Impregnation with Microcrystalline Wax to Improve Rosewood Dimensional Stability and Surface Hardness

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Air-dried rosewood (*Aniba rosaeodora*) samples with sizes of 50 mm (length) by 50 mm (width) by 20 mm (thickness) were pretreated with NaOH to increase their permeability. The specimens were then impregnated with microcrystalline wax at a temperature of 100 °C to obtain various weight gains at four treatment durations. After impregnation, the swelling and shrinkage extents and surface hardness of the rosewood were measured. The results showed that, compared with untreated specimens, the linear swelling extent, volumetric swelling extent, and linear shrinkage extent of the impregnated specimens decreased by 75.23%, 59.85%, and 80.70%, respectively, and the surface hardness of the treated specimens increased by 43.36%. The impregnation with wax significantly increased the dimensional stability and surface hardness of the rosewood.

Keywords: Dimensional stability; Impregnation; Microcrystalline wax; Surface hardness; Swelling and shrinkage extent

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INTRODUCTION

Wood is a natural polymer composed of cellulose, hemicellulose, and lignin. Due to the presence of a large amount of hydroxyl groups in the polymer, it exhibits a capacity for water absorption and desorption. Defects such as warping and checking may occur when wood has been used in an environment with large fluctuations in relative humidity. These defects reduce the service life of wood products.

In order to improve dimensional stability and durability, wood has been modified in many ways (Fadl and Basta 2005; Nicholson and Hoffman 2006; Park and Wilderman 2010). These methods can be classified into two main types: chemical modification and physical modification (Avramidis *et al*. 2011). Chemical modification involves impregnating wood with polymers, resins, or other chemicals to fill in voids within the wood, even sometimes causing chemical reactions to occur within the wood. The chemical modification of wood can achieve good results in dimensional stability; however it can be harmful to the environment and health (Chen *et al*. 2008). Thermal modification, which can be regarded as a physical modification, has been widely applied in the wood industry to increase the dimensional stability in wood. The chemical groups within wood with a high capacity for water absorption, including in hydroxyl and carboxyl, are altered after thermal treatment. This tends to decrease the absorption and cell wall swelling extents of wood (Klammt and Kretschmar 1945). Thermal modification offers excellent performance in improving water repellency; however, large scale commercial application is still restrained due to deficiency of darkened color and lowered wood strengths and high dependency on energy consumption (Zhang *et al*. 2007).

The impregnation of wax is a potentially novel wood modification method in the wood research field. Wax impregnation modification involves three major steps (Brown 1962; Ashmore and Laganella 2013). First, microcrystalline wax with a low melting point used as the treatment medium is heated from solid to liquid state. The wood wax is then impregnated with the hot fluid, either with or without pressure. The final step is the solidification of the microcrystalline wax in wood cell lumens and intercellular space of the wood (Li *et al*. 2014). Thus, it is possible to increase dimensional stabilization without weakening the mechanical property of wood as well as maintaining its natural color and texture, in contrast to common thermal modification. Additionally, it is also environmentally friendly compared with various chemical treatment methods, which pose environmental pollution risks and threats toward human health. While some previous studies (Wang and Winistorfer 2000; Gu *et al*. 2005) have dealt with the thickness swelling behavior of both commercial and lab-made OSB products, fewer researchers have focused on evaluation of water uptake behavior of rosewood. The objective of the present study was to investigate the effect of treatment duration on the weight percentage gain (WPG), swelling and shrinkage extents, and surface hardness of rosewood (*Aniba rosaeodora*) treated with wax impregnation under atmospheric conditions, hoping to provide some helpful references for further studies of rosewood dimensional stabilization.

EXPERIMENTAL

Materials

Air-dried rosewood with a moisture content (MC) of 12 to 15% was used in this study. Clear wood specimens with four sides, planed to a size of 50 mm (grain direction) by 50 mm (width) by 20 mm (thickness) were used.

Microcrystalline wax with low molecular weight of 500 to 800 g and a melting point of 55 to 60 °C was supplied by Fu shun Drying Instrument Company, China.

Methods

Before the impregnation, a 2.5% NaOH solution mixed with 0.5% Na_2SiO_3 was used to extract the gums, resins, and other extractives in the wood to increase permeability. The solution was stirred for 5 min until homogeneity was obtained. Rosewood specimens were then submerged in the solution. The specimens were placed in a water bath with a constant temperature of 60 °C for 1.5 h. After the extraction, the specimens were dried at a constant temperature of 70 °C and RH of 65% to 12% MC.

The dried specimens were fully immersed into liquefied microcrystalline wax at 60 °C. The liquid wax was gradually heated to 100 °C at increments of 10 °C every 30 minutes. Four treatment durations were selected at 2, 4, 6, and 8 h and four replicates were performed for each treatment. After impregnation, the specimens were kept at a constant temperature of 30 °C for 1 h. The specimens were then equalized in a climate chamber set to 20 °C with 65% RH.

The impregnated wood specimens were placed into the climate chamber in order to perform the thermal cycling tests. The dimensional stability was measured according to GB/T 17657-2013 (China). Test samples were placed in climate chamber set to 80 °C for 120 min and then were frozen at -20 °C for 120 min, replicating this cycle 4 times. Consequently, tangential, radial, and longitudinal dimension data were recorded for the samples. Wood surface hardness was tested with universal mechanical testing machine in Fig. 1 (WDW-50, Japan).

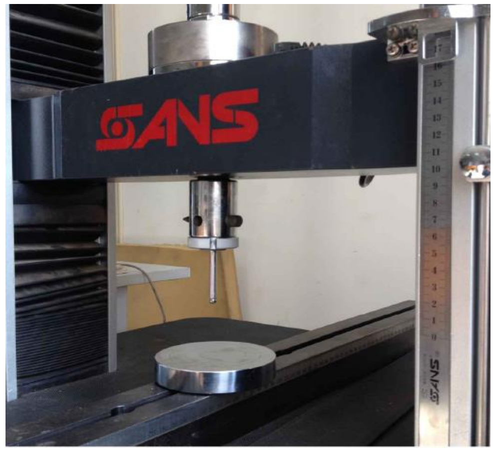

Fig. 1. Surface hardness measurement with WDW-50 hardness testing machine.

RESULTS AND DISCUSSION

Figure 2 shows the impact of treatment time on weight percentage gain. The WPG of the specimens increased with treatment time by 8.69%, 13.65%, 13.70%, and 14.11% at 2 h, 4 h, 6 h, and 8 h of impregnation, respectively. WPG increased rapidly during the first 4 h but slowed after that. This implied that the wood structure had been impregnated with microcrystalline wax which limited further penetration of microcrystalline wax after 4 h of treatment. That solid wax covered the wood specimens' surface and clogged passage into the interior.

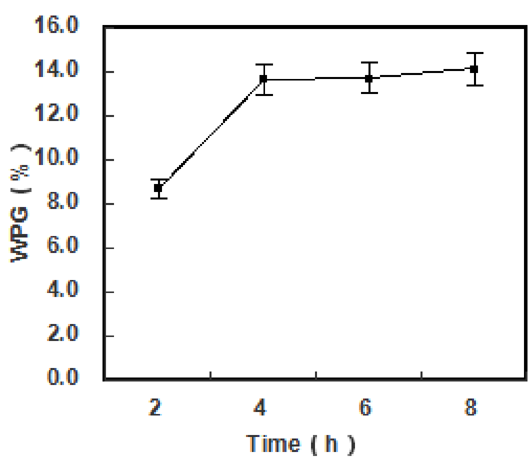

Fig. 2. Relationship between wax impregnation treatment time and WPG during the impregnation of wax

The relationship of treatment duration and the linear and volumetric swelling extents for both the control and treated specimens is shown in Fig. 3. The extents of linear and volumetric swelling decreased during the first 4 h and remained almost constant after that. As shown in the figure, compared with the untreated samples, the tangential swelling extents of treated samples decreased significantly by 15.14%, 54.18%, 56.57%, and 60.0% for the treatment durations of 2, 4, 6, and 8 h, respectively. The radial swelling extents decreased by 9.36%, 70.51%, 71.79%, and 75.23%. The volumetric swelling extents decreased by up to 59.85%.

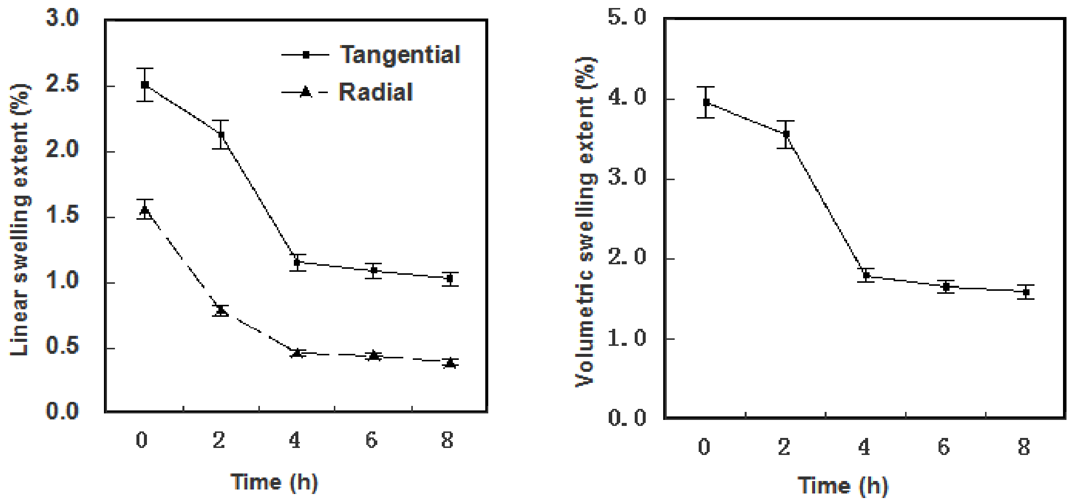

Fig. 3. Relationship between wax impregnation treatment time and (a) linear and (b) volumetric swelling extents.

Analysis of variance revealed that both the linear and volumetric swelling extents were reduced significantly during the initial 4 h of treatment and very little after that. Wax treatment reduced the swelling and enhanced dimension stability. The microcrystalline wax in the wood structure functioned as an excellent bulking medium. The swelling of the cellular walls of wood in damp environments was adequately restrained due to the empty space being filled with wax. The deposition of solid microcrystalline wax on the cell wall also hindered the movement of water molecules. The high temperature impregnation treatment at 100 °C caused certain amounts of hydroxyl groups to lose their capability to combine with water molecules (Rowell 2012). This also resulted in sorption hysteresis, which brought down linear and volumetric swelling extents and improved wood dimensionality (Metsa-Kortelainen *et al*. 2006; Borrega and Karenlampi 2010).

Figure 4 illustrates the effect of microcrystalline wax treatment time on the linear shrinkage extent of test samples. It was observed that the shrinkage extent of wax-impregnated wood was much less than that of the untreated group, particularly during the initial four hours of treatment.

Both the tangential and radial shrinkage extents decreased significantly. The linear shrinkage extent remained almost unchanged after 4 h treatment. The tangential and radial shrinkage extents decreased by more than 70% in eight hours, compared with untreated specimens. The reduction in shrinkage extent after treatment was closely related to the long-hydrophobic chain of the microcrystalline wax and the bulking effect of compound wax (Arthur and Kretaschmar 1999). During impregnation, the microcrystalline wax became consolidated within the cell walls and created a thin layer to prevent the movement of water molecules (Li *et al*. 2014).

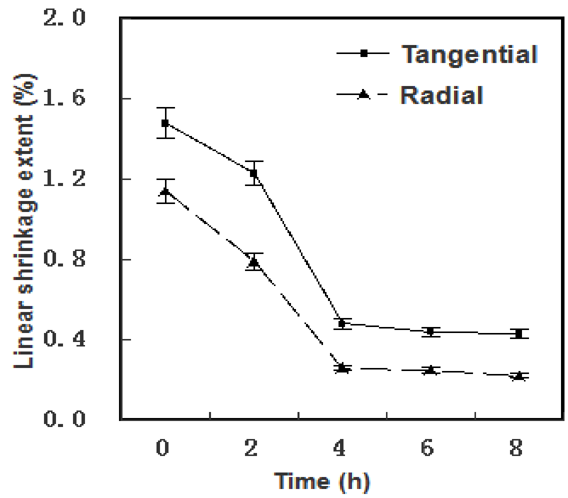

Fig. 4. Relationship between the impregnation treatment time and the linear shrinkage extent

Figure 5 shows the results of the universal mechanical testing machine used to evaluate surface hardness and the effect of microcrystalline wax impregnation treatment time on surface hardness. Surface hardness exhibited a significant increase as a result of wax treatment; the longer the treatment time, the greater the surface hardness for the initial 6 h of treatment, after which it did not improve much. When compared with the control group, the hardness of wood specimens increased by 2.05%, 7.88%, 34.72%, and 43.36%, after treatments lasting 2, 4, 6, and 8 h, respectively.

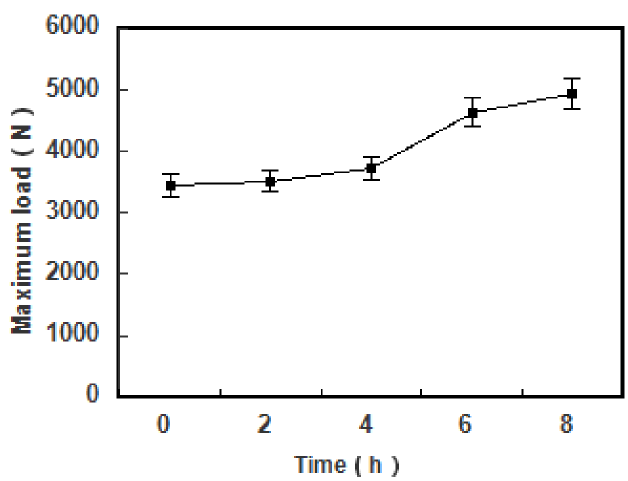

Fig. 5. Relationship between the impregnation treatment time and surface hardness

CONCLUSIONS

1. Air-dried rosewood was successfully impregnated with microcrystalline wax at 100 °C. Pretreatment with 2.5% NaOH solution was observed to increase the effectiveness of wood impregnation. WPG reached 14.11% after 4 h of treatment.

2. The tangential and radial shrinkage of treated wood was reduced by 70.95% and 80.70% compared with the untreated wood specimens after 4 h of treatment. The linear and volumetric swelling extents were reduced and surface hardness was increased with time of impregnation. Compared with the untreated specimens, the extents of swelling were reduced by 75.23% after 4 h of impregnation.
3. The hardness of the rosewood was increased by 43.36% after 8 h of treatment from 3445 to 4939 N. Wax treatment reduced the swelling and enhanced dimensional stability.

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