Performance of composite boards from long strand oil palm trunk bonded by isocyanate and urea formaldehyde adhesives

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Abstract. In this research, the obtained long strand were produced from the outer part of oil palm trunk and then hot-prepressed. The three-ply composite boards were made from hot-prepressed long strand and use bonded by isocyanate and urea formaldehyde adhesives with a glue spread variation of 150 g/m², 225 g/m², and 300 g/m². The board target density was 0.65 g/cm³, face and back layers orientation is the same and the core layer was perpendicular to the face and back layers. The research results showed that : (1) composite boards bonded by isocyanate performed better physical and mechanical properties compared to those of bonded by urea formaldehyde, (2) utilization of higher glue spread level would improve the physical and mechanical properties of the composite board. (3) composite boards bonded by isocyanate and urea formaldehyde adhesives at glue spread of 225 g/m²,300 g/m², respectively were enough to fulfill the JIS A 5908 (2003) standard.

Keywords : composite board, long strand, isocyanate, urea formaldehyde, oil palm trunk.

1. Introduction

Indonesia has a vast oil palm plantation. Based on data from Statistic Indonesia the area of oil palm plantations in Indonesia reached 11.3 million ha, spread over 24 provinces with an average growth rate of 2.78% per year [1]. Oil palm plantations have grown rapidly since the 1980s. One of the reason was the increasing demand for crude oil palm to meet the needs of local and global markets. Increasing of oil palm plantation area was directly proportional to the waste production. Oil palm trees at the age of 25 to 30 years old was no longer productive so needs to be re-planting. The oil palm at that time normally reach the height of 7 to 13 meters and possess diameter from 45 to 65 cm. Oil palm trunk has some problems if used as furniture or light construction, especially in terms of dimensional stability, strength, durability, and machining properties [2]. The utilization of oil palm trunk waste has several constraints, such as poor dimensional stability, strength and resistance to weak organism and poor machining properties [3]. The stability of the oil palm trunk dimension was very low with the variation of shrinkage of 9.2-74%, its strength was in strong class III-IV, durability of durable class V and the properties of class V machining [4,5,6].

The trunk used was 1/3 of the outer part of the trunk which has better anatomical structure. Only 1/3 of the outer part of the oil palm trunks have good strength properties that can be used as building materials and furniture, while 2/3 of the inside was not good [7]. The saw yield with modified sawmill was 30% in average [8]. One of techniques to improve the quality of oil palm trunk as materials was by hot pre-pressed technique which was successfully applied for solid wood. Wood compaction was a process for increasing wood density by altering cell structure using physical or mechanical means
The compacting that has been done on some types of solid wood before has been able to improve its quality. Based on the results of previous studies using solid wood, solidification was able to improve physical and mechanical properties significantly for example Agathi [10]. Therefore, in this research, the compaction treatment on the oil palm trunk was expected to improve its quality as a lightweight construction material.

Utilization of oil palm trunk waste for composite boards was a smart effort to handle the Indonesian wood shortage problems and environmental problems caused by tremendous oil palm trunk waste in the plantation area. The composite board was ideally developed as a substitute for the main wood product because it has advantages such as raw materials can be from various non-timber waste (agricultural waste, plantation waste and household waste) [11]. The manufacture of composite boards can also improve the quality of waste oil palm trunk so that it will increase economic value. In addition, the use of composite products will improve the properties of oil palm trunk as raw material board. The advantages of composite boards are: it can be produced in large dimensions based on the requirement, high dimensional stability, and can be produced from low quality wood or non-wood raw materials [12].

2. Materials and Methods

2.1 Materials

The materials used in this research were oil palm trunks (*Elaeis guineensis* Jacq.) with age 25 to 30 years. Trunk waste harvested from oil palm plantations in Jasinga, Bogor West Java. The adhesives used were isocyanate and urea formaldehyde adhesives.

2.2 Methods

The composite boards sample dimensions were 35.0 cm in length, 35.0 cm in width, and 1.5 cm in thickness, and the target density was 0.65 g/cm³. The boards production was started from the stage of oil palm trunk harvesting using chain saw. The trunk used was 1/3 of the outer part of the trunk. Then the sortiment was made long strand pieces with dimension 120 cm in length, 6 cm in width, and 1 cm thickness. Long strands were hot pressed for 60 minutes with a temperature of 150 °C and a pressure of 20 kg/cm² to getting a 0.6 cm strand thickness. The long strand was then spreaded by adhesive of 150 g/m², 225 g/m², and 300 g/m² in each adhesive type and arranged perpendicular between layers of three layers. The next stage was the process of hot pressing according with the type of adhesive. Composite boards bonded by isocyanate and urea formaldehyde were hot pressed at 150°C and 130°C, respectively. All composite boards were hot pressed for 15 minutes, at 20 kg/cm² pressure. After hot pressing, the board was conditioning for two weeks, and subsequently the physical and mechanical properties were tested according to JIS A 5908 (2003) standard [13].

2.2.1 Testing of Properties of Composite Board

Testing of Physical Properties

The physical properties of the board tested include: density, moisture content, water absorption, and thickness swelling. Density testing was performed during dry air board conditions JIS A 5908 (2003). The samples dimensions were 10 cm in length, 10 cm in width, and 1.5 cm in thickness.

The density test can be calculated by the equation:

\[
\rho \text{ (g/cm}^3\text{)} = \frac{\text{Mass}}{\text{Volume}}
\]
Testing of moisture content was calculated based on baseline weight (A) and oven dry weight (B) for 24 hours and temperature 103 ± 2 ° C. The value of moisture content was calculated by the equation:

$$MC (\%) = \frac{A-B}{B} \times 100 \%$$

The samples dimensions of water absorption were 5 cm in length, 5 cm in width, and 1.5 cm in thickness. The testing was conducted according to JIS A 5908 (2003) standard. Initial weight as baseline of the samples determine by weighed it (m1) then immersed in water at room temperature for 2 and 24 hours. The value of water absorption (WA) was calculated by the equation:

$$WA (\%) = \frac{m_2-m_1}{m_1} \times 100 \%$$

Thickness swelling was calculated based on the thickness before immersion (t1) measured on all four sides and averaged in dry air and thickness after immersion (t2) in water at room temperature for 2 hours and 24 hours. The value of thickness swelling (TS) was calculated by the equation:

$$TS (\%) = \frac{t_2-t_1}{t_1} \times 100 \%$$

**Testing of Mechanical Properties**

The mechanical properties of the board were tested according to JIS A 5908 standard. The mechanical properties tested were Modulus of Elasticity (MOE) and Modulus of Rupture (MOR).

a. MOE test with destructive testing method used Universal Testing Machine (UTM) instrument. The MOE test used span length of 22.5 cm. The test sample dimensions were 5 cm in width, 27.5 cm in length, and 1.5 cm in thickness.

b. MOR test was performed together with MOE testing using the same sample. In MOR testing, when loading on the MOE test was continued until the test sample was damaged (broken). The MOE and MOR values were obtained from the equation:

$$MOR (\text{kg/cm}^3) = \frac{3PL}{2bh^2} \quad \text{MOE (kg/cm}^3) = \frac{\Delta P L^3}{4\Delta Y bh^3}$$

Explanation:
MOE = Modulus of Elasticity (kg/cm²)
MOR = Modulus of Rupture (kg/cm²)
ΔP = Loading under Proportion Limit (kg)
ΔY = Deflection load (cm)
P = Maximum load (kg)
L = Span length (cm)
b = Sample width (cm)
h = Sample thickness (cm)

**2.2.2 Data Analyze Procedure**

This research used a complete factorial randomized design model with two factors and confidence level of 5%. If the results of statistical analyzes above 0.05 then the results have not significant effect, if the results of analyze below 0.05 then have significant effect, and if below 0.01 then the results have a very significant effect. All data measured in 5 replications and processed using statistical program.
\[ Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \epsilon_{ijk} \]

\( Y_{ijk} \): The observed value of type of adhesive factor of the stage \( i \) and the glue spread factor of the stage \( j \) with the repetition stage \( k \).

\( \mu \): The average value of expectations.

\( A_i \): The main effect of the type of adhesive on the board.

\( B_j \): The main effect of the glue spread on the board.

\( (AB)_{ij} \): Influence of interaction from combination of adhesive type and glue spread on the board.

\( \epsilon_{ijk} \): Experiment error.

3. Results and Discussions

3.1 Density

![Histogram of composite boards density.](image1)

The density of wood is the mass contained in the unit of wood volume [14]. Density is one of the board properties used to predict board strength. Figure 1 shows the board density varies between adhesive types and glue spread treatment. Boards bonded by isocyanate adhesive ranged from 0.70 to 0.71 g/cm³ while those of bonded by urea formaldehyde adhesive ranged from 0.62 to 0.68 g/cm³. The board density increased compared to those of solid oil palm trunks. The solid oil palm trunk density ranged from 0.26 to 0.45 g/cm³ [15]. Higher of composite boards density caused by the application of hot pressed treatment during composite board production. The composite board density increases with increasing of pressure on hot pressing process [9]. The result of statistical analysis showed that the glue spread and adhesive type had no significant effect on the composite board density.

3.2 Moisture content

![Histogram of composite boards moisture content.](image2)
Moisture content is a value used to express the amount of water present in a material or a lignocellulose product [16]. Figure 2 shows the moisture content of the composite boards bonded by isocyanate adhesive ranged from 12.04 to 12.16% with an average of 12.09%. The moisture content of composite boards bonded by urea formaldehyde adhesive ranged from 12.70 to 13.75% with an average of 13.28%. The boards bonded by urea formaldehyde adhesive has an average moisture content higher than JIS A 5908 (2003) standard which requires moisture content below 13%. This was to be influenced by the environmental conditions and urea formaldehyde adhesive failed to prevent the boards absorbing excessive water vapor from the environment. The value of moisture content of oil palm trunks ranged from 219.9 to 379.4% [15]. In addition, according to Putra [17] said that the moisture content of composite board was very dependent on the surrounding air conditions, because the raw material was ligno-cellulosic which had hygroscopic characteristic. The strength of the board will increase when the moisture content decreases below the fiber saturation point. That happened because the condition of the cell wall will be more compact so that the cellulose bond was stronger. The structural unit (micro-fibril) gets close and the tensile force between cellulose molecules gets stronger [14]. Composite board bonded by urea formaldehyde with glue spread 150 g/m² and 300 g/m² failed to meet JIS A 5908 (2003) standard which set up moisture content ranged from 5 to 13%, while those of bonded by isocyanate fulfilled the standard. Based on the statistical analysis, the adhesive type had significant effect on the moisture content of the composite board, while glue spread did not.

3.3 Thickness swelling

![Figure 3](image3.png)

Figure 3. Histogram for thickness swelling after 2 hours of water immersion.

![Figure 4](image4.png)

Figure 4. Histogram for thickness swelling after 24 hours of water immersion.

Thickness swelling is one of the parameters that determine the quality of a composite board. Thickness swelling is a quantity that expresses the thickness of the test sample in percent to the initial thickness after the test sample was immersed in water at room temperature for 24 hours [18]. Figures 3
and 4 show the composite board bonded by isocyanate and urea formaldehyde adhesives at two hours of water immersion has a thickness swelling ranged from 3.30 to 5.80% and 5.09 to 11.28%, respectively. While at the water immersion of 24 hours ranged from 4.62 to 12.06% and 7.65 to 17.24%, respectively. The composite board bonded by isocyanate adhesive has a thickness swelling less than compared to those of bonded by urea formaldehyde adhesive. This was because, the isocyanate adhesive has waterproof characteristics, quickly hardened and rapidly matures at lower temperatures and was more tolerant of particulate matter or high-water veneer [19]. The JIS A 5908 (2003) standard set up thickness swelling not more than 25% for 24 hours of water immersion. Statistical analysis showed that the glue spreads and adhesive types had significantly affected the thickness swelling of the composite boards.

3.4 Water Absorption

![Figure 5. Histogram for water absorption after 2 hours water immersion.](image)

![Figure 6. Histogram for water absorption after 24 hours of water immersion.](image)

The water absorption represents the amount of water absorbed by the test sample in percent to its initial weight after the test sample was immersed in water at room temperature for 24 hours [4]. Water absorption was not required in JIS A 5908 (2003). Figures 5 and 6 show that the water absorption of 2 hours and 24 hours of composite boards bonded by isocyanate adhesive ranged from 24.72 to 27.98% and 45.28 to 53.18%, respectively. Whereas those of bonded by urea formaldehyde adhesive ranged from 30.11 to 38.48% and 51.53 to 64.99%, respectively. That water entering the board was divided into two kinds, namely water entered the empty hollow inside the board and into the material of the board [11]. The research results showed that compaction in both adhesive types made the boards more compact, preventing water from entering the board [20]. Although glue spread of 300 g/m² has a smaller water absorption, the statistical analysis indicated that the glue spread levels and adhesive types had no significant effect on composite board water absorption.
3.5 Modulus of Elasticity (MOE)

Modulus of Elasticity (MOE) is a measure of material stiffness or material in resisting form changes or flexures that occur due to loading and only valid in the extent of proportion [17]. Figures 7 and 8 show that the composite boards bonded by isocyanate adhesive had MOE values which were parallel to the grain and perpendicular to the grain ranged from $28.9 \times 10^3$ to $56.2 \times 10^3$ kg/cm² and $4.2 \times 10^3$ to $7.2 \times 10^3$ kg/cm², respectively. Whereas those of bonded by urea formaldehyde adhesive ranged from $28.5 \times 10^3$ to $47.3 \times 10^3$ kg/cm² and $2.9 \times 10^3$ to $5.4 \times 10^3$ kg/cm², respectively. In both types of adhesive, glue spread level at 150 g/m² resulted the smallest MOE values while the largest values resulted from those of glue spread at 300 g/m². Composite boards of oil palm trunk waste bonded by isocyanate adhesives had an average MOE better than those of bonded by urea formaldehyde adhesives. The isocyanate adhesive was one of the water-based adhesives that so well bonds with porous materials such as wood and other ligno-cellulosic materials such as oil palm trunk[9,21]. The MOE values of boards increased linearly following the increasing of glue spread used in board production. Based on JIS A 5908 (2003) standard, the composite board with glue spread at 150 g/cm² failed to fulfill the standard, while the glue spread of 225 g/m² and 300 g/m² fulfilled the standard. The MOE parallel to the grain of the composite boards were higher compared to those of solid oil palm trunk. The average MOE of solid oil palm trunks was $15.7 \times 10^3$ kg / cm² [21]. Statistical analysis indicated that glue spreads and adhesive types had significantly affected the MOE values.
3.6 Modulus of Rupture (MOR)

![Figure 9](image1.png)

Figure 9 Histogram of composite boards MOR parallel to the grain.

![Figure 10](image2.png)

Figure 10. Histogram of composite boards MOR perpendicular to the grain.

Modulus of Rupture (MOR) is the maximum load that could be resisting until damaged. Figures 9 and 10 showed that the MOR values parallel and perpendicular to the grain of composite boards bonded by isocyanate adhesive ranged from 274 to 371 kg/cm² and 69 to 125 kg/cm², respectively. While those of bonded by urea formaldehyde adhesives ranged from 182 to 369 kg/cm² and 39 to 91 kg/cm², respectively. The composite boards bonded by isocyanate adhesive fulfilled the JIS A 5908 (2003) standard, while those of bonded by urea formaldehyde fulfilled the standard at glue spread of 300 g/m². The composite board bonded by isocyanate resulted higher MOR compared to those of bonded by urea formaldehyde, and MOR parallel to the grain were higher compared to those of perpendicular to the grain. This phenomenon was influenced by the testing positions that the applied force across the fibers length in face and back layers at parallel to the grain. This results also higher compared to solid oil palm trunk. This phenomenon proved that compaction with high temperatures increased the MOR value of oil palm trunks [22]. The MOR value increased following increasing of glue spread used in composite board production. MOR parallel to the grain of solid oil palm trunk ranged from 97-151 kg/cm² [10]. Statistical analysis indicated that glue spreads and adhesive types had significantly affected the MOR of composite boards made from oil palm trunk waste.

4. Conclusions

Based on the test results could be concluded that: (1) composite boards bonded by isocyanate performed better physical and mechanical properties compared to those of bonded by urea formaldehyde, (2) utilization of higher glue spread level would improve the physical and mechanical properties of the composite boards. (3) composite boards bonded by isocyanate and urea formaldehyde
adhesives at glue spread of 225 g/m², 300 g/m², respectively were enough to fulfill the JIS A 5908 (2003) standard.

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