Fixation of Soft-inner Part of Oil Palm Trunk by Close System Compression Method

R Hartono1*, W Dwianto2, I Wahyudi3, F Febrianto3, T Morooka4

1 Faculty of Forestry, University of Sumatera Utara, Jalan Dr. Mansur Medan, 20135
2 Research Center for Biomaterials, Indonesian Institute of Sciences, Jl. Raya Bogor Km.46, Cibinong Bogor 16911, Indonesia
3 Faculty of Forestry, Bogor Agriculture University, Darmaga, Bogor, 6000
4 Research Institute for Sustainable Humanosphere, Kyoto University, Japan

*rudihartono@usu.ac.id

Abstract. Compression by closes system compression (CSC) improved quality of the soft-inner part of oil palm trunk (S-OPT). The problem of compressed-wood was spring back or recovery of set, if it was exposed to moisture content. The objective of these study were to evaluate the recovery of set (RS) and weight loss (WL) of S-OPT by CSC. These methods were compared with heat treatment (HT) and steam treatment (ST). Density of S-OPT was 0.3 g/cm³. All samples were compressed to compression ratio of 50%. The compression of HT method used the temperature of 120, 140, 160, 180 and 200 °C for 0, 10, 30, 60 and 180 minutes; and ST method used temperature of 120, 140, 160, 170 and 180 °C for 0, 5, 10 and 30 minutes; while CSC method used temperature of 120, 140, 160, 180 and 200 °C for 0, 10, 20, 30 and 40 minutes. The results showed that the temperature and compression time contributed to the RS and WL values for all methods. Increasing compression temperature and time leads to decreased the RS value and to increased the WL value. The lower RS value indicated that S-OPT fixation would be better or high dimensional stability. Fixation of S-OPT by ST method was achieved at temperature of 170 °C for 30 min, CSC at temperature of 180 °C for 30 min, while HT method has not fixated until 200 °C for 180 min.

1. Introduction

Indonesia has very large oil palm plantation. In 2014, the area has reached 10.76 million ha spread across 25 provinces [1], where the largest area was in Riau and North Sumatera. Usually, oil palm tree will be replanted after 25 years old. When replanting, it will generate large amount of potential biomass particularly in the form of trunks. According to Febrianto and Bakar [2], replanting of oil palm plantation can produce 50.1 m³/ha saw wood originated from hard outer part of the trunk while 2/3 of its soft inner part still becomes waste.

The utilization of oil palm trunk had several problems, especially the soft inner of oil palm trunk (S-OPT). This is due to weakness of oil palm trunk, such as dimension stability, strength, durability and low machining properties. Its necessary to improve the quality of S-OPT, such as used the compression method.

Wood compression methods could be applied to improve the physical and mechanical properties of wood. Amin et al., [3] reported that this method significantly increased the physical and mechanical properties of Indonesian tropical woods, such as randu (Bombax ceiba L.), Angsana (Pterocarpus...
indicus), mindi (Melia azedarach L.), jengkol (Pithecellobium jiringa), Maesopsis (Maesopsis eminii), and mango (Mangifera spp.). Also this methods could be applied on non-wood species such as coconut oil wood and oil palm trunk have been developed [4], [5], [6].

However the major problem of compressed wood is recovery of set, which mean after compression, wood will recover to its initial thickness if it is exposed to moisture because of release of its internal stresses. Therefore permanent fixation of deformation is required to utilize compressed wood as commercial woods.

Many attempts have been made to fix the compressed wood, such as heat treatment (HT), steam treatment (ST), Close system compression (CSC). The HT method or heating wood under dry condition at high temperature was one methods to fixed wood. Inoue & Norimoto [7] reported that permanent fixation could be achieved at heating temperature 180°C for 20 hours; 200°C for 5 hours; or 220°C for 3 hours. Inoue et al. [8] developed a compression method to improve permanent fixation of compressive deformation in a short time by hygrothermal treatment using moisture in wood, which is called ST methods. Inoue et al. [8] reported that permanent fixation could be achieved at heating temperature 180°C for 8 min, 200°C for 1 min. The ST methods was modified by Amin and Dwianto (2006) with call Close system compression (CSC) method. This method resulted in a good fixation of randu wood [9].

In previous study, Hartono et al [10] reported that densification of the S-OPT by CSC successfully increased the density, modulus of elasticity, modulus of rupture, and compressive strength of S-OPT up to 90%, 190%, 155%, and 120%, respectively. Therefore, the objective of this study was to evaluated the fixation of S-OPT (based on recovery of set and weight loss) by close system compression (CSC). This methods will be compared with heat treatment (HT) and steam treatment (ST).

2. Materials and Method

Oil palm trunk (OPT) was collected from 40-year-old plantation in Bogor, Indonesia. Samples were prepared from soft inner of oil palm trunk (S-OPT) with the average density of 0.3 g/cm³. Samples for steam treatment (ST) having dimensions of 30 mm x 20 mm x 10 mm, while for heat treatment (HT) and close system compression (SCS) having having dimensions of 50 mm x 40 mm x 20 mm in length, width, and thickness, respectively with 6 replication.

In this study, the evaluated for fixation test was done by recovery of set (RS) and weight loss (WL). The result of CSC methods will be compared with HT and ST methods.

Before compression, all samples were dried in the oven at 103°C ± 2°C for 24 h and the oven-dried weight (Wo) and thickness (To) was measured. Then, for CSC and ST samples were soaked in water until saturated, while for HT sample was put in room condition. Samples of S-OPT were compressed to a compression ratio of 50%, based on Hartono et al [11], with 6 replication. The temperature and time variation of wood compression was showed at Table 1.

| No | Compression Method         | Temperature (°C) | Time (Minutes) |
|----|----------------------------|------------------|----------------|
| 1  | Heat treatment             | 120, 140, 160, 180, 200 | 0,10, 30, 60, 180 |
| 2  | Steam treatment            | 120, 140, 160, 170, 180 | 0, 5, 10, 30    |
| 3  | Close system compression   | 120, 140, 160, 180, 200 | 0,10, 20, 30, 40 |

The recovery test and weight loss were performed by soaking the samples in room-temperature water for 24 h and then in hot water (100°C) for 30 min [12]. The recovery of set (RS) and the weight loss (WL) was calculated as follows:

\[
RS = \left[ \frac{(Tr - Tc)}{(To - Tc)} \right] \times 100\% \tag{1}
\]

\[
WL = \left[ \frac{(Wo - Wr)}{Wo} \right] \times 100\% \tag{2}
\]

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Where $T_0$ is oven-dried thickness before compression, $T_c$ is oven-dried thickness after compression, $T_r$ is oven-dried thickness after recovery, $W_0$ is oven-dried weight before compression and $W_r$ is oven-dried weight after recovery. All the dimensions of the samples were measured in the oven-dry condition.

3. Results and Discussion

3.1. Recovery of Set

The result showed that RS value by SCS, HT and ST method were $97.35\%(-19.20\%)$, $97.35\%-8.85\%$, $95.29\%-6.49\%$, respectively. The RS value was showed at Figure 1.

![Figure 1](image)

**Figure 1.** Compression temperature and time on RS value by several compression methods, (a) heat treatment, (b) steam treatment, (c) close system compression
Based on the charts, it appears that compression temperature and time give effect to the RS value on all compression methods. The RS decreased with increasing compression temperature and time. A lower RS value indicates that S-OPT fixation would be better.

Comparison of RS value from 3 compression methods at 120°C, 140°C, 160°C and 180°C for 30 min were showed at Figure 2.

![Figure 2. The RS value from several compression methods](image)

Compression method that has been done will produce different RS values. The most rapid method of fixation was ST, followed by CSC and the slowest was HT. CSC method was between the HT and ST method, but produced similar RS to the ST method.

ST and CSC method have similar principles, hot steam that delivered or produced will be trapped in an airtight equipment press. The difference was that in the ST method hot steam flowing from the boiler to the press machine, while in the CSC method, hot steam was produced from water coming out from the wood. Hot steam will soften the hemicellulose and lignin. Softening hemicellulose and lignin can accelerate wood deformation and fixation.

Heat treatment will degrade cellulose from hydroxyl groups that begins at amorphous regions and continue to the semi-crystalline regions, then the last at the crystalline regions. The change from amorphous to crystalline regions areas decreased of water absorption and indicated of good dimensional stability [13]

ST method requires a short time to produce wood fixation. Inoue et al. [8] reported that a permanent fixation of Sugi wood was achieved at a temperature of 180°C for 8 min or 200°C for 1 min. While on the S-OPT, a permanent fixation was achieved by ST method at 170°C for 30 min and by CSC at 180°C of 30 min. This difference is due to differences in S-OPT tissue structure, where in S-OPT is more dominated by ground paranchyme and few vascular bundles. The chemical composition on the ground paranchyme tissue contains a lot of extractive substances especially starch.

Permanent fixation with HT method requires a longer time. Inoue & Norimoto [7] reported that the permanent fixation at Sugi wood at a temperature of 180°C for 20 h, or 200°C for 5 h, or 220°C for 3 h. While the S-OPT, permanent fixation had not been achieved at temperature of 200°C for 3 h and still resulted RS value of 8.85%.

Permanent fixation mechanism on the HT method was caused by the release of internal stress in the microfibrils through degradation of hemicellulose components, whereas on the ST method, it was caused by cross-linking reaction of chemical components in the matrix and increased of crystalline regions in the cellulose structure [14]
3.2. Weight Loss

The result showed that WL value by SCS, HT and ST method were 1.71–21.06%, 2.83–11.86%, and 3.67–21.63%. The WL with HT, ST and CSC methods was showed at Figure 3.

![Compression temperature and time on WL value by several compression methods, (a) heat treatment, (b) steam treatment, (c) close system compression](image-url)

**Figure 3.** Compression temperature and time on WL value by several compression methods, (a) heat treatment, (b) steam treatment, (c) close system compression
From Figure 3 showed that compression temperature and time contributed to the WL value on all methods which were attempted. The WL value increased with increasing compression temperature and time. The greater WL value indicated that S-OPT chemical components would be degraded.

Comparison of WL from 3 compression methods at 120 °C, 140 °C, 160 °C and 180 °C for 30 min were showed at Figure 4

![Figure 4](image)

Figure 4. The WL value from several compression method

As shown in Figure 4, there was a tendency that WL value would increase a long with temperature and time compression. WL lowest value was resulted by HT method, followed by CSC and greatest value by ST method. It was seen that WL value by CSC method was between the HT and ST method.

ST and CSC were compression method by combining several factors such as temperature, compression time, and hot steam from water in wood which evaporates during the compression process. Increased temperature and pressure steam will soften the chemical components of wood or even can degrade it.

Softening and degradation of the chemical components of wood depends on several conditions, they were compression time, temperature, moisture, steam. Outline of softening and degradation temperatures of wood components can be seen in Table 2 [15]

| Chemical Component of Wood | Tg, °C | Severe degradation start at, °C |
|----------------------------|--------|---------------------------------|
| Cellulose                  |        |                                 |
| Dry                        | >230    | >200                            |
| Wet                        | >220    | >200                            |
| Hemicellulose              | 160-220 | <25                             |
| Dry                        | >160    | >160                            |
| Wet                        | <25     | >160                            |
| Lignin                     | >150    | 60-90                           |
| Dry                        | >160    | >160                            |
| Wet                        | >90     | >160                            |

Note: Tg = The glass transition temperature

Table 2 showed that in dry conditions, lignin softening occurs at temperatures above 150 °C, while the hemicellulose at 160-220 °C. It is clear that the condition of the sample affect the WL value. In the dry conditions of the test sample as in HT method, the WL value was smaller than those on ST and CSC method. WL value on the HT method up to temperature of 200 °C for 180 min reached 11.86%.

In wet conditions, softening the lignin and hemicellulose has occurred at a low temperature of between 60-90 °C for lignin and below 25 °C for hemicellulose. Degradation both occur at temperatures above 160 °C.

In addition to temperature and S-OPT condition, hot steam pressure will also affect the value of WL. Hot steam pressure will push moisture out from S-OPT. The release of water vapor from S-OPT was
likely to cause damage to the chemical components so that some chemical components of S-OPT especially volatile substances and extractive substances also will leak out. This showed the high value of WL was ST method and CSC.

The ST method achieved the WL value higher than CSC method. It was caused by the steam pressure. In the method of ST, hot steam pressure were generated from the boiler and the pressure can be adjusted up to 10 kg/cm$^2$, while the CSC method relied only on water that was in the S-OPT. The WL value on ST method temperature of 180 $^\circ$C for 30 min reached 21.63%, while the CSC method only 12.59%.

The relationship between the RS and WL value from S-OPT by CSC and ST method was presented in Figure 5.

![Figure 5](image_url)

**Figure 5.** Relationship between RS and WL value by CSC and ST method

Based on Fig 9 showed that on CSC and ST method, the WL value to 3%, still slightly lower the RS value. However, after the WL value of 3%, a very drastic decline of RS took place. The fixation of CSC and ST were achieved by WL value of 12.59% and 19.17%, respectively. WL value resulted by the CSC method was smaller than ST method.

### 3.3. Comparison of RS and WL value between S-OPT and Sengon Wood

Comparison of RS and WL between S-OPT and Sengon wood with CSC method was presented in Table 3. Both types of wood have the same density with average 0.3 g/cm$^3$. Compression was done for 30 minutes. The RS and WL value of Sengon wood were referenced from Amin et al. [16]

| Temperature ($^\circ$C) | RS (%) | WL (%) | RS (%) | WL (%) |
|-------------------------|--------|--------|--------|--------|
| S-OPT                   |        |        |        |        |
| 120                     | 89.33  | 3.22   | 61.45  | 0.75   |
| 140                     | 54.32  | 3.89   | 37.52  | 1.90   |
| 160                     | 8.37   | 7.17   | 3.44   | 4.14   |
| 180                     | 1.36   | 12.59  | 1.60   | 10.52  |

* Source: Amin et al. [16]

Table 3 was shown that the RS value of S-OPT at 120 $^\circ$C, 140 $^\circ$C and 160 $^\circ$C greater than Sengon wood, but at a temperature of 180 $^\circ$C, it was almost the same value. S-OPT at a temperature of 180 $^\circ$C
for 30 minutes reached RS of 1.36% and WL of 12.59%, while on Sengon wood, resulted RS of 1.60% and WL of 10.52%.

The differences of RS and WL value of S-OPT and Sengon wood due to differences in anatomical structure and chemical properties between them. S-OPT were more dominated by ground parenchyme, whereas parenchyme cells in Sengon relatively limited. Ground parenchyme tissue contains a lot of starch. The starch content in the ground parenchyme tissue reached of 5.9% [17]. When compressed by CSC method, with a long compression time and steam pressure, then extractive substances especially starch that present will be dissolved and carried out, resulting in higher WL value of S-OPT than Sengon wood.

4. Conclusions
Compression temperature and time greatly contributed to RS and WL value for all of compression method. Increasing compression temperature and time leads to decreased the RS value and to increased the WL value. The lower RS value indicated that S-OPT fixation would be better or high dimensional stability. The fastest compression method to resulted fixation was ST method, followed by CSC method, and last HT method. However, the highest WL value of S-OPT was produced by ST method, followed by CSC and the lowest was the HT method. Fixation of S-OPT with ST method achieved at temperature of 170 °C for 30 min, with the CSC at 180 °C for 30 min, while HT method at 200 °C for 180 min had not reached fixation. Although fixation with CSC method is not as fast as with ST method, but this method has several advantages, among others more simple, easy to apply, can be used in large-sized specimen. The difference of RS and WL value between S-OPT and Sengon wood were due to differences in anatomical structure and chemical composition. S-OPT anatomical structures dominated by ground parenchyme tissue which contains starch and fewer vascular bundles.

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