

# EFFECT OF BOARD THICKNESS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD MADE FROM RED MERANTI (*Shorea leprosula*) SAWDUST WASTE

*Karakteristik Fisika dan Mekanika Papan Partikel dari Limbah Serbuk Gergaji Meranti Merah (Shorea leprosula)*

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## ABSTRACT

The wood processing industry produces red meranti (*Shorea leprosula*) sawdust waste. This waste is generally not optimally utilized and can have negative impact. The use of sawdust as a raw material for particleboard is an environmentally friendly and economically valuable solution, given that particleboard has the potential to replace solid wood in the wood industry. This study aims to utilize red meranti sawdust waste as raw material for particleboard production using urea formaldehyde adhesive with different particleboard thicknesses. This study evaluates the effect of thickness variations (1 cm, 1.5 cm, and 2 cm) on the physical properties (moisture content, density, and thickness swelling) and mechanical properties (elasticity/MoE, breaking strength/MoR, and tensile strength) of particleboard. The results of testing the physical properties of particleboards showed that the average moisture content ranged from 10.92 % to 11.76 %, the density ranged from 0.54 g/cm<sup>3</sup> to 0.6 g/cm<sup>3</sup>, and the thickness swelling ranged from 4.05 % to 12.02 %. Mechanical property testing of particleboard showed that the average MoE ranged from 9,110 kg/cm<sup>2</sup> to 67,813 kg/cm<sup>2</sup>, MoR ranged from 9.44 kg/cm<sup>2</sup> to 37.93 kg/cm<sup>2</sup>, and internal bonding ranged from 0.292 kg/cm<sup>2</sup> to 0.396 kg/cm<sup>2</sup>. Based on the results of statistical analysis, it shows that in testing physical properties, thickness variation does not affect moisture content and density, but affects the thickness swelling of particleboards after being immersed for 2 and 24 hours. In mechanical property testing, thickness variation did not affect internal bonding, but it did affect MoE and MoR. Overall, this study confirms the potential of red meranti sawdust waste as a raw material for particleboard, although improvements are needed in increasing mechanical strength, particularly MoR and internal bonding.

Keywords: Mechanical properties; Particle board; Physical properties; Red meranti; Urea formaldehyde

## ABSTRAK

Industri pengolahan kayu menghasilkan limbah serbuk gergaji kayu meranti merah (*Shorea leprosula*). Limbah ini umumnya belum dimanfaatkan secara optimal dan dapat menimbulkan dampak negatif. Pemanfaatan serbuk gergaji sebagai bahan baku papan partikel menjadi solusi yang ramah lingkungan sekaligus bernilai ekonomis, mengingat papan partikel berpotensi menggantikan kayu solid dalam industri kayu. Penelitian ini bertujuan untuk memanfaatkan limbah serbuk gergaji kayu meranti merah sebagai bahan baku pembuatan papan partikel menggunakan perekat urea formaldehida dengan variasi ketebalan papan partikel yang berbeda. Studi ini mengevaluasi pengaruh variasi ketebalan (1 cm, 1,5 cm, dan 2 cm) terhadap sifat fisika (kadar air, kerapata, dan pengembangan tebal) dan sifat mekanika (elastisitas/MoE, keteguhan patah/MoR, dan keteguhan tarik) papan partikel. Hasil pengujian sifat fisika papan partikel menunjukkan rata-rata nilai kadar air berkisar dari 10.92 % sampai 11.76 %, kerapatan berkisar dari 0.54 g/cm<sup>3</sup> sampai 0.6 g/cm<sup>3</sup>, dan pengembangan tebal berkisar dari 4.05 % sampai 12.02 %. Pada pengujian sifat mekanika papan partikel menunjukkan rata-rata nilai MoE berkisar dari 9110 kg/cm<sup>2</sup> sampai 67813 kg/cm<sup>2</sup>, MoR berkisar dari 9.44 kg/cm<sup>2</sup> sampai 37.93 kg/cm<sup>2</sup>, dan keteguhan tarik berkisar dari 0.292 kg/cm<sup>2</sup> sampai 0.396 kg/cm<sup>2</sup>. Berdasarkan hasil analisis statistik menunjukkan bahwa pada pengujian sifat fisika, variasi ketebalan tidak berpengaruh terhadap kadar air dan kerapatan, namun berpengaruh terhadap pengembangan tebal papan partikel setelah direndam selama 2 dan 24 jam. Pada pengujian sifat mekanika, variasi ketebalan tidak berpengaruh terhadap keteguhan tarik, namun berpengaruh terhadap MoE dan MoR. Secara keseluruhan penelitian ini mengkonfirmasi potensi limbah serbuk gergaji kayu meranti merah sebagai bahan baku papan partikel, meskipun perlu perbaikan dalam peningkatan kekuatan mekanika, khususnya MoR dan keteguhan tarik.

Kata kunci: Meranti merah; Papan partikel; Sifat fisika; Sifat mekanika; Urea formaldehida

## A. INTRODUCTION

The wood processing industry plays an important role in the construction and furniture sectors. This is because wood is a versatile, strong, and aesthetically pleasing material, making it widely used in various industries (Dharanidharan *et al.* 2023). In addition, wood is also a material that can be found in various regions, especially Indonesia, which has 68.97 million hectares of production forests (Akbar & Najah 2022). However, the wood processing process produces large amounts of waste, especially in the form of sawdust from meranti wood. This is because for every 100 kg of meranti wood that is processed through cutting or sawing, around 8.77 kg will become sawdust waste (Koroh *et al.* 2022).

Meranti wood waste is generally not optimally utilized, thus potentially causing significant environmental impacts. According to Agyemang *et al.* (2024), uncontrolled burning of this waste can pollute the air and soil. In addition, the accumulation of sawdust risks clogging waterways or rivers, which can ultimately reduce flow capacity and increase the potential for flooding (Masyrroh & Rahmawati 2021). Furthermore, the burning of sawdust contributes to increased greenhouse gas emissions, while excessive exposure to dust has the potential to cause respiratory health problems in the surrounding community, especially if the waste is left to accumulate or is burned without proper management (Dewi *et al.* 2023). These impacts demonstrate the need for strategies to process and recycle meranti wood waste into alternative products that are more environmentally friendly and economically valuable. One relevant approach is the use of sawdust as a raw material for manufacturing particle board. According to Owodunni *et al.* (2020), particle board is an engineered wood product that has significant potential to replace solid wood in various applications. The use of sawdust waste as a raw material for particle board not only contributes to reducing the volume of industrial waste, but also offers a more sustainable and economical solution for the wood industry sector.

Several previous studies support this statement by showing that the use of sawdust waste in particleboard manufacturing can increase raw material efficiency while reducing dependence on solid wood (Firdasari *et al.* 2023). Koroh *et al.* (2022) also reported that meranti wood sawdust waste has the potential to be used as raw material for particleboard with good physical and mechanical properties. In line with this, Sarinah *et al.* (2015) emphasized that meranti wood sawdust can improve the strength and aesthetics of the final product, thereby adding value to wood waste that was previously underutilized.

In its application, there are a number of factors that affect the physical and mechanical properties of particleboard, including board thickness and particle size. This is in line with Si *et al.* (2025), who reported that inappropriate particleboard thickness can affect its physical and mechanical properties. In addition, Bekhta *et al.* (2023) explain that increasing the thickness of particleboards can reduce the chance of water penetrating into the particleboards, thereby minimizing thickness swelling. Therefore, to produce high-quality particleboard from meranti sawdust, in addition to the correct particle size and board thickness, the choice of adhesive is also a crucial factor. One commonly used adhesive is urea formaldehyde, as reported by Omer (2023). Urea formaldehyde adhesive is known to have high adhesion, relatively short drying time, and low production costs, making it effective in binding wood particles into solid and stable products (Ariska *et al.* 2024). However, an inappropriate proportion of adhesive can actually reduce the quality of the board, for example, by making it brittle or too rigid, causing it to crack easily.

In addition to its availability, meranti (*Shorea leprosula*) has several intrinsic characteristics that make its sawdust suitable for particleboard manufacturing. Meranti wood has a medium density (around 0.575 g/cm<sup>3</sup>) and a slightly coarse to coarse texture, which generally makes it easy to process (Ghozali *et al.* 2022; Cabuy *et al.* 2023; Alwi *et al.* 2025). Its relatively low extractive and oil content increases its adhesion to urea formaldehyde resin, thereby enhancing internal bond strength (Joni *et al.* 2025). Furthermore, Joni *et al.* (2025) also reported that meranti fibers contain sufficient lignin and cellulose, contributing to the dimensional stability and mechanical strength of the resulting panels. These properties indicate that meranti sawdust not only provides an abundant and renewable raw material but also offers good physical and chemical characteristics for producing high-quality particleboard.

Based on the description above, the problem that arises is how to utilize red meranti (*Shorea leprosula*) wood sawdust waste into particleboard products that have physical and mechanical properties in accordance with standards, while considering the effect of variations in the thickness of the resulting boards. The purpose of this study is to analyze the utilization of red meranti (*Shorea leprosula*) sawdust waste as raw material for particleboard production using urea formaldehyde adhesive at varying thicknesses. This study focuses on testing the physical and mechanical properties of the resulting particleboard, so that it can provide an overview of the product quality and its potential use as an environmentally friendly and economical alternative material in the wood industry.

## B. METHODS

### Materials and Tools

This study used red meranti (*Shorea leprosula*) sawdust waste, with urea formaldehyde adhesive as the binding agent. The equipment used included digital scales, 40 - 60 mesh sieve shaker, 30 cm x 30 cm particleboard molds, press machine, drying oven, iron plates, microcaliper, hammer, desiccator, 10 ml measuring cup, circular saw, mixing tub, and writing instruments.

### Procedures

#### 1. Material preparation

The collected material consists of red meranti wood sawdust obtained from PT Cahaya Samtraco Utama, Samarinda, East Kalimantan, which is the sieved using 40 - 60 mesh sieve (Suryani *et al.* 2023). At this stage, particles that are too large will be retained by the 40 mesh sieve, while particles that are too fine will pass through the 60 mesh sieve. The sawdust fraction retained on the 60 mesh sieve is then used as raw material in the manufacture of particleboard. The adhesive used in this study was urea formaldehyde (UF), which had a solid content of 65 %, pH of 7.5 - 8.5, and viscosity of 150 - 200 cP at 25 °C.

#### 2. Drying

The red meranti sawdust is the dried in an oven at a temperature of  $103 \pm 2$  °C for 24 hours to achieve a moisture content of 10 - 12 %. This moisture content range was selected because it is considered optimal for particleboard production, as stated by Dukarska *et al.* (2021), the optimal particle moisture content should not exceed 15 %.

#### 3. Mixing particles with adhesive

The adhesive used in the mixture is set at 20 % of the weight of the particles in dry conditions (Owodunni *et al.* 2020). Referring to the SNI 03-2105-2006 standard, the resulting particleboard is targeted to have a density of 0.7 g/cm<sup>3</sup> with three thickness variations: T1 (1 cm), T2 (1.5 cm), and T3 (2 cm). These symbols (T1, T2, and T3) are used throughout the text to indicate the respective thickness treatments. The composition of the particle and adhesive mixture is shown in Table 1.

**Table 1.** Composition of red meranti particles and urea formaldehyde adhesive mixture

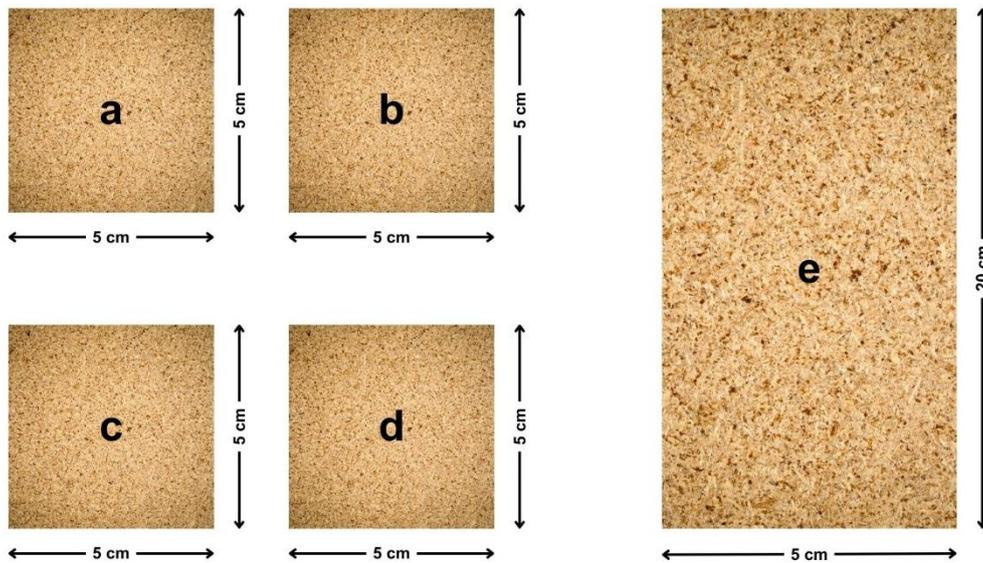
Treatment	Particle Weight (g)	Adhesive Weight (g)	Mixture Weight (g)
T1	529.2	185.22	714.42
T2	793.8	277.83	1071.63
T3	1058.4	370.44	1424.84

#### 4. Compression

The mixture of particles and adhesive is placed in a 30 cm x 30 cm mold, then cold pressed for 3 – 5 minutes to form a preform. After that, hot pressing is carried out at a temperature of 130°C with an initial pressure of 285 kg/cm<sup>2</sup> for 1 minute, followed by a pressure of 215 kg/cm<sup>2</sup> for 9 minutes. This gradual pressure method aims to increase heat and adhesive penetration in the early stages and to avoid excessive compression in the later stages, which can cause over densification (Boruszewski *et al.* 2016; Tian *et al.* 2024). A total of nine particleboards were produced, consisting of three treatments, each with three replications.

#### 5. Preparation of test samples

The particleboard produced measured 30 cm x 30 cm with three thickness variations, namely 1 cm, 1.5 cm, and 2 cm. Test samples were cut from each particle board for physical and mechanical testing in accordance with SNI 03-2105-2006 standards. Test samples for moisture content, density, thickness swelling, and internal bonding were cut to a size of 5 cm x 5 cm, while test samples for modulus of elasticity (MoE) and modulus of rupture (MoR) were cut to a size of 20 cm x 5 cm with a span of 15 cm. The test sample collection scheme is shown in Figure 1.



**Figure 1.** Test sample collection scheme from particleboard samples; a = moisture content, b = density, c = thickness swelling, d = internal bonding, and e = MoE and MoR.

*6. Physical and mechanical properties testing*

Testing was conducted to determine the quality of particleboard based on its physical and mechanical properties in accordance with SNI 03-2105-2006. Physical tests included moisture content, density, and thickness swelling after immersion in water. Mechanical tests include MoE, MoR, and internal bonding.

*7. Experimental Design and Data Analysis*

The study used a completely randomized design (CRD) with three thickness treatments and five replicates, resulting in 15 experimental units. The data obtained from each physical and mechanical properties test were analyzed using analysis of variance (ANOVA) to determine the effect of thickness on the tested parameters. The formulas used for ANOVA are as follows:

$$F = \frac{MS_{treatments}}{MS_{error}}$$

where  $MS_{treatments}$  refers to the mean square of treatments, and  $MS_{error}$  represents the mean square of error.

If there were significant differences ( $F_{count} > F_{table}$ ), they were followed up with the Least Significant Difference (LSD) test at a significance level of 5 %. The formulas used for LSD are as follows:

$$LSD = t_{\alpha, d_{error}} \times \sqrt{\frac{2 \times MSE}{r}}$$

where  $t_{\alpha, d_{error}}$  is the t-value at  $\alpha = 0.05$  with the corresponding error degrees of freedom, MSE denotes the mean square error, and r is the number of replications.

**C. RESULTS AND DISCUSSION**

**Physical Properties**

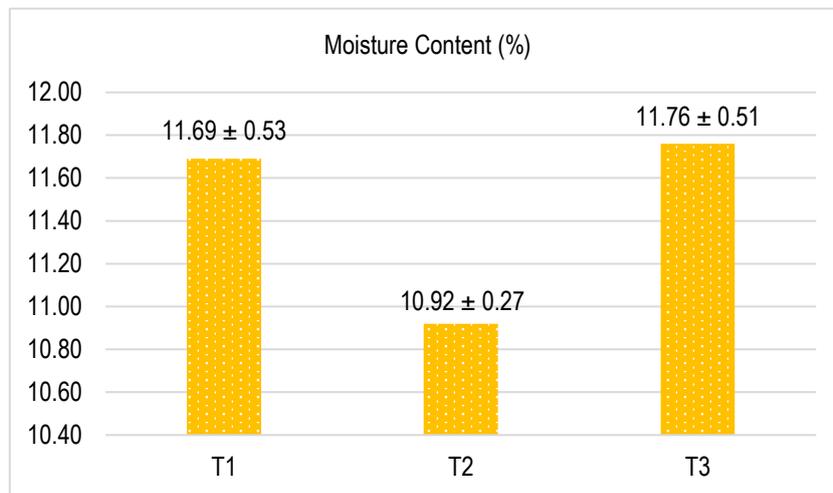
Physical properties testing is conducted to determine the quality of particleboard in terms of moisture content, density, and thickness swelling after immersion. These parameters are important because they are directly related to the dimensional stability and durability of the board against environmental changes. Moisture content indicates the level of hygroscopic balance of the material, density is used to describe the relationship between the weight and volume of particleboard, while thickness swelling reflects the ability of the board to maintain its shape after immersion to water. The results of testing these three parameters are presented in Table 2.

## 1. Moisture Content

The results show that the moisture content of particleboards varies in each treatment, namely 11.69 % in T1, 10.92 % in T2, and 11.76 in T3 (Figure 2). These values are still within the range permitted by the SNI 03-2105-2006 standard, which is a maximum of 14 %. This indicates that all boards met the standard requirement. This conformity can be attributed to two main factors, namely the properties of the raw materials and the pressing process. In terms of raw materials, the moisture content of red meranti wood is reported to be in the range of 11.79 - 14.1 % (Lee *et al.* 2024). With the application of optimal pressing control, the moisture content of red meranti sawdust, which was initially slightly above the standard, could be reduced to below the maximum limit required, resulting in particleboard with a moisture content in accordance with the SNI standard.

**Table 2.** Physical properties of particleboard

Physical Properties	T1	T2	T3
Moisture content (%)	11.69	10.92	11.76
Density (g/cm <sup>3</sup> )	0.6	0.56	0.54
Thickness swelling (2 hours) (%)	7.35	5.47	4.05
Thickness swelling (24 hours) (%)	12.02	8	6.7



**Figure 2.** Moisture content of particleboard

In addition, the use of thermosetting urea formaldehyde adhesive also contributes to the water evaporation process during pressing. When the adhesive hardens due to exposure to high temperatures, water vapor is released from the board structure (Athariqa *et al.* 2022). This condition shows that variations in particleboard thickness do not have a significant effect on the final moisture content, with evidence that the  $F_{count}$  value is smaller than  $F_{table}$  (Table 3). Thus, the production process parameters applied, particularly the temperature and pressing pressure settings, have been proven to be able to consistently control the moisture content in all particle boards, regardless of differences in thickness.

**Table 3.** ANOVA results for moisture content of particleboard

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	$F_{count}$	$F_{table}$	
					5 %	1 %
Treatment	2	2.2189	1.1094	1.07 <sup>i</sup>	3.89	6.93
Error	12	12.4066	1.0339	-	-	-
Total	14	14.6255	-	-	-	-

\* = significant

\*\* = significant

i = insignificant

Furthermore, the uniformity of moisture content across various particleboard thicknesses confirms the effectiveness of the production parameters applied. As reported by Panuntun *et al.* (2021), who emphasized that pressing, pressing temperature, or a combination of both affect water absorption in particleboards. Maintaining moisture content below the maximum threshold is not only important to meet quality standards but also to ensure dimensional stability and mechanical strength, as excessive moisture content is often associated with increased thickness swelling and decreased particleboard

strength (Siska & Indrayanti 2020; Sargent 2022). Thus, the results of this study reinforce the evidence that the integration of raw material preparation, pressing control, and the use of thermosetting adhesives can affectively optimize the moisture content of particleboard produced from wood sawdust waste.

2. Density

The density of particleboards exhibited variations across treatments, with average values of 0.6 g/cm<sup>3</sup> for T1, 0.56 g/cm<sup>3</sup> for T2, and 0.54 g/cm<sup>3</sup> for T3 (Figure 3). These values fall within the acceptable range specified by the SNI 03-2105-2006 standard, namely 0.4 - 0.9 g/cm<sup>3</sup>. The conformity of density values to the standard can be attributed to the utilization of red meranti sawdust as raw material, which inherently possesses relatively uniform and favorable natural density characteristics (Dwiyanti *et al.* 2024).

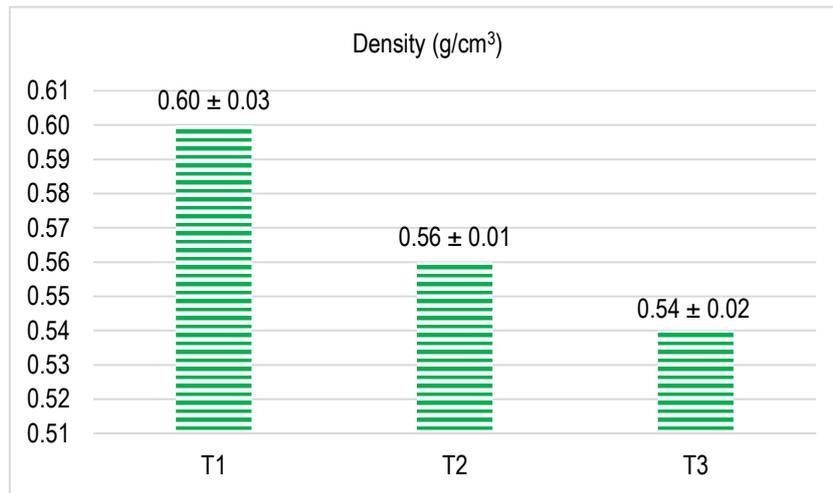


Figure 3. Density of particleboard

The observed differences among treatments can be attributed to variations in board thickness, pressing pressure distribution, and resin penetration. Thinner boards tend to achieve higher density because the applied pressure during hot pressing is more effectively transferred throughout the particle mass, resulting in a more compact structure. Conversely, in thicker boards, heat and pressure penetration are less uniform, causing incomplete compression in the core layer and slightly lower density (Muhamad *et al.* 2025). In addition, the use of urea formaldehyde adhesive, known for its high bonding strength and good penetration into the wood particle pores, contributed to the formation of compact inter-particle bonding. This condition resulted in a denser particleboard structure and enhanced dimensional stability (Chen *et al.* 2025; Li *et al.* 2025).

Furthermore, the analysis results show that the density value of particleboards is not significantly affected by thickness variations, as indicated by the F test results which give an F<sub>count</sub> value smaller than F<sub>table</sub> (Table 4). This finding indicates that the raw material preparation, adhesive addition, and pressing processes were carried out homogeneously and consistently, so that the thickness of the board was not a factor determining density variation. In addition, these results also confirm that the particleboard manufacturing method applied in this study is capable of controlling the distribution of particles and adhesives evenly throughout the particleboard, resulting in relatively uniform density values at each thickness level.

Table 4. ANOVA results for density of particleboard

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F <sub>count</sub>	F <sub>table</sub>	
					5 %	1 %
Treatment	2	0.0091	0.00456	2.22 <sup>i</sup>	3.89	6.93
Error	12	0.0246	0.00205	-	-	-
Total	14	0.0337	-	-	-	-

\* = significanty

\*\* = significant

i = insignificant

However, the density value produced is still slightly below the research target of 0.7 g/cm<sup>3</sup>. This condition can be caused by several factors, including the size of particles used, the proportion of adhesive, and the pressing process. Relatively smooth particles tend to form micro-voids that are not completely filled by the adhesive, resulting in a lower final

density of the particle board that targeted (Hasan *et al.* 2020; Fehrmann *et al.* 2022). In addition, the urea formaldehyde adhesive used, which is only 20 % of the dry weight of the particles, may not be optimal for covering all the pores between the particles. Another influential factor is the pressure and pressing time settings, where uneven heat distribution, especially in thicker particleboards, can reduce compaction efficiency (Goncalves *et al.* 2020; Nogueira *et al.* 2022).

Although the density value did not fully reach the target, this results is still in accordance with the SNI standard. This indicates that the particleboard produced still meets national quality standards and has the potential to be applied in the wood panel industry. However, improvements in adhesive formulation, particle size optimization, as well as pressure and pressing temperature settings can be considered for further research to achieve more optimal density.

### 3. Thickness Swelling

The results show that the thickness development values after 2 hours of immersion were 7.53 % for T1, 5.47 % for T2, and 4.05 % for T3. After immersion for 24 hours, the thickness swelling values increased to 12.02 % for T1, 8 % for T2, and 6.7 % for T3 (Figure 4). Based on the SNI 03-2105-2006 criteria, all particleboards still met the tolerance limit (<12 %) after 2 hours of immersion. However, after 24 hours of immersion, only T2 and T3 still met the criteria, while T1 exceeded the limit with a value of 12.02 %. The increase in swelling thickness observed after 24 hours compared to 2 hours is due to longer water absorption and gradual penetration into the inner layers of the particleboard. During the first two hours, water is mainly absorbed by surface and near-surface particle. However, as the immersion time increases, capillary action allows water to reach deeper layers, softening the urea formaldehyde adhesive bonds and causing the wood fibers to expand. As stated by Muhamad *et al.* (2025), the higher the water absorption capacity of wood, the higher its thickness expansio. Statistical analysis also showed significant differences between treatments in terms of thickness swelling for both 2 hours and 24 hours immersion (Table 5 and Table 6).

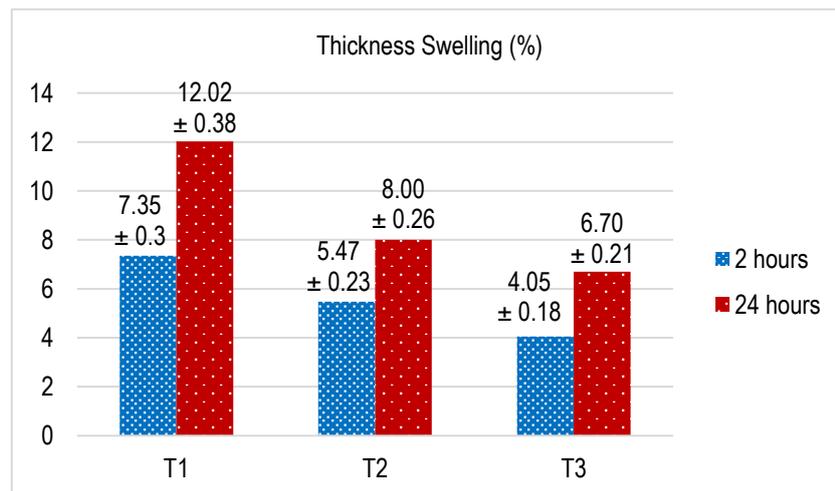


Figure 4. Thickness swelling of particleboard

Table 5. ANOVA results for thickness swelling with 2 hours immersion of particleboard

Source of variance	Degrees of freedom	Sum of squares	Mean square	F <sub>count</sub>	F <sub>table</sub>	
					5 %	1 %
Treatment	2	27.088	13.544	46.50**	3.89	6.93
Error	12	3.496	0.2913	-	-	-
Total	14	30.584	-	-	-	-

\* = significanty

\*\* = significant

i = insignificant

Table 6. ANOVA results for thickness swelling with 24 hours immersion of particleboard

Source of variance	Degrees of freedom	Sum of squares	Mean square	F <sub>count</sub>	F <sub>table</sub>	
					5 %	1 %
Treatment	2	76.481	38.241	87.91**	3.89	6.93
Error	12	5.216	0.435	-	-	-
Total	14	81.697	-	-	-	-

\* = significanty

\*\* = significant

i = insignificant

The phenomenon can be explained by differences in particleboard thickness, which affect water absorption resistance and dimensional stability. Particleboard with greater thickness, such as those in T2 and T3, tend to have a more compact and stable structure, resulting in lower water permeability and thickness swelling rates that remain below the threshold set by SNI 03-2105-2006. These findings are consistent with the report by Kariuki *et al.* (2020), which states that increasing the thickness of particleboards can reduce the rate of water penetration into the interior thereby minimizing thickness swelling.

In addition, the contribution of thermosetting urea formaldehyde plays a role in controlling thickness swelling. During the high-temperature pressing process, urea formaldehyde adhesive undergoes a polymerization reaction that forms cross-links between particles, while also pushing water out of the particleboard structure. These bonds strengthen the internal structure of the particleboard and reduce its water absorption capacity, so that thicker boards with even adhesive distribution tend to be more stable against dimensional changes. This is in line with the findings of Athariqa *et al.* (2022), who stated that the resistance of particleboards to thickness swelling is influenced by the quality of the adhesive bonds formed during the pressing process.

### Mechanical Properties

The results of testing the mechanical properties of particleboard in this study are presented in full in Table 7. The three main parameters analyzed include MoE, MoR, and internal bonding. In particleboard testing, internal bonding is more commonly known as Internal Bond Strength (IBS), whereas in solid wood and plywood testing, this parameter is more often referred to as internal bonding.

Table 7. Mechanical properties of particleboard

Mechanical Properties	T1 (L/T ratio = 20)	T2 (L/T ratio = 13.33)	T3 (L/T ratio = 10)
MoE (kg/cm <sup>2</sup> )	67,813	27,690	9,110
MoR (kg/cm <sup>2</sup> )	37.93	20.26	9.44
Internal bonding (kg/cm <sup>2</sup> )	0.396	0.326	0.292

#### 1. Modulus of Elasticity (MoE)

The results show that the MoE value of particleboard varies with each thickness treatment. T1 obtained an average value of 67,813 kg/cm<sup>2</sup>, T2 obtained 27,690 kg/cm<sup>2</sup>, and T3 obtained 9,110 kg/cm<sup>2</sup> (Figure 5). Based on the SNI 03-2105-2006 standard, the minimum MoE value required is 20,400 kg/cm<sup>2</sup>. Thus, particleboards in treatments T1 and T2 have met the standard, while T3 has not met the requirements. This is because thinner particleboards (T1 and T2) exhibit higher stiffness and greater resistance to deformation under bending loads, while the thicker particleboard (T3) tends to have lower stiffness due to reduced stress distribution efficiency along its neutral axis. ANOVA shows that thickness variation has a very significant effect on the MoE value, with the  $F_{count}$  value (40.41) much greater than  $F_{table}$  at a significance level of 1 % (6.7) (Table 8). The LSD post-hoc test confirmed that the difference in the mean MoE values between thicknesses T1 and T2 was 40122.76 between T1 and T3 was 58702.42, and between T2 and T3 was 18579.67. These differences are greater than the LSD values at both the 5 % and 1 % levels, so the differences between treatments are considered significant to highly significant.

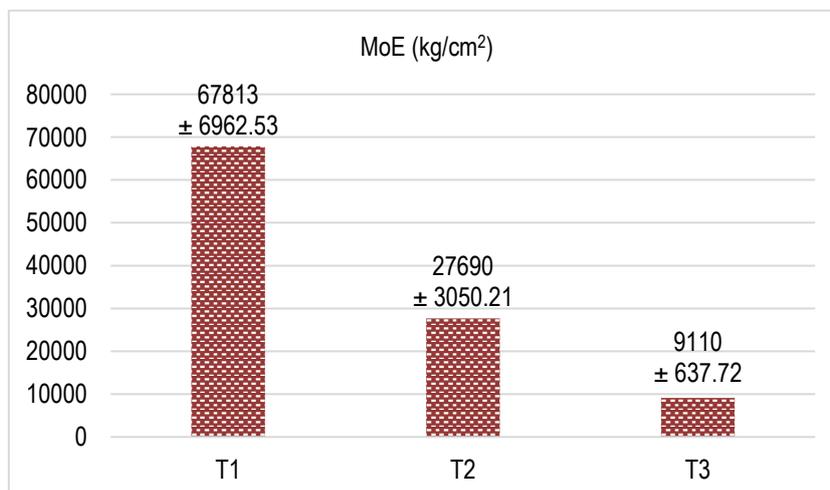


Figure 5. MoE of particleboard

This condition occurs because variations in particleboard thickness directly affect the MoE value, which represents bending strength. Particleboards with greater thickness have a higher capacity to withstand elastic deformation due to bending loads, resulting in a significant increase in the MoE value. This finding is also in line with the opinion of Desiasni *et al.* (2022), who states that an increase in particleboard thickness will have a positive effect on the resulting bending strength (MoE). This is because the greater the volume of material that makes up the particleboard, the more evenly the bending load can be distributed, making the particleboard stiffer and more resistant to deformation. Meanwhile, in this study, an inverse relationship was observed between thickness and MoE, where thicker particleboards showed lower MoE values. This phenomenon occurs due to the effect of the length-to-thickness (L/T) ratio and internal stress distribution during bending. Thinner boards have a higher L/T ratio, causing greater deflection under load and resulting in a higher calculated MoE value. In contrast, thicker boards (T3) have a lower L/T ratio, leading to smaller deflection and lower apparent MoE value (Table 7). These findings are consistent with the reports of Zhang *et al.* (2020), who stated that a decrease in the L/T ratio in thicker panels can lower the MoE of particleboard.

**Table 8.** ANOVA results for MoE of particleboard

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F <sub>count</sub>	F <sub>table</sub>	
					5 %	1 %
Treatment	2	9001690347.09	4500845173.54	40.4021**	3.81	6.7
Error	13	1448215939.69	111401226.13	-	-	-
Total	15	10449906286.79	-	-	-	-

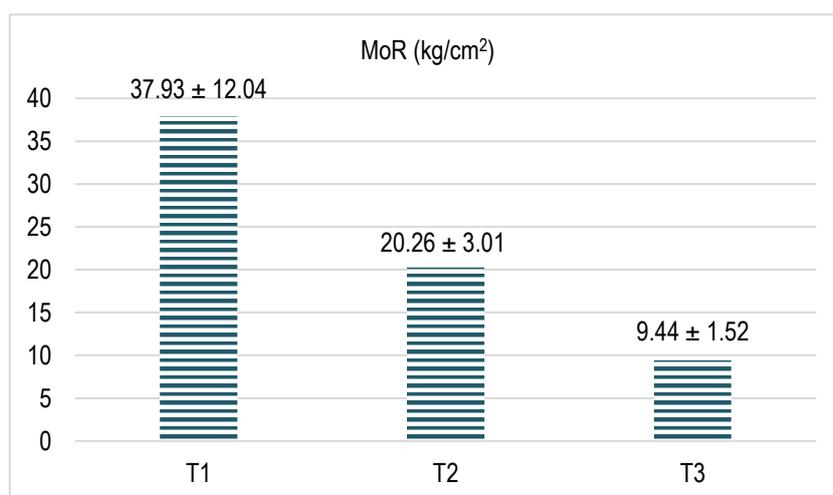
\* = significant

\*\* = significant

i = insignificant

## 2. Modulus of Rupture (MoR)

The results show that the MoR value of particleboard varies with each thickness treatment. T1 obtained an average value of 37.93 kg/cm<sup>2</sup>, T2 obtained 20.26 kg/cm<sup>2</sup>, and T3 obtained 9.44 kg/cm<sup>2</sup> (Figure 6). This value indicates that the MoR of the particle board tested does not meet the standard set in SNI 03-2105-2006, which is 82 kg/cm<sup>2</sup>. This difference may be due to the relatively low density of the particleboard produced (0.54–0.6 g/cm<sup>3</sup>) compared to the target density of 0.7 g/cm<sup>3</sup>, resulting in reduced interparticle bonding effectiveness. In addition, limited adhesive distribution and uneven heat and pressure transfer during pressing, especially in thicker boards, may cause the adhesive to cure imperfectly, thereby reducing the MoR value (Dera *et al.* 2023; Indrayanti *et al.* 2023; Aisyah *et al.* 2025). This phenomenon shows that as the thickness of the board increases, the inside of the board tends to experience lower compaction and weaker bonds due to limited heat penetration. This causes the density produced by thin boards to be higher than that of thick boards. Therefore, the decrease in MoR value as thickness increases can be caused by differences in density levels. In line with what was stated by Laksono *et al.* (2021), the higher the density of particle boards, the higher the MoR value.



**Figure 6.** MoR of particleboard

Particleboard with a thickness of 1 cm (T1) showed the highest MoR value compared to particleboard with a thickness of 1.5 cm (T2) and 2 cm (T3). This condition was due to the relatively higher density of the 1 cm thick particleboard, which directly contributed to increased mechanical strength, particularly MoR. This statement is in line with that stated by Korai

(2022), that the denser the particle arrangement in the particleboard, the better the interparticle bond formed, so that the particleboard is able to withstand greater bending loads before experiencing damage.

**Table 9.** ANOVA results for MoR of particleboard

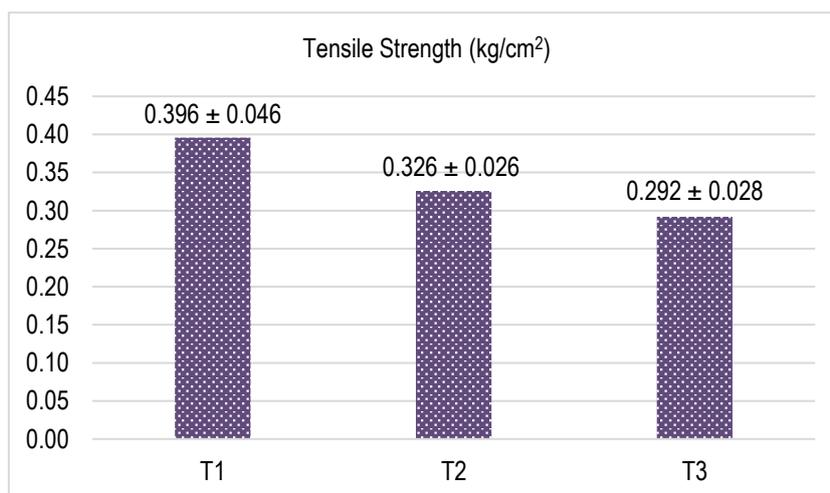
Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F <sub>count</sub>	F <sub>table</sub>	
					5 %	1 %
Treatment	2	2067.5911	1033.5911	4.38*	3.81	6.7
Error	13	3065.6539	235.8195	-	-	-
Total	15	5133.2450	-	-	-	-

\* = significant at the 95 % confidence level

ANOVA also shows that varying thicknesses affect the MoR, as indicated by the statistical test results where the F<sub>count</sub> value is greater than the F<sub>table</sub> value (Table 9). In addition, it can be seen that the average difference in MoR between thicknesses T1 and T2 is 17.66, which is smaller than the LSD 5 % and 1 % (20.98), so the difference between thicknesses T1 and T2 is not significant. The difference between T1 and T3 is 28.48, which is greater than the LSD 5 % but smaller than the LSD 1 % (29.25), so the difference is significant at a 5 % confidence level. The difference between T2 and T3 is 10.8205, which is smaller than the LSD 5 % and 1 %, so there is no significant difference between the thickness of T2 and T3 in relation to MoR. This indicates that particleboard thickness does indeed affect the MoR value, but not all differences in thickness result in statistically significant differences. Greater particleboard thickness tends to increase breaking strength (MoR), but this increase only shows a significant difference if the difference in thickness is large enough, as is the case between thicknesses T1 and T3. Meanwhile, the differences between T1 and T2, and T2 and T3 are not large enough to produce a significant difference in MoR.

### 3. Internal Bonding

The results show that the internal bonding value of particleboard varies with each thickness treatment. T1 obtained an average value of 0.396 kg/cm<sup>2</sup>, T2 obtained 0.326 kg/cm<sup>2</sup>, and T3 obtained 0.292 kg/cm<sup>2</sup> (Figure 7). This value indicates that the internal bonding of the particle board tested does not meet the standard set in SNI 03-2105-2006, which is 1.5 kg/cm<sup>2</sup>. This inadequate performance may be caused by the relatively low density of the board, which limits the interparticle bonding area and weakens stress transfer within the particleboard. In addition, an adhesive content of 20 % of oven-dry weight may not be sufficient to produce strong internal bonds, especially in thicker boards where adhesive distribution tends to be less uniform. Furthermore, the pressing process may not provide adequate heat penetration to the core of thicker boards, resulting in incomplete curing of the urea formaldehyde adhesive and weak interfacial bonds. The geometry and surface roughness of the sawdust particles used may also limit adhesive penetration, ultimately reducing bond effectiveness and contributing to low internal bonding values (Rzyska-Pruchnik & Kowaluk 2021; Mirindi 2024).



**Figure 7.** Internal bonding of particleboard

This trend is also in line with the density test results, where thinner boards (T1) have a higher density (0.6 g/cm<sup>3</sup>) compared to thicker boards (T3) which have a lower density (0.54 g/cm<sup>3</sup>). Higher density allows wood particles to come into closer contact with each other and the adhesive to work more effectively, while lower density results in more voids and weaker internal bonds. Therefore, the decrease in density with increasing thickness directly contributes to the

weakening of the internal bonding value in thicker particle boards. These results are in line with those reported by Ginting & Rini (2021) that the density value of particleboard is directly proportional to its internal bonding value.

ANOVA also shows that has been conducted also found that thickness variation does not affect the internal bonding, as indicated by the  $F_{\text{count}}$  value being smaller than  $F_{\text{Table}}$  (Table 10). Referring to Ariska *et al.* (2024), this condition can occur because cracks due to the internal bonding of the surface tend to be caused by an inappropriate proportion of urea formaldehyde, rather than thickness variation. Similarly, according to Fehrmann *et al.* (2022), compared to thickness variations, the main factor causing particle boards to have poor surface internal bonding is the use of meranti sawdust particles that are not uniform or too small.

**Table 10.** ANOVA results for internal bonding of particleboard

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	$F_{\text{count}}$	$F_{\text{table}}$	
					5 %	1 %
Treatment	2	0.02795	0.01398	2.55 <sup>ns</sup>	3.81	6.7
Error	13	0.0657	0.00548	-	-	-
Total	15	0.09365	-	-	-	-

ns = insignificant at the 95 % confidence level

The significant differences in all of these mechanical property tests cannot be entirely attributed to variations in thickness. The difference is also influenced by the span-to-thickness ratio (L/T ratio) applied during testing. In this study, the span length was kept constant at 20 cm, while the thickness of the boards varied (1, 1.5, and 2 cm), resulting in different L/T ratios: 20, 13.3, and 10, respectively. According to the SNI 2105:2006 and JIS A 5908 standards, flexural tests must maintain a span of approximately 14–20 times the thickness of the specimen to ensure comparable flexural moments. Therefore, the variation in the L/T ratio in this study affected the measured MoE, MoR, and internal bonding values. A higher L/T ratio (as in T1) results in greater flexural deflection, yielding higher MoE values, while a lower L/T ratio (as in T3) results in smaller deflection and lower MoE values. This phenomenon has been reported by Zhang *et al.* (2020) regarding the span-to-depth/span-to-thickness effect on the flexural properties of wood and fiber/particle composites.

In Addition, MoR values are also influenced by the L/T ratio. MoR describes the maximum strength that can be withstood before fracture. With a constant span, thicker boards (smaller L/T ratio) experience greater moment forces on the bottom flange, but their deformation is smaller, thereby reducing fracture energy. Conversely, thinner boards (high L/T ratio) experience greater deflection and relatively lower fracture moments, but their bending stress may appear higher due to a greater moment-to-thickness ratio. In line with Dayadi (2022), if the L/T ratio is not uniform in the test, it will limit direct comparisons between all treatments.

For internal bonding, the effect of the L/T ratio does not directly originate from the test geometry, but from the effect of stress distribution within the board structure. When the L/T ratio is not uniform, the bending force applied to the board causes uneven tensile stress distribution in the inner layers, which can affect the internal internal bonding measurement results. Boards with a larger L/T ratio (thinner) tend to experience a wider stress distribution along the thickness, so their internal internal bonding values may appear higher than those of thicker boards with a small L/T ratio. This effect is caused by differences in the L/T ratio values, as stated by Rzyska-Pruchnik & Kowaluk (2021) that uneven L/T ratio values have a significant effect on internal bonding values.

Thus, the differences in MoE, MoR, and internal bonding test results between each treatment not only reflect the physical properties of the material, but are also the result of the influence of specimen geometry and non-uniform L/T ratios. To obtain more representative results, mechanical testing should use a span length adjusted to the specimen thickness ( $L \approx 14\text{--}20T$ ) so that the loading and deformation conditions are equivalent in each treatment.

## D. CONCLUSION

Based on the results of the study, it can be concluded that particleboard made from red meranti (*Shorea leprosula*) sawdust waste produced with urea formaldehyde adhesive shows variations in physical and mechanical properties that are influenced by differences in thickness. The moisture content obtained ranged from 10.92 % to 11.76 %, density from 0.54 g/cm<sup>3</sup> to 0.6 g/cm<sup>3</sup>, and thickness swelling from 4.05 % to 12.02 %, which are still within the acceptable standard range. Meanwhile, the mechanical properties showed the highest values of MoE 67,813 kg/cm<sup>2</sup>, MoR 37.93 kg/cm<sup>2</sup>, and internal bonding 0.396 kg/cm<sup>2</sup>. Statistical analysis confirmed that thickness variation did not affect moisture content, density, or internal bonding, but had a significant effect on thickness swelling and certain mechanical properties, particularly MoE and MoR. Thus, this study proves that red meranti sawdust waste has a potential to be utilized as raw material for particleboard, although further optimization is still needed to improve mechanical performance to meet higher quality standards. Among all treatments, particleboard with a thickness of 1 cm (T1) showed the best overall performance in terms of mechanical strength and dimensional stability, with the highest MoE, MoR, and internal bond strength values,

while maintaining acceptable physical characteristics. Therefore, a thickness of 1 cm can be considered the optimal dimension for producing particleboard from red meranti sawdust waste under the conditions applied in this study.

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## AUTHOR'S DECLARATION

- Conflicts of Interest: None.
- We here by confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for republication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- No potentially identified images or data are present in the manuscript.

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