The effect of phenol formaldehyde impregnation at various concentrations on quality of densified-oil palm trunk

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Abstract. The purpose of this study was to improve the quality of oil palm trunk (OPT) after impregnation with Phenol Formaldehyde (PF) resin at various concentration and compression. The inner part of OPT with an average density of 0.28 g/cm³ was used as samples. The OPT was impregnated with PF (5%, 10%, 15% and 20%) by the vacuum-pressure method, then compressed by close system compression. The physical and mechanical properties including weight gain (WG), recovery set (RS), compression parallel to grain, modulus of rupture (MOR) and elasticity modulus (MOE) were examined. The results show WG after PF impregnation was 5.29-53.81% and RS value was 0.99 -27.92%. The physical and mechanical properties have increased with increasing PF concentration. The density value, compression parallel to grain, MOR and MOE were 107.15-217.86%, 39.27-248.31%, 159.71-379.22% and 52.92-171.58%, respectively. The impregnation PF of 20% was the best treatment.

1. Introduction

Palm oil (*Elaeis guineensis* Jacq) originates from West Africa. The large expansion of this plant has increased rapidly to various worlds including Indonesia. In Indonesia, oil palm is one of the prime crops of the plantation sub-sector. It can be seen from the increasing number of oil palm plantations from year to year. In 2015, the area of oil palm plantations reached 11.26 million ha, with a production of 31.07 million tons. The total export volume currently reaches 33,519,211,155.09 tons with a value of US$ 21,256,997,276.19 [1].

The economic life of oil palm plants ranges from 24-26 years [2]. After reaching this age, trees must technically be cut down and rejuvenated. According to Badrun [3], oil palm plants that want to be rejuvenated cover an area of 250 thousand ha/year. It is estimated that from this area 42.5 million m³/ha of trunk waste can be produced. It shows that the waste of palm oil trunk (OPT) is very potential to be used as a substitute for raw materials for the timber industry.

The OPT belongs to the monocot group. In general, the anatomical structure of the trunk is composed of vascular bundles and parenchyma. The vascular functions are as a component that supports the transport structure and system, while the parenchyma serves as a food store.

The density of vascular bundles at the outer of OPT is higher and decreases toward the center, whereas the parenchyma tissue at the outer part of OPT is lower and increases toward the center. High vascular bundle density will have a high-density value [4, 5]. The outer part of OPT was dominated by vascular bundle around 25-30%, while the other was the soft inner part [4].

The OPT is rarely used, especially the soft-inner part of OPT (S-OPT). It is because the physical and mechanical properties of OPT are not good. Some weakness of OPT on physical properties are high shrinkage, high moisture content, high-density variations, low durability and low modulus of elasticity.
and modulus of rupture [4, 6]. The utilization of OPT needs to be done by improving the physical and mechanical properties. One way to improve the quality of OPT is done by densification and impregnation of phenol formaldehyde (PF).

Densification by compressing is very suitable for S-OPT. The S-OPT is dominated by cell parenchyma, so it can be compressed with compressing ratio of 50% [7]. In previous work, compressing of S-OPT has been done using a closed system compression (CSC) method under several temperatures and durations. The CSC is very successful in increasing the physical properties of S-OPT such as density values that increased up to 90%. Also, mechanical properties of S-OPT, such as compressive strength, modulus of elasticity (MOE) and modulus of rupture (MOR) of S-OPT increased up to 120%, 190% and 155%, respectively [8].

Impregnation of PF into the wood could reduce hygroscopic wood [9], improve wood stability [10], improve the mechanical properties of wood [11, 12] and increase wood durability from fungal and termite attacks [13]. In previous work, the combination of PF impregnation resin of 20% and CSC methods significantly improved the density, MOR, MOE and compressive strength of S-OPT up to 176%, 309%, 287%, and 191%, respectively [14].

This study intends to analyze the impregnation of PF with various concentrations into S-OPT and densification with compressing level of 50% on physical and mechanical properties of S-OPT, and also to obtain the optimal PF resin concentration.

2. Materials and methods

2.1. Materials

The material used in this study was oil palm trunk approximately 40 years in age from Bogor, Indonesia. The sample was soft inner part of oil palm trunk (S-OPT) with a dimension of 150 mm (length) × 50 mm (width) × 20 mm (thickness). The other material was Phenol formaldehyde (PF) from Palmolive Adhesive Industry, Probolinggo with a resin content of 42.5%.

2.2. Methods

2.2.1. PF impregnation and densification. Samples S-OPT were oven dried at 60 °C until constant weight, then dimension and weight were measured. The average density of S-OPT after drying was 0.28 ± 0.01 g/cm³. Then, samples were put in the box and impregnated PF resin of 5%, 10%, 15% and 20%, with five replications. The PF resin impregnation used vacuumed at 600 mmHg for 1 h and and pressure of 1 kg/cm² for 30 minutes. As comparison, a sample a sample control without PF impregnation was used. After PF resin impregnation, sample curing was performed in an oven at 60 °C for 15 hours. The samples of S-OPT were compressed with a compression ratio of 50% at 135 °C for 10 minutes. After compression, the samples were conditioned for two weeks before further testing. The final size of S-OPT sample was 150 mm × 50 mm × 10 mm in length, width, and thickness, respectively.

2.2.2. Physical properties evaluation.

a. Weight gain (WG)

The S-OPT samples size were 20 mm × 20 mm × 10 mm. The percentage of weight gain (WG) due to resin impregnation was determined by measuring samples weight before (W₀) and after impregnation (W₁), then calculated using the equation :

\[ WG = \frac{W_r - W_o}{W_i} \times 100\% \]  

(1)

b. Recovery of the set (RS)

The samples with the size of 20 mm × 20 mm × 10 mm were soaked in room-temperature water for 24 h and then in boiling water (100 ± 3 °C) for 30 min [15]. The RS was calculated as follows:
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\[ RS(\%) = \frac{T_r - T_c}{T_o - T_c} \times 100\% \]  

(2)

Where To is the initial thickness, Tc is the thickness after compression, and Tr is the thickness after recovery. All the dimensions of the samples were measured in the oven-dry condition.

c. Density

The density of S-OPT samples with a size of 20 mm × 20 mm × 10 mm was determined by measuring their air-dry weight (M) and volume (V). The air-dry density was calculated using the equation:

\[ D = \frac{M}{V} \]  

(3)

2.2.3. Mechanical properties evaluation.

a. Modulus of rupture (MOR) and Modulus of elasticity (MOE)

The MOR and MOE were conducted using Universal Testing Machine. The size sample for MOE and MOR test were 150 mm (length) × 10 mm (width) × 10 mm (thickness). The MOR and MOE were calculated using the equation:

\[ \text{MOR (kg/cm}^2) = \frac{3PL}{2bh^3} \]  

(4)

\[ \text{MOE (kg/cm}^2) = \frac{P_p L^3}{4Y_p bh^3} \]  

(5)

where P is the maximum load (kg), Pp is the load at the proportional limit (kg), h is the height sample, b is the width sample (cm), L is the length span (cm), and Yp is the deflection (mm).

b. Compressive strength tests

The samples size for compressive strength (R) test were 40 mm × 10 mm × 10 mm. The compressive strength was conducted using a Universal Testing Machine. The compressive strength (R) was calculated using the equation:

\[ R \ (\text{kg/cm}^2) = \frac{P}{bh} \]  

(6)

where R is compressive strength, P is the maximum load (kg), b is the width sample (cm) and h is the height sample.

2.2.4. Data analysis. The data analysis design was a completely randomized design (CRD). The results of the physical and mechanical tested were submitted to an overall analysis of variance (ANOVA). The homogeneity of the means among treatment was tested using the Duncan’s Multiple Range Tests.

3. Results and Discussion

3.1. Physical properties

The result of this study on the physical properties of S-OPT with a variation of PF resin concentration, such as weight gain (WG), recovery of the set (RS) and density is shown in table 1.

Based on table 1, it can be seen that the PF concentration used was higher. The WG and density value will increase, while the RS value decreases. The impregnation method used to enter PF resin was a vacuumed-pressure and compressing method. This method can increase the weight gain (WG) of S-OPT up to 53.81%. The entry of PF resin can increase the density value of 107.14–217.86% from its initial density, while the RS value decreases until the RS value of 1% with using PF concentration of 20%.
Table 1. The WG, RS and density value with a variation of PF resin concentration.

| Treatment     | WG    | RS        | Density   |
|---------------|-------|-----------|-----------|
| Control       | 0     | 86.46 ± 5A| 0.28 ± 0.01A|
| PF 5%         | 5.29 ± 1.8B | 27.92 ± 4.3A| 0.58 ± 0.03B|
| PF 10%        | 26.3 ± 4.1C | 17.72 ± 2.3B| 0.72 ± 0.03C|
| PF 15%        | 42.44 ± 3.2D | 2.37 ± 1.9C | 0.83 ± 0.08D|
| PF 20%        | 53.81 ± 4.2E | 1 ± 0.6D   | 0.89 ± 0.07D|

Notes: WG: weight gain; RS: recovery of the set; standard deviation followed by the same capital letter mean that the value are not significantly different at 5% significance level according to Duncan’s multiple range test.

The result of variance analysis shows that all treatments were significantly different from the WG, RS and density values. The increase in WG value will be followed by an increase in density value and decreased RS value (figure 1).

Based on figure 1, it is shown that WG is directly related to density, but it is inversely related to RS. The decreasing of RS value indicates that the stability of S-OPT increases. Impregnation of PF resin by vacuum-pressure method can enter a vast PF into the OPT structure. The PF resin will mostly fill the parenchymatous ground tissue and the vessel. The presence of PF resin in the S-OPT structure is presented in figure 2.

PF resin that enters S-OPT structure will fill the vessel and ground parenchymatous tissue. The more PF resin that enters S-OPT structure, the better the physical properties of S-OPT. It is indicated by the increasing density and the decreasing RS of S-OPT (figure 1).

Some researchers reported that the entry of PF resin into the wood structure would increase stability and reduce the hygroscopic of wood [9, 10]. Likewise, the entry of PF into the S-OPT structure would improve the physical properties of S-OPT [14].
3.2. Mechanical properties

The result of mechanical properties of S-OPT with a variation of PF resin, such as MOR, MOE, and compressive strength is shown in Table 2. Based on Table 2, it can be seen that MOR, MOE, and compressive strength values increase with increasing of PF concentration used. The value of mechanical properties increases significantly with the entry of PF into S-OPT. PF that enters S-OPT structure will fill the cavities in the S-OPT, indicated by the increasing of WG value. The mechanical properties increase significantly along with the increasing of WG values as shown in Figure 3.

Table 2. The MOR, MOE and compressive strength value with a variation of PF resin concentration and compression.

| Treatment | MOR       | MOE                | Compressive Strength |
|-----------|-----------|--------------------|----------------------|
| Control   | 71 ± 7A   | 9446.21 ± 1236A    | 55 ± 9A              |
| PF 5%     | 185 ± 25B | 14445 ± 1711B      | 76 ± 10AB            |
| PF 10%    | 197 ± 26B | 16306 ± 2319B      | 85 ± 10B             |
| PF 15%    | 271 ± 34C | 20583 ± 2605C      | 128 ± 27C            |
| PF 20%    | 341 ± 40D | 25654 ± 2426D      | 191 ± 31D            |

Notes: MOR : Modulus of Rupture; MOE : Modulus of Elasticity; standard deviation followed by the same capital letter mean that the value are not significantly different at 5% significance level according to Duncan’s multiple range test.

Figure 2. Micrographs of S-OPT at transverse section: PF in vessels and Parenchymatous ground tissue.

Figure 3. The mechanical properties of impregnated OPT, (A) compressive strength and MOR, (B) MOE value.
Based on figure 3, it can be seen that WG is directly related to mechanical properties. The higher the WG, the higher the mechanical properties, such as MOR, MOE and compressive strength. This phenomena was agree with the previous studies reported impregnated of wood [11] and on impregnated of bamboo strips [16]. Figure 4 shows the relationship between WG and mechanical properties. The regression analysis shows that the correlation between WG and MOR, WG and MOE, WG and compressive strength can be described by a second-order polynomial.

![Figure 4](image)

**Figure 4.** Relationship between weight gain (WG) of S-OPT after PF resin impregnation and (A) MOR, (B) MOE, (C) compressive strength.
The relationship between WG and the mechanical properties in this study is shown by the polynomial line, where the equation for the WG and MOR is
\[ y = 0.0238x^2 + 2.8311x + 113.11 \] with \( R^2 = 0.8307 \); the WG and MOE is
\[ y = 2.1838x^2 + 138.76x + 11317 \] with \( R^2 = 0.8518 \); and WG and compressive strength is
\[ y = 0.0543x^3 - 0.6639x + 64.057 \] with \( R^2 = 0.8869 \). It indicates that MOR, MOE and compressive strength have a significant relationship with WG, indicated from the high value of \( R^2 \) up to 0.83.

In this study, impregnated PF with variation concentration increases the MOR, MOE and compressive strength value of 159.71-379.22%; 52.92-171.58% and 39.27-248.31%, respectively. This value is higher than only compressing with the CSC method, which mechanical properties, such as MOR, MOE and compressive strength values, were 14-155%, 43-192% and 19-123%, respectively [8]. This value is not much different from the value of mechanical properties using the same method, namely vacuum-press on 20% PF impregnation [14].

4. Conclusion
Impregnation of PF with various concentrations accompanied by compression is significant to improve the physical and mechanical properties of S-OPT. The higher PF resin entry into vessel and the ground parenchymatous tissue of S-OPT, the higher the physical and mechanical properties value. The PF concentration of 20% resulted in higher physical and mechanical properties than other PF concentrations.

5. References
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