

EFFECT OF HOT PRESSING MODIFICATION ON SURFACE PROPERTIES OF RUBBERWOOD (*HEVEA BRASILIENSIS*)

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ABSTRACT

This research aims to investigate the effect of thermal modification by hot pressing on surface characteristics of rubberwood. For this purpose, rubberwood specimens were thermally modified by hot pressing in an open system at three different temperatures (170, 185, and 200°C) for two different durations (1.5 or 3 h). Based on the results, the values of chromatic aberration (ΔE), contact angle and glossiness increased, and roughness decreased with increasing temperature and enlarging duration further. Although the contact angle had increased, it was still less than 90°. This aesthetic surface of rubberwood could be retained by using transparent organic coatings. The thermally modified rubberwood with excellent performance could be used as a material for solid wood flooring, wallboard, and furniture applications.

KEYWORDS: Thermal modification, rubberwood, surface characteristics, compression ratio.

INTRODUCTION

Rubberwood (*Hevea brasiliensis*) is one of the most important wooden raw materials in South East Asia. The fundamental purpose of planting rubberwood is harvesting latex. Generally, the rubber trees will be probably felled when they are around 20 years due to a decrease in latex production. Thus, rubberwood is an important by-product resource and commonly used as industrial raw materials (Jiang et al. 2019). The rubber tree cultivated in Thailand is felled about 300 thousand hm² every year, and rubberwood exported to China accounts for 90% above (Cheng et al. 2017). Thus, it is one kind of sustainable development of artificial forest commodity material. Rubberwood, which features beautiful textures and excellent machining performance, is suitable for making wooden products such as furniture and solid wood flooring. However, rubberwood is extremely prone to mildew, moth, and decay, owing to a higher content of nutrients in the wood, about 8% of starch and free sugar (Jie et al. 2018, Li et al. 2012). Thermal modification is an effective method to enhance dimensional stability and biological durability, nowadays, without

the use of chemicals to improve the applied value of low nature wood (Cademartori et al. 2015). Therefore, it is necessary to conduct thermal modification to improve the quality of rubberwood and enhance its utilization value.

The thermal modification technology can also change the color of the wood surface. The wood surface is darkened after heat treatment. The color changes in the heat-treated wood surface were due to the degradation products from the hemicellulose and lignin. Previously research showed that the color of heat-treated wood was mainly affected by some factors, such as temperature, duration, wood species, and moisture content (Ding et al. 2017, Esteves et al. 2008, Yildiz et al. 2006, Yu et al. 2010). Generally, the surface color of heat-treated wood changed with the increase of heat treatment temperature and duration. The deep color is appealing to customers because it is similar to the rare wood, such as sandalwood and rosewood.

However, the mechanical strength of heat-treated wood typically reduced significantly by using traditional thermal modification techniques, due to the thermal degradation of the chemical components in the cell walls. The bending strength, modulus of elasticity, compression strength, and impact bending strength of rubberwood heat-treated at 230°C for 3 h decreased 63.74%, 41.22%, 26.16%, and 57.07%, respectively, compared with the control groups (Zhao et al. 2019). In general, the mechanical properties of heat-treated wood gradually decreased with the increase of the heat treatment temperature and duration. The primary factor leading the reduction of mechanical properties was the degradation of hemicellulose and parts of the amorphous cellulose (Cai et al. 2019, Korkut et al. 2015). Another study on poplar wood (*Populus tomentosa*), the wood was thermally treated at 195°C for 3 hours and then subjected to hot pressing at 160°C. The results showed that the surface hardness, modulus of elasticity, and modulus of rupture of treated wood increased by more than 30% (Du et al. 2013). This combined modification method can effectively compensate the loss of mechanical properties caused by heat treatment.

To improve the physical and mechanical properties of heat-treated rubberwood, the rubberwood could be compressed with a relatively low compression ratio, and then it was heat-treated under a pressure of about 1 MPa by hot pressing. The physical and mechanical properties of the thermally modified rubberwood were improved significantly due to the compression (Zhou et al. 2019). However, during the heat treatment process, the surface characteristics of rubberwood have changed evidently, which has a great influence on its practical applications. Thus, it is necessary to research this aspect. In this study, the effects of heat treatment temperature and duration on the surface characteristics of heat-treated rubberwood were investigated. The obtained results could be effectively guided the practical productions of the thermally modified rubberwood and realized its high value-added utilization.

MATERIALS AND METHODS

Wood material

Rubberwood (*Hevea brasiliensis*) was harvested from Thailand. Rubberwood samples used in this study, with the moisture content of 14% and air-dried densities of 0.72 g·m⁻³, were purchased from the wood market. Wood board samples, measuring 300 × 105 × 20 mm (longitudinal (L) × tangential (T) × radial (R) direction), were prepared. Seven groups of samples (six for heat treatment by hot pressing and one for control) were prepared, and each group had 18 samples.

Thermal modification

The thermal treatment of rubberwood was performed with a laboratory-type single-opening hot press (BY302×2/15, Suzhou Xinxili, China). Three different temperatures (170, 185, and

200°C) and two different durations (1.5, 3 h) were selected for the heat treatment of rubberwood. The heat treatment process was divided into four stages.

In the first phase, the upper and lower hot plates were heated to the target temperature (170, 185 and 200°C), then the samples were placed on the lower hot plate. To control the target thickness of heat-treated wood, two 18 mm thick metal plates were placed on the lower hot plate on both sides of the samples. The hot-press was closed so that the upper surface of the sample had contact with the upper hot plate. Until the core temperature of the samples reached the target temperature, the samples were compressed. In the second phase, the pressure increased to 14 MPa in 30 sec and kept 3 min, and the wood was compressed to target thickness (18 mm) by using a distance stop. The compression ratio of wood was 10%. In the third phase, the pressure decreased to 2 MPa, and the wood samples were heat-treated at the target temperature for 1.5 or 3 h. In the last phase, the hot plates were cooled down to room temperature by introducing the flowing water into the hot plates for 30 min under the pressure of 2 MPa, and then the wood samples were taken away from the hot-press.

In order to determine the surface properties of heat-treated rubberwood, the treated and control samples were cut into small clear samples with dimensions of 50 (L) × 50 (T) × 18 (R) mm. All the samples were conditioned at 20°C and 65% relative humidity for 2 months prior to further testing. Surface performance tests were conducted in a laboratory with 25°C and 60% relative humidity from August to November 2019.

Chromatic aberration

The color measurements were measured according to GB/T 3979 (2008). The changes in surface color of the heat-treated rubberwood samples were measured by automatic colorimeter (Model:SC-80C, Zhuhai Tian Chuang, China) with D65 illuminant and a 10° standard observer. Ten replicates were used for each group, and the average value was calculated.

The values of L^* , a^* , and b^* of the samples were measured at five different locations on each. ΔE^* was used to indicate the difference between the color of the treated samples and the color of the control in this study. It had embodied the greater difference between the measured object and the control color that ΔE^* value was larger. And ΔE was calculated according to Eq. 1, and the average value was calculated:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

where: L^* - the brightness ranging from black (0) to white (100), a^* - the color coordinate from red (positive) to green (negative), b^* - the color coordinate from yellow (positive) to blue (negative).

Contact Angle

The water contact angle of the wood surface was measured according to GB/T 30693 (2014). The water drop size was 4 μ l. The datum after the water droplet contacts the wood surface for 15 s was recorded. Five replicates were used for each group, and the contact angles were measured at five different points of the same sample surface, and the average value was calculated.

Surface roughness

The stylus method was a well-accepted contact technique to evaluate the surface roughness of wood samples. Hence the surface roughness of the samples parallel to the fiber direction was measured by the stylus method according to DIN EN ISO 4287 (2009). The samples used for roughness tests were polished with 500 purpose sandpaper, and the values of the same measured

position were recorded before and after polishing. Five replicates were used for each group, and the surface roughness was measured at five different points of the same sample surface, and the average value was calculated. Three roughness parameters, including mean arithmetic deviation of profile (R_a) which is the average distance from the profile to the mean line over the length of assessment, mean peak-to-valley height (R_z), and maximum roughness (R_y) were used to evaluate surface roughness characteristics of the heat-treated wood samples.

Glossiness

Glossiness was a measure of the ability of a surface to reflect light. The surface glossiness of wood samples was measured using a gloss meter (KGZ-IC, Tianjin, China). The test angle was set at 60° according to ASTM standard D 2457-03 (Zhao et al. 2019). The samples for the glossiness tests were polished with 500 purpose sandpaper, and the values of the same measured position were recorded before and after polishing. Five replicates were used for each group, and the glossiness was measured at five different points of the same sample surface, and the average value was calculated. Measurements were carried out at two directions (Parallel to the fiber direction and perpendicular to the fiber direction). The glossiness of parallel to the fiber direction is denoted as GZL, and the glossiness of perpendicular to the fiber direction is denoted as GZT. The unit is GU.

For all parameters, multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant differences between average values of control and treated samples were determined using Duncan’s multiple range test at P value of 0.05.

RESULTS AND DISCUSSION

Chromatic aberration

The surface color of the heat-treated wood and control group are presented in Fig. 1. From Fig. 1, the surface color of heat-treated wood gradually deepened with the increase of heat treatment temperature. With the increase of treatment temperature, the surface color changed from beige to purplish brown. This color was a comfortable, warm tone that had attracted lots of people. Unlike the physical dyeing method, the distribution of the surface color was more uniform by using this thermal modification technique. Changes in color parameters of the untreated control group and the treatment group rubberwood are listed in Tab. 1.



Fig. 1: The color variation of the surface between untreated and thermal modified rubberwood.

Tab. 1: Color CIE Lab parameters and color difference between untreated and thermal modified rubberwood.

Temperature (°C)	Duration (h)	L*	a*	b*	ΔE^*
-	0	76.16	7.69	20.36	/
170	1.5	62.89	11.32	24.31	14.31
170	3	58.46	12.46	22.73	18.48
185	1.5	56.60	12.78	21.82	20.26
185	3	52.06	14.35	20.58	25.00
200	1.5	41.78	15.04	15.69	35.47
200	3	37.44	14.93	13.33	40.01

As the heating temperature rose, lightness (L^*) decreased steadily, and the longer duration, the more obvious the effect. The values of L^* of heat-treated wood decreased by 50.84% compared with the untreated control group. The parameter a^* increased slowly, and the parameter b^* decreased slightly, indicating that the color of the heat-treated wood was changed to red and blue with the increase of temperature and duration. As the duration was the same, the ΔE^* of the treatment group decreased obviously with the increase of treatment temperature. A similar trend was also noted by Sun et al. (2019).

Statistical analysis indicated that the P values of L^* and b^* with respect to treatment temperature and duration were both less than 0.05. Thus, both temperature and duration have significant effects on L^* and b^* values. After comparing the value of F, it is evident that treatment temperature is the most significant factor influencing L^* and b^* . The effect of temperature and duration on a^* is not significant, while the effect on ΔE^* is significant extremely. According to some previous studies, the main reason for the above results was that the thermal cracking reaction between cellulose and hemicellulose. A large number of hydroxyl groups were oxidized into carbonyl and carboxyl groups, thereby deepening the color of the wood. This was similar to the cause of color change in conventional heat-treated wood (Shukla et al. 2014, Srinivas et al. 2012). In addition, the change of wood extract content, especially phenols, caused by thermal modification was also an important factor affecting wood surface color (Esteves et al. 2008).

Contact angle

Fig. 2 presents the physical picture of the water contact angle of the control group and the treatment group. Fig. 3 shows the actual values of the water contact angle of each treatment group. The water contact angle of heat-treated wood increased with the increase of the treatment temperature and time. Statistical analysis indicated that treatment duration had significant effects on values of contact angle than temperature. Actually, during the heat treatment process, changes in physical and chemical occurred in the surface layers, which resulted in forming a modified surface with new characteristics (Li et al. 2011, Qin et al. 2019). During the heat treatment process, the porosity in the wood surface reduced significantly due to the surface densification, which resulted in the increase of the contact angle value of wood surface (Diouf et al. 2011, Unsal et al. 2005). In addition, the number of hydroxyl groups in the wood surface decreased notably because of the thermal degradation of the wood chemical components, which also resulted in the increase of the water contact angle.

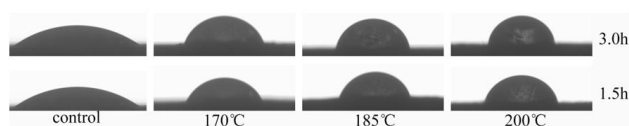


Fig. 2: The picture of water contact angle of the thermally modified rubberwood and untreated wood.

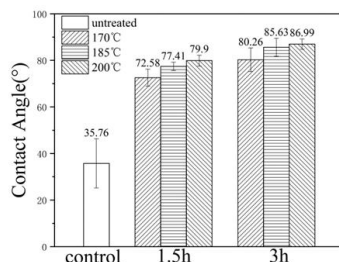


Fig. 3: The actual values of water contact angle of the thermally modified rubberwood and untreated wood.

Nonetheless, changes in the water contact angle of the treatment group was not obvious in this study. The contact angle of the samples heat-treated at 200°C for 3 h was 86.99°, still less than 90°. Because the contact angle value of the water droplet was lower than 90°, the wood surface exhibited hydrophilic property, resulting from the presence of hydroxyl groups in the heat-treated wood surface. In general, the hydrophilic surface was beneficial to make a good bond between the wood and coatings. The surface coatings need to wet, flow or penetrate into the cellular structure of wood to make a good bond between the wood and coatings. The results showed that the wettability of the specimens generally decreased with increasing treatment temperature. Although the effect on bonding strength between wood surface and coatings is small (Aleš et al. 2013).

Surface roughness

Changes in surface roughness parameters (R_a , R_z , and R_y) of the control group and the treatment group are presented in Fig. 4 (before sanding) and Fig. 5 (after sanding). As shown in Fig. 4, the untreated control group exhibited the highest surface roughness, while the lowest surface roughness was found in the specimens heat-treated at 200°C for 3 h. The parameter of R_z was measured to be 18.01 μm for the untreated control wood, while it was determined as 8.05 μm for the samples heat-treated at 200°C for 3 h (Fig. 4b). Similar results were found in the R_y value. The surface-densified wood specimens showed a glossy and smooth appearance after heat treatment processing. During the heat treatment process, the wood fibers in the surface layers were softened that some cell walls in the surface layers were plasticized and compressed, which improves the surface smoothness of the heat-treated wood (Ayrlmis et al. 2019).

In addition, significant changes in R_a was not observed among the treatment groups. The variation trend of the three parameters becomes clearer after sanding. As shown in Fig. 5, the values of three parameters decreased with increasing treatment temperature and time. When the wood was treated for three hours, the values of R_a and R_z were almost similar to the untreated control wood. It was distinctly that the three parameters of the treatment groups after sanding

were higher than those before sanding, especially the parameter R_z . With a compression ratio of only 10%, sanding may cause the densified layers in the wood surface to be destroyed. The results among treatment groups also showed that the value of higher temperature and shorter duration was roughly equal to that of lower temperature and longer duration. In consequence, the desired surface roughness may be obtained at a higher temperature but shorter duration, or at a lower temperature but longer duration. Statistical analysis indicated that treatment temperature was more significant than treatment time on surface roughness.

During the heat treatment process, surface densification reduced the porosity of the wood and made a glossy surface, which decreased the roughness of the wood surface. There was a negative correlation between the roughness and the compression ratio. Previously studies reported that surface roughness of heat-treated wood decreased with increasing treatment temperature and time (Aytin et al. 2015, Bekhta et al. 2014, Ratnasingam et al. 2012). This increase in smoothness or decrease in roughness was very important for many applications of solid wood. It is well known that the larger the surface roughness, the more coatings and adhesive is required. There should be enough coatings and adhesive to fill the valleys and form a continuous adhesive layer of equal thickness. Thus, further studies are needed to establish a correlation between surface roughness and coating material amount. To know which type of surface topography in terms of roughness parameters provides a higher bonding strength and fewer coatings, we might be able to choose appropriate parameters of surface roughness. It is also important to know if sanding is a necessary step.

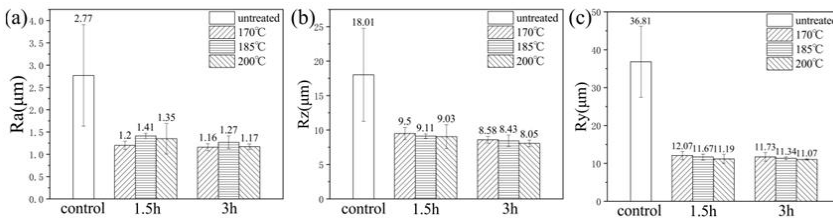


Fig. 4: Surface roughness of rubberwood (before sanding): (a) R_a , (b) R_z , and (c) R_y .

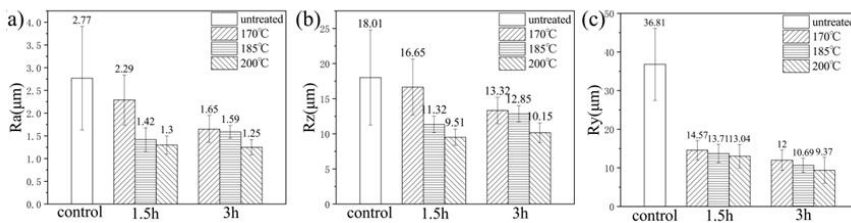


Fig. 5: Surface roughness of rubberwood (after sanding): (a) R_a , (b) R_z , and (c) R_y .

Glossiness

Changes in glossiness parameters (GZL and GZT) of the untreated control group and the treatment group are presented in Fig. 6 (before sanding) and Fig. 7 (after sanding). As shown in Fig. 6 and Fig. 7, the results show that the values of GZL and GZT increased with increasing treatment temperature and time no matter before or after sanding. The glossiness values of the treatment group were higher than those of the untreated control group. While the highest value

of glossiness is found in the specimens treated at the highest temperature (200°C) and the longest time (3 h). A typical finding for glossiness measurements for all specimens is that glossiness values, when measured along the grain, are higher than those measured across the grain. This can be explained by the anatomical structure on the surface of wood. The wood texture is parallel to the long axis of the cell. Then when the light ray enters along the grain, part of the light is refracted from inside the cell along the long axis of the cell, and the other is refracted along the outer wall of the cell. When light enters the vertical texture, the inner diameter of the cell is much smaller than its length. Thus the light is blocked by the inner wall of the cell (He et al. 2016).

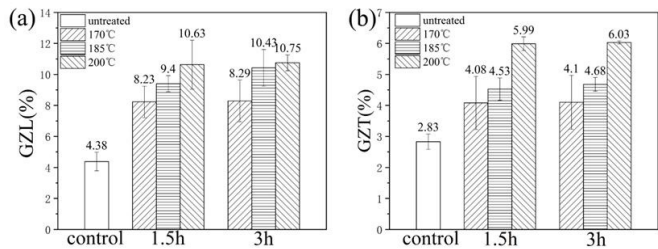


Fig. 6: Surface glossiness of rubberwood (before sanding): (a) GZL, and (b) GZT.

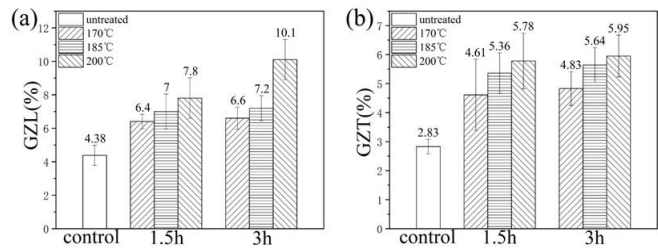


Fig. 7: Surface glossiness of rubberwood (after sanding): (a) GZL, and (b) GZT.

Other studies reported that the glossiness values of heat-treated wood specimens decreased with increasing treatment duration and temperature (Ahmet 2011). This can be explained that heat treatment was combined with wood densification in this study compared with previous studies where only wood heat treatment was applied. Wood compression was the main reason for improving the glossiness of the wood surface. The main reason for the increased glossiness of the wood surface was that the wood was compressed (Bekhta et al. 2014).

Obviously, the natural characteristics of wood have an influence on surface roughness and further on glossiness properties. Smaller roughness values correspond to higher gloss values. The reason is that the increasing roughness means more complex surfaces, and lead to the light scattering more irregular.

CONCLUSIONS

This study investigated the influences of heat treatment by hot pressing on the surface properties of rubberwood. The results showed that the values of contact angle and glossiness

increased slightly, and the color of wood changed darker significantly. The values of roughness decreased slightly with increasing heat treatment temperature and duration. The maximum value of roughness was obtained as the samples heat-treated at 200°C for 3 h. The heat-treated rubberwood with a warm tone is suitable for some applications. Further research is also needed to establish the quantitative relationships among color, roughness, glossiness and coatings of thermally modified wood.

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