Color and dimensional stability of fast growing teakwood by mild pyrolysis and combination process

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Abstract. Fast-growing teakwood had been subjected to Mild Pyrolysis (MP) and combination (MP + steam) processes. Performa of treated wood was evaluated by surface color change, mass loss, and dimensional stability. The CIELab system was used to evaluate the color change, while anti-swelling efficiency was used to determine dimensional stability. The two processes were conducted within pyrolysis reactor under atmospheric pressure in the presence of limited oxygen. MP process was applied by heating the wood for 2 hours at 170 and 190°C without steam, while combination process was employed by flowing steam for 0.5 and 1 hour during the 2 hours heating period. The result showed total color change and dimensional stability increased along with the increase in temperature. Even though MP process could reduced water absorption and swelling, but combination process permits a better results. Treated wood by MP and steam has lower total color change and mass loss, but greater dimensional stability.

1. Introduction
Fast-growing teak (Tectona grandis L.f.) wood has different properties compared to conventional teakwood planted by Perum Perhutani. Pale color, low dimensional stability, and low durability are some significant differences [1-2]. These characteristics resulted in relatively less desirable and limiting wood utilization. Therefore, quality improvement of fast-growing teakwood needs to be done.

Thermal modification process was applied in this study for two reasons. Firstly, it is relatively simple and environmental friendly process, and secondly it is an alternative to coloring wood without adding paint or chemical. Thermal modification process could improve dimensional stability and durability of wood [3-5]. This process has several names such as le bois perdre, rectification, and Oil Heat Treatment (OHT). The main differences among them are related to material used, process condition applied, and the equipment [6]. The famous products from this process are thermowood and plato.

Pyrolysis, one of thermal modification process, is carried out at high temperature namely 402-702°C without or with limited oxygen (inert atmosphere), and was originally intended to produce charcoal [7]. In order to keep the sample in the form of wood, the process must be carried out at a lower temperature, i.e. 160-260°C. Such kind of process is known as MP. MP has been studied by several researchers and the result shows well improvement in dimensional stability, appearance, and durability of wood.
[3,4,8,9]. Generally, nitrogen gas was used in the process in order to obtain inert atmosphere and prevent combustion of wood.

In previous study, MP process using a reactor without adding nitrogen gas was applied for fast-grown teakwood were in green condition [1]. The results showed that treated wood surface is darkening, while dimensional stability and its durability against termite are increase. The optimal process was MP at 200°C for 4 hours. Even though some improvements obtained, the existence of wood defect cannot be avoided. At 230°C for 6 hours treatment, Modulus of Rupture (MOR) reduced more than 50% and carbon layer existed on the wood surface. Some modifications, therefore, need to be done to minimize these negative effects.

According to Missio et al. [10], combined treatment could be utilized to reduce the negative impact of treated wood. Steam provides more effective heat transfer and acts as heating medium and shielding gas, and as the result drying defects was significantly reduced [11-13]. The main objective of this study was, therefore, to investigate effect of MP and combination (MP + steam) processes on color and dimensional stability of fast-growing teakwood.

2. Materials and Methods

2.1. Materials
Fast-growing three teak trees with 20-25 cm diameter at breast height was cut from plantation forest area in Bogor District, West Java Province, Indonesia. Four logs 3 m long from the basal area of the 8-year-old trees were used in this study. Logs were converted into wood sample and then air-dried for 2 months to obtain the moisture content of 18%. Wood samples of 5 (w) x 1 (t) x 15 (l) cm were used for color measurement, while sample of 2.5 (T) x 2.5 (R) x 10 (L) cm was used for mass loss and dimensional stability measurements. Number of replications for each parameter of each combination process was 5 times.

2.2. Methods

2.2.1. MP process and combination processes
The process was carried out within a small pyrolysis reactor under atmospheric pressure in the presence of limited oxygen. MP process only was applied by heating the sample for 2 hours at different temperatures (170 and 190°C) without steam, while combination (MPS) process was employed by flowing steam into the reactor at different durations (0.5 and 1 hour) during the 2 hours heating period. After finishing the process, the reactor was turned off and allowed to cool naturally. Wood samples were then taken out at the next day and stored at room temperature before testing.

2.2.2. Mass loss measurement
Mass loss was determined by comparing the mass of wood samples before (M0) and after (Mf) process. The value was measured by formula by equation:

\[
\text{Mass loss (\%)} = \frac{M_0 - M_f}{M_0} \times 100
\]

2.2.3. Color measurement
The color measurement of wood surface before and after process was carried out by the CIE Lab* system. The HP Deskjet Ink Advantage 1515 scanner was used to collect the images. The image was processed by Image-J Fiji software to determine L*a*b* for color change measurement. The L*, a*, and b* coordinates were represented degree of lightness, greenness and redness, and degree of blueness and yellowness, respectively. The measurement was carried out at ten different points (five points on each surface) of each sample. The total color difference before and after treatment (ΔE) was calculated based on equation 2. The ΔE value was then classified as small (1.0–3.0), moderate (3.0–6.0), and large (> 6.0) considered to Hunter Lab (1996).

\[
\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}
\]
2.2.4. Dimensional stability measurement

Anti-Swelling Efficiency (ASE) was used as indicator to evaluate dimensional stability [14]. The swelling was measured at nine different marked positions (@3 positions for T, R, and L direction) before and after soaking wood sample within water for 24 hours at room temperature. Water absorption (A), volumetric swelling (S), and ASE was determined using formula by equation 3, 4, and 5, respectively:

\[
\% A = \left[ \frac{W_t - W_0}{W_0} \right] \times 100
\]

\[
\% S = \left[ \frac{V_t - V_0}{V_0} \right] \times 100
\]

\[
\% ASE = \left[ \frac{S_c - S_t}{S_c} \right] \times 100
\]

where: \( W_t \) is sample weight after soaking, \( W_0 \) is sample weight before soaking, \( V_t \) is sample volume after soaking, \( V_0 \) is sample volume before soaking, \( S_c \) is swelling of control wood, and \( S_t \) is swelling of heated wood.

3. Results and Discussion

Color change in wood surface due to processes was presented in Figure 1. It shows that temperature has significant effect on wood color, conversely for steam flow (Table 1). The surface treated teakwood tends to be darker and color uniformity is well increases compared to those of untreated wood. This result was similar to [5,12]. When steam is applied, the brightness will improve. Since total color change (\( \Delta E \)) of all treatments was greater than 6, so that they are classified as large color changes (Figure 2). Result also shows that the \( \Delta E \) is greater in treated wood without steam (MP process). Compared to that of MP process, total color change of treated wood with steam flow (MPS process) decreased by 11.25 and 13.79% at temperature of 170 and 190°C, respectively. This may be caused by the release of accumulated decomposition products of cell wall components on the wood surface. The dark of the board surface is caused by decomposition of the accumulated low-molecular carbohydrates [15].

![Figure 1](image-url)

**Figure 1.** Wood color change of treated teakwood, (a) untreated, (b) 170°C, (c) 170°C + 0.5 hours steam, (d) 170°C + 1 hours steam, (e) 190°C, (d) 190°C + 0.5 hours steam, (g) 190°C + 0.5 hours steam

The color of wood surface is often used to estimate the severity of treatment applied. The darker of the treated wood indicates the higher intensity of treatment. The higher intensity treatment (higher temperature and longer duration) could have negative impact on wood properties [16,17].
Decomposition or/and modification of chemical component of wood plays important role in the change in color of wood surface [18].

**Table 1.** Two-way analysis of variance of effect of temperature and steam on mass loss, color change, and anti-swelling efficiency of treated teakwood at the 95% confidence level

|                      | Mass loss |               | Color change (ΔE) |               | Anti-swelling efficiency (ASE) |
|----------------------|-----------|---------------|-------------------|---------------|-------------------------------|
|                      | F         | P-value       | F                 | P-value       | F                             | P-value       |
| Temperature (T)      | 199.849   | 0.000**       | 263.706           | 0.000**       | 36.464                       | 0.000**       |
| Duration of steam (S)| 9.901     | 0.001**       | 4.384             | 0.24 ns       | 3.291                        | 0.55 ns       |
| T x S                | 8.684     | 0.001**       | 0.877             | 0.429 ns      | 2.244                        | 0.128 ns      |

*significant effect (P<0.05); **very significant effect (P<0.01); ns, not significant effect

**Figure 2.** Total color change (ΔE) of MP and MPS treated teakwood

**Figure 3.** L*a*b* value of MP and MPS treated teakwood

Figure 3 shows the three color coordinates (L*, a*, and b*) before and after process. The lightness of wood surface decreased after treatment as shown by the decrease of L* value. This result indicates
that wood color becomes darkening, and it is suitable to Figure 1. But, generally with steam inside the reactor, wood surface becomes more brightness. Result also shows that after treatment, wood surface becomes more redness and yellowness which indicated by a* and b* value increased, respectively. Similar results have been reported in previous study [5,18]. Thermal modification caused color change to yellow, brown, red or grey [18].

Usually, wood quality of treated wood is predicted through mass loss after the treatment. Mass percentage loss of temperature 170⁰C and 190⁰C was 14.99% and 18.46%, respectively (Figure 4). The higher the temperature, the greater the mass loss. Similar to the total color change, steam flow has positive effect to lowering the mass loss. Lower mass loss was obtained because of the removal of volatile degradation products from the reactor, especially acetic acid [19]. Therefore, further degradation of polysaccharides should be minimized.

Consequently, mechanical properties are expected slightly decreased after processing because mass loss is related to mechanical properties of wood. Result shows that modulus of elasticity and modulus of rupture reduced significantly when the mass loss above 16% [3,20]. Based on analysis of variance (Table 1), both temperature and steam have significant effect to mass loss.

In current study, dimensional stability was evaluated by water absorption, volumetric swelling, and ASE. Based on data obtained, these two process was able to improve dimensional stability because water absorption decreases (Figure 5) as well as volumetric swelling (Figure 6). Water absorption was reduced by 14% and 30% at temperature of 170⁰C and 190⁰C, respectively compared to untreated wood; while the swelling was only about 3-5%.
Result shows that ASE was increased along with increasing the temperature (Figure 7). This finding is different from [5]. He stated that ASE of heated young teakwood at temperature of 150°C and 180°C was 29.17% and 26.47%, respectively. Although combination temperature and steam has no significant effect on ASE (Table 1), the ASE of combinations process was slightly greater than that of MP process.

![Figure 7. Water absorption, swelling, and ASE of MP and MPS treated teakwood](image-url)

The increase in wood stability indicates a decrease in wood hygroscopicity. Previous study reported that the increased dimensional stability was a contribution from decomposition or transformation chemical component of cell wall especially hemicellulose [9], the increased in relative proportion of crystalline cellulose [21], as well as the decreased in the amount of hydroxyl groups of wood [22].

From the study, it was clear that fast-grown teakwood which is treated by MP or by combination process has better characteristics than control wood. The wood became more stable and its colour almost similar to old teakwood. From the two aspects, treated wood is a good quality raw material for various purposes. Therefore, both of these processes have great potential to be applied in wood industries. If doing so, it will strongly support community teak forest development activities.

4. Conclusion
Mild Pyrolysis process generated darkening of wood surface and increase dimensional stability. After processing, wood surface shifted towards red and yellow, while the brightness decreases. The highest dimensional stability was obtained at 190°C with combination of steam for 1 hour. At this process, mass loss reached 16.92%, while water absorption and swelling was low. Steam flow into the pyrolysis reactor during MP process could minimized the negative impact of thermal modification. This combination resulted in lower mass loss but higher dimensional stability of treated wood.

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