Morphological Behavior of Densified Low-Density Plantation Wood Species: A Preliminary Study

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ABSTRACT This work presents the morphological effect of densification technique employed on underutilized low-density plantation wood species, Batai (*Falcataria moluccana)* with an average density of 360 kg/m^3 on air-dried weight. Timbers were cut into laminas, air-dried and conditioned. Laminas were pre-treated using pressurized steamer at 130^{o}C, 175 kPa for 10 minutes to soften the wood structure. Densification process happens when the laminas were hot pressed immediately at 170^{o}C, 2 MPa, for 45 minutes. The targeted thicknesses of densified laminas were controlled with 5 mm, 10 mm, and 15 mm metal stoppers. The laminas were left to cool in the hot press machine until the temperature of the lamina reached below 100^{o}C to reduce springback effect before conditioning. Undensified laminas were used as control. Light microscopy was used to observe the morphological structure for both densified and undensified laminas. The microscopic result showed that the vessels of cell structures can be collapsed easily. The volume of the void spaces had decreased compared to undensified lamina which contributed to the improvement in the density of the lamina. However, as the densified lamina were left to condition until 7 days, the vessels started to swell up.

KEYWORDS: Densification; Low-density Wood Species; Plantation Wood; Morphology.
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INTRODUCTION

With the increasing demand for good quality wood materials, overly reliance on high-quality wood has caused the drastic decrease of these natural resources in the forest. Besides, the density of wood is the characteristics frequently used in determining the quality of the wood itself. Densification of wood has existed over a century with the earliest discovery was found in 1900 and patented in the USA. Since then, many other investigations which aim to modify the features of wood have been found, with various terms being employed such as Lignostone/ Lignofol, Compreg, Staypak, Thermo-Mechanical, Thermo-Hygro-Mechanical, Viscoelastic-Thermal-Compression, and Thermo-Vibro-Mechanic (Şenol & Budakçı, 2016).

The main objective of this wood modification is to enhance the negative features of wood materials, especially on low-density wood species. Morsing (2000) have summarized the modification of wood into three stages, i) softening or plasticizing of cell well, ii) compress the wood while it is still in a softened state, and iii) fixation of the wood in deformed state or moulding. Many types of research have been carried out to determine the effect of densification method on low-density wood species. The types of species include beech wood (Dömény *et al.*, 2018), Maritime pine wood (Esteves *et al.*, 2016), paulownia wood (Yu *et al.*, 2018), Scots pine (Laine *et al.*, 2013), poplar wood (Dogu *et al.*, 2016). The density of these species ranges from 280 kg/m^3 up to 710 kg/m^3, which are in the range of light to medium hardwoods. Apart from pine wood, less study has been carried out regarding other low-density plantation wood species such as Batai wood which has average dried weight density of 360 kg/m^3 (Meier, 2019). Batai wood is one of the fast-growing plantation wood species which reported to have a clear bole and could grow up to 45 meters high (Bhat *et al.*, 1998). Therefore, this study aims to determine the effect of densification on Batai wood (*Falcataria* *moluccana*) in the aspect of microscopic view with three different targeted thicknesses (5 mm, 10 mm, and 15 mm).

METHODOLOGY

The batai woods were first sawn, planed, and kiln-dried. After that, the woods were cut into laminas in which the length ranges from 100 mm to 500 mm, 100 mm width and 20 mm thick. The laminas were then left to condition at 20°C, 65% relative humidity. Prior to pressing, the laminas were pre-treated with steam by using a modified steam chamber. The steaming of laminas was carried out for 20 minutes at boiling point. Subsequently, the laminas were pressed using a hot press machine at 170°C for 45 minutes (Dogu *et al.*, 2016), where the different pressures were applied to achieve different targeted thicknesses. The pressures ranging from 12 MPa to 6 MPa have applied for the thickness of 5 mm to 15 mm. Metal stoppers of 5 mm, 10 mm, and 15 mm were used to control the desired thicknesses of the laminas at the end of the process.

The different targeted thicknesses resulted in different compression set were calculated using formula 1 (Laine *et al.*, 2016).

$$Compression\ set\ (\%) = \frac{Original\ thickness - Targeted\ thickness}{Original\ thickness} \times 100\% \tag{1}$$

The density of wood before and after pressing was calculated by using formula 2. The changes in density of laminas when left to condition until one week were also recorded. As for the microscopic view, high-performance research microscope NIKON SMZ1500 was used in this study.

$$Density\ (\frac{kg}{m3}) = \frac{Mass\ (kg)}{Volume\ (m^3)} \tag{2}$$

RESULT AND DISCUSSION

Figure 1 refers to the average density of lamina compressed to targeted thicknesses of 5 mm (5T), 10 mm (10T), and 15 mm (15T). Lamina compressed until 5 mm has the highest average density as compared to 10 mm and 15 mm targeted thicknesses of laminas. The average density directly after compression could reach up to 184%, which is 919.72 kg/m^3. As the laminas were left to conditioned for 1-week, average density only decreases gradually from day to day. This might due to the release of inner stresses as it was in contact with the surrounding moisture. Gong *et al.* (2006) found that higher compression set tends to springback easily due to the inner stresses stored during the densification process. This sufficiently explained because 5 mm targeted thickness has a compression set of 75% as shown in Table 1.

However, Figure 2(b) to 2(d) gave different types of implications where the lamina was compressed in a way that the vessels, as well as fibres of the wood structures, were completely pressed, and no void volume could be detected directly after compression. As the batai lamina left to condition until day 4, the vessels can be seen to swell up a little but remain in the deformed state until day 7. Tu *et al.* (2014) once claimed that the higher the compression set of wood, the higher the deformation rate and large reduction in the void volume. Although the average density decreases gradually in this study, the vessels of the wood structures do not affect greatly, further work will be done to discover this behaviour.

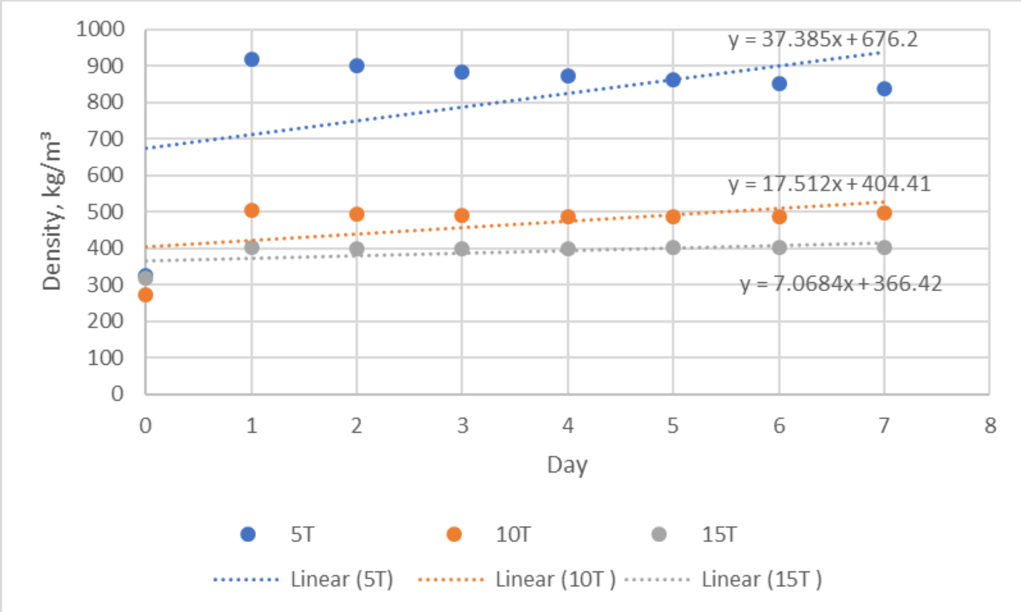

Figure 1. Average density of wood compressed until targeted thicknesses of 5 mm, 10 mm, and 15 mm respectively.

Table 1. Compression set for different targeted thicknesses of wood after densification.

Targeted thickness (mm)	Compression set (%)
5	75
10	50
15	25

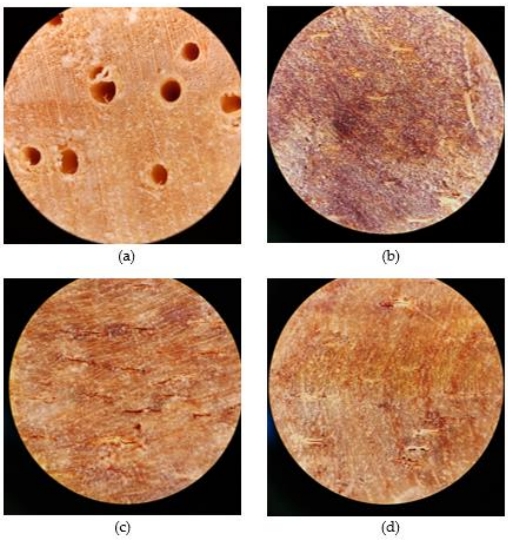

Figure 2. (a) Vessels of undensified wood. (b) Microscopic view of vessels densified with 5 mm targeted thickness at day 1. (c) Microscopic view of vessels densified with 5 mm targeted thickness at day 4. (d) Microscopic view of vessels densified with 5 mm targeted thickness at day 7.

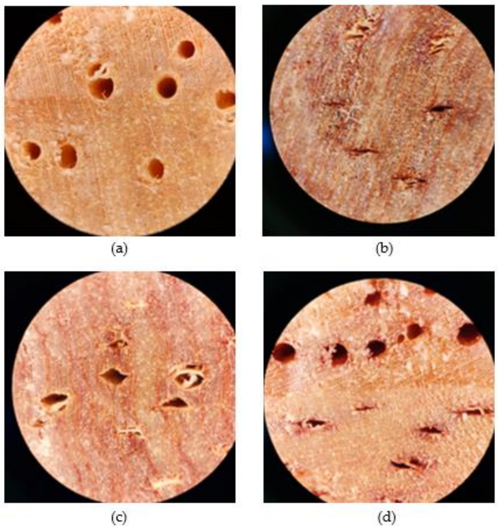

Figure 3. (a) Vessels of undensified wood. (b) Microscopic view of vessels densified with 10 mm targeted thickness at day 1. (c) Microscopic view of vessels densified with 10 mm targeted thickness at day 4. (d) Microscopic view of vessels densified with 10 mm targeted thickness at day 7

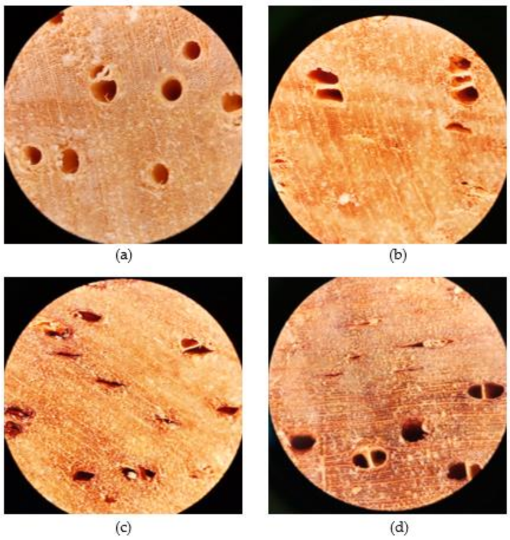

Figure 4. (a) Vessels of undensified wood. (b) Microscopic view of vessels densified with 15 mm targeted thickness at day 1. (c) Microscopic view of vessels densified with 15 mm targeted thickness at day 4. (d) Microscopic view of vessels densified with 15 mm targeted thickness at day 7.

Apart from that, the wood compressed until 10 mm has a relatively lower increase in average density after pressing process as compared to 5 mm targeted thickness. Figure 1 gives the average density after compression was 503.25 kg/m^3 while the initial undensified wood has an average density of 273.57 kg/m^3. The average increase in density was approximately 84%. Figure 3(b) shows the behaviour of vessels directly after densification, the vessels collapsed but not completely closed. As it conditioned until the 4th day (Figure 3c), only part of the vessels swells a little. When reaching to 7th day (Figure 3d), the vessels at the surfaces of densified lamina tends to recover back to the state of undensified lamina. This behaviour might due to the surfaces have in contact with moisture. Parasini *et al.* (2014) once claimed that when the absorbed moisture surpasses the bound water in the cell wall, wood tends to swell which will affect dimensional stability. Therefore, moisture content might be responsible for the changes in 10 mm targeted thickness of the wood.

Lastly, the average density of wood compressed until 15 mm targeted thickness has increased by 27% after densification. It is lower as compared to the previous two thicknesses, 5 mm and 10 mm respectively, but the average density remains stable at 400 kg/m^3 until day 7. As the compression set for 15 mm targeted thickness was only 25%, less deformation rate can be detected. This is further explained in Figure 4(b) where the vessels were compressed and collapsed only at the surfaces of the wood. The shapes of vessels at the middle of the laminas were in rectangular shape where they did not close completely. When conditioned until one week, the vessels at the middle of the laminas have higher tendency to recover (Figure 4d). The reason for this is the internal stresses that stored up were relaxed during conditioning. The hygroscopic nature makes it easier for the laminas to exchange water molecules with the surrounding environment to achieve equilibrium moisture content (EMC) (Zhou *et al.*, 2013) and this only happens at the middle of the wood.

CONCLUSION

In summary, the density of low-density plantation wood species can be improved through the process of densification. This happens as the wood structures especially the vessels can be seen to collapse and changes its structures. The reduction in the void volume of the lumen in wood cell wall has contributed to the increase in density of the wood itself. More work will be done to determine the moisture content which closely related to the density as well as the mechanical performance when manufactured into the structural product.

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