through bonding force (Prayitno, 1996). Particleboard surpasses traditional wood in advantages such as being knot-free, durable, and crack-resistant, emphasizing economic considerations in utilizing waste from various plant materials (Nasution and Mora, 2018). Lignocellulosic materials can be modified into particleboards, including castor seed meal, coconut shell (Widyorini *et al.*, 2018), coconut coir (Hasan *et al.*, 2020), oil palm stems (Hashim *et al.*, 2010), bagasse (Oliveira *et al.*, 2016), palm fronds (Santoso *et al.*, 2017), salak fronds (Juliana *et al.*, 2012), corn stalks (Soleimani *et al.*, 2017), and sorghum (Sutiawan *et al.*, 2022). The use of filler composite materials is an effective approach to managing agro-industrial waste and natural fibers (de 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. The previous research succeeded in using OPEFB to make exotic particleboards (Lubis *et al.*, 2018). OPEFB prepared with a density of

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700 kg·m^{-3} and 14% urea formaldehyde had the best composition of elastic and rupture modulus of particleboard according to EN 312-3 standard (Wahab *et al.*, 2015). However, the OPEFB board is weak because the larger fiber size causes cavities between the particles. The existence of these cavities causes the board's strength 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 highly suitable for improving the physical characteristics of particleboard from OPEFB, such as moisture content and density, as well as mechanical characteristics like Modulus of Rupture (MOR) and Modulus of Elasticity (MOE), is the addition of resin (Ramli *et al.*, 2002). Increasing the proportion of filler reduces shrinkage and residual stress (Aruniit *et al.*, 2011). Additionally, particleboard from OPEFB and mahogany filler was found in a ratio of 15:50 (Sunardi *et al.*, 2020).

Polyvinyl acetate (PVAc) is commonly used as a binder or adhesive in particleboard manufacturing. PVAc provides strong adhesion between wood particles, promoting cohesion and structural integrity in the final product. PVAc is known for its water-resistant properties, which can be advantageous in applications where the particleboard may be exposed to moisture or humidity. PVAc is versatile and widely used in woodworking and composite material industries because of its excellent bonding characteristics and ease of application.

Meanwhile, avocado seed can be used as a filler material in particleboard. Filler materials are substances added to the particleboard mix to enhance specific properties or reduce costs. Utilizing avocado seeds in particleboard contributes to sustainable practices by repurposing a by-product that would otherwise be discarded. The composition of avocado may introduce unique characteristics to the particleboard, potentially influencing its mechanical and thermal properties. Adding finer-sized avocado seeds is expected to fill the empty spaces between the empty palm oil bunches and make the particleboard denser. Avocado seeds are often discarded as waste after consuming the fruit, so finding a productive use for them could be environmentally beneficial. Utilizing these seeds as a filler in particleboard represents an eco-friendly approach by repurposing a material that would otherwise be discarded. Avocado seeds have a spherical shape with a 2.5 – 5 cm diameter. This shape can be advantageous as it may help fill empty spaces between particles, contributing to the density of the particleboard. Avocado seeds contain various compounds, including alkaloids, flavonoids, steroids, terpenoids, saponins, and tannins (Kopon *et al.*, 2020). These natural compounds may contribute to the overall properties of the particleboard, potentially enhancing its characteristics. Beyond their use as a filler, avocado seeds have other potential uses in various industries, such as medicine, fiber, and oil (Esau, 1977). This can improve physical and mechanical characteristics, such as density, modulus of rupture, and thickness swelling.

Combining PVAc and avocado seed in a composite for particleboard can lead to a material with enhanced properties. The composite may exhibit a balance of the adhesive strength from PVAc and the filler properties from avocado. The composite may offer a cost-effective solution if avocado seeds can be sourced inexpensively or are a by-product of another industry. Researchers and manufacturers may explore different ratios of PVAc and avocado seed in the composite to tailor the material properties according to specific application requirements. Utilizing a composite of PVAc and avocado seed aligns with sustainability goals by incorporating renewable resources and recycling agricultural by-products.

Thus far, there has not been specific information about the widespread use of a composite material made from PVAc and avocado seed in particleboard manufacturing. The use of unconventional materials in composite panels and particleboards is an area of ongoing research and development, and innovations need to be carried out since then. Therefore, this study aims to analyze the influence of the adhesive/particle ratio on particleboard's physical and mechanical characteristics 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 water, oil, and dirt content. Afterward, the OPEFB was dried in the sun and sieved using a sieve machine. The adhesive was made by mixing avocado seed flour (0.4, 0.8, 1.2, 1.6, 1.0, and 2.0 w/w of total sample) and polyvinyl acetate into a solution of polyvinyl alcohol, toluene, and dibutyl phthalate with masses of 63.3, 22.7, and 5%, respectively. The adhesive was weighed as needed; in this study, the adhesive/particle ratio used was 1.6, 1.4, 1.2, 1.1, and 0.8. The polyvinyl acetate adhesive was mixed into the particles until thoroughly homogenous. The particle and adhesive mixture were 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 pressing was done using a hot press machine for approximately 15 minutes. The hot sheet was left for ± 10 minutes. Drying was carried out at room temperature for seven days (Ginting *et al.*, 2016), and characterization was carried out.

Particleboard Density

Both sides of the particleboard were measured for length at a distance of 25 mm from the edge with an accuracy of 0.1 mm (Figure 1).

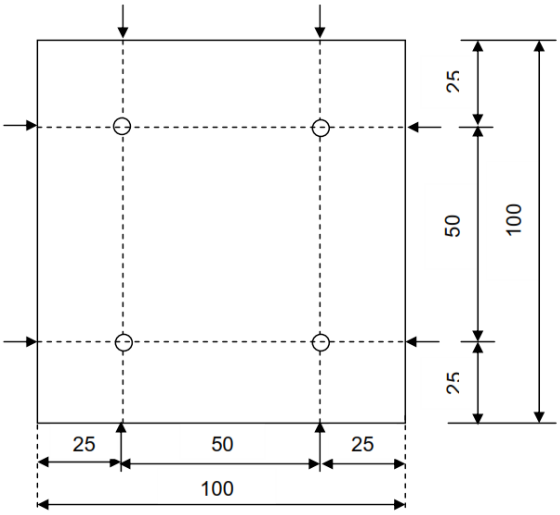

Figure 1. Measurement of sample test density

The thickness was measured at all four corners, 25 ± 0.05 mm from the corner (at the point of intersection of length and width measurements). The sample was weighed with an accuracy of 0.1 g. Density was determined as in Equation (1).

$$Density\left(\frac{g}{cm^3}\right) = \frac{W}{V} \quad (1)$$

W is the weight (gram), and *V* is the volume (cm^3) = length (cm) × width (cm) × thickness (cm), with precision up to 0.01 g/cm^3.

Particleboard Moisture Content

Sample tests were weighed to determine the initial weight with a precision of up to 0.1 grams. The samples were dried in an oven at 103 °C ± 2 °C. They were placed in a desiccator and then weighed. This activity was repeated every six hours until the weight remained constant (absolute dry weight), where the maximum weight difference was 0.1%. Moisture content was determined as in Equation (2).

$$Moisture\ Content\ (\%) = \frac{Iw - Dw}{Iw} \times 100 \quad (2)$$

Iw is the initial weight (gram), and *Dw* is the absolute dry weight (gram).

Thickness Swelling

Samples were measured for thickness at the center with an accuracy of 0.05 mm (Figure 1). They were immersed in water in a horizontal position at 25 °C ± 1 °C, about 3 cm below the water surface, for ± 24 hours. The samples were then lifted, wiped with a cloth, and measured for thickness. Thickness swelling was determined as in Equation (3).

$$Thickness\ swelling(\%) = \frac{T2 - T1}{T1} \times 100 \quad (3)$$

T1 was the thickness after water immersion (mm), and *T2* was the thickness before water immersion (mm).

Tensile Strength and Modulus of Elasticity

Samples were measured in length, width, and thickness at 20 × 5 × 0.3 cm. The samples were placed on supports using *Servo Control System Universal Testing Machine* A1-7000M. These samples were pulled vertically at a speed of approximately 2 mm/minute, and their tensile strength was recorded. The modulus of elasticity was determined as in Equation (4).

$$Modulus\ of\ Elasticity\ \left(\frac{kgf}{cm^2}\right) = \frac{Tensile\ strength\ \left(\frac{kN}{mm^2}\right) \times 1.01972}{Nominal\ strain\ (mm/mm)} \quad (4)$$

Modulus of Rupture of Particleboard

Samples were measured in length, width, and thickness at 20 × 5 × 0.3 cm. The samples were placed horizontally on their supports. The load was applied to the center of the sample at a speed of approximately 10 mm/minute until the deflection occurred. The maximum load required was recorded. The modulus of rupture was determined as in Equation (5).

$$Modulus\ of\ Rupture\ (kgf/cm^2) = \frac{3FS}{2LT^2} \quad (5)$$

F was the maximum load (kgf), *S* was the support span (cm), *L* was the length (cm), and *T* was the thickness (cm).

RESULT AND DISCUSSION

Particleboard Density

Density is a physical property that shows the ratio between the mass of an object 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 density values of the composite board produced in this study are displayed in Figure 2.

Based on Figure 2, it can be observed that the physical property of particleboard with all avocado seed filler contents shows a density in the range of 0.3 – 0.6 g/cm^3. It is evident in Figure 1 that the density of the particleboard increases with the increasing ratio of adhesive/particle and the percentage of avocado seed filler. This phenomenon aligns with previous research indicating that the density of the resulting particleboard is related to the ratio of the adhesive used (Hasan *et al.*, 2020). The greater the amount of adhesive used in manufacturing particleboard, the higher the density value of the resulting particleboard. Similarly, with a higher percentage of avocado seed filler, the density of the resulting particleboard increases. Consistent with previous studies, adding filler increases density (Sunardi *et al.*, 2017).

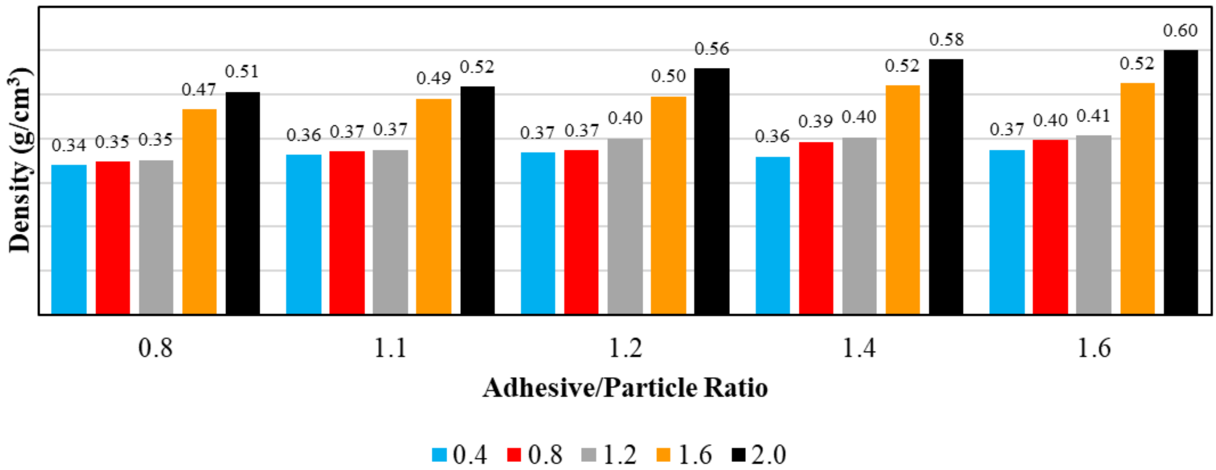

Figure 2. Results of the particleboard density test with various adhesive/particle ratios.

However, it is important to note that the suitability and performance of avocado seeds as filler depend on various factors, including their availability, chemical and physical properties, cost-effectiveness, and specific requirements of the particleboard manufacturing process.

According to the results presented in Figure 2, 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 particleboard density tends to increase with the percentage of avocado seed filler and the adhesive/particle ratio. Specifically, the highest particleboard density (0.6 g/cm^3) is achieved with an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seed. Standards for testing particleboard require that good particleboard density is 0.4 – 0.9 g/cm^3, which falls within the range of medium-density particleboard. The board complies with the standard of SNI 03-2105-2006 and JIS A 5908:2003, namely 0.4 – 0.9 g·cm^{-3}. In summary, adding avocado seed filler in the particleboard manufacturing process, especially at higher percentages and specific adhesive/particle ratios, has a positive influence on the resulting particleboard density.

Particleboard Moisture Content

Particleboard moisture content significantly affects dimensional stability, strength, and overall performance. Moisture content indicates the water content present in the particleboard expressed as a percentage of its dry weight. It is typically determined by heating, then calculating 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 3. Based on Figure 3, it can be seen that the average results of the particleboard moisture content tests 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%.

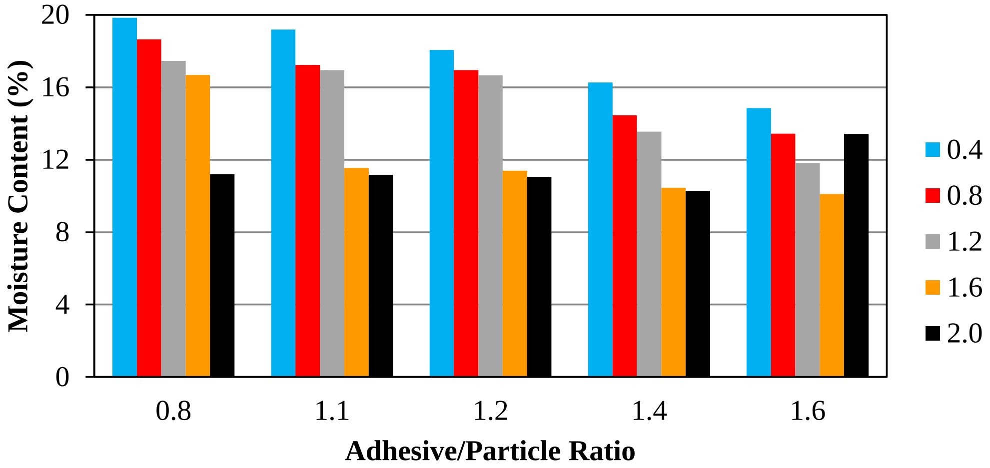

Figure 3. The results of the moisture content test with various adhesive/particle ratios.

Based on Figure 3, the highest particleboard moisture content is found with 0.8% avocado seed filler with a water content value of 19.84%, while the lowest water content value is with 1.6% avocado seed filler with a moisture content value of 10.1%. This indicates that the filler acts as a moisture barrier, reducing the overall moisture absorption of the particleboard. The size and distribution of filler particles impact the overall structure of the particleboard. These fine particles may create a denser structure that is less permeable to moisture, affecting the moisture content. The chemical composition of the filler influences how it interacts with moisture. The filler may have natural water-repelling properties. In addition, the interaction between the avocado seed filler and the binder used in particleboard making affects the board's resistance to moisture. Proper bonding between particles and binders contributes to lower moisture absorption. The manufacturing process itself, including factors like temperature and pressure during board formation, impacts the moisture resistance of particleboard. It is important to note that the specific effects will depend on the unique characteristics of the filler material and the overall composition of the particleboard. Therefore, more experimental data and testing are typically required to assess the moisture-related properties of particleboard with avocado seed filler.

In Figure 3, the highest particleboard moisture content is found in those made with an adhesive/particle ratio of 0.8, with a particleboard 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 moisture content of particleboard tends to decrease (Aprillia *et al.*, 2019). This can be explained by the fact that a higher adhesive composition allows for a broader distribution of adhesive, strengthening the bonds between particles, making it difficult for water molecules to penetrate, and thereby reducing the moisture content of particleboard. Using a higher adhesive-to-particle ratio means adding a greater amount of adhesive to the wood particles.

The density of particleboard is not linearly correlated with moisture content, primarily because of how the material responds to changes in humidity. It indicates that oil palm empty fruit bunch particles have cell walls that can release moisture. As the bunch particles swell and the binder absorbs moisture, the structural integrity of the particleboard can be affected. This can result in changes in the board's density that are not strictly proportional to the change in moisture content. Because of multiple factors and their nonlinear interplay, the relationship between density and moisture content in particleboard is not linear.

Thickness Swelling

Thickness swelling refers to the increase in thickness when the particleboard absorbs water after 24 hours of soaking. It is a critical property that reflects the board's dimensional stability when exposed to moisture. More water absorption causes thicker swelling, negatively impacting overall performance and lowering dimensional stability. The results of testing the thickness swelling value by soaking the particleboard in water for 24 hours can be seen in Figure 4.

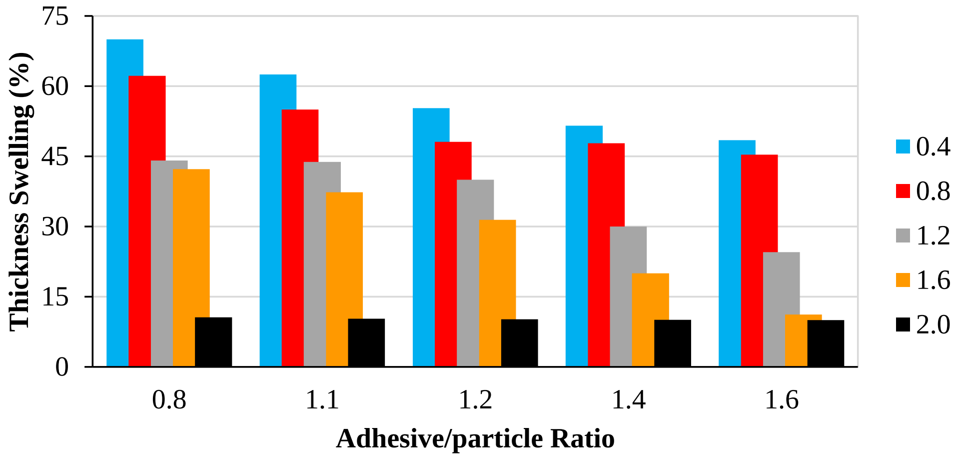

Figure 4. The results of the particleboard thickness swelling with various adhesive/particle ratios.

Based on Figure 4, 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. It shows that avocado seed filler has a hygroscopic nature, meaning it can release moisture. The filler's ability to release water could contribute to thickness swelling when the particleboard is exposed to high humidity or direct water contact. The interaction between the avocado seed filler and the binder used in particleboard making is crucial. Proper bonding between particles and binders enhances the board's resistance to thickness swelling.

Figure 4 shows the results of testing the thickness of particleboard soaked in cold water at 25 ℃ 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, complying with JIS A 5908-2003 and SNI 03-2105-2006 regulations that require a maximum swelling of 12%. Insufficient adhesive can result in weak or incomplete bonding between the particles, reducing the particleboard's strength and integrity. On the other hand, excessive adhesive can clog the void spaces between the particles, reducing the permeability of the panel. This can hinder moisture release within the board and decrease overall moisture resistance. With a high adhesive-to-particle ratio, it becomes more challenging for the adhesive to penetrate the wood particles fully, 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 increases swelling, warping, and decreased dimensional stability.

Several factors influencing particleboard thickness include 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

MOE describes the measure of the particleboard's resistance to deformation or bending that occurs up to the elastic limit. It is a measure of the material's stiffness, indicating its ability to deform under pressure. The higher the MOE of the particleboard, the more elastic the board will be. The MOE test results are presented in Figure 5.

Based on Figure 5, it is observed that the highest MOE value was found in 2% avocado seed filler with a MOE value of 10,837.4 kgf/cm^2, while the lowest MOE value was found in 0.4% avocado seed filler with a MOE value of 4,947.1 kgf/cm^2. It shows that the amount or percentage of avocado seed filler incorporated into the particleboard formulation can significantly impact the higher percentages of filler lead to changes in the board's mechanical properties, including the MOE. The size, shape, and distribution of avocado seed filler particles affect the overall structure and mechanical properties of the particleboard. Fine particles may contribute to a more uniform and dense structure, potentially enhancing the MOE. A strong bond between the finer particles and the adhesive improves mechanical properties, including the MOE.

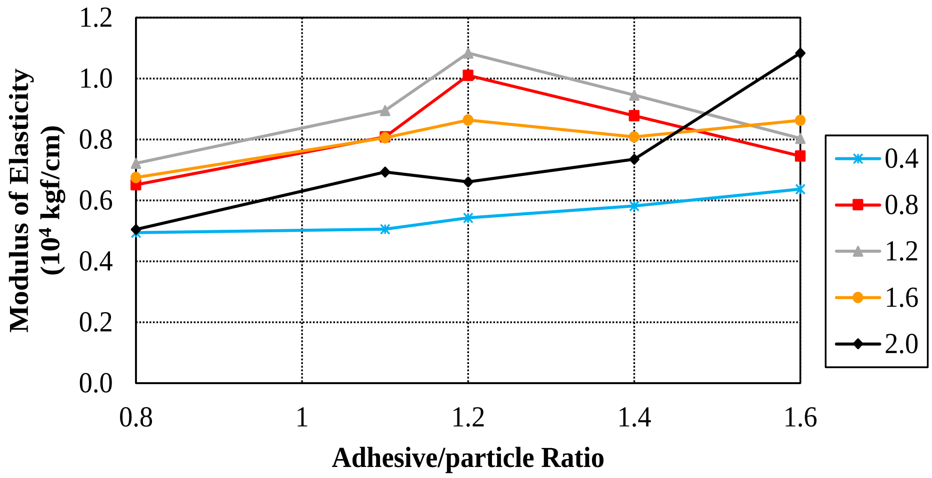

Figure 5. The results of particleboard MOE with various adhesive/particle ratios.

Uniform distribution of the filler within the particleboard is important. Uneven distribution may result in areas of weakness or inconsistency in the material, affecting its overall stiffness. Changes in the density of the particleboard, which are influenced by the presence of the filler, can affect the MOE. Higher-density boards tend to have higher MOE values. It is important to note that the specific effects vary based on the experimental conditions, the specific characteristics of the avocado seed filler, and the overall formulation of the particleboard.

In Figure 5, 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 is found at an adhesive/particle ratio of 0.8. This is in accordance with previous research showing that the MOE can be affected by the type and composition of board adhesive used and the adhesion among the particles. According to SNI 03-2105-2006 regulation, the MOE value is required to be 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 (Riska *et al.*, 2016).

The amount of adhesive and raw materials used in particleboard manufacturing determines its static bending strength. The adhesive-to-particle ratio can affect 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, providing better load transfer between particles.

In this study, efforts were made to mold oil palm bunch particles in a specific orientation. During the mat-forming process, layers of bunch particles are arranged in a controlled manner. The particles in each layer are coated in the same direction for parallel orientation. The goal is to create a board with consistent and predictable mechanical characteristics that involve aligning particles for increased strength in a specific direction. 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.

Modulus of Rupture of Particleboard

The modulus of rupture is the property of the particleboard to withstand loads from a perpendicular direction until the board breaks. It measures a material's ability to withstand bending or breaking under applied stress. The values of the MOR test are presented in Figure 6.

Figure 6 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%. This is because of the strong particle bond between the oil palm particle and the adhesive. The mixture of adhesive may not have been evenly mixed with the empty oil palm fruit bunches. The more adhesive that is mixed with the particleboard, the more difficult it will be to break the particleboard. The strength of particleboard can be determined from the bond strength of each particle that makes up the board (Haygreen & Bowyer, 1989). 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, such as oil, extractives, lignin, and silica, interfere with adhesion, which can reduce the fracture toughness of the board (Nasser, 2012).

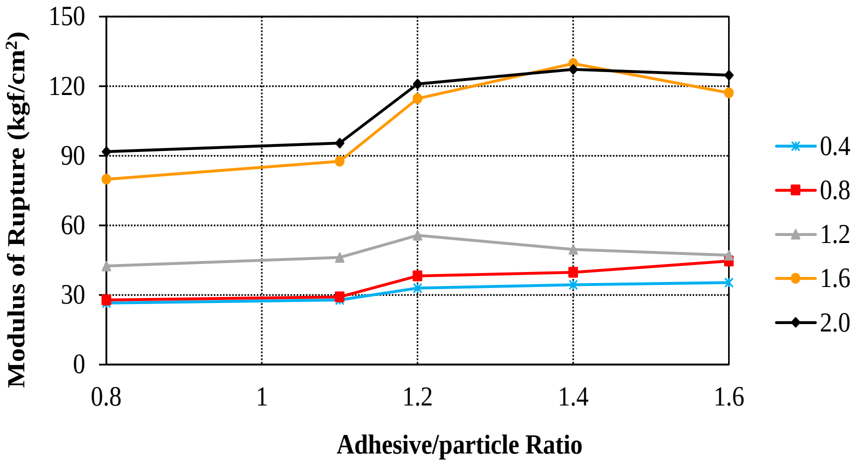

Figure 6. MOR test results for particleboard with various adhesive/particle ratios.

The adhesive-to-particle ratio significantly affects 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 influences 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.

In Figure 6, 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, meeting the SNI Standard 03-2105-2006, which requires a particleboard MOR of at least 82 kgf/cm^2. The percentage of avocado seed filler incorporated into the particleboard has a significant impact. Higher filler percentages may lead to changes in the board's mechanical properties, including the MOR. Uniform distribution of the filler within particleboard is important. Uneven distribution may result in areas of weakness or inconsistency in the material, affecting its overall resistance to bending stress.

Tensile Strength

The next test is a tensile strength test, where the test object is subjected to a tensile load until the particleboard breaks. The tensile test values can be observed in Figure 7. The tensile strength test aims to measure the ability of particleboard to withstand tensile or stretching forces.

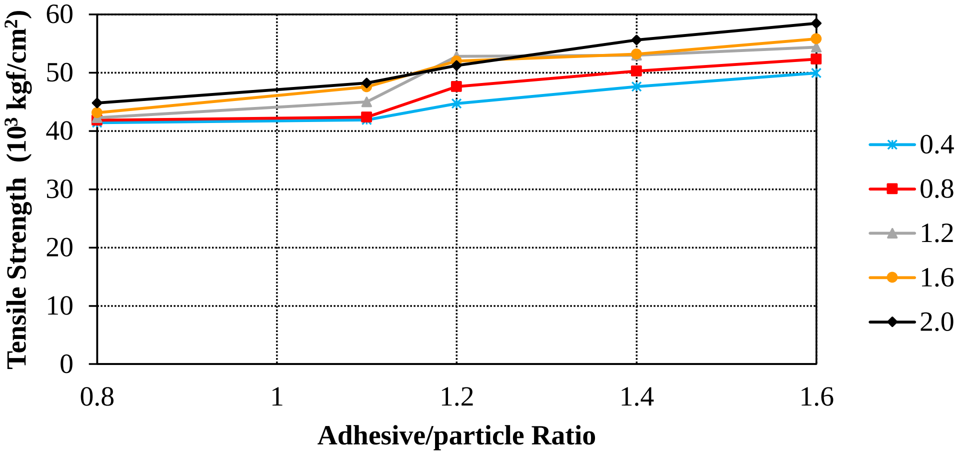

Figure 7. Tensile strength test results with various adhesive/particle ratios.

Based on Figure 7, it can be seen that the lowest tensile test value was found at an adhesive/particle ratio of 0.8, which was 41.406 kgf/cm^2, while the highest tensile test value was found at an adhesive/particle ratio of 1.6, with a tensile strength value of 58.454 kgf/cm^2. The adhesive-to-particle ratio has an impact on the tensile strength of particleboard, although the relationship is not as clear-cut as in the case of MOR. 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, resulting in 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 influences the arrangement of bunch 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. Adhesive properties affected by this ratio can influence the bond strength between the particles and, as a result, impact the tensile strength value of the particleboard. The adhesive-to-particle ratio and tensile strength are crucial to observe because of the complex nature of their relationship.

In Figure 7, 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 reinforcement material of the particleboard to shift.

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, meeting the JIS A 5908:2003 and SNI 03-2105-2006 regulations. The lowest moisture content was obtained in particleboard with an adhesive/particle ratio of 0.8:1 and a filler percentage of 0.4% avocado seeds. All moisture content test results comply with JIS A 5908:2003 regulations, with moisture content in the range of 5%–13%, and SNI 03-2105-2006, which requires a maximum moisture content of 14%. The smallest thickness swelling was produced on the particleboard 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, which demand 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, reaching 10,837.4 kgf/cm^2. However, MOE test results do not meet the 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%, meeting the SNI 03-2105-2006 regulation, which required a minimum particleboard MOR value of 82 kgf/cm^2. The highest tensile strength value of 58,45 kgf/cm^2 was achieved for particles with an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seed filler. Based on the research findings, the best particleboard with polyvinyl acetate adhesive was produced at an adhesive/particle ratio of 1.6:1 and a filler percentage of 2% avocado seed filler. In summary, the future perspective for particleboard research using oil palm empty fruit bunches and avocado seed filler is likely to focus on sustainability, waste utilization, material optimization, and potential commercialization. The success of these efforts could contribute to more environmentally friendly practices in the wood and material industries.

CONFLICT OF INTEREST

There is no conflict of interest in this article.

AUTHOR CONTRIBUTION

MRL: Conceptualization, Data Analysis, Methodology; FR: Project Administration, Manuscript Review, Validation; TS: Investigation and Manuscript Drafting; K: Editing, Resources, Software; FRH: Funding Acquisition, Supervision, Visualization.

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