Jurnal Inovasi Teknologi Terapan
Vol. 04, No. 2, (2026) e-ISSN :3026-0213

Impact of Palm Frond Particle Size on the Characteristics of Biodegradable Particleboard

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Received:24 Juli 2026; Received in revised form:29 Juli 2026; Accepted: 30 Juli 2026

Abstract

Particleboard is a composite material based on lignocellulose that can be produced from agricultural waste, serving as an alternative to traditional wood products. This study utilized waste from oil palm fronds and empty fruit bunches as raw materials for the production of particleboard. The oil palm fronds were processed into filler particles of varying sizes: 80-mesh, 60-mesh, and 35-mesh. The composition of the raw materials included 50% oil palm frond particles, 15% empty fruit bunch fiber, 20% PVAc adhesive, and 15% epoxy resin. The particleboard was manufactured using a single-punch cold-press process at a pressure of 0.30 MPa for 120 minutes, followed by curing at 150°C for 60 minutes. Various characteristics of the particleboard were tested, including density, water content, thickness swelling, modulus of rupture (MOR), and modulus of elasticity (MOE). The results indicated that the particle size of 80-mesh yielded the best properties, with a density of 0.88 g/cm³, a water content of 5.51.6%, thickness swelling of 1.13%, a MOR of 19.79 MPa, and a MOE of 1.08 GPa. All specimens met the standards set by SNI 03-2105-2006 for density, water content, thickness swelling, and MOR; however, the MOE value did not meet the required standards.

Keywords: *Particleboard; Particle size; Physical properties; Mechanical properties*

Abstrak

Papan partikel merupakan material komposit berbasis lignoselulosa yang dapat dibuat dari limbah pertanian sebagai alternatif pengganti kayu. Penelitian ini memanfaatkan limbah pelepah dan tandan kosong kelapa sawit sebagai bahan baku papan partikel. Pelepah kelapa sawit digunakan sebagai pengisi dengan variasi ukuran partikel mesh 80, mesh 60, dan mesh 35, sedangkan komposisi material terdiri atas 50% partikel pelepah kelapa sawit, 15% serat tandan kosong kelapa sawit, 20% perekat PVAc, dan 15% resin epoksi. Papan partikel diproduksi menggunakan proses cold press single punch pada tekanan 30 bar selama 120 menit, dilanjutkan curing pada suhu 150°C selama 60 menit. Karakterisasi meliputi pengujian densitas, kadar air, pengembangan tebal, modulus of rupture (MOR), dan modulus of elasticity (MOE). Hasil menunjukkan bahwa ukuran partikel mesh 80 menghasilkan sifat terbaik dengan densitas 0,88 g/cm³, serapan air 5,51%, pengembangan tebal 1,13%, MOR 19.79 MPa, dan MOE 1.08 GPa. Seluruh spesimen memenuhi persyaratan SNI 03-2105-2006 untuk densitas, serapan air, pengembangan tebal, dan MOR, sedangkan MOE belum memenuhi standar.

Kata kunci: Papan partikel; ukuran partikel; Sifat fisik; Sifat mekanik

1. INTRODUCTION

Particle board is a composite material made from lignocellulose that is commonly used in the furniture and light construction industries. Traditionally, the primary raw material for particle board has been wood. However, the decreasing availability of wood due to deforestation and the increasing demand for environmentally friendly materials have led to a rise in the use of biomass waste as an alternative raw material [1]. Utilizing agricultural waste aligns with the principles of a circular economy, as it minimizes waste and enhances the value of renewable resources [2].

Indonesia, being the world's largest palm oil producer, generates substantial amounts of biomass waste, including fronds and empty palm oil fruit bunches. These waste products are rich in cellulose and lignin, making them potential reinforcing materials for biodegradable particle boards [3]. The use of palm oil waste not only decreases reliance on wood but also promotes more sustainable management of plantation waste [4].

The performance of particle board is influenced by several factors, including the size of the particles [5]. Particle size affects the surface area in contact with the adhesive, the distribution of pores, and the quality of the interfacial bond. Smaller particles generally lead to higher density, better dimensional stability, and enhanced mechanical strength [6]. However, if the particles are too fine, it can increase the adhesive requirements and cause agglomeration, highlighting the need for an optimal particle size [7].

Several studies have investigated the impact of particle size on the properties of particle board. Sunardi et al. [8] found that using mesh-80 palm oil stem powder resulted in the highest density, hardness, and flexural strength, along with the lowest thickness swelling. Sunardi et al. [5] also demonstrated that increasing the mesh size improved density and reduced the thickness expansion of oil palm fiber-based composite boards. More recent studies confirm that particle size distribution plays a crucial role in enhancing the structural homogeneity and bond quality between particles [9].

However, previous research has primarily focused on single types of palm oil waste as the main ingredient and has concentrated more on the influence of adhesive composition or type. There has been limited research on how palm frond particle size affects biodegradable particle boards reinforced with empty fruit bunch (EFB) fibers using PVAc–epoxy hybrid adhesives. The relationship between particle size and the physical and mechanical properties of particle boards in hybrid composite systems has also been infrequently studied.

This study aims to analyze the effect of different palm frond particle sizes on the physical properties (density, moisture content, and thickness expansion) and mechanical properties (modulus of rupture and modulus of elasticity) of biodegradable particle boards reinforced with EFB fiber. The findings are expected to identify the optimal particle size and support the use of palm oil waste as a sustainable raw material for particle boards that meet the standards outlined in SNI 03-2105-2006 [10].

2. RESEARCH METHODS

2.1 Materials

Empty oil palm fruit bunches. Before pretreatment, EFB consists of about 29.37% cellulose, 14.40% hemicellulose, and 22.66% lignin, making it a promising candidate for reinforcing lignocellulose-based composites [11]. Figure 10 show the empty oil palm fruit bunch fiber.

Figure 1. Empty Oil Palm Fruit Bunch Fiber

Recent studies indicate that using EFB as a raw material for particleboard can enhance the mechanical strength, dimensional stability, and sustainability of the final product, positioning it as a viable alternative to wood in the composite panel industry.

Oil palm fronds. Oil palm fronds consist of approximately 35–40% cellulose, 25–30% hemicellulose, and 8–15% lignin [12]. These components provide excellent mechanical properties and stiffness, making palm fronds suitable for composite material applications. Sieves with mesh sizes of 35, 60, and 80 were used to separate particles. To ensure accurate particle sizing, the sieving process was conducted in stages, beginning with the 80-mesh sieve, followed by the 60-mesh sieve, and finally the 35-mesh sieve.

Figure 2. Oil Palm Frond Powder

Polyvinyl acetate (PVAc). PVAc is a polymer-based adhesive that is commonly used in the wood and paper industries, as shown in Figure 3(a). It is favored for its strong adhesion, ease of application, long shelf life, and relatively low environmental impact compared to formaldehyde-based adhesives [13]. However, it has some drawbacks, such as low resistance to water, high temperatures, and long-term loads due to its viscoelastic properties. To enhance its mechanical performance and environmental resistance, PVAc is often combined with other resins [14].

Epoxy resin. Epoxy resin (Figure 3(b) is commonly used as a matrix and reinforcement in composite materials due to its ability to enhance strength while reducing brittleness [15]. When compared to other thermosetting resins, epoxy resins exhibit minimal shrinkage during the curing process, require relatively low fabrication pressures, and achieve effective crosslinking when mixed with an appropriate hardener.

(a) (b)

Figure 3. Material for binder: (a) PVAc adhesive, (b) epoxy resin

2.2 Pretreatment of Oil Palm Particle and Fiber

Palm oil particles and fibers were treated with 5% NaOH for two hours [16]. After treatment, the particles and fibers were washed with clean water to eliminate any remaining NaOH and then dried in the sun. The alkali treatment process is illustrated in Figure 4.

Figure 4. Alkali Treatment

2.3 Composite Manufacturing Process

The first step is to calculate the volume fraction of the composite material: 50% oil palm frond particles, 15% empty oil palm fruit bunches fiber, 20% PVAc adhesive, and 15% epoxy resin.

Figure 5. Composite Manufacturing Process

After this calculation, all materials are mixed to achieve a homogeneous mixture before being placed into the mold. In the mold, the composite is subjected to a pressure of 0.3 MPa for 120 minutes using a single-punch cold-press technique. Once the compaction process is complete, the specimen is removed from the mold and undergoes a curing treatment at a temperature of 150°C for 60 minutes, as shown in Figure 5.

2.4 Materials Characterization

Density. Density testing involves weighing the mass of a dry sample and dividing it by the sample's volume. According to SNI 03-2105-2006, the accepted density range is between 0.4 and 0.9 g/cm³. The Equation (1) is used to calculate the composite density [17, 18]:

$$\rho = \frac{m}{V} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (1)$$

Where, m is mass of sample (g), and V is volume of sample (cm^3).

Water absorption percentage. The water absorption percentage is determined by measuring both the wet and dry masses of a sample. The dry mass is obtained by oven-drying the sample at two-hour intervals for a total of 24 hours. The Equation (2) used to calculate the water absorption [18].

$$WA(\%) = \frac{w_1 - w_0}{w_0} \times 100\% \dots\dots\dots\dots (2)$$

Where w_0 represents the initial weight and w_1 represents the weight after being immersed in water (in grams).

Thickness swelling. The thickness swelling test is performed to assess the dimensional stability of particleboard. According to SNI 03-2105-2006, the thickness swelling value should not exceed 12%. The Equation (3) used to calculate thickness swelling of composite.

$$TS(\%) = \frac{T_t - T_0}{T_0} \times 100 \dots\dots\dots\dots\dots\dots (3)$$

Where, T_t is thickness of composites after water immersion (mm), and T_0 is thickness of dry specimens before immersion in distilled water (mm).

Modulus of rupture (MOR). Fracture strength testing is performed to assess a material's resistance to loading applied at the point of bending according to the ASTM D790 standard. The specimen size should be 80 mm × 15 mm × 6 mm. The Equation (4) used to determine the MOR [19].

$$\sigma = \frac{3P_{max}L}{2bh^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (4)$$

Where, Pmax is maximum load at fracture (N), L is support distance (mm), b is width of the test specimen (mm), and h is thickness of the test specimen (mm).

Modulus of elasticity (MOE). MOE testing evaluates a specimen's resistance to deformation under loading.

Statistic analysis. Statistical analysis is utilized to identify the optimal particle size through various weighting techniques. Flexural strength and flexural modulus focus on larger-the-better characteristics, whereas density, water absorption percentage, and thickness expansion concentrate on smaller-the-better characteristics.

3. RESULT AND DISCUSSION

3.1 Densitas Papan Partikel

Density is theoretically defined as mass per unit volume. Variations in particle size will affect the density of the composite material. The density value can be calculated using the formula in Equation (1). The density tests are shown in Figure 6.

The highest density for this composite board was found with particle size of 80-mesh, with a value of 0.88 g/cm^3, followed by particle sizes 60 and 35 μm, with values of 0.85 g/cm^3 and 0.83 g/cm^3, respectively. Based on the SNI 03-2105-2006 standard for particleboard, the density value ranges from 0.40 to 0.90 g/cm^3, so all three particle sizes meet the applicable standards.

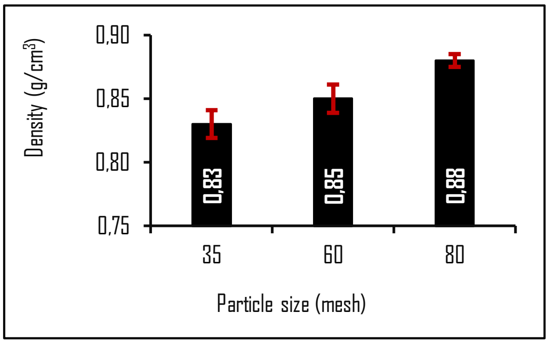

Figure 6. The Relationship Between Particle Size And The Density Of Composites

This research finding is supported by research by Sunardi et al. [5], which found the best density value at particle size 80-mesh, with a value of 0.985 g/cm^3. Therefore, the smaller the particle size resulting in better bonding between particles and increased composite density. This is due to the even distribution of particles in composite board production. A smaller particle size bonds well with the adhesive, reducing air voids in the composite board [20].

3.2 Percentage of Water Absorption

The percentage of water absorption increases with larger particle sizes, as shown in Figure 7. The lowest water absorption percentage observed was 5.51% at a particle size of 80-mesh, while the highest measured 8.52%. A composite board with a particle size of 60-mesh exhibited a water absorption percentage of 6.81%.

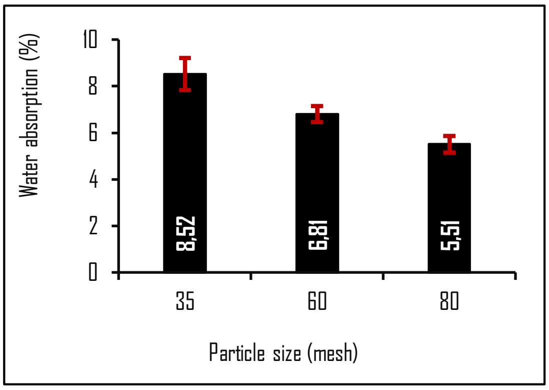

Figure 7. The Relationship Between Particle Size And The Water Absorption Of Composites

Figure 7 states that the results of thickness swelling and water absorption tests are inversely proportional to the particle size used. These findings are in line with those reported by Umaru et al. [21], which shows that the larger the particle size, the greater the percentage of compressive water absorption. In natural fiber-based composites, the initial water absorption mechanism typically follows Fickian behavior.

However, if fiber swelling occurs, leading to interface degradation or the formation of microcracks from prolonged soaking, the diffusion mechanism may shift to non-Fickian (anomalous) diffusion. As a result, the absorption rate will no longer align with the predictions of Fick's Law, as shown in Figure 8. This phenomenon has been widely observed in lignocellulosic composites, primarily due to the hydrophilic nature of the fibers, which causes swelling and alters the internal structure during the soaking process.

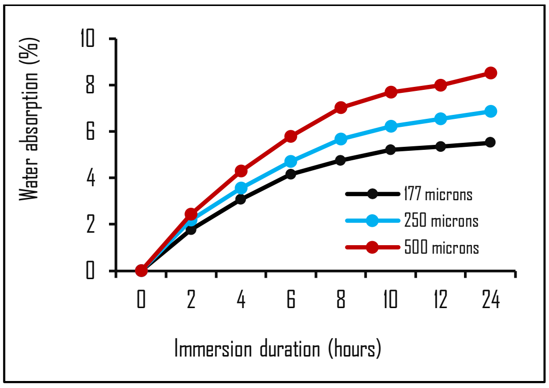

Figure 8. Water Absorption Behaviour

3.3 Pengembangan Tebal

Thickness swelling testing was performed by immersing the specimens in water at room temperature for 24 hours, following the designated testing procedure. The percentage of thickness swelling was calculated using Equation (3), and the results are displayed in Figure 9. The percentage of thickness swelling increased as the particle size of the oil palm frond increased. Specifically, the thickness swelling values were 1.80%, 1.35%, and 1.13% for the 35-mesh, 60-mesh, and 80-mesh, respectively. These findings indicate that finer particle sizes lead to improved dimensional stability. A lower thickness swelling value reflects the particleboard's enhanced ability to resist water absorption, which results in smaller dimensional changes.

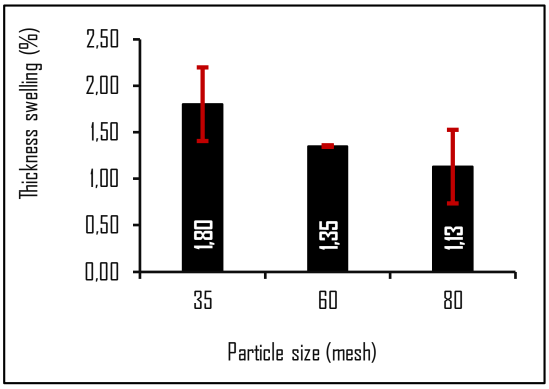

Figure 9. The Relationship Between Particle Size And The Dimension Stability Of Composites

All specimens met the criteria outlined in SNI 03-2105-2006, which specifies a maximum thickness swelling value of 12%. In comparison to study by Sunardi et al. [8], which reported a maximum thickness swelling of 1.59% for 80-mesh, the oil palm frond particleboard in this study demonstrated superior dimensional stability. These results are also consistent with research by Sunardi et al. [5], which found that increasing the particle size increases thickness swelling due to lower particleboard density and decreases interparticle bond quality.

This relationship shows that thickness swelling is inversely proportional to density. The finer the particle size, the higher the resulting density, which leads to fewer voids within the particleboard and reduced water penetration. As a result, the particleboard's capacity for water absorption decreases, resulting in smaller thickness changes after immersion. This phenomenon indicates that increasing density strengthens interparticle bonds and enhances the dimensional stability of the particleboard.

3.4 Modulus of Rupture

The modulus of rupture is a test designed to determine a material's maximum resistance to a given load before it breaks. This test employs the three-point bending method according to ASTM D790 standards. The test specimen measures 100 mm in length, 15 mm in width, and 6 mm in thickness. The modulus of rupture value can be calculated using the formula provided in Equation (4). The results of the modulus of rupture tests are outlined in Figure 10.

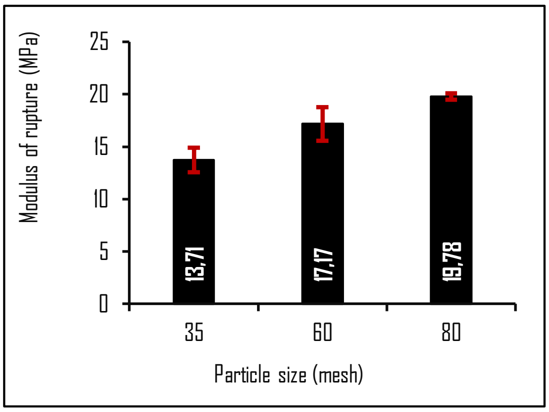

Figure 10. The Relationship Between Particle Size And The Composite's Modulus Of Rupture

According to Figure 10, the modulus of rupture decreases with smaller particle sizes. The lowest modulus of rupture was observed at a particle size of 35-mesh, with a value of 13.71 MPa. Conversely, the highest modulus of rupture was recorded at a particle size of 80-mesh, with a value of 19.78 MPa. The modulus of rupture at a particle size of 60-mesh was measured at 17.17 MPa. According to the SNI 03-2105-2006 standard for particle board, the minimum required modulus of rupture is 8.04 MPa. Thus, the three particle sizes—80-mesh, 60-mesh, and 35-mesh—meet the standard criteria for particle board.

These findings can be compared to research conducted by Sunardi et al. [8], which reported an increased modulus of rupture, with the best result for mesh particle 80-mesh being 14.36 MPa. This indicates that the average modulus of rupture from tests using oil palm frond filler is higher than that derived from oil palm stem filler. Furthermore, research by Desiasni et al. [20] supports the assertion that the modulus of rupture decreases with larger particle sizes.

The theoretical basis behind these results suggests that the modulus of rupture is directly proportional to the density; a finer filler grain size correlates with higher density. Thus, achieving a high mechanical modulus of rupture is essential for ensuring that the composite board material exhibits good resistance to pressure and changes in weather conditions [22].

3.5 Modulus of Elasticity

The modulus of elasticity measures the ability of particleboard to maintain its elastic shape under bending loads. The testing was conducted simultaneously with the modulus of rupture test using the three-point bending method. The MOE values are presented in Figure 11.

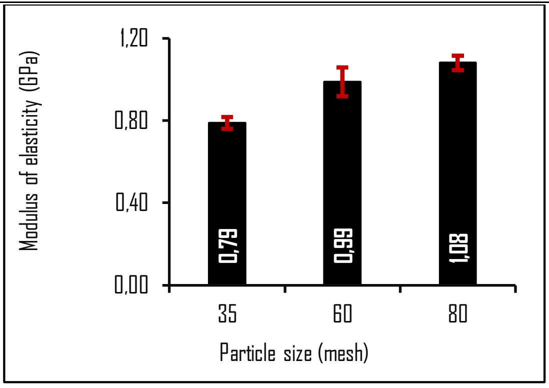

Figure 11. The Relationship Between Particle Size And The Composite's Modulus Of Elasticity

The MOE value decreased with larger oil palm frond particle sizes: 0.79 GPa for the 35-mesh, 0.99 GPa for the 60-mesh, and 1.08 GPa for the 80-mesh particle sizes. However, all specimens fell short of the minimum requirement set by SNI 03-2105-2006, which is 200 GPa. The increase in MOE is influenced by the finer particle size, which results in a more homogeneous distribution of fillers, increased density, and better bonding between particles, fibers, and the matrix. These conditions facilitate a more uniform distribution of bending loads and reduce the likelihood of pull-outs and voids, thereby enhancing the stiffness of the material. This relationship shows that the MOE value is directly proportional to the density of the particleboard.

3.6 Statistical analysis

The optimal performance of particle board can be assessed using the weighting technique and the multi-response performance index (MRPI), as demonstrated in Table 1, Table 2, and Table 3.

Table 1. Eksperimental data

Mesh	D	WA	TS	MOR	MOE
35	0.83	8.52	1.8	13.71	0.79
60	0.85	6.81	1.35	17.17	0.99
80	0.88	5.51	1.13	19.79	1.08

Note:
D = density (g/cm^3)
WA = water absorption (%)
TS = thickness swelling (%)
MOR = Modulus of rupture (MPa)
MOE = Modulus of elasticity (GPa

Table 2. Normalization of test result data

Mesh	D	WA	TS	MOR	MOE
35	1.20	0.12	0.56	13.71	0.79
60	1.18	0.15	0.74	17.17	0.99
80	1.14	0.18	0.88	19.79	1.08

Table 3. Weighting and MRPI

Mesh	W_D	W_{WA}	W_{TS}	W_{MOR}	W_{MOE}	MRPI
35	0.34	0.26	0.25	0.27	0.28	6.91
60	0.33	0.33	0.34	0.34	0.35	9.15
80	0.32	0.41	0.41	0.39	0.38	11.12

Table 3 indicates that particle board made with palm frond particle size demonstrates optimal performance. This is supported by a MRPI value of 11.12, a density of 0.88 g/cm³, a water absorption percentage of 5.51%, a thickness expansion of 1.13%, a modulus of rupture (MOR) of 19.79 MPa, and a modulus of elasticity (MOE) of 1.08 GPa.

4. CONCLUSION

A composite particleboard made from empty oil palm fruit bunch fibers and oil palm frond powder filler was successfully produced. The findings of the study can be summarized as follows:

1. The particle size of the oil palm fronds significantly influences the physical and mechanical properties of the biodegradable particleboard. As the mesh size increases, the density, modulus of rupture, and modulus of elasticity also increase, while moisture content and thickness swelling decrease. The 80-mesh particle size provided the best results, with a density of 0.88 g/cm³, a water absorption of 5.51%, a thickness swelling of 1.13%, a MOR of 19.79 MPa, and a MOE of 1.08 GPa.
2. All particleboard samples met the requirements of SNI 03-2105-2006 for density, water absorption, thickness swelling, and MOR. However, the MOE values for all variations were below the standard. This indicates that the stiffness of the boards is not optimal, likely due to an uneven distribution of fibers and fillers, as well as suboptimal bonding between the matrix, fillers, and fibers.

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