

# Physical and Morphological Changes in Heat-Treated and Densified Fast-Growing Timber Material

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**Abstract.** Heat treatment is a modification method that can alter the polymeric components of wood (cellulose, hemicellulose and lignin). Densification technology has emerged as one of the promising technologies capable of improving the properties of low-density wood. In this study, the effects of heat treatment and densification on moisture content, density, and morphological features of low-density *Paraserianthes falcataria* laminas were examined. Laminas were heat-treated (100°C, 120°C and 140°C for 1 hour) and compressed at 50% compression ratio. Non-heat-treated laminas, on the other hand, were compressed at 40-60% compression ratios. The changes in pores area, moisture content and density of the heat-treated and densified laminas were identified. The lowest moisture content for heat-treated laminas was at 120°C. Laminas with 60% compression ratio were observed to have the highest deformed pores, where it increased the density of the laminas. In summary, heat treatment and densification affected the properties of the laminas. Heat treatment at high temperatures resulted in decreased density and moisture content, while increasing the compression ratio during densification increased the density. The results suggest that combining heat treatment and densification could be a viable method for improving the properties of low-density wood.

## 1 Introduction

The decreasing supply of wood resources has become a growing concern in the last few decades, leading manufacturers to explore alternatives such as low-density wood [1]. However, this wood class has limitations, such as poor density and inadequate mechanical strength [2–4]. Therefore, low-density wood has been continuously subjected to treatments as researchers seek to enhance its performance and applicability.

Heat treatment and densification are promising technologies applied to wood to improve its properties [4,5]. Densification involves wood compression using high pressing temperatures, which enhances their density and mechanical performance [3]. This treatment modifies the cellular structure of wood, reducing void spaces and making it compact [2,4]. Heat treatment, on the other hand, is a modification method that can alter the polymeric

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components of wood (cellulose, hemicellulose, and lignin), where the temperature is usually set to 100°C and above, ranging from 15 to 24 hours [6]. Previous studies on densification demonstrated that the increase in density of low-density wood helped improve the mechanical properties (e.g., Modulus of Elasticity, Modulus of Rupture, compression strength), where the improvement of mechanical performance was mainly influenced by the notable improvement in density [7]. As for heat-treated wood, a previous study found that the heat-treated wood had a lower density than the untreated one [8]. Heat treatment also decreased the equilibrium moisture content of wood as the treatment temperature and duration increased [9]. Moreover, the dimensional stability of the wood improved after being heat-treated [5]. However, wood becomes more brittle after exposure to high temperatures and prolonged treatment durations [10].

This study aimed to investigate the influence of heat treatment and densification on the moisture content, density, and pores of *Paraserianthes falcataria*. This is to address the existing research gap and provide valuable insights into the combined effects of heat treatment and densification and the application of different compression ratios during densification.

## 2 Materials and Methods

### 2.1 Raw material preparation

Kiln-dried laminas from *Paraserianthes falcataria* in Figure 1 were obtained from Sapulut Development Sdn. Bhd. with an equilibrium moisture content of 12%. Heat treatment, densification process and tests were conducted at Universiti Malaysia Sabah.



**Fig. 1.** *Paraserianthes falcataria* laminas (left) and oven-drying process (right).

### 2.2 Heat Treatment

The laminas were subjected to heat treatment at three temperatures (100°C, 120°C, and 140°C) for 1 hour and labelled as HT 100, HT120 and HT 140, respectively. 100 ml of water was used alongside the heat treatment to prevent the laminas from cracking [11]. After heat treatment, data on physical properties were collected before the densification process..

### 2.3 Densification

The densification process was conducted by referring to previous study, where the laminas were compressed using a hot-press machine (100°C, 6 MPa, 920 seconds) equipped with a cooling mechanism [4]. Heat-treated laminas were compressed at 50% compression ratio (CR), while non-heat-treated laminas were compressed at different compression ratios (40%,

50%, 60%). The compression ratio was determined by referring to the formula in equation (1).

$$CR = \frac{t_i - t_f}{t_i} \times 100\% \quad (1)$$

## 2.4 Pores Area Observation

The pores area on the cross-sectional of the densified and control (non-densified) laminas were observed using Nikon SMZ1500 stereo microscope with 3X magnification.

## 2.5 Moisture Content Test

Moisture content of the laminas were determined in accordance with ASTM D4442-07 (Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials) [12]. A total of four test pieces with dimensions of 8/10/12/20 mm (thickness) x 50 mm (width) x 300 mm (length) were prepared from each parameter. The initial weights of the test pieces were measured before being oven-dried at  $103 \pm 2^\circ\text{C}$  for 24 hours, as illustrated in Fig. 1. The test pieces were weighed again to determine their oven-dry weight. Moisture content was determined using equation (2).

$$MC = \frac{w_i - w_f}{w_f} \times 100\% \quad (2)$$

Note:

MC = Moisture content (%),  $w_i$  = Initial weight (g),  $w_f$  = Oven-dried weight (g)

## 2.6 Density

The density of the laminas was identified using ASTM D2395-14 (Standard Test Method for Density) [13]. A total of four test pieces with dimensions of 8/10/12/20 mm (thickness) x 50 mm (width) x 300 mm (length) were prepared from each parameter. The density was determined using equation (3).

$$D = \frac{m}{v} \quad (3)$$

## 2.7 Statistical Analysis

Statistical analysis was performed using Statistical Package for Statistical Sciences (SPSS) software. Multiple comparison was conducted using post-hoc (LSD) test, with  $p \leq 0.05$ .

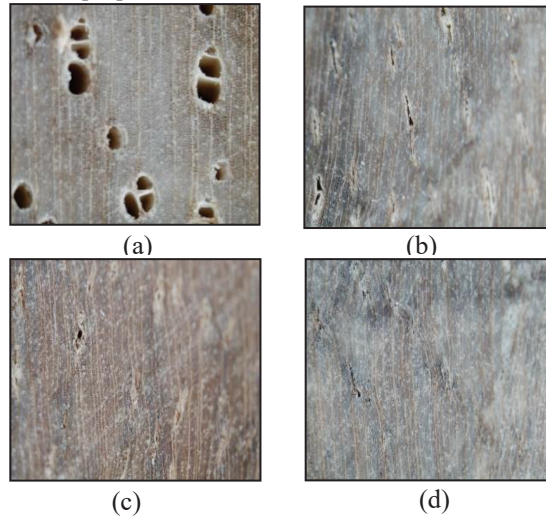
# 3 Results And Discussion

## 3.1 Heat-treated laminas

### 3.1.1 Pores Area

Fig. 2 shows the pores area of heat-treated and densified *Paraserianthes falcataria* laminas. The control had the highest number of visible pores than other parameters, while HT 140 and HT 120 have the least number of visible pores. Higher pores deformation was observed as the heat treatment temperature increased. Similarly, another study discovered that applying

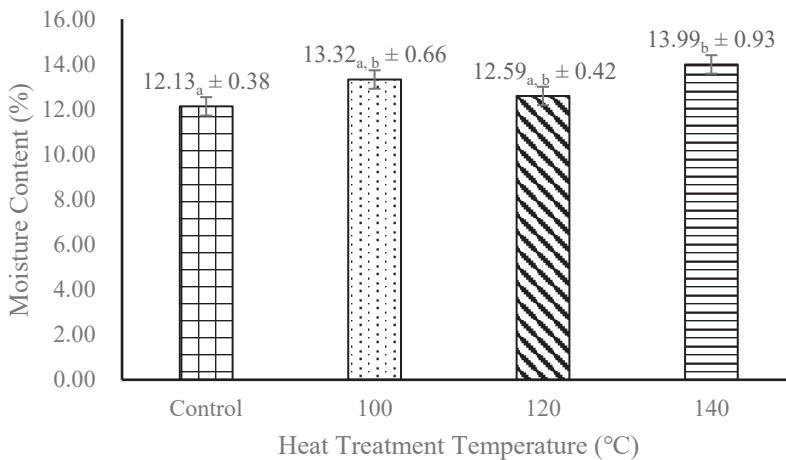
heat treatment enabled the wood structure to soften, thus improving the compressibility of wood during densification [14].



**Fig. 2.** Laminas pores area observation stereo microscope; (a) control, (b) HT100, 100°C, (c) HT 120, 120°C, and (d) HT 140, 140°C.

### 3.1.2 Moisture Content

It is essential to know the amount of moisture content in wood as moisture content affects the physical properties of wood. Figure 3 shows the moisture content of heat-treated and densified *Paraserianthes falcataria* laminas. Control had the lowest moisture content and HT 140 had the highest moisture, where both were significantly different from each other. Meanwhile, no significant differences were found between control, HT 100 and HT 120. In addition, HT 100, HT 120 and HT 140 also showed no significant differences.

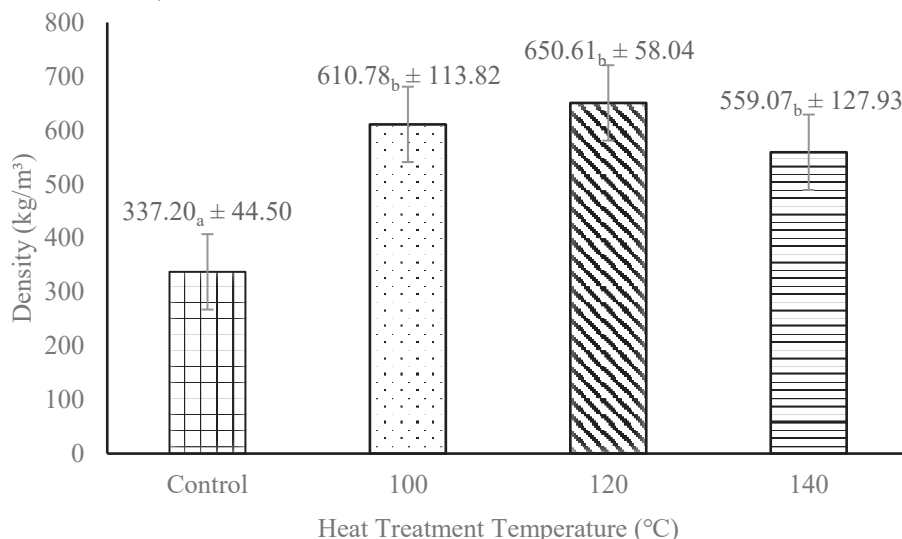


**Fig. 3.** Means and standard deviations of moisture content at different temperatures with alphabets (a, b) indicating significant different ( $p \leq 0.05$ ).

The result displayed in Fig. 3 showed that HT 140 has higher moisture level than other parameters, despite the finding made by a previous study shown that increased heat treatment temperature led to decreased moisture content [15]. On the other hand, HT 100 had higher moisture content than HT 120, which was similar to the outcome from the previous study [15]. However, statistical analysis indicated that both are not significant different from each other. Similarly, HT 140 also did not have significant differences with other parameters, except for control. These interpretations indicated that no difference in moisture content although heat treatment temperature was increased.

### 3.1.3 Density

Wood density is associated with the mechanical strength of wood [2]. Fig. 4 showed that the control had the lowest density and HT 120 had the highest density. There are significant differences between control and other parameters. Meanwhile, no significant difference was found between HT 100, HT 120 and HT 140.



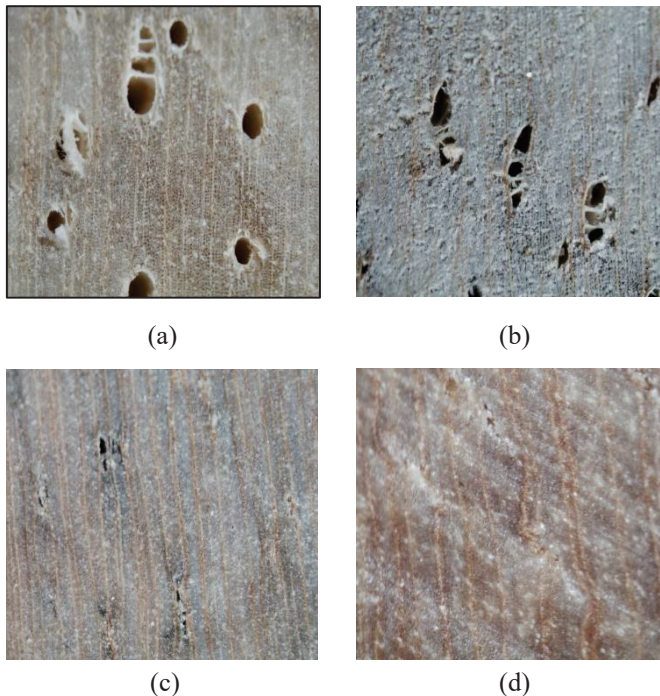
**Fig. 4.** Means and standard deviations of density at different temperatures with alphabets (a, b) indicating significant different ( $p \leq 0.05$ ).

Densification had remarkably enhanced the density of the laminas. However, increasing the heat treatment temperature did not have any influence on the density. Although HT 140 had lower density than HT 120 and HT 100, the statistical analysis showed that these parameters were not significantly different from each other. A similar finding was found in other study, where increasing the heat treatment resulted in decreased density [11]. The density decreased due to the degradation of polymeric components of wood (hemicellulose, cellulose and lignin) [6]. The purpose of the heat treatment is to enhance the dimensional stability; however, increasing the temperature might lead to reduction in density [6].

## 3.2 Non-heat-treated laminas

### 3.2.1 Pores Area

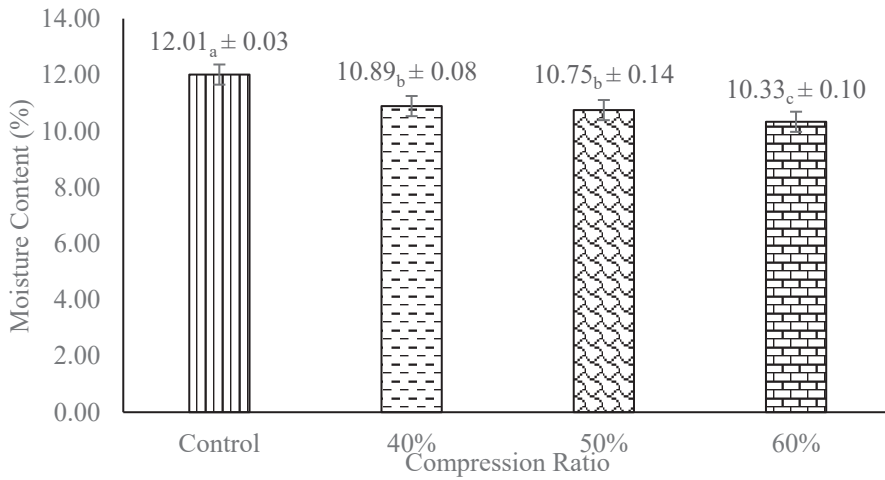
The pores observation displayed in Fig. 5 showed that 60% CR to have the lowest number of pores visible. 40% CR on the other hand, was shown to have deformed pores on top section, while having visible pores on the middle section, which indicated that it was only surface densified. As for 50% CR and 60% CR, higher number of pores were deformed on all sections, indicating that both were bulk densified. These results were similar to previous studies, where increasing CR have resulted in higher pores deformation rate [2,16].



**Fig. 5.** Pores observation using stereo microscope; (a) control, (b) 40% CR, (c) 50% CR, (d) 60% CR.

### 3.2.2 Moisture Content

The result is illustrated in Fig. 6, showing that 60% CR had the lowest moisture content value, followed by 50% CR, 40% CR and control. Statistically, 60% CR had a significant difference with all parameters, while 40% CR and 50% CR had no significant difference.

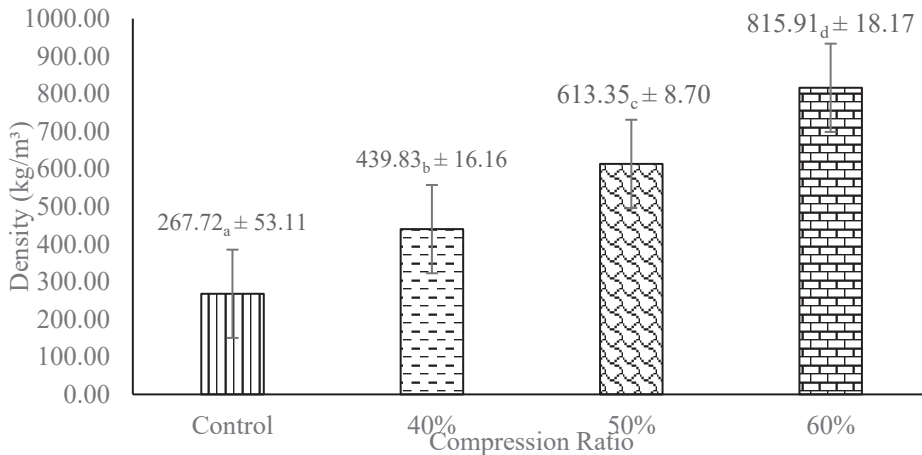


**Fig. 6.** Means and standard deviations of moisture content for densified laminas with different compression ratios with alphabets (a, b, c) indicating significant difference ( $p \leq 0.05$ ).

A previous study on the densification of coconut wood found that a lower CR enabled a higher frequency of moisture movement throughout the wood since the vessels were not flattened [17]. However, it contradicted this study, where the moisture content decreased as CR increased. These results are similar to the previous study by Zhao et al., where applying higher CR led to decreased moisture content [18]. The author also stated that higher CR reduced greater volume of lumens where most of the water is stored in the wood [18]. Nonetheless, applying 50% CR seems unnecessary since it showed no significant difference with 40% CR. Overall, all parameters obtained ideal moisture content recommended for further processing.

### 3.2.3 Density

The outcome displayed in Fig. 7 shown that 60% CR obtained the highest density, followed by 50% CR, 40% CR and control. Statistical analysis showed that all parameters have significant differences from each other.



**Fig. 7.** Means and standard deviations of density for densified laminas with different compression ratios with alphabets (a, b, c, d) indicating significant difference ( $p \leq 0.05$ ).

Higher CR led to a higher deformation rate of vessels, as shown in Figure 7, which also increased the density. Another similar study on *Pinus sylvestris* L. indicated that the wood achieved the highest density when 60% CR was applied during the densification process [16]. However, the author stated that applying higher CR (> 60% CR) might not be necessary for wood with original air-dried density starting from 500 kg/m<sup>3</sup>, because remarkable improvement in mechanical strength had already been achieved with a maximum of 60% CR (915 kg/m<sup>3</sup>) [16]. In this study, using 60% CR resulted in a remarkable increase in density (815.91 kg/m<sup>3</sup>), a recommended density for heavy-duty applications (e.g., building material) [17].

## 4 Conclusion

In conclusion, the findings provide insight into the pore characteristics, moisture content, and density of *Paraserianthes falcataria* laminas under various treatment conditions. Pores area evaluation on heat-treated laminas revealed that higher heat treatment temperatures reduced the number of visible pores. However, the moisture content of the heat-treated laminas varied inconsistently with heat treatment temperature. Despite prior studies suggesting that higher heat treatment temperatures result in lower moisture content, the results showed that HT 140 had higher moisture levels than other parameters. Densification, instead of heat treatment temperature, significantly influenced the density of the heat-treated laminas, with HT 120 exhibiting the highest density. In the case of the non-heated laminas, pores area observation revealed that increasing the CR resulted in a greater rate of pores deformation. 60% CR had the fewest visible pores. In contrast to previous studies, the moisture content of the non-heated laminas decreased as the CR increased. Despite this, all parameters achieved appropriate moisture content values for further processing. The density of the non-heat-treated, densified laminas increased with increasing CR, consistent with previous research. Among the parameters, 60% CR produced the highest density, which is appropriate for heavy-duty applications. These findings highlight the value of heat treatment and densification techniques in improving the properties of low-density wood. Further research and optimization of heat treatment and densification parameters could help to develop high-performance wood materials with improved mechanical properties and applicability.

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