Wettability Properties of Heat-Treated Oil Palm Trunk Under Various Heating Times

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Abstract. Oil palm trunk has become one of the waste that could damage the environment. Efforts that could be made to minimize the impact oil palm trunk’s existence were to turn the oil palm trunk into composite products. A composite product that could be made from palm oil trunks was blockboard. Oil palm trunk could be used as cores on block boards. Oil palm stems as raw material still have weaknesses. This weakness was the low dimensional stability due to hygroscopic properties. The treatment that could be done to increase dimensional stability while improving the adhesive quality was heat treatment. In this study, heat treatment of 140 °C and 160 °C for 1, 2, and 3 hours was carried out. The obtained results were 116.10⁰, 128.44⁰, and 133.52⁰ for 1, 2, and 3 hours of treatment sequentially. The L* value in the heat-treated OPT tended to decrease, while the a* and b* values tended to increase compared to the control. The brightness level (L*) of the heat-treated OPT was more affected by temperature than the heat treatment time. Meanwhile, the a* and b* values were almost identical between treatments but differed from the controls. The total color change (ΔE) of the heat-treated OPT was not too large between treatments (moderate dark orange), but differed from the control (mostly desaturated dark orange).

Keywords: oil palm trunk, colour change, heating time, heat treatment, wettability

1. Introduction
Palm oil is one of the most valuable commodities from an economic perspective in Indonesia. Indonesia would have an area of 14.309.256 ha of oil palm plantations in 2018 [1]. The income obtained by the state was relatively high from these commodities. However, many problems were arising from the palm oil industry. One of them was the oil palm trunk (OPT) which was no longer productive in producing waste that caused environmental problems.

Oil palm will reach an unproductive period at the age of 25-30 years so that it has the potential to became waste at that age after the replanting process [2]. OPT waste reaches 60 million m3 per year, assuming replanting every 25 years and OPT volume of 125 m3 per hectare [3]. This condition would cause problems, especially in the environmental sector, such as air pollution due to burning OPT waste and unpleasant odors due to the degradation process. Therefore, it was necessary to take appropriate waste countermeasures to minimize the impact on the
One of the efforts that can be made to overcome environmental problems and be able to increase the added value of OPT was to make it a composite board product. Composite board products that have been made from BKS included plywood, particleboard [4], sandwich board [5], and laminated veneer lumber (LVL) [6] [7]. Composite board products that could also be produced from BKS raw materials were blockboards. Blockboard was a composite product made from palm oil pieces for the middle (core) and finish as the face and back parts that were glued together and pressed under a predetermined pressure [8]. OPT as a lignocellulosic material has a weakness when used as a raw material for composite boards, namely hygroscopic properties. The hygroscopic properties or the ability to absorb and release water that OPT owned caused the raw material's low dimensional stability value [9].

The treatment that could be performed on BKS to reduce its hygroscopic properties and increased dimensional stability was heat treatment. This has been proven by [10], who explained that heat treatment was able to increase the dimensional stability and physical-mechanical properties of composite products made from lignocellulosic material. Heat treatment was thought to improve the dimensional stability quality of OPT as a raw material for blockboard. The parameter that could be used to prove this was the raw material wettability test. The wettability test could also determine the adhesive penetration quality for a substrate that will be used as a composite product. The higher the wettability value would make a better adhesive penetration process [11]. Therefore, this research aims to determine the wettability value of heat-treated OPT as raw material for block boards.

2. Materials and Method

2.1 Materials
More than 25 years old oil palm trunk was obtained from Cikabayan, IPB University, Bogor, West Java, Indonesia. The oil palm trunk that was used in this research was the middle 1/3, which was not differentiated longitudinally. Oil palm trunks that had been felled were air-dried to ± 15%. OPT was cut in the horizontal direction of the fiber. The size of the OPT used was 5 x 5 x 1.5 cm. OPT oven at 60 ± 3 °C for 3 days to ± 10% moisture content (MC). Furthermore, OPT was given heat treatment with temperatures of 140 °C and 160 °C for 1, 2, and 3 hours respectively.

2.2 Wettability Test
Wettability is determined from the results of the contact angle of the PF adhesive against OPT. The OPT sample was placed on a flat table parallel to the camera. The adhesive was dropped by screw method with the estimated drop volume of 0.02 ml. 5 points measured the contact angle for each sample. The dropping of adhesive was recorded for 170 seconds. Recorded videos were cut with GOM Player software in increments of 10 seconds.

Furthermore, the sample contact angle images were measured using Image-J 1.46 with drop snake plugin analysis. The resulting contact angles were taken from both sides and averaged. The data obtained were 18 points for each sample dropping video. Furthermore, from these data, a curve of contact angle along time was determined.

The constant contact angle value was determined by the regression equation between time (x) and the contact angle (y) using the SAS PROC NLIN program (Shi and Gardener 2001) was determined by the XLSTAT program. The equation of the S / G model was this equation:

$$\theta = \frac{\theta_i \cdot \theta_e}{\theta_i + (\theta_e - \theta_i) \exp \left[K \left( \frac{\theta_e - \theta_i}{\theta_e - \theta_i} \right) t \right]}$$  \hspace{1cm} (1)

"θ" was the contact angle at a given time, "θi" was the first contact angle, "θe" was the equilibrium contact angle, t was time, and K was the constant rate of change of the contact angle.

2.3 Color Parameter Analysis
Measurement and analysis of the OPT’s color difference was carried out by determining the brightness (L*), red, green (a*), and yellow and blue (b*) using a portable color difference meter model CDX-105. Each test sample is scanned at five different points to obtain an L* a* b* value. The L* a* b* value was taken on the control sample and the heat modified OPT treatment and converted online on the colorhexa page. The Δ E color change value was calculated based on the CIE Lab method with the following formula:
\[ \Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \]  

\( \Delta E \) was the color change, \( \Delta L \) was the brightness difference, \( \Delta a \) was the red or green color difference, and \( \Delta b \) was the yellow or blue difference.

2.4 Data Analysis
OPT heat treatment's effect on the value of contact angle and color was analyzed using a two-factor factorial, completely randomized design. The factors used were heat treatment temperature (140 °C and 160 °C) and time (1 hour, 2 hours and 3 hours) respectively. Furthermore, Duncan's further test was carried out for further testing. Each treatment was repeated 3 times. The wettability test and color test were carried out 5 times for each treatment.

3. Results and Discussion
The wettability quality indicator of the substrate was determined by contact angle value. It has good wettability if it has a contact angle of less than 90° [12]. We knew that heat-treated oil palm trunk (OPT) has a higher contact angle than control, especially at 2 and 3 hours treatment (Table 1). From analysis of variant (ANOVA) \( \theta e \) value of OPT was affected by temperature, time, and the interaction between temperature and time (P<0.05). Duncan analyze showed that the average of \( \theta e \) values at 140 °C and 160 °C were 128.58° and 123.46° sequentially. Those results have a higher value than control (118.29°). In other conditions at different times, an average value of \( \theta e \) raised over time of heat treatment. Those were 116.10°, 128.44°, and 133.52° for 1, 2, and 3 hours of treatment sequentially. Those values have a higher value than the control (118.29°), except at the 1-hour heat-treatment process. There was no difference between heat-treated OPT and control significantly caused by a short time of treatment.

| Table 1. Value of equilibrium contact angle and K value for untreated and heat-treated oil palm trunk |
|-----------------|-----------------|-----------------|-----------------|
| Treatment       | Time (hour)     | \( \theta e \) (°) | K               |
| Control         | -               | 118.29          | 0.0036          |
| HT 140 °C       | 1               | 128.74          | 0.0021          |
| HT 140 °C       | 2               | 126.03          | 0.0015          |
| HT 140 °C       | 3               | 130.97          | 0.0004          |
| HT 160 °C       | 1               | 103.46          | 0.0014          |
| HT 160 °C       | 2               | 130.85          | 0.0012          |
| HT 160 °C       | 3               | 136.05          | 0.0005          |

Wettability value was affected by the density of adhesive’s extractive contents, adhesive’s viscosity, surface roughness, and moisture content [13]. The increasing of contact angle tends to produce a low wettability value [14]. The results of research by [7] showed that the value of the contact angle phenol-formaldehyde (PF) on OPT ranged from 126° to 114°. The contact angle value of outer OPT and inner OPT ranged from 105.44° to 108.78° [15]. This is expected due to the content of extractive substances and the rough surface of the OPT. The material's rough surface will make it more difficult for the adhesive to flow and reduce wettability on the surface of the material [15]. OPT has a very porous anatomical structure (large volume voids), as well as high extractive content (14.24%), so that it also provides a high contact angle value [16] [17]. The presence of extractive substances will form a "weak boundary layer" which made the interaction between adhesive and substrate (wood material) nor or less optimal [18]. Extractive ingredients such as grease and wax will prevent the adhesive from entering the wood.

The type of adhesive used also affects the penetration into the cavity of the OPT cells. Nor [19] stated that PF adhesive has a high molecular weight, so that it was difficult to penetrate from the OPT surface into the cell cavity. PF adhesive quality will be optimal if it reacts under alkaline conditions, and the reactivity will be lower when reacted under acidic conditions [20]. According to Nor [19], the pH of OPT is 5.6. This supports the phenomenon related to the high value of the OPT contact angle in this research.

Thermal modification on OPT caused color change. Color change was measured using the CIELAB method. Overall, it could be seen that the L* values in the thermally modified BKS tend to decrease, while the a* and b* values tend to increase compared to the control. This phenomenon was similar to [21] who stated that a* and b* behavior is the opposite of L* behavior. According to [22], the value of L* represents the brightness (lightness)
which ranges from 100 (pure white) to 0 (black), while +a* represents reddish color, −a* represents green, +b* represents yellowish color, and −b* represents blue.

Table 2, showed that the brightness level (L*) of the heat-treated OPT decrease with increasing temperature and heat treatment time. The ANOVA results supported this phenomenon, which showed that the L* value in the heat-treated OPT was affekted by the temperature treatment (P <0.05). The average L* heat-treated OPT values for heat treatment temperatures of 140 and 160 °C were 46.56 and 44.26, respectively. At different heat treatment times, the average of L* OPT heat-treated values was 45.72, 46.44 and 44.08 for treatment times of 1, 2, and 3 hours respectively. This value was lower than the control (50.06). According to [23], heat treatment could change the color of wood to darker than the control due to changes in wood chemical components such as degradation of amorphous polysaccharides (hemicellulose). The degradation of hemicellulose will increase as the temperature is applied and caused the wood to lose its brightness [24]. According to de [25], the low L* value was related to the extractive content and degradation of hemicellulose, especially pentose, and increased lignin content due to heat treatment.

The average a* and b* values at different treatment temperatures were 7.11 and 22.47 for temperature treatment of 140 °C, and 7.57 and 22.31 for temperature treatment of 140 °C. This value was higher than the control, which was 6.45 and 20.71, respectively. The high a* and b* values are generally associated with the condensation, degradation, and oxidation of the cells of wood or other lignocellulosic materials. The condensation process could occur in lignin and other extractives and allows the formation of by-products, thus increasing the intensity of the red tone in the wood [25].

The total color change was expressed as a value ΔE [26]. Table 2 shows that the color change in OPT was not too large between treatments, but it was different from the control. This phenomenon was supported by the colorhexa results, which show that the control OPT was mostly desaturated dark orange, while the thermal modified OPT was dark moderate orange. This was presumably because the OPT temperature was not too big and was treated in dry conditions. Wood produced a very striking change when the heat was treated in wet conditions [27]. The colour change was due to the hydrolysis of hemicellulose, which increased ΔE [27].

Table 2. Value of equilibrium contact angle and K value for untreated and heat-treated oil palm trunk

| Treatment | Time (hour) | L* | a* | b* | ΔE |
|-----------|-------------|----|----|----|----|
| Control   | -           | 50.06 | 6.45 | 20.71 | - |
| HT 140 °C | 1           | 47.26 | 7.12 | 23.05 | 24.13 |
| HT 140 °C | 2           | 47.26 | 7.17 | 22.56 | 23.67 |
| HT 140 °C | 3           | 45.17 | 7.05 | 21.83 | 22.95 |
| HT 160 °C | 1           | 44.18 | 7.96 | 23.21 | 24.55 |
| HT 160 °C | 2           | 45.62 | 7.11 | 21.96 | 23.09 |
| HT 160 °C | 3           | 42.99 | 7.64 | 21.76 | 23.06 |

4. Conclusion
Heat-treated OPT has a greater contact angle value than control. The longer the thermal modification time, the higher the OPT contact angle value. However, heat treatment with a time of 1 hour has a contact angle value that is not much different from the control caused by the short modification time. Thermal modification on OPT caused color change. The L* value in the heat-treated OPT tended to decrease, while the a* and b* values tended to increase compared to the control. The brightness level (L*) of the heat-treated OPT was more affected by temperature than the heat treatment time. Meanwhile, the a* and b* values were almost identical between treatments but differed from the controls. The total color change (ΔE) of the heat-treated OPT was not too large between treatments (moderate dark orange), but differed from the control (mostly desaturated dark orange).

5. Acknowledgments
We sincerely acknowledge the Guru Besar under 45 ITERA Research Grant (B/404/IT9.C1/PT.01.03/2020) from the Institut Teknologi Sumatera, Republic of Indonesia for the financial support.
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