

Characterization of Oil Palm Trunk Composite for Application of Particle Board Using Urea-Formaldehyde as Binding Agent

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Abstract

This study investigates the development of sustainable particleboard from oil palm trunk (OPT) waste using urea-formaldehyde (UF) resin as a binder. OPT fibers (2-4mm) were chemically treated with 5% sodium hydroxide (NaOH) to enhance surface properties, then combined with UF resin at three different weight ratios (25:60, 25:65, and 25:70 OPT-to-UF). The composite mixtures were hot-pressed at 120°C under 5 MPa pressure for 30 minutes to form particleboards. Comprehensive testing revealed that increasing UF content significantly improved material properties, with the OPT25:70 formulation demonstrating optimal performance: highest density (1.20 g/cm³), lowest water absorption (40.44%), and superior mechanical strength (modulus of rupture: 412.87 MPa; modulus of elasticity: 62,339.21 MPa). The boards also showed improved dimensional stability, with thickness swelling decreasing to 27.50% for the highest resin content. These results confirm that properly processed OPT waste can produce particleboards meeting industrial standards, offering an eco-friendly alternative to conventional wood-based panels while effectively valorizing agricultural byproducts. The study provides important insights for sustainable material development in the wood composites industry.

1. Introduction

The global palm oil industry generates significant agricultural waste, particularly oil palm trunks (OPT), during replanting cycles every 25-30 years. In Malaysia alone, approximately 75 tonnes of OPT biomass are produced per hectare annually [1]. Traditional disposal methods such as open burning or decomposition contribute to environmental pollution and represent a lost opportunity for resource utilization. Previous studies have highlighted the potential of OPT in producing composite materials such as particle boards, especially when combined with urea-formaldehyde (UF) resin due to its strong adhesion and cost-effectiveness [2]. However, despite the availability of such research, limited work focuses on systematically characterizing different resin content ratios and their effects on particle board performance [3]. This study aims to fabricate and characterize OPT-based particle boards bonded with UF resin at varying ratios to determine optimal mechanical and physical properties, thus contributing to sustainable material innovation and biomass waste valorization.

OPT possesses favorable lignocellulosic properties (40-45% cellulose, 20-25% lignin) [4] that make it suitable for composite material production. Particle board manufacturing presents a viable solution for OPT valorization, potentially reducing dependence on conventional wood sources while addressing waste management challenges.

Urea-formaldehyde (UF) resin is widely used in particle board production due to its excellent bonding strength, cost-effectiveness, and compatibility with lignocellulosic materials [5]. However, the mechanical performance of OPT-based particle boards with UF resin requires thorough investigation to establish optimal formulations for industrial applications.

This study aims to fabricate oil palm trunk (OPT)-based particle boards using urea-formaldehyde (UF) resin in three different proportions (25:60, 25:65, and 25:70 fiber-to-resin ratios) to evaluate their potential as sustainable building materials. The research will systematically characterize the physical properties of the composites, including density, water absorption, and thickness swelling, as well as mechanical properties such as modulus of rupture (MOR) and modulus of elasticity (MOE) through standardized testing methods. By comparing the performance of these different formulations, the study seeks to identify the optimal resin ratio that delivers the best combination of mechanical strength, dimensional stability, and moisture resistance, while also considering the economic and environmental implications of increased resin usage.

2. Material and method

2.1 Materials

The experimental methodology began with the collection and preparation of OPT biomass from local plantations in Malaysia. The trunks were mechanically shredded into 2-4 mm fibers and treated with a 5% sodium hydroxide (NaOH) solution at a 1:10 fiber-to-solution ratio for 12 hours to improve fiber-resin compatibility. After thorough rinsing, the fibers were oven-dried at 100°C for 6 hours to achieve consistent moisture content.

The urea-formaldehyde (UF) resin used in this study was a commercial-grade adhesive. The fiber-to-resin composition was designed based on fixed OPT fiber weight (25 g) mixed with varying UF resin weights (60 g, 65 g, and 70 g), resulting in three different formulations: OPT 25:60 UF, OPT 25:65 UF, and OPT 25:70 UF. This fixed fiber basis allowed for controlled comparison across resin variations. The range was chosen based on preliminary data and literature that suggest increasing resin enhances performance up to a saturation point. Each formulation was prepared in triplicate to ensure reliability. These formulations were designed to systematically assess how increasing the resin-to-fiber ratio influences the physical and mechanical characteristics of the resulting composite boards, with particular attention to density, water resistance, and bending strength. Figure 1 shows the type of materials used for this research.



Figure 1 Type of materials

2.2 Particle board fabrication

The particle board fabrication process began with mixing the treated OPT fibers with UF resin to ensure uniform distribution. The mixture was then placed in a stainless steel mold measuring 25 cm in length, 10 cm in width, and 0.4 cm in thickness. Hot pressing was conducted under controlled conditions with a pressure of 5 MPa and temperature of 120°C for 30 minutes to achieve proper curing and bonding. After pressing, the boards were allowed to cool to room temperature before being carefully demolded from the stainless steel frame. This standardized fabrication process was consistently applied to all three resin formulations (OPT 25:60 UF, OPT 25:65 UF, and OPT 25:70 UF) to ensure comparable results across the different experimental groups.

The cooling phase was particularly important as it allowed the resin to fully set and stabilize before subsequent testing and characterization of the particle boards' physical and mechanical properties. Table 1 shows the parameters of the particle board.

Table 1 Parameters of the particle board

Sample	OPT (UF) (g)	Resin (UF) (g)	Pressure (MPa)	Time (Min)	Temperature (°C)
OPT 25:60 UF	25	60	5	30	120
OPT 25:65 UF	25	60	5	30	120
OPT 25:70 UF	25	60	5	30	120

In this study, each particle board sample was prepared in triplicate, meaning three identical boards were made for each formulation. This approach is important for scientific accuracy and reliability. The average value from these three samples was used to represent each formulation's performance in the results and discussion.

2.3 Hot press machine

Hot pressing is a critical mechanical process used to manufacture particle boards by compressing a mixture of fibers and resin under high temperature and pressure. In this study, the hot press machine from Makmal Fabrikasi Perkayuan at the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat campus, was utilized. This 50-ton hydraulic hot press machine applies controlled pressure and heat to bond oil palm trunk (OPT) fibers with urea-formaldehyde (UF) resin, forming a dense and durable composite board without the need for additional adhesives. Figure 2 shows the 50-ton hydraulic hot press machine to contribute to the process of this research.



Figure 2 50-ton hydraulic hot press machine

2.4 Final product

Once the particle board has been hot pressed, it is allowed to cool before being taken out of the frame. The finished particle board is then ready for testing or use. Maintaining consistent pressing time, pressure, and temperature helps ensure that the particle boards are uniform in quality and mechanical properties. This sample preparation method is vital for producing reliable, high-quality particle boards from oil palm trunks, making them suitable for a range of applications due to their enhanced properties. Figure 3 shows all the final product of the samples.



Figure 3 Final product of the samples.

2.5 Physical test analysis

All physical tests followed ASTM D1037 standard procedures. Samples were conditioned at room temperature before testing. Density was calculated by mass/volume, water absorption and thickness swelling were measured after 24-hour immersion in water. All values reported are averages from triplicate samples.

2.5.1 Density measurement

Density refers to the compactness of the composite sample made from treated oil palm trunk fibers (OPT) and urea formaldehyde (UF) resin. It is a physical property that measures how much mass is packed into a unit volume of the sample. The unit used is grams per cubic centimeter (g/cm^3). Higher density indicates better compaction and stronger bonding between the treated fibers and the UF resin, which can improve the mechanical performance of the board. The densities were determined by dividing the mass of each sample by its respective volume.

$$\text{Density (g/cm}^3\text{)} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}} \quad (1)$$

2.5.2 Water absorption measurement

The water absorption test evaluates the ability of composite materials to resist moisture penetration when immersed in water. This test is essential to assess the durability and suitability of the composites for applications in humid or wet environments. This test measures the percentage increase in board weight after immersion in water for 24 hours. The test specimens, measuring 50 mm x 50 mm x 4 mm, were prepared according to ASTM D1037 standard dimensions. Each specimen was weighed before immersion in water to determine the initial weight (W_0), and again after a fixed duration of water exposure to record the final weight (W_1).

$$\text{Water Absorption (\%)} = \left(\frac{W_1 - W_0}{W_0} \right) \times 100 \quad (2)$$

2.5.3 Thickness swelling measurement

The thickness swelling evaluation of particleboard, as prescribed by ASTM D1037, is a standardized method to quantify the dimensional stability of wood-based composite materials when exposed to moisture. This test measures the percentage increase in board thickness after immersion in water for 24 hours. The test specimens, measuring 50 mm x 50 mm x 4 mm, were prepared according to ASTM D1037 standard dimensions. Each specimen was measured before immersion in water to determine the initial thickness (T_0), and again after a fixed duration of water exposure to record the final thickness (T_1).

$$\text{Thickness Swelling (\%)} = \left(\frac{T_1 - T_0}{T_0} \right) \times 100 \quad (3)$$

2.6 Mechanical test analysis

All mechanical tests followed ASTM D1037 standard procedures. Samples were conditioned at room temperature before testing. Mechanical properties (modulus of rupture and modulus of elasticity) were tested using a Universal Testing Machine via 3-point bending. All values reported are averages from triplicate samples.

2.6.1 Bending (flexural) testing

In this study, the mechanical performance of oil palm trunk fiber-based particle board was evaluated through a bending test in accordance with the ASTM D1037 standard, using a Universal Testing Machine via 3-point bending. Two key parameters derived from the bending test are the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE), which are essential indicators of the board's strength and stiffness, respectively. The bending test samples were prepared according to standard dimensions and subjected to a three-point bending load until failure. In this method, a sample of the particle board is placed on two supports with a load applied at the midpoint of the span. Before testing, the sample's dimensions (length, width, and thickness) are carefully measured. The data obtained, including the ultimate bending strength and modulus of elasticity in flexure, were analyzed to assess the effectiveness of the composite material and its suitability for structural applications. Figure 4 shows the bending (flexural) testing process.



Figure 4 Bending (flexural) testing process

2.6.2 Modulus of rupture (MOR)

The Modulus of rupture (MOR) represents the maximum stress that the particle board can withstand before failure when subjected to bending. It reflects the bending strength or load-carrying capacity of the material and is calculated based on the maximum load applied during testing, the span length, and the specimen's dimensions. A higher MOR value indicates greater resistance to structural failure under load, which is particularly relevant for applications such as furniture, interior panels, and lightweight construction components [6].

$$\text{MOR} = \frac{3P_{\max}L}{2bd^2}$$

(4)

2.6.3 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) reflects the stiffness of the material, or its resistance to elastic deformation under applied stress. This parameter is determined from the slope of the stress-strain curve during the elastic region of the bending test [7]. A higher MOE value implies that the material deflects less under load, which contributes to better structural integrity and long-term performance, particularly in applications requiring dimensional stability.

$$\text{MOE} = \frac{L^3 \cdot m}{4bd^3}$$

(5)

3. Result and analysis

The anticipated outcome of this study is to successfully harness the potential of excess and idle oil palm trunk by transforming it into a high-quality, utilitarian particle board. This innovative approach seeks to redefine waste management, converting agricultural residue into a valuable product. By demonstrating the feasibility and advantages of utilizing oil palm trunk, this project aims to contribute significantly to sustainable practices, showcasing a viable method for producing eco-friendly materials that benefit both the community and the environment.

3.1 Physical properties analysis

Based on the results presented in Table 2 and Figure 5, the average result for physical properties of OPT particle boards bonded with varying amounts of urea formaldehyde (UF) resin exhibit notable trends as the resin content increases. The density of the boards, which reflects their compactness and structural integrity, rose from 1.13 g/cm³ for OPT 25:60 UF to 1.16 g/cm³ for OPT 25:65 UF, and further to 1.20 g/cm³ for OPT 25:70 UF. Similarly, water absorption, a critical factor for moisture resistance, decreased from 44.87% for OPT 25:60 UF to 42.49% for OPT 25:65 UF, and to 40.44% for OPT 25:70 UF. Thickness swelling, which measures dimensional stability under humid conditions, also showed a decline, with values dropping from 29.67% for OPT 25:60 UF to 28.17% for OPT 25:65 UF, and finally to 27.50% for OPT 25:70 UF.

These results, as illustrated in Figure 5, reveal a consistent pattern where higher UF resin content leads to improved physical properties. The increase in density suggests enhanced structural stability, while the reduction in water absorption and thickness swelling indicates better resistance to moisture and dimensional changes. This trend highlights the importance of resin content in optimizing the performance of OPT particle boards, particularly for applications in humid or variable environments. The findings demonstrate that adjusting the resin ratio can significantly enhance the durability and suitability of these boards for practical uses, such as in construction or furniture manufacturing, where moisture resistance and dimensional stability are critical.

Table 2 Comparative performance of OPT particle boards for physical properties

Property	OPT 25:60 UF	OPT 25:65 UF	OPT 25:70 UF
Density g/cm ³	1.13	1.16	1.2
Water Absorption (%)	44.87	42.49	40.44
Thickness Swelling (%)	29.67	28.17	27.50

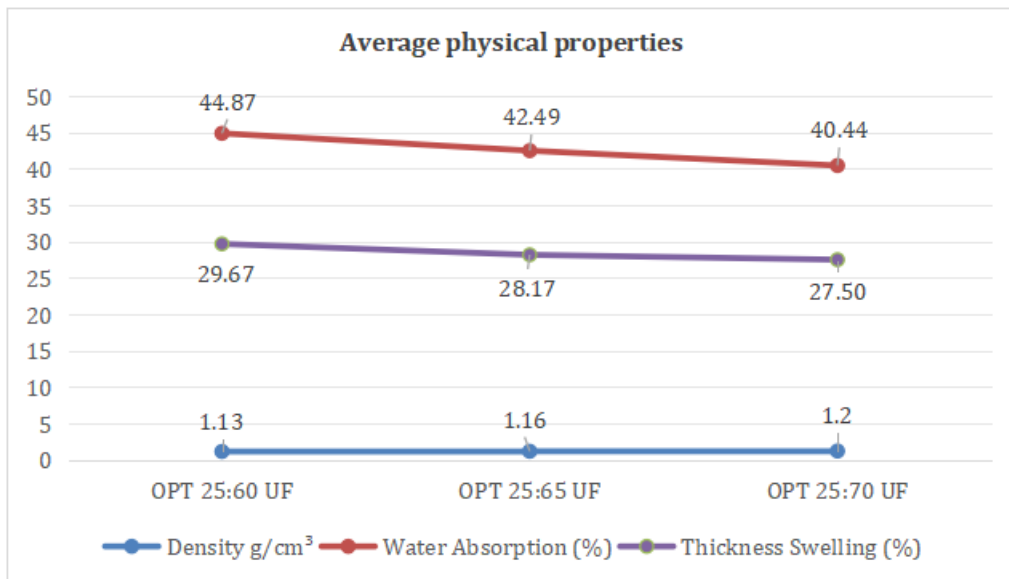


Figure 5 Average result of physical properties

3.2 Mechanical properties analysis

Based on the results presented in Table 3 and Figure 6, the average result for mechanical properties of OPT particle boards bonded with varying amounts of urea formaldehyde (UF) resin show a clear improvement as the resin content increases. The modulus of rupture (MOR), which measures the maximum load the board can withstand before breaking, increased from 243.78 MPa for OPT 25:60 UF to 333.39 MPa for OPT 25:65 UF, and further to 412.87 MPa for OPT 25:70 UF. Similarly, the modulus of elasticity (MOE), which indicates the board's stiffness and resistance to deformation, also showed a significant rise with increasing resin content. The MOE

values were 23,120.70 MPa for OPT 25:60 UF, 55,555.28 MPa for OPT 25:65 UF, and 62,339.21 MPa for OPT 25:70 UF.

These results, as illustrated in Figure 6, demonstrate a positive correlation between the amount of UF resin used and the mechanical performance of the particle boards. Both MOR and MOE values increased substantially with higher resin content, indicating that the addition of more UF resin enhances both the strength and stiffness of the OPT particle boards. This trend suggests that optimizing the resin content is crucial for producing particle boards with superior mechanical properties, making them more suitable for structural applications.

Table 3 Comparative performance of OPT particle boards for mechanical properties

Property	OPT 25:60 UF	OPT 25:65 UF	OPT 25:70 UF
MOR (MPa)	243.78	333.39	412.87
MOE (MPa)	23,120.70	55,555.28	62,339.21

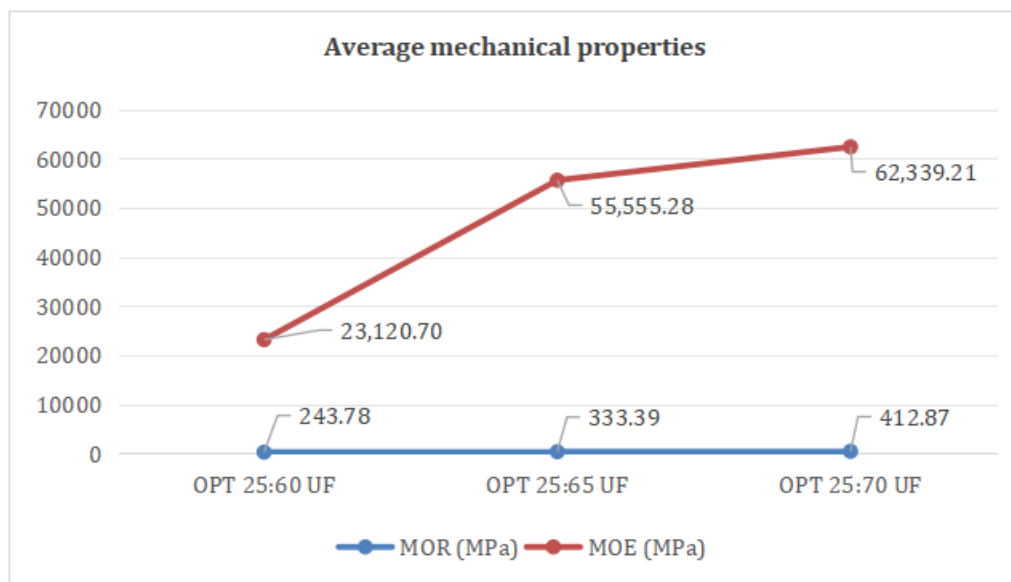


Figure 6 Average result of mechanical properties

4. Conclusion

Based on the findings of this study, it can be concluded that oil palm trunk (OPT) biomass, when combined with urea-formaldehyde (UF) resin, holds significant potential for producing sustainable and high-performance particleboards. The research demonstrated that increasing the UF resin content (from 25:60 to 25:70 fiber-to-resin ratio) consistently improved both the physical and mechanical properties of the particleboards. The OPT25:70 formulation exhibited the highest density (1.20 g/cm³), lowest water absorption (40.44%), and superior mechanical strength (MOR: 412.87 MPa; MOE: 62,339.21 MPa), along with enhanced dimensional stability (thickness swelling: 27.50%).

These results indicate that OPT biomass, when properly processed, can serve as a viable alternative to conventional wood-based panels, meeting industrial standards while addressing environmental concerns associated with agricultural waste disposal. The study highlights the importance of optimizing resin content to achieve the desired balance between performance, cost, and sustainability, offering valuable insights for the wood composites industry in promoting eco-friendly material development.

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