



Sustainable Particleboards from Invasive Cogon Grass using Epoxy Resin: A Greener Alternative to Wood-Based Panels

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Highlights

- Cogon grass particleboards were investigated using epoxy resin as an eco-friendly wood alternative.
- Methanol percentages and particle size were tested for optimal properties.
- Particleboards were pressed at 25°C, and mechanical properties were assessed.

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Abstract

This study explores cogon grass (*Imperata cylindrica*), an invasive species, as a sustainable raw material for particleboard production. Epoxy resin was used as a binder, with methanol added to enhance processing and mechanical performance. The effects of particle size (<60 mesh and >60 mesh), five methanol concentrations (1.5%–3.5%), and binder-to-particle ratios (1.4:1 to 2.2:1) were evaluated. Boards were pressed at 25°C for 15 minutes. Physical and mechanical properties were analyzed, including density, moisture content, thickness swelling, tensile strength, yield strength, and modulus of elasticity derived from tensile testing. Results showed densities ranging from 0.568 to 0.942 g/cm³, moisture content below 6.6%, and zero thickness swelling after 24-hour immersion. The best mechanical results reached 11.96 MPa for tensile strength and 125.82 MPa for yield strength, with a maximum modulus of elasticity of 190.09 MPa. While MOE values were derived from tensile testing and not flexural analysis as required by SNI 03-2105-2006, results indicate cogon grass particleboards are promising for indoor use.

1. INTRODUCTION

The rising demand for wood products and decreasing industrial wood production [1] have led to environmental issues like deforestation. In Indonesia, particleboard production increased from 26.04 million m³ in 2021 [2] to 166.65 million m³ in 2022 [3], along with a rise in raw timber production. This study explores using cogon grass (*Imperata cylindrica*), an invasive species, as an alternative material for particleboard production because of its high cellulose and lignin content. Cogon grass, common in tropical regions and invasive globally, offers environmental, economic, and technical benefits by reducing deforestation and adding value to the plant. It belongs to the *Poaceae* family [4], which covers about 200 million hectares globally [5].

Cogon grass, which contains saponins, flavonoids, coumarins, phenols [6], and hydrated silica (SiO₂·nH₂O) [7], significantly correlates with mechanical properties, but glycosides show inverse correlations with modulus of elasticity, hardness, and internal bonding [8]. Nano-composite materials containing cellulose fibres have good gas permeability [9]. In Aceh Province, Indonesia, this grass is also known as *japgrass*, *bladygrass*, *speargrass*, *alang-alang*, and *lalang-lalang* [10]. The growth of cogon grass remains unchecked, impacting both ecological and economic areas in some regions [11].

Once established, cogon grass outcompetes native vegetation, forming extensive monocultural expanses with very low species diversity [12]. In Japan, it hinders agricultural practices and increases weed control costs because of herbicide restrictions [13]. Effective control in forests often requires chemical methods

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[14]. In Malaysia, cogon grass is abundant along roadside and open areas where it demonstrates aggressive growth [15]. Despite its invasiveness, cogon grass can be utilized effectively, particularly in Southeast Asia, where it covers extensive areas [16], and is used in various applications like roofing [17] and polymer composites [18].

Particleboards made from lignocellulosic raw materials should meet technical standards comparable to those made from softwood [19]. They help reduce illegal logging and forest area reduction by adding value to raw materials, reducing production costs, and utilizing residual biomass [20]. Previous studies have explored cogon grass particleboards using glycerine [1], but no research has examined using epoxy resin as its binder. However, the research took 8 hours to grind the cogon grass particles to a size of 90–170 mesh. Irrespective of the adhesive used, particleboard made from bagasse exhibited superior modulus of elasticity compared to the other agricultural biomass [21]. Bagasse particleboards had lower impacts in all categories compared to pine particleboards but consumed 9.9% more energy. Epoxy offers good adhesion, high strength, and thermal stability. The term epoxy has been used beyond its original application for fibre reinforced polymer composites [22]. Epoxy contains polar functional groups including hydroxyl (-OH) and amino (-NH₂), which allow it to easily adsorb onto surfaces and function as an effective anticorrosive material [23]. These groups enhance adhesion between matrix and reinforcement, resulting in high strength, thermal stability, and low moisture absorption [24], along with low shrinkage, high cohesion, and minimal creep [25].

This is the first study to investigate the use of epoxy resin combined with methanol as a binder for producing particleboards from cogon grass. While previous studies have used natural adhesive like glycerine or citric acid, none have evaluated the synergistic effect of epoxy and methanol on the mechanical and physical properties of cogon grass-based particleboards. This novel approach introduces a high-performance composite that harnesses epoxy's strength and methanol's plasticizing role, aiming to develop sustainable panels with improved characteristics. This study not only contributes to invasive species utilization but also offers a new direction in particleboard manufacturing using synthetic binders. Therefore, this combination is expected to produce particleboards with physical and mechanical properties that comply with Indonesian national standards, while offering bio-based materials.

2. METHODOLOGY

2.1. Materials

The cogon grass was obtained from Paoman Subdistrict, Indramayu, West Java, Indonesia. The cogon grass used had a height of 1.0–1.5 meters and was trimmed at a distance of approximately 10 cm from the ground. Other materials used were bentonite (90%, AMCOL), epoxy (Sikadur®-31 CF Normal, Indonesia), calcium carbonate (Omya, Switzerland), methanol (99.9%, Methanex), titanium dioxide (98%, Chemours). The cogon grass was cleaned, cut, and blended to reduce its size. It was sun-dried for four days to minimize investment and operational costs, and then oven at 80°C for 24 hours. The temperature was regularly checked at intervals of 30 minutes to ensure it remains at 80°C. The dried material was sieved to separate particles smaller than 60 mesh from those larger than 60 mesh.

2.2. Preparation of Epoxy-Based Adhesive

To ensure reproducibility and enable meaningful interpretation of the mechanical properties, it was important to specify the composition and curing conditions of the epoxy adhesive used in this study. The epoxy resin applied was Sikadur®-31 CF Normal, a two-component, thixotropic, structural adhesive based on a bisphenol-A epoxy system. The epoxy resin (68%) was then combined with the additive formulation (20.4% calcium carbonate, 8.2% titanium dioxide, 3.4% bentonite, and various amounts of methanol: 1.5%, 2.0%, 2.5%, 3.0%, and 3.5%) without hardener and stirred for 15 minutes to ensure homogeneity.

Calcium carbonate acted as a filler to reduce the overall cost of the adhesive without significantly impacting its performance. Titanium dioxide was used as a white pigment to improve the opacity and brightness of the adhesive. Bentonite was a clay that acted as a thixotropic agent giving the adhesive thixotropic

properties (i.e., the ability to become less viscous under shear stress and more viscous at rest). Methanol can act as a plasticizer, temporarily reducing the rigidity of the epoxy resin during processing. Methanol can evaporate easily, contributing to the formation of ground-level ozone and smog. Proper ventilation in areas where methanol was used was set to minimize inhalation exposure. Although Sikadur®-31 CF can cure at ambient temperature, this study applied heat-assisted curing at 140°C for 15 minutes in preparation of particleboards using a hot press to accelerate the crosslinking reaction and improve adhesive bonding within the particleboard structure. This curing protocol, although different from standard ambient curing, was selected to suit the thermosetting behavior of the composite matrix and reduce production time.

2.3. Preparation of Particleboards

Epoxy-based adhesive and cogon grass particles were utilized to produce particleboards using an epoxy systems comprising a 1.4:1 to 2.2:1 mass ratio blend. Particleboards were produced by mixing 50 grams of cogon grass particles (either smaller or larger than 60 mesh) with the adhesive solution. The preparation began by mixing the mixture epoxy-based adhesive with cogon grass particles in a mechanically stirred container at 500 rpm for 15 minutes to achieve a uniform mixture. The resulting adhesive-particle mixtures were poured into silicone molds and cured in a muffle oven. The curing process involved heating and pressing at 140°C for 15 minutes without removing the molds. The temperature was monitored regularly during the pressing process. It was checked at intervals of three minutes to ensure it stays at 140°C. After cooling for 48 hours, the composites were demolded and allowed to undergo a post-curing process at room temperature for seven days. Each formulation was prepared in triplicate for subsequent mechanical and material testing.

2.4. Parameter Test Analysis

Tests were conducted to measure density, moisture content, and thickness expansion according to the Indonesian national standard, SNI 03-2105-2006, using a Tensile Testing Machine. This study did not use ASTM standard because ASTM standard did not specify the requirements for particleboards used in general applications. SNI standards are specifically designed to meet the local environmental, economic, and regulatory conditions of Indonesia. Adhering to this standard ensures that the particleboard meets the specific requirements and expectations of the Indonesian market.

2.5. Density Analysis

Density was measured by comparing the volume and mass of the particleboard using a balance with an accuracy of 0.1 gram. The first step measured the volume of the particleboard, which had dimensions of 10 × 10 cm. Volume measurement was done by measuring length, width, and thickness. The density of the particleboard produced was then calculated using Equation (1)

$$\text{Density} = \frac{b}{V} \quad (1)$$

where b was the mass of the particleboard to be determined (grams) and V was the volume of the particleboard (cm³).

2.6. Moisture Content Analysis

Moisture content was determined by weighing particleboard samples before and after drying them in an oven at 103°C, followed by cooling in a desiccator. First, the particleboard produced was cut into 10 × 10 cm pieces, weighed, and then placed in an oven at 103°C. Afterward, the particleboard was placed in a desiccator for up to 6 hours before it was weighed to obtain the mass of the particleboard sample that no longer changes. The percentage of moisture content was then calculated using Equation (2)

$$\text{Moisture content (\%)} = \frac{(w_i - w_d)}{w_d} \times 100 \quad (2)$$

where w_i is the weight of the test sample before oven drying (g) and w_d is the weight of the test sample after oven drying (g).

2.7. Thickness Swelling after Immersion Analysis

Thickness swelling was assessed by measuring particleboard samples before and after immersing them in water for 24 hours. This testing was carried out by cutting the particleboard into 5×5 cm pieces, immersing them in water at 25°C for 24 hours with a distance of 3 cm from the surface of the immersion water. After 24 hours, the thickness of the particleboard after immersion was measured using a calliper. The results obtained were used to calculate the percentage of thickness expansion using Equation (3)

$$\text{Thickness swelling (\%)} = \frac{(t_f - t_i)}{t_i} \times 100 \quad (3)$$

where t_i is the initial thickness before immersion (cm) and t_f is the thickness after immersion (cm).

2.8. Particleboard Color Observation

Color observation was done by photographing the particleboards and analyzing the photos with Adobe Photoshop CS6 to identify the color of the particleboard produced in this study.

2.9. Tensile Strength Analysis

Tensile strength was measured by clamping particleboard samples in a Tensile Testing Machine and pulling until failure. Based on this analysis, a parameter representing the tensile strength of the particleboard was obtained.

2.10. Yield Strength Analysis

Yield strength was tested using a Tensile Testing Machine to determine the stress at which the material began to deform plastically. Yield strength was a measure of the maximum stress a material could withstand before it began to change shape plastically or underwent permanent deformation. This property test was conducted using a Tensile Testing Machine for the best particleboard.

2.11. Modulus of Elasticity Analysis

The modulus of elasticity was calculated from the stress-strain curve obtained during tensile testing. In measuring the modulus of elasticity, a representative sample of the particleboard was prepared according to the dimensions and shape required for the testing method. The modulus of elasticity test was conducted using a Tensile Testing Machine for the best particleboard. The linear elastic region of the stress-strain curve obtained was determined from the tensile test. The modulus of elasticity (MOE) was calculated using Equation (4)

$$MOE = \frac{\sigma}{\varepsilon} \quad (4)$$

where MOE is modulus (MPa), σ is stress in linear region (MPa), and ε is strain (unitless). While the mechanical testing in this study focused on tensile strength, yield strength, and modulus of elasticity (derived from tensile testing), notably the SNI 03-2105-2006 standard specifically requires flexural MOE as key mechanical performance indicators for particleboards. Flexural MOE, typically conducted using a three-point bending method, was not performed in this study because the tensile MOE has provided the general description of material strength. As a result, the mechanical results reported here—although informative—should be interpreted as indicators of the material's uniaxial tensile behavior, not its bending

performance as defined by the SNI standard. Future work recommended to include flexural testing to fully assess compliance.

3. RESULTS AND DISCUSSION

Based on the research conducted, differences in the values of particleboard tests were obtained both physically and mechanically. The test values obtained from each particleboard can be seen in the following discussion.

3.1. Density

Density is one of the physical properties that provides a comparison between the mass of an object to its volume. The density value is calculated by comparing the mass of the particle board with the volume of the particleboard. The initial moisture content of cogon grass and the particleboard itself can affect dimensional stability (volume) and resistance to warping or swelling. Good dimensional stability ensures that particleboards maintain their shape and size over time, resisting warping, swelling, or shrinking because of changes in humidity or temperature. This property is crucial for maintaining structural integrity and fit in various applications. Figure 1 shows the results of particleboards tested for density.

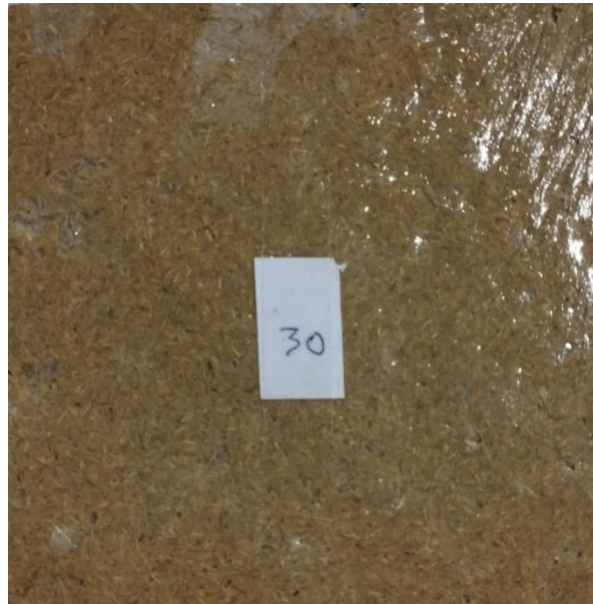


Figure 1. The sample that has been tested for its density

Figure 2 shows that increasing the adhesive/cogon grass ratio generally leads to higher density because more binder fills the voids among particles. Reducing the adhesive/cogon grass ratio leads to lower density as there is less adhesive to fill voids and bond particles together.

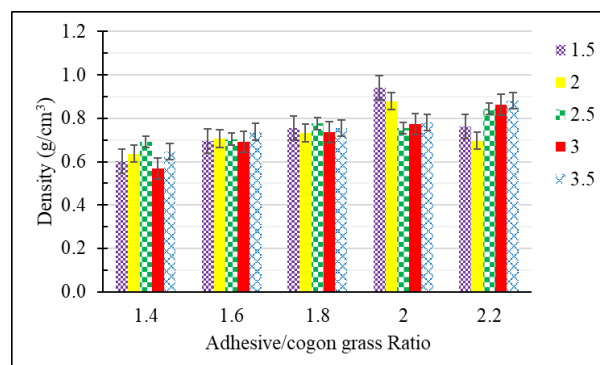


Figure 2. Density of boards at various ratios of adhesive/cogon grass and particles > 60 mesh

Density values ranged from 0.568 to 0.942 g/cm³ depending on particle size, binder ratio, and methanol concentration. The optimum density of 0.881 g/cm³ was achieved with a >60 mesh particle size, a binder-to-particle ratio of 2.2:1, and 3.5% methanol. This value complies with SNI 03-2105-2006 standards, which require a minimum density of 0.40 g/cm³ for general-purpose particleboards. The highest density value obtained is 1.088 g/cm³ with a binder/epoxy ratio of 2.2:1 (w/w) and particle size less than 60 mesh. The lowest density particleboard is with a binder/epoxy ratio of 1.4:1 (w/w), which is 0.648 g/cm³. This is because the interaction between the binder and epoxy particles in the 2.2:1 ratio sample is tighter and has fewer empty spaces between particles compared to the 1.4:1 ratio sample. The 2.2:1 binder/particle ratio is the best in terms of particleboard density.

Figure 3 shows that coarser particles tend to create particleboards with lower density. This is because larger particles result in larger voids and less efficient packing within the particleboard. Void or porosity is gaps or imperfect shapes in the particle arrangement that can cause the particleboard to have low density. Finer particles create particleboards with higher density because they can fill gaps between larger particles, resulting in a denser and more uniform structure. High porosity in particleboards can form because air is trapped during the mixing and pressing process of the boards [26].

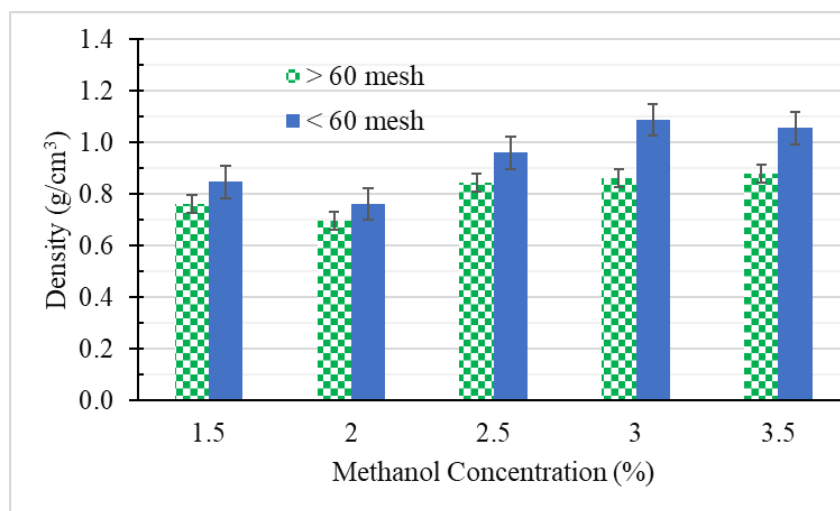


Figure 3. Density of particleboard at adhesive/cogon grass ratio 2.2:1

Figure 3 shows that samples with an adhesive/cogon grass ratio of 2.2:1, particle size less than 60 mesh, and 2.5% methanol have a density exceeding the SNI 03-2105-2005 limit. This density is influenced by the smaller size of the cogon grass particles, allowing them to fill the void spaces well, thereby reducing the size of the voids. Additionally, the higher moisture content in the samples also contributes to the increased density exceeding the standard, making particles larger than 60 mesh the best size in terms of density. A 2.2:1 adhesive ratio is chosen as the optimal condition because it yields the highest density for particles larger than 60 mesh. Controlling these factors is crucial for producing particleboards with consistent desirable physical properties for various applications.

3.2. Moisture Content

Moisture content is the result of the weight difference of the board before and after drying, divided by the weight after drying. Resistance to moisture absorption is important for particleboards used in humid or wet environments. Figure 4 shows the particleboard samples tested for moisture content. Lower adhesive/cogon grass ratio can result in higher moisture content because of less adhesive coverage and more gaps for water absorption. The moisture content of the boards was below 6.6% across all formulations, with the lowest value recorded at 4.92%. These results meet SNI standards, which specify a maximum moisture content of 14%. Moisture content was primarily influenced by methanol concentration, where higher methanol tended to reduce moisture because of improved curing. Based on Figure 4, it shows that the average moisture content test results of particleboards are in the range of 4.92%–5.96%.

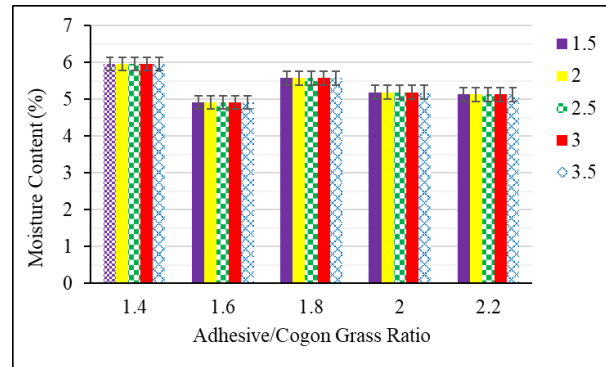


Figure 4. The moisture content of particleboard with particle size larger than 60 mesh

These research results indicate that all particleboard samples obtained meet the SNI 03-2105-2006 standard, which requires particleboard moisture content to be less than 14%. Figure 4 shows that the second lowest moisture content of particleboards is found in the adhesive/cogon grass ratio of 2.2:1 (w/w) with a moisture content value of 5.13%. This ratio is also chosen as the best in terms of particleboard moisture content. A higher adhesive/cogon grass ratio can lead to lower moisture content since more binder helps to seal the particleboard and reduce moisture absorption.

Figure 5 shows the results of testing the moisture content of particleboards with adhesive/cogon grass ratio of 2.2:1. When methanol containing epoxy is used in particleboard production, the presence of methanol can contribute to an increase in the final product's water content. Methanol has hygroscopic properties, meaning it can easily absorb moisture from the surrounding environment. During the manufacturing process, if particleboards come into contact with moisture or humid conditions, the methanol in the epoxy can absorb some of that moisture. This absorption leads to an increase in the water content of particleboards. A methanol concentration of 3.5% can still be chosen as the best in terms of water content. Methanol influences the moisture content of particleboards by affecting the adhesive curing process, reducing hygroscopicity, improving adhesive penetration and distribution.

These mechanisms collectively contribute to a lower moisture content and better moisture resistance in the final particleboard product. Resin curing is usually required for epoxy to harden and form durable bonds. If the curing process is incomplete or inadequate, the epoxy may not be fully polymerized, leaving residual methanol. Unreacted methanol acts as a moisture absorber, contributing to higher moisture content in particleboards with methanol concentrations of 3% or higher. Higher moisture content can lead to several issues, such as reduced adhesive strength, compromised mechanical properties, and potential long-term durability concerns.

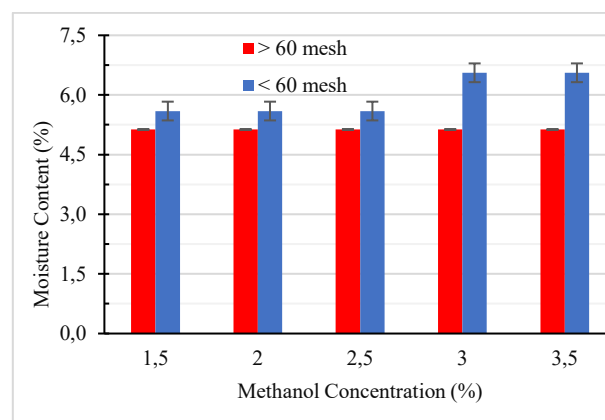


Figure 5. Moisture content of particleboard at an adhesive/cogon grass ratio of 2.2:1

Methanol is used as a thinner in epoxy formulations to adjust viscosity and facilitate processing. However, methanol has a lower molecular weight than epoxy and evaporates more easily during the curing process. The loss of methanol can create voids or empty spaces in the curing epoxy matrix. These voids can act as

entry paths for moisture into the particleboard, resulting in higher moisture content at methanol concentrations of 3%.

3.3. Thickness Swelling

Thickness swelling refers to the increase in thickness dimensions of particleboards after immersion in water for 24 hours. The proportion of adhesive used can affect the bonding quality and durability of the particleboard. Remarkably, all samples exhibited 0% thickness swelling after 24-hour water immersion. This indicates complete dimensional stability, likely because of the hydrophobic nature of the epoxy resin and effective surface curing. These results exceed the dimensional stability expectations of SNI 03-2105-2006, which allows up to 12% swelling.

Particleboards with good water resistance are suitable for applications where they may be subjected to abrasion, scratching, or impact, ensuring longer-term aesthetic and functional performance. Particleboard compression is recommended at a temperature of 140°C and a pressure of 245.17 MPa [27], while in this study, the temperature used is the same but at atmospheric pressure. This causes water not to be absorbed into all filler parts, resulting in no thickness swelling. Even distribution of the binder throughout the filler parts will make it difficult for water to enter, resulting in minimal thickness swelling.

Table 1. Thickness swelling of particleboard from various materials

Particleboard Type	Thickness Swelling, 24 h (%)	References
Afzelia Africana wood residues	0.97	[28]
Sugarcane	4.43	[21]
Bamboo waste	6.00	[29]
Corn stalk	16.70	[30]
Walnut wood residues	20.70	[19]
Rye straw chips	22.20	[31]
Cogon grass (this study)	0.00	

The comparison of particleboards from several materials can be seen in Table 1. Low thickness swelling can be related to the influence of water molecules that reduce the rigidity of the cellulose structure in the raw material [32]. Even distribution of the binder can function to prevent water from entering the boards. Even distribution makes particleboards more compact, making it difficult for water to penetrate them. Understanding this property is essential for ensuring particleboards meet the durability requirements and performance expectation in their intended applications.

3.4. Color Analysis

The color of the boards plays a role in quality control, aesthetics, color matching, defect identification, and research and development efforts related to the manufacturing and application of particleboard. Color analysis is a valuable tool for quality control and assurance in particleboard production. Color analysis was conducted using Adobe Photoshop CS6 to evaluate surface uniformity of the particleboard (Figure 6). The observed color variations were influenced primarily by binder-to-particle ratios and curing of the epoxy resin. This helps ensure that the color is consistent, matches the desired density or gradation, and meets overall aesthetic requirements with a dominance of reddish colors (51–68). Consistent and appealing colors generally enhance marketability aligning with consumer preferences, supporting design trends, and indicating quality. The results showed that color variation was primarily influenced by the binder-to-particle ratio and methanol concentration. Boards with a binder/particle ratio of 2.2:1 and methanol concentrations of 3.0–3.5% exhibited the most uniform and consistent color, likely because of more even adhesive distribution and better curing. In contrast, lower binder ratios or excessive methanol led to uneven in coverage and visible discoloration or patchiness, indicating possible manufacturing defects, such as uneven resin distribution or inadequate curing. These findings suggest that optimal binder levels and controlled methanol content are essential to achieve desirable visual appearance and minimize surface irregularities. This analysis helps in applications like furniture and interior design, where color match with other is vital.

Moreover, color analysis helps identify early actions to improve quality by adding colorants to approximate the average value. It also aids in research and development by understanding how factors like material composition and manufacturing processes affect color properties, and optimizing production techniques. With color analysis, it can be assessed that particleboards with particle sizes > 60 mesh, a binder/particle ratio of 2.2:1, and a methanol concentration of 3.5% are within an acceptable range. Particleboards with particle sizes < 60 mesh, a binder/particle ratio of 2.2:1, and a methanol concentration of 3% meet the desired color standard as they are closest to the average value. In many applications, the color of particleboard needs to be matched with other components or existing materials.



Figure 6. Sample color of particleboard using Adobe Photoshop CS6 software

Through color analysis, it can be determined whether the color of the particleboard is consistent with the desired target or if adjustments are needed to achieve the desired match. This is particularly important in industries such as furniture manufacturing or construction, where color harmony and variation are crucial, even with relatively low concentration (9–28). Color variations play a role in the marketability and user acceptance of particleboards. Color variations can also attract niche markets and environmentally conscious consumers. Balancing aesthetic appeal with functional and economic considerations is key to maximizing the market potential of particleboards. These implications and implementing effective strategies, manufacturers can produce high-quality, visually appealing particleboards that meet market demands and customer expectations.

Color analysis of particleboard is also beneficial for research and development purposes. It allows the impact of various factors, such as raw material composition, type of resin, manufacturing process, and surface treatment, on the color properties of the particleboard to be understood. This information is used to optimize production techniques, develop products, or enhance the performance and appearance of the boards, so that low color gradation (43–91) can be maintained.

3.5. Tensile Strength

Tensile strength is a mechanical property that measures the maximum stress a material can withstand before breaking or failing under tension. Alternative lignocellulosic materials (cogon grass) can cause variations in mechanical properties and consistency of the particleboard. Figure 7 shows the tensile strength of boards with an adhesive/cogon grass ratio of 2.2:1 and particles > 60 mesh. At lower concentrations, methanol acts as a plasticizer, improving the flexibility and workability of the epoxy resin. This can enhance the bonding between particles, leading to increased tensile strength. This paper does not discuss the morphological structure of particleboard as this issue will be addressed in another paper.

While SNI 03-2105-2006 requires flexural MOE, this study conducted tensile testing because it has provided the general description of material strength, even though it is not specifically in flexural aspect.

The highest tensile strength recorded was 11.96 MPa. The SNI standard requires a minimum tensile strength of 0.3 MPa. The lowest tensile strength, 2.94 MPa, is found in the sample with a methanol concentration of 2%. Higher tensile strength contributes to the durability of particleboards in applications where they need to support weight or withstand pressure without deformation or failure. Based on Figure 7, it shows that the particleboard can withstand forces that try to pull it apart or elongate it.

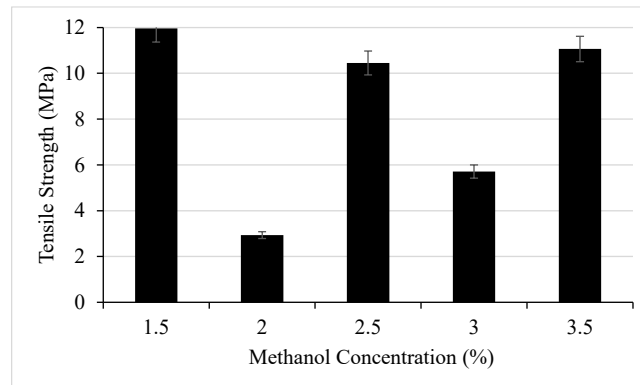


Figure 7. Results of tensile strength of particleboard with varying adhesive ratios

Methanol influences the tensile strength of particleboards by enhancing adhesive curing, improving penetration and distribution, and modifying particle surface properties. These mechanisms collectively contribute to a stronger and more resilient particleboard with improved tensile strength. However, the effect of methanol in the adhesive can vary depending on the manufacturing process used. Factors such as temperature, pressure, and pressing duration can influence curing and adhesive bonding. Controlling these variables is crucial to achieve the desired tensile strength. In this study, the pressure used during pressing was not stable, resulting in varied tensile strength in relation to the amount of methanol used.

At higher concentrations, the excess methanol can weaken the adhesive matrix by increasing the evaporation rate during curing, leading to porous structures and weaker bonds. This results in reduced tensile strength. However, the 2% methanol concentration still produced relatively good tensile strength. Lower tensile strength means the particleboard may fail under lower stress conditions, affecting the performance of the material in load-bearing applications.

The variability and reproducibility of tensile strength in particleboard are influenced by a combination of factors related to raw materials, manufacturing processes, and testing. To minimize variability and improve reproducibility, it is better to focus on standardized production practices, rigorous quality control, adherence to testing standards, and optimization. These efforts ensure that particleboard products meet desired mechanical performance criteria consistently.

3.6. Yield Strength

Yield strength refers to the stress level at which a material begins to exhibit plastic or permanent deformation without breaking. Figure 8 shows the yield strength at a adhesive/cogon grass ratio of 2.2:1 and particles > 60 mesh. Methanol acts as a plasticizer, reducing the rigidity of the particleboard and making it more flexible. This effect is beneficial at low to moderate concentrations but becomes detrimental at higher concentrations where the adhesive may not cure properly, resulting in weaker bonds.

The SNI 03-2105-2006 standard does not specify the yield strength for particleboard but does require a minimum flexural strength of 8.04 MPa. Flexural strength is the ability of a material to absorb energy or resist breaking when subjected to bending stress. The maximum yield strength was 125.82 MPa at 2% methanol concentration. Therefore, the 2% methanol concentration is considered the best condition. Methanol's high volatility means that it evaporates during the curing process. At higher concentrations, this can lead to the formation of pores and voids within the adhesive matrix, weakening the overall structure and reducing yield strength.

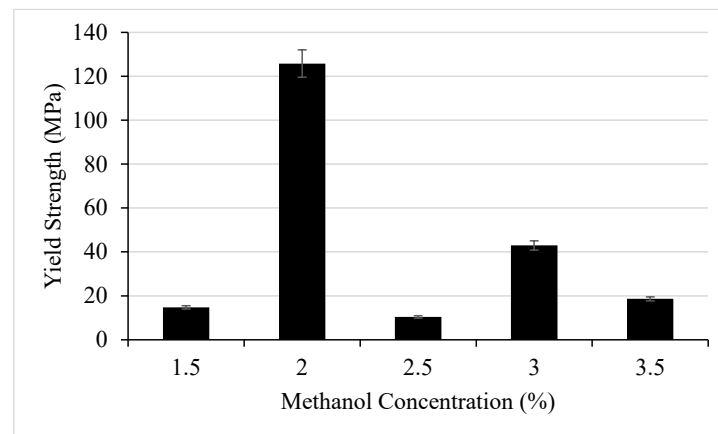


Figure 8. Yield strength of particleboard with varying adhesive percentages

According to Figure 8, the lowest yield strength, at 10.40 MPa, is found in the sample with a methanol concentration of 2.5%. Appropriate methanol levels can improve the penetration of the adhesive into the particles, enhancing the interfacial bonding and mechanical properties of the particleboard. However, excessive methanol can cause premature evaporation, leading to poor adhesion and yield strength performance. The yield strength of particleboard can vary significantly depending on the type of particleboard, moisture content, grain direction, and specific material. However, particleboard typically does not exhibit a clear yield point like metals do. Instead, particleboard tends to fail through gradual deformation or fracture under stress. Nevertheless, for engineering and design purposes, the yield strength of particleboard parallel to the grain is approximately 40–80 MPa (5800–11,600 psi). This value is quite general and can vary based on the specific material, quality, and condition of the particleboard. The yield strength in this study is higher compared to the maximum yield strength of carbon composite material samples, namely 347.43 MPa. This is likely because of differences in knot, grain imperfections, and moisture content, which can all significantly affect yield strength.

Methanol aids in the evaporation and drying of the adhesive during the manufacturing process. The optimal methanol concentration is a balance that provides enough plasticizing effect to enhance flexibility and adhesive penetration without causing excessive volatilization and porosity. Typically, a concentration range of around 1.5% to 3.5% (w/w) is used, but the exact optimal concentration depends on the specific formulation and processing conditions. Factors such as pressing parameters can also interact with methanol concentration and affect the final properties of the particleboard. Optimizing pressing parameters requires consideration of other quality characteristics, such as dimensional stability. When exposed to high humidity or moisture, particleboard tends to absorb water and swell. This swelling can cause dimensional changes and potentially affect the yield strength of the board. Consequently, the yield strength can vary with the amount of methanol used.

3.7. Modulus of Elasticity

The modulus of elasticity (MOE), also known as Young's modulus, is a material property that describes its stiffness or elasticity [32]. Figure 9 shows the MOE test results of particleboard with a glue/reed ratio of 2.2:1 and particles > 60 mesh. Moderate methanol concentrations can help maintain the elasticity of the epoxy resin, allowing it to distribute stress more evenly throughout the particleboard. This can result in a higher modulus of elasticity. The highest MOE was 190.09 MPa, below the required flexural MOE threshold of 3000.83 MPa. These results demonstrate promising strength under tension, but flexural performance should be evaluated in future studies for full compliance.

The MOE values reported in this study was calculated from the linear portion of the stress-strain curve obtained during tensile testing, using a universal tensile testing machine. This reflects the material's stiffness under uniaxial tension. However, it is important to clarify that the SNI 03-2105-2006 standard (3000.83 MPa) specifically requires MOE to be measured using a flexural (bending) test, such as a three-

point bending method, to assess stiffness under bending loads. As such, while the tensile MOE reported here provides useful insight into material behavior, it does not substitute for the flexural MOE required for full compliance with SNI standards. Future research should include flexural testing to fully assess bending performance.

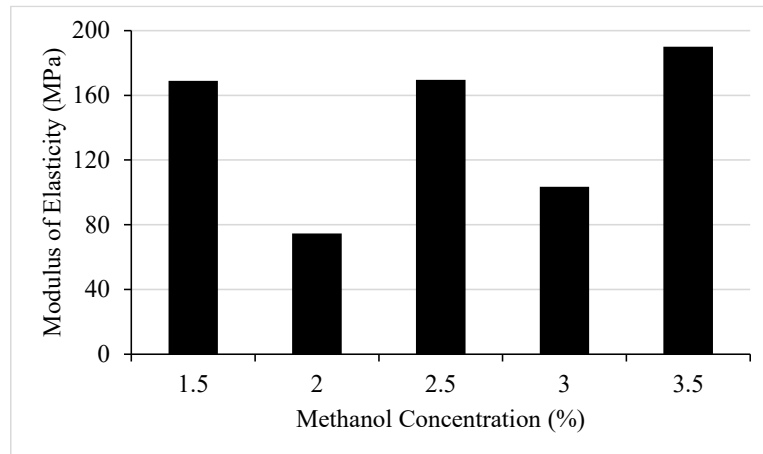


Figure 9. MOE test results of particleboard with varying adhesive percentages

Based on Figure 9, it shows that the boards produced are less stiff with low structural integrity, making it unlikely to withstand loads and minimize deflection. The 2% methanol concentration is chosen as the best condition in terms of MOE. Methanol concentration in the adhesive can affect its performance and properties, including the adhesive strength and stiffness of the particleboard produced. However, the specific effect of methanol concentration on the modulus of elasticity of particleboard can vary depending on the uniformity of adhesive application. If the adhesive is applied unevenly, it can result in areas with inadequate adhesive coverage or gaps between particles. This can lead to weaker bonds, affecting the MOE of the board.

3.8. Comparative Evaluation with Similar Biomaterials

To better contextualize the performance of cogon grass-based particleboards, key mechanical and physical properties were compared with findings from previous studies involving other lignocellulosic biomaterials. The highest tensile strength obtained in this study was 11.96 MPa, exceeding that of particleboards made from sugarcane (approximately 4.4 MPa) [21] and corn stalks (~3.44–5.90 MPa) [30]. The density ranged from 0.568 to 0.942 g/cm³, comparable to particleboards produced from bamboo waste (0.60–0.75 g/cm³) [29] and rice husk (0.50–0.80 g/cm³) [33]. Meanwhile, the highest modulus of elasticity (MOE) achieved was 190.09 MPa, which falls within the typical range for bagasse-based boards (98.07–245.17 MPa) [21], although still below the minimum flexural MOE of 3000.83 MPa required by the SNI 03-2105-2006 standard. These comparisons demonstrate that particleboards produced from cogon grass using epoxy resin and methanol possess competitive mechanical properties relative to established agricultural residues, indicating their potential as a viable and sustainable material for interior applications and value-added panel products.

4. CONCLUSION

The results indicate that cogon grass-based particleboards meet or exceed SNI standards for density, moisture content, and thickness swelling. Although tensile properties were strong, flexural properties remain untested and must be addressed to confirm structural compliance. The optimal formulation—>60 mesh particle size, 2.2:1 binder ratio, and 3.5% methanol—offered the best combination of performance and stability. The density of 0.881 g/cm³ and a moisture content of 6.56%, both meet SNI 03-2105-2006 standards. The highest tensile and yield strength were 11.96 MPa and 125.82 MPa, respectively. While the modulus of elasticity reached 190.09 MPa, it fell of the SNI-required flexural MOE (3008.83 MPa), which was not directly tested. The boards are suitable for indoor applications like wall paneling. However, the

lack of flexural MOE limits the ability to fully conform compliance with SNI 03-2105-2006. Future research should include bending tests, durability studies, binder alternatives, and processing optimization to enhance performance and commercial viability. Manufacturing particleboard from cogon grass offers significant environmental benefits. This opens up avenues for sustainable development, and environmental stewardship through the utilization of cogon grass. One important limitation of this study is the omission of flexural MOE testing, which are explicitly required by the SNI 03-2105-2006 standard for particleboard evaluation. The study instead relied on tensile testing to assess mechanical properties, which provides insight into strength and stiffness under tension but not bending. Consequently, while the results indicate promising material performance, the mechanical compliance with SNI cannot be fully confirmed without flexural data. Future research should incorporate standardized bending tests to ensure a comprehensive evaluation of the particleboard's structural behavior.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

- [1] Lubis, M., Wijaya, S., Ginting, M.H.S., and Harahap, M.B., "Effect of cogon grass powder (*Imperata cylindrica* L. Beauv) composition and particle size on physical and mechanical properties of unsaturated polyester resin particle board products", AIP Conference Proceedings, 2267: 020055, (2020). DOI: <https://doi.org/10.1063/5.0016031>
- [2] Internet: Statistics of Forestry Production 2021, In BPS-Statistics Indonesia, <https://www.bps.go.id/id/publication/2022/07/29/e6e4600abae56ef5d4507463/statistik-produksi-kehutanan-2021.html>, (2022).
- [3] Yani, A., Indrasari, N., Wicaksono, B.R., Rudiana, E., Hakim, E.H.N., Jannah, M., Zet, L., Purwanti, F.I., Putri, F.A., Novantia, Rizqi, A., Calista, P., and Palupi, H., Statistics of Forestry Production 2022, BPS-Statistics Indonesia, Jakarta, (2023).
- [4] Jumaidin, R., Khiruddin, M.A.K., Saidi, Z.A.S., Salit, M.S., and Ilyas, R.A., "Effect of cogon grass on the thermal, mechanical, and biodegradation properties of thermoplastic cassava starch biocomposite", International Journal of Biological Macromolecules, 146: 746-755, (2020). DOI: <https://doi.org/10.1016/j.ijbiomac.2019.11.011>
- [5] Ramsey, C.L., Jose, S., Miller, D.L., Cox, J., Portier, K.M., Shilling, D.G., and Merritt, S., "Cogongrass [*Imperata cylindrica* (L.) Beauv.] response to herbicides and disking on a cutover site and in a mid-rotation pine plantation in southern USA", Forest Ecology and Management, 179(1-3): 195–207, (2003). DOI: [https://doi.org/10.1016/S0378-1127\(02\)00515-7](https://doi.org/10.1016/S0378-1127(02)00515-7)
- [6] Jung, Y.K., Shin, D., "Imperata cylindrica: A review of phytochemistry, pharmacology, and industrial applications", Molecules, 26: 1454, (2021). DOI: <https://doi.org/10.3390/molecules26051454>
- [7] Kow, K.W., Yusoff, R., Aziz, A.R.A., and Abdullah, E.C., "Characterisation of bio-silica synthesized from cogon grass (*Imperata cylindrica*)", Powder Technology, 254: 206-213, (2014). DOI: <https://doi.org/10.1016/j.powtec.2014.01.018>

- [8] Mensah, P., Govina, J., Asante, J.O.O., Seidu, H., Junior, F.R., Paula, E.A.D.O., Pedrosa, T.D., and Melo, R.R.D., “Durability and resistance of eco-friendly particleboards produced from agroforestry residues”, *Revista Materia*, 28(2), (2023). DOI: <https://doi.org/10.1590/1517-7076-rmat-2023-0027>
- [9] Farooq, A., Patoary, M.K., Zhang, M., Mussana, H., Li, M., Naeem, M.A., Mushtaq, M., Farooq, A., and Liu, L., “Cellulose from sources to nanocellulose and an overview of synthesis and properties of nanocellulose/zinc oxide nanocomposite materials”, *International Journal of Biological Macromolecules*, 154: 1050-1073, (2020). DOI: <https://doi.org/10.1016/j.ijbiomac.2020.03.163>
- [10] Kassim, A.S.M., Aripin, A.M., Ishak, N., Hairom, N.H.H., Fauzi, N.A., Razali, N.F., and Zainulabidin, M.H., “Potential of cogon grass (*Imperata cylindrica*) as an alternative fibre in paper-based industry”, *ARPN Journal of Engineering and Applied Sciences*, 11(4): 2681-2686, (2016).
- [11] Yusof, Y.M., Othman, S.A., “A review on the use of natural fibres of cogon grass mixed with concrete for radiation shielding materials”, *Journal of Nuclear and Related Technologies*, 18(2): 23-31, (2021).
- [12] MacDonald, G.E., “Cogongrass (*Imperata cylindrica*)—Biology, Ecology, and Management”, *Critical Reviews in Plant Sciences*, 23(5): 367-380, (2010). DOI: <https://doi.org/10.1080/07352680490505114>
- [13] Xuan, T.D., Toyama, T., Fukuta, M., Khanh, T.D., and Tawata, S., “Chemical interaction in the invasiveness of cogongrass (*Imperata cylindrica* (L.) Beauv.)”, *Journal of Agricultural and Food Chemistry*, 57(20): 9448-9453, (2009). DOI: <https://doi.org/10.1021/jf902310j>
- [14] Minogue, P.J., Brodbeck, B.V., and Miller, J.H., “Biology and control of cogongrass (*Imperata cylindrica*) in Southern Forests”, *EDIS*, 2018(2): 1-6, (2018). DOI: <https://doi.org/10.32473/edis-fr411-2018>
- [15] Kassim, A.S.M., Aripin, A.M., Ishak, N., and Zainulabidin, M.H., “Cogon grass as an alternative fibre for pulp and paper-based industry: On chemical and surface morphological properties”, *Applied Mechanics and Materials*, 773-774(2015): 1242-1245, (2015). DOI: <https://doi.org/10.4028/www.scientific.net/AMM.773-774.1242>
- [16] Syamani, F.A., Kusumah, S.S., Astri, L., Prasetio, K.W., Wibowo, E.S., and Subyakto, S., “Effect of pre-drying time and citric acid content on *imperata cylindrica* particleboards properties”, *IOP Conference Series: Earth and Environmental Science*, 209: 1-11, (2018). DOI: <https://doi.org/10.1088/1755-1315/209/1/012034>
- [17] Ruksakulpiwat, C., Wanasut, W., Singkum, A., and Ruksakulpiwat, Y., “Cogon grass fiber-epoxidized natural rubber composites”, *Advance Materials Research*, 747: 375378, (2013). DOI: <https://doi.org/10.4028/www.scientific.net/AMR.747.375>
- [18] Kongkaew, P., Praneekrit, P., Rudchapo, T., and Khampui, K., “Mechanical and physical properties of water hyacinth and cogon grass fiber reinforced epoxy resin composites”, *Journal of Physics: Conference Series*, 2145: 012036, (2021). DOI: <https://doi.org/10.1088/1742-6596/2145/1/012036>
- [19] Pedzik, M., Auriga, R., Kristak, L., Antov, P., and Rogozinski, T., “Physical and mechanical properties of particleboard produced with addition of walnut (*Juglans regia* L.) wood residues”, *Materials*, 15: 1280, (2022). DOI: <https://doi.org/10.3390/ma15041280>
- [20] Faria, D.F., Guimaraes, J.C.O., Protasio, T.D.P., Mendes, L.M., and Junior, J.B.G., “Conventional low-density particleboards produced with particles from *Mauritia flexuosa* and *Eucalyptus Spp.* Wood”, *Clean Technologies and Environmental Policy*, 24(9): 1-11, (2008). DOI: <https://doi.org/10.21203/rs.3.rs-980174/v1>

- [21] Lee, S.H., Lum, W.C., Boon, J.G., Kristak, L., Antov, P., Pedzik, M., Rogozinski, T., Taghiyari, H.R., Lubis, M.A.R., Fatriasari, W., Yadav, S.M., Chotikum, A., and Pizzi, A., "Particleboard from agricultural biomass and recycled wood waste: a review", *Journal of Materials Research and Technology*, 20: 4630-4658, (2022). DOI: <https://doi.org/10.1016/j.jmrt.2022.08.166>
- [22] Som, S.N.M., Baharuddin, M.N.M., Zain, N.M., and Shaari, M.R., "The making of particleboard from palm oil fiber and dust wood with epoxy as a resin", *International Journal of Recent Technology and Engineering*, 8(4): 11016-11019, (2019). DOI: <https://doi.org/10.35940/ijrte.D5420.118419>
- [23] Verma, C., Olansunkanmi, L.O., Akpan, E.D., Quraishi, M.A., Dagdag, O., Gouri, M.E., Sherif, E.D., and Ebenso, E.E., "Epoxy resins as anticorrosive polymeric materials: A review", *Reactive and Functional Polymers*, 156: 10741, (2020). <https://doi.org/10.1016/j.reactfunctpolym.2020.104741>
- [24] Paluvai, N.R., Mohanty, S., and Nayak, S.K., "Synthesis and modifications of epoxy composites: A Review", *Polymer-Plastics Technology and Engineering*, 53(16): 1723-1758, (2014). <https://doi.org/10.1080/03602559.2014.919658>
- [25] Gibson, G., "Epoxy resins", *Brydson's Plastics Materials*, 773-797, (2017).
- [26] Lubis, M.R., Maimun, T., Kardi, J., and Masra, R.B., "Characterizing particleboard made of oil palm empty fruit bunch using central composite design", *Makara Journal of Science*, 22(1): 17-28, (2018). DOI: <https://doi.org/10.7454/mss.v22i1.6988>
- [27] Boruszewski, P., Borysiuk, P., Maminski, M., and Czechowska, J., "Mat compression measurements during low-density particleboard manufacturing", *Bioresources*, 11(3): 6909-6919, (2016). DOI: <https://doi.org/10.15376/biores.11.3.6909-6919>
- [28] Sotannde, O., "Evaluation of cement-bonded particle board produced from afzelia Africana wood residues", *Journal of Engineering Science and Technology*, 7(6): 732-743, (2012).
- [29] Laemlaksakul, V., "Physical and mechanical properties of particleboard from bamboo waste", *International Journal of Materials and Metallurgical Engineering*, 4(4): 276-280, (2010). DOI: <https://doi.org/10.5281/zenodo.1074531>
- [30] Astari, L., Sudarmanto, and Akbar, F., "Characteristics of particleboards made from agricultural wastes", *IOP Conference Series: Earth and Environmental Science*, 359: 012014, (2019). DOI: <https://doi.org/10.1088/1755-1315/359/1/012014>
- [31] Mirski, R., Dziurka, D., and Banaszak, A., "Properties of particleboards produced from various lignocellulosic particles", *Bioresources*, 13(4): 7758-7765, (2018). DOI: <https://doi.org/10.15376/biores.13.4.7758-7765>
- [32] Lubis, M.R., Razi, F., Salsabilla, T., Kausar, K., and Husein, F.R., "Adhesive-particle ratio and avocado seed filler on the characteristics of particleboard made from oil palm oil empty fruit bunches", *Alchemy Jurnal Penelitian Kimia*, 20(1): 7081, (2024). DOI: <https://doi.org/10.20961/alchemy.20.1.76881.70-81>
- [33] Hamdan, M.H.M., Siregar, J.P., Cionita, T., Jaafar, J., Efriyohadi, A., Junid, R., and Kholil, A., "Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites", *The International Journal of Advanced Manufacturing Technology*, 104: 1075-1086, (2019). DOI: <https://doi.org/10.1007/s00170-019-03976-9>