WOOD RESEARCH
64 (1): 2019
165-176

EFFECTS OF WAX AND DIMETHYL SILICONE OIL MIXED IMPREGNATION ON DIMENSIONAL STABILITY OF TWO HARDWOODS

Jing Qian, Jinpeng Li, Zhenyu Wang, Lijie Qu, Yu Ding
Songlin Yi, Zhengbin He
Beijing Forestry University, College of Materials Science and Technology
Key Laboratory of Beijing For Wood Materials and Engineering
Beijing P.R.China

(Received October 2018)

ABSTRACT

In this experiment, cocobolo (*Dalbergia retusa* Hesml.) and African padauk (*Pterocarpus soyauxii*) specimen were selected before treating with wax, wax + 20% dimethyl silicone oil, wax + 40% dimethyl silicone oil at 120°C for 3 h and 6 h respectively. The weight gain percentage (WPG), radial swelling coefficients (RS), tangential swelling coefficients (TS), chemical composition and strength of hydroxyl groups were investigated. The results indicated that three factors affect dimensional stability, including the impregnation time, tree species and ratio of wax /dimethyl silicone oil. The degree of a melioration in the dimensional stability increase as the impregnation time increase from 3h to 6h. The effect of the impregnation on the dimensional stability of the African padauk was better than that of the cocobolo. Wax+ 40% dimethylsilicone oil was the optimal condition in this study. Wax and dimethylsilicone oil mixed impregnation can improve the dimensional stability to a certain extent, which provides a new idea for the wood modification.

KEYWORDS: Wax impregnation, dimethyl silicone oil, cocobolo (*Dalbergia retusa* Hesml), African padauk (*Pterocarpus soyauxii*), dimensional stability.

INTRODUCTION

Wood has numerous advantages, rendering it applicable in all aspects of human life (Cui and Kamdem 2000). Rosewood has been cherished by people since the Ming and Qing dynasties. It was initially made intoimperial furniture, handicrafts due to its fine texture and other good properties. Asa large number of rosewood importing,it was supplied to the private sector gradually. Rosewood, as described in the Chinese standard for hongmu, encompasses 33 wood species that belong to 5 genera (*Pterocarpus* spp., *Dalbergia* spp., *Cassia* spp., *Diospyros* spp. and *Millettia* spp.) and are classified into 8 categories in China (GB/T 18107-2000).

Cocobolo (*Dalbergia retusa* Hesml.), widely known as "small-leaf hongsuanzhi" in China, is Class II endangered species. African padauk (*Pterocarpus soyauxii*), is not classified as rosewood; however, it exhibits characteristics, including high hardness,high density, and good durability, which are similar to those of boisde rose (*Dalbergia louvelii* R. Viguier) and red sanders (*Pterocarpus antalinus* L.f.). Several studies have been conducted on the identification of 3 types of wood (Gu et al. 2014, Yang et al. 2012). Both types of wood are of high economic and cultural value and deserve further research. Wood is mainly composed of cellulose, hemicellulose, and lignin, and a large number of hydroxyls are found in cellulose and hemicellulose molecules; the same is true for rosewood (Tjeerdsma and Militz 2005). Rosewood productstend to crack with changes in temperature and humidity, seriously affecting its quality (Liu et al. 2016).

A number of reviews have focused on the proper modification of rosewood prior to its application (Liu et al. 2016, Möttönen et al. 2015). Wood modification is a means of altering the material to overcome or ameliorate one or more of its disadvantages. Some modifications have been classified by Norimoto and Gril (1993) by referring to changes taking place at the cell wall level. Hill (2006) further subdivided the wood modification methods into chemical modification, thermal modification, surface modification and impregnation modification.

The use of wax in China has a history spanning more than 3,000 years, and wax impregnation likely originated from Chinese Ming-style furniture. Wax was used as a water repellent to reduce hygroscopicity and water absorption (Feist and Mraz 1978, Scholz et al. 2010a, Xie et al. 2013, Chen Yu et al. 2017), thereby improving the dimensional stability of wood for long-term use. Some studies have classified wax impregnation as a type of chemical modification, but this definition is not accurate because the process involves no chemical reaction. Wax impregnation is usually conducted at elevated temperature, either in vacuum or under pressure (Scholz et al. 2010b).The depth of impregnation of the wood is related to the viscosity of the wax and to the porosity of the wood. The rate of hygroscopicity and water absorption can be reduced after waxes fill the cell cavity (Papadopoulos and Pougioula 2010). Different from the chemical modifications, treatment of wood using waxes improved all the mechanical properties evaluated (Hill 2006, Scholz et al. 2009, Mundinger and Rettenbacher 2005).

Research shows that heat treatment, usually at temperatures below 260°C, can improve the quality of the wood (Sidorova 2008, Gökhan Gündüz et al. 2009). Oil heat treatment (OHT) is another treatment that provides effectively and uniformly transfers heat in wood, is already in use in Germany (Gunstone 2011). Vegetable oils are proved suitable as heat-modified heat transfer media since their boiling point exceeding 260°C (Cheng et al. 2013). Under anaerobic conditions, vegetable oil acts as a medium; a certain amount of oil is absorbed into the modified wood, which can improve wood performance.The boiling point of dimethylsilicone oil is higher than 200°C. Okon et al. (2017) once used dimethylsilicone oil to improve the dimensional stability of Chinese fir.

As many become interested in pursuing good health, environmental a fety and protection in the use of wood products becomes increasingly critical. Several studies have been conducted to improve the properties of different wood species. However, to the best of the authors' knowledge, few impregnation testshave been performed directly with melted wax at 120°C under atmospheric pressure. No previous studies have used dimethylsilicone oil in the combined treatment with wax to modify cocobolo or African padauk. This study aims to evaluate the improvement in the dimensional stability of 2 types of wood with different dimethylsilicone oil and wax ratios.

MATERIALS AND METHODS

Materials

Cocobolo (4.80% moisture content) and African padauk (5.20% moisture content) specimens with an air-dry density of 0.96 g·cm^{-3} and 0.77 g·cm^{-3} respectively, were collected from Yi Jiu Xuan company, China. Nondurable heartwood was selected as the test material and cut into a size of 20 mm (longitudinal) × 20 mm (radial) × 20 mm (tangential). The specimens were free of knots and lacked visible evidence of infection by mold, stain, or fungi.

In addition, 85 # microcrystalline wax, with a melting point of 82°C-87°C, was also used. Dimethylsilicone oil, a colorless (or light yellow), tasteless, and high-transparency liquid with a thermal conductivity of 0.134-0.159 W/(M*K), can be used long-term at -50°C-200°C.

Determination of initial moisture content

Air dry samples were numbered, weighed and recorded, in accordance with GB/T 1931–1991–2009 to determine moisture content.

Wax impregnation

A total of 105 specimens of each species were selected before they were randomly classified into 7 groups (A, B, C, D, E, F, and G), with 15 specimens numbered 1–15 in each group. The experimental design is presented in Tab. 1.

A certain amount of dimethylsilicone oil in accordance with the experimental conditions was added into the fluid wax obtained by melting the solid wax in a steel tank (32 × 16 × 16 cm) at 120°C. The test material was immediately dipped into the stirring-well mixture to prevent liquid from curing. After impregnation, the wood samples were wiped to remove residual impregnation liquid and then cooled in a silica gel desiccators balance at room temperature.

Tab. 1: Experimental design of the processes conducted at 120°C.

Group information	A	B	C	D	E	F	G
Dimethyl silicone oil proportion (%)	0	0	20	20	40	40	_
Impregnation time (h)	3	6	3	6	3	6	_
Impregnation temperature (°C)	120	120	120	120	120	120	_

Characterization experiments

Weight gain rate (WPG) was conducted on an AR124CN electronic balance (Ohaus Instruments (Shanghai) Co.) and calculated by using the following Eq. 1:

$$\Delta G=\frac{G_1\text{-}G_0}{G_0}\times 100 \qquad (\%) \tag{1}$$

where: ΔG- WPG of the specimen after waximpregnation relative to that before treatment (%),
G_1- denotes the weight of the specimen after wax impregnation (g),
G_0 - the weight of the specimen after drying (g).

All of the specimens underwent hygroscopicity testing at a constant temperature and in a humidity chamber (DHS-500, Beijing Yashilin Test Equipment Co. Beijing, China) at 20°C and relative moisture content of 65% in accordance with the standard of GB/T 1934.2-1991-2009. After moisture absorption, the radial dimension and the tangential dimension of each test specimen were recorded to calculate the radial swelling coefficients (RS) and the tangential swelling coefficients (TS) by using Eq. 2 and then determining the average data for each group:

$$RS=\frac{R_1\text{-}R_0}{R}\times 100 \qquad (\%) \qquad (2)$$

where: RS - radial moisture absorption rate of the specimen (%),
R_1-denotesthe radial dimension of specimen after impregnation,
R_0- radial dimension of specimen before impregnation (mm).

$$TS=\frac{T_1\text{-}T_0}{T_0}\times 100 \qquad (\%) \qquad (3)$$

where: TS -tangential moisture absorption rate of specimen (%),
T_1 -denotesthe tangential dimension of specimen after impregnation,
T_0- tangential dimension of specimen before impregnation (mm).

The Fourier Transform Infrared (FTIR) spectra of 4 samples selected randomly from group F and group G were obtained by infrared spectrometry (TENSOR27, Tianjin Optical Instrument Factory, China). Measurements of 4000-450 cm^{-1} were recorded. Prior to testing, all the selected samples were prepared as 100-120 purpose wood flour and then dried at 103°C±2°C.

RESULTS AND DISCUSSION

Effects of impregnation time on dimensional stability of two hardwoods

Weight gain percentage

Fig. 1 compares the WPGof the 2 types of woodin 3 different impregnation solutions. Under these 3 impregnation conditions, the WPG of the same material for 6 h was higher than that for 3 h, but the increase in WPG during the 3–6 h period was significantly smaller than that during the 0-3h period. Combined with the specific values of Tab. 2, the increases in the WPG for the cocobolo during the 3–6 h period were 13.20% (wax), 23.70% (wax + 20% dimethylsilicone oil), and 13.90% (wax + 40% dimethylsilicone oil) of 0–3 h; meanwhile, the increases in WPG for the African padauk during the 3–6h period were 50.19% (wax), 57.14% (wax + 20% dimethyl silicone oil), and 18.75% (wax + 40% dimethylsilicone oil) of 0–3 h. Impregnation may be basically completed at a certain time point after 3 h, and the impregnation solution cannot be further filled for an extended time. It has a negligible effect of prolonging the impregnation time in actual production.

Tab. 2: The weight gain percentage under different impregnation conditions.

Time	Impregnation condition	Species	
		Cocobolo (%)	African padauk (%)
3h	wax	6.20	2.57
	wax + 20% DSO	5.57	2.38
	wax + 40% DSO	5.97	3.04
6h	wax	7.03	3.86
	wax + 20% DSO	6.89	3.74
	wax + 40%DSO	6.80	3.61

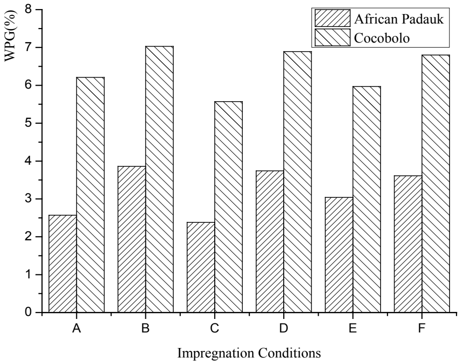
DSO refers to dimethyl silicone oil

Fig. 1 revealed that under the same time and impregnation condition, the penetration ability of the impregnation liquid for the 2 types of hardwood markedly varies, and that of the cocobolo was larger. The difference in WPG among the species may be attributed to the porosity of the wood. According to Liu and Zhao (2012) the actual density of wood refers to the density of wood cell wall material, which is about 1.5 g·cm^{-3}. This finding indicates that if wood contains no pores, the proportion of wood in an absolute dry state is 1.5. The porosity of wood can be calculated using the following Eq. 4.

$$P = \left(1 - \frac{\rho_0}{\rho_{0W}}\right) \times 100 \qquad (\%) \tag{4}$$

where: P - porosity of wood (%),
ρ_0- absolute dry density of wood (g·cm^{-3}),
ρ_{0w}- actual density of wood (g·cm^{-3}).

The porosities of cocobolo and African padauk were 48.66% and 35.66%, respectively. These results indicate that the higher the porosity, the higher the WPG of wood.



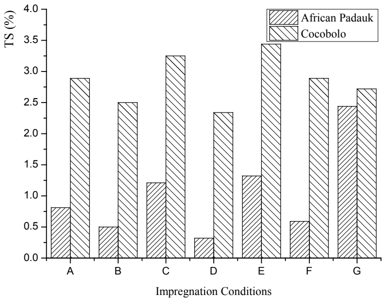
A: wax impregnated 3 h; B: wax impregnated 6 h, C: wax+ 20% dimethylsilicone oil impregnated 3 h, D: wax + 20% dimethyl silicone oil impregnated 6 h, E: wax + 40% dimethylsilicone oil impregnated 3 h; F: wax + 40% dimethylsilicone oil impregnated 6 h.

Fig. 1: The weight gain percentages of two kinds of wood in different impregnation conditions.

Comparison of dimensional stability

When moisture enters and exits the wood, hygroexpansion occurs. However, the shrinkage and swelling in different grain orientations vary, reflecting the anisotropy of wood. Research indicates that the 3 dimensions in descending order, as determined by dimensional variation in shrinkage and swelling, are as follows: tangential>radial>longitudinal (Sun and Liu 2007). Therefore, choosing RS and TS provides a more meaningful analysis.

Fig. 2 shows the TS of the 2 species under different impregnation treatments. Before modification, the TS of cocobolo is similar to that of African padauk despite the slightly larger size of the cocobolo.The improvement in radial dimensional stability of the different species exerted a different effect after dipping. Under the wax impregnation, the TS of 6 h was lower than that of 3 h, indicating the increases in the wax absorbed by wood and radial dimensional stability. Cocobolo failed to significantly improve the radial dimensional stability, with TS of 0.17% after dipping for 3 h, this result was higher than that of the untreated wood. Meanwhile, impregnation for 6 h decreased by 0.22% relative to that of the control group. This reduction may be attributed to the presence of certain amounts of extracts, including phenols, alcohols, ethers, fatty acids, lipids, and aromatic and hydrocarbon compounds in cocobolo. Extracts can increase the dimensional stability of the wood. During treating, wax and dimethylsilicone oil enter into the interior of the wood while some extractives may be removed from the wood. The impregnated liquid can improve the dimensional stability of the wood; however, that portion of the increase cannot sufficiently offset the decrease due to the extract; thus, the overall dimensional stability decreases. The TS of the African padauk after impregnation was significantly lower than that of the control group. The TS of the unprocessed material (2.44%) was 5 times that of the material impregnated for 6 h (0.5%).



A: wax impregnated 3 h; B: wax impregnated 6 h, C: wax+ 20% dimethylsilicone oil impregnated 3 h; D: wax + 20% dimethylsilicone oil impregnated 6 h, E: wax + 40% dimethylsilicone oil impregnated 3 h; F: wax + 40% dimethylsilicone oil impregnated 6 h, G: untreated material

Fig. 2: The tangential swelling coefficients of two kinds of wood in different impregnationconditions.

The changes in the TS of the 20% dimethylsilicone oil-impregnated test material was similar to that of the wax-impregnated test material. The cocobolo in 20% dimethylsilicone oil-impregnated condition, in descending order, was wax+ 20% dimethylsilicone oil 3 h>control group> wax+ 20% dimethylsilicone oil 6 h. The TS of the African padauk was reduced about 7 times as low as 0.32% after treatment for 6 h. In the 40% dimethylsilicone oil experimental group, the TS of the cocobolo treated for 3 or 6 h was higher than that of the untreated material, whereas the TS of the African padauk showed varying degrees of reduction.

Tab. 3: The swelling coefficients of two kinds of wood in different impregnation conditions.

Time	**Species**	**Impregnation conditions**	**TS (%)**	**RS (%)**
3 h	Cocobolo	A	2.89	1.90
		C	3.25	1.64
		E	3.44	2.22
	African padauk	A	0.81	0.62
		C	1.21	0.93
		E	1.32	1.12

6 h	Cocobolo	B	2.50	1.88
		D	2.34	2.16
		F	2.89	2.03
	African padauk	B	0.50	0.33
		D	0.32	0.32
		F	0.59	0.51
Control group	Cocobolo	——	2.72	1.44
	African padauk		2.44	1.60

TS: tangential moisture absorption rate; RS: radial moisture absorption rate, A: wax impregnated 3 h; B: wax impregnated 6 h, C: wax+ 20% dimethylsilicone oil impregnated 3 h; D: wax + 20% dimethylsilicone oil impregnated 6 h, E: wax + 40% dimethylsilicone oil impregnated 3 h; F: wax + 40% dimethylsilicone oil impregnated 6 h.

The RS values of the 2 species in different impregnation treatments are presented in Fig. 3. The RS of the species impregnated for 6 h is lower than that impregnated for 3 h. Cocobolo has not obtained the optimal treatment effect; relative to the control group, RS tends to show a slight increase. Combined with the concrete values listed in Tab. 3, the African padauk shows a clear increase in radial dimensional stability. The RS decreases from 1.6% (control group) to 0.33% (6 h) during wax impregnation.

As the weight ratio of dimethylsilicone oil/wax increases from 0 to 20%. The RS decreases from 0.93% (3h) to 0.32% (6 h), which is 1/5 that of the control group. When the ratio continues to rise to 40%, the RS declines subsequently as the treatment time increases from 0 h to 6 h.

The afore mentioned analysis indicates that in the 3 impregnation treatments, extending the impregnation time can improve the dimensional stability to a certain extent until the maximum impregnation time is reached. The RS and TS after impregnation for 6 h are lower than RS and TS after impregnation for 3 h. The stability of the African padauk was improved to varying degrees, whereas the modification effect of cocobolo is small or rarely observed no due to their own material properties.

Effect of dimethyl silicone oil-to-wax weight ratio on the dimensional stability of two hardwoods

Weight gain percentage

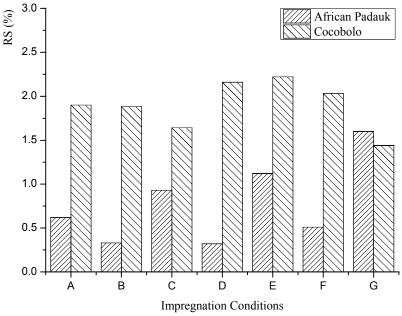
The study by (Guan et al. 2016) on various wax-modified wood species indicates that different wax types exert an effect on the increasing degree of dimensional stability. As shown in Fig. 1, the same specie obtains different WPG values in different impregnation liquids when the impregnation time is 3 h. According to the specific value, with an increase in the proportion of dimethylsilicone oil from 0% to 40%, the WPG of the cocobolo reached 6.21% in wax, decreases subsequently by 0.64%, and increased again to 5.97%. The fluctuation in the WPG of the African padauk agrees well with the findings for the cocobolo. The maximum WPG of the African padauk, 3.04%, was obtained in Group F. When the impregnation time was 6 h, the WPG of the cocobolo and African padauk was almost similar in 3 under 3 dipping conditions and decreased with the increase in the proportion of dimethyl silicone oil.

Comparison of dimensional stability

In Fig. 2, the TS of the African padauk under impregnation treatment for 3 h was lower than that of the untreated on; TS decreased most significantly to 1.63% in Group A. Meanwhile, the TS of the cocobolo did not decrease but instead increased with the increase in dimethylsilicone.

After 6 h's impregnation, both species gained the smallest tangential deformation of 2.34% and 0.32% in the wax+20% dimethylsilicone oil treatment respectively; these values were reduced by 13.97% and 86.89% relative to those of the control group. The tangential dimensional stability of the cocobolo was slightly enhanced, except for that in the wax+40% dimethylsilicone oil treatment.

Analysis of Fig. 3 indicates that the species varied in RS under the same experimental conditions. The radial deformation of the cocobolo increased regardless of the treatment time (3 or 6 h) and reached 2.16% when dipped in wax+20% dimethyl silicone oil for 6 h; in addition, it increased by 0.72% relative to that of the control group. The radial stability of the African padauk increased. The minimum RS decreased to 0.62% after impregnation for 3 h, which was as low as more than half than the untreated material. Meanwhile, the same results were obtained in both wax and wax+20% dimethylsilicone oil treatments for 6h, the result for the untreated material decreased to 1/5.



A: wax impregnated 3 h; B: wax impregnated 6 h, C: wax+ 20% dimethyl silicone oil impregnated 3 h; D: wax + 20% dimethylsilicone oil impregnated 6 h, E:wax + 40% dimethylsilicone oil impregnated 3 h; F: wax + 40% dimethylsilicone oil impregnated 6 h. G: untreated material.

Fig. 3: The radial swelling coefficients of two kinds of wood in different impregnation conditions.

Combined with the 3 existing impregnation conditions, the best impregnation conditions for African padauk in this experiment was obtained using wax+ 20% dimethyl silicone oil impregnated for 6 h, and both the TS and RS can be reduced to 0.32%. The tangential stability and the radial dimensional stability increased by about 7 and 4 times, respectively. Cocobolo has not been improved because of the stability of the material.

FTIR

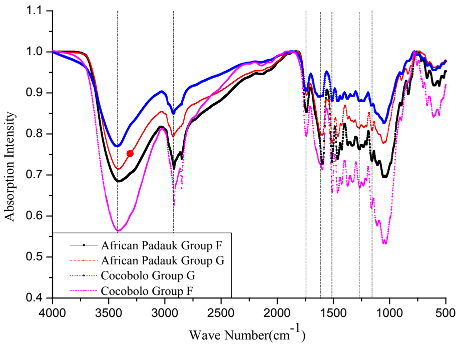
Wax modification aims to improve the dimensional stability by using the hydrophobic properties of wax. The wax can wrap the hygroscopic-free hydroxyl groups after entering the wood, thereby reducing the deformation considerably.

To investigate the changes in the component in 2 species and to determine the factors affecting the variation in the modification of the 2 species in micro perspective, the FTIR spectra of Groups G and F were obtained in the 500-4000 cm^{-1} region, as presented in Fig. 4. By infrared spectra peak identification, Tab. 4 shows the characteristic peaks corresponding to the chemical composition.

The peak observed at 3410 cm^{-1} was attributed to the bending vibration of – OH, which was corrected with the moisture absorption of wood. The 1800-400 cm^{-1} region includes the main functional groups for organic material, which have been characterized for cellulose, hemicellulose, and lignin. The bands at 1600, 1508, and 1266 cm^{-1} were attributed to the aromatic carbon skeleton vibration of lignin.The peak in the region near 1735 cm^{-1} belonged to the C=O bending motion, indicating the presence of hemicellulose, lipids, and ketones and was related to the hygroscopicity of wood to a certain degree. In addition, the absorption bands at 2900 cm^{-1} were attributed tothe C-H stretching vibration, representing cellulose. The peak at 1160 cm^{-1} was attributed to the stretching vibrations of C-O-C, representing cellulose and hemicellulose. The chemical compositions of the 2 species were rather similar, but the strengths of absorption varied markedly across the groups. As shown in Fig. 4, the absorption peaks of -OH and -C=O in the cocobolo are significantly stronger than those in the African padauk, which can be attributed to the greater hygroscopicity of the cocobolo than that of the African padauk (Luo 2013, Santana and Okino 2007).

Tab. 4: The analysis of FTIR print about two kinds of hardwood.

Wave number (cm^{-1})	Group attribution	Chemical composition
3410	O-H stretching vibration	Cellulose, phenol, alcohol, carboxylic acid compounds
2900	C-H stretching vibration	Cellulose
1735	C=O stretching vibration	Hemicellulose, lipids, ketones
1600	Aromatic carbon skeleton vibration	Lignin
1508	Aromatic carbon skeleton vibration	Lignin, aromatic hydrocarbons
1463	C-H bending vibration, CH_3, CH_2 asymmetric bending vibration	Lignin, ether compounds
1427	Aromatic carbon skeleton vibration, C- H bending vibration	Lignin, cellulose
1266	G ring and acyloxy C-O stretching vibration	Lignin
1160	C-O-C stretching vibration	Cellulose, hemicellulose
895	Anisotropic carbon (C1) vibration frequency	Cellulose



F: wax + 40% dimethylsilicone oil impregnated 6 h; G: untreated material.

Fig.4: FTIR print of two kinds of untreated and wax+40% dimethylsilicone oil treated hardwood.

Compared with the untreated samples, 2 new characteristic peaks appeared in the specimens treated with wax+40%dimethylsilicone oil at 2919 and 2849 cm^{-1}, corresponding to asymmetric and symmetric stretching vibrations for C-H (CH2 and CH3). The characteristic peaks of lignin became stronger after treatment,which may be attributed to the increase in the proportion of lignin in the experimental material. No obvious variation in characteristic peaks was observed for C-O-C at 1160 cm^{-1} before and after impregnation for all samples, whereas a slight increase in characteristic peaks was observed for C=O at 1735 cm^{-1} after treating. In addition, after impregnation, the intensity of -OH at 3410 cm^{-1} decreased in the African padauk samples, whereas that in the cocobolo increased. For the African padauk, the reason may be that part of the wax that entered into the interior of wood blocks contained a certain amount of hydroxyl groups, thereby improving the dimensional stability. The relatively stronger hydroxyl absorption strength and the dimensional stability in the cocobolo have not improved as a whole which can be attributed to the following points. On one hand, less wax can enter into the interior of the wood when the proportion of dimethylsilicone oil in the mixed system is too large because the internal volume of wood is limited; thus, many free hydroxyl groups are not effectively covered. On the other hand, the extractives are removed from the wood after impregnation, thereby exposing the interior of the wood to an increasing number of free hydroxyls.

CONCLUSIONS

This study aimed to further explore a method of physically modifying wood by impregnation. Impregnation with different ratios of wax and dimethylsilicone oil can improve the dimensional stability of cocobolo and African padauk to a certain extent (except for cocobolo impregnated in wax + 40% dimethylsilicone oil for 6 h). After impregnation for 6 h, the dimensional stability of the samples is improved relative to that impregnated for 3 h. After the same impregnation treatment, the degree of improvement exhibited by the 2 species varied.The WPG reflects the amount of impregnation fluid that enters into the wood during impregnation. When analyzing a specific type of wood, the degree of improvement of the dimensional stability can be evaluated using the WPG, which is positively correlated with the former. The porosity of the wood is positively correlated with WPG; that is, the greater the porosity, the higher the WPG. FTIR can help determine whether the wax that enters into the wood can cover part of the free hydroxyls. In this study, the cocobolo and African padauk can achieve the maximum dimensional stability in the wax + 20% dimethyl silicone oil impregnation environment for 6 h. The TS and RS of the African padauk decreased to 1/7 and 1/4 the TS and RS, respectively, of the control group. The TS of the cocobolo decreased to 86.03% that of the untreated material.

ACKNOWLEDGMENTS

The authors thank the Beijing Forestry University major scientific research achievements cultivation project: The Key Technology of High Efficiency Pretreatment of Solid Wood Furniture (2017CGP014) forproviding the financial support of the project.

REFERENCES

1. Chen Yu, Cao Jinzhen., 2017: Effect of dicumyl peroxide (DCP) on properties of paraffin wax based Pickering emulsion stabilized by montmorillonite. Journal of Forestry Engineering 2(5): 36-40.
2. Cheng, D., Chen, L., Jiang, S., Zhang, Q., 2013: Oil uptake percentage in oil-heat-treated wood, its determination by soxhlet extraction, and its effects on wood compression strength parallel to the grain. BioResources 9(1): 120–131.
3. Cui, W., Kamdem, D.P., 2000: Wood products and wood protection in China. Holz als Roh- und Werkstoff 58: 387-391.
4. Feist, W.C., Mraz, E.A., 1978: Protecting millwork with water repellents. Forest Prod. J. 28: 31–35.
5. GB /T 1931-1991-2009: Method for determination of the moisture content of wood.
6. GB /T 1934. 2-1991-2009: Method for determination of the swelling content of wood.
7. GB/T 18107-2000: Hongmu.
8. Gökhan Gündüz, Aydemir, D. , B. Kaygın, Aytekin, A., 2009. The effect of treatment time on dimensionally stability, moisture content and mechanical properties of heat treated Anatolian chestnut (*Castanea sativa* Mill.) Wood. Wood research 54(2): 117-126.
9. Gu, Y., Shou, G., Zhang, W., Zhao, D., 2014: Application of near infrared spectroscopy for discrimination of similar rare woods in the Chinese market. Journal of Near Infrared Spectroscopy 22: 423-432.
10. Guan, J., He, Z.B.,Yi, S.L., 2016: Influence of different paraffin wax impregnation on the dimensional stability of beech wood. Journal of Nanjing Forestry University (Natural Sciences) 40(5): 143-147.
11. Gunstone, F., 2002: Vegetable oils in food technology: composition, properties and uses. Wiley-Blackwell Pub. 676 pp.
12. Wiley Backwel Hill Calum, A.S., 2006: Wood modification: chemical, thermal and other processes. John Wiley &.Sons, 239 pp.
13. Liu, Y.X, Zhao, G.J., 2006: Wood resource materials science. China Forestry Publishing House, 362 pp.
14. Liu, J.H., Qian, J., Qiu, S., BaoJ., Song-Lin, Y.I., 2016: Study on dimensional stability and extractives of thermal-treated *Pterocarpus santalinu* and *Pterocarpus tinctorius*. China Forest Products Industry 10(4):15-19.
15. Luo, S., Wu, Y., and Huang, J. 2013: Thermal and chemical properties of benzene-alcohol extractives from two species of redwood. In: International Conference on Biobase Material Science and Engineering Pp 156-160.
16. Möttönen, V., Bütün, Y., Heräjärvi, H., Marttila, J., Kaksonen, H., 2015: Effect of combined compression and thermal modification on mechanical performance of aspen and birchwood. Pro Ligno 11(4): 310-317.
17. Mundigler, N., Rettenbacher, M., 2005: Natwood technology- a material thermal wood modification. In: Hill, C.A.S., Militz, H. (eds) The Second European Conference on Wood Modification. Gőttingen, Germany, Pp 270–275.
18. Norimoto M, Gril J, 1993: Structure and properties of chemically treated woods. Recent Research on Wood and Wood-Based Materials 38(22): 135-154.
19. Okon, K. E., Lin, F., Lin, X., Chen, C., Chen, Y., Huang, B., 2017: Modification of Chinese fir (*Cunninghamia lanceolata* L.) wood by silicone oil heat treatment with micro-wave pretreatment. European Journal of Wood & Wood Products (2): 1-8.

20. Papadopoulos, A.N., Pougioula, G., 2010: Mechanical behaviour of pine wood chemically modified with a homologous series of linear chain carboxylic acid anhydrides. Bioresource Technol 101: 6147–6150.
21. Santana, M.A.E., Okino, E.Y.A., 2007: Chemical composition of 36 Brazilian Amazon forest wood species. Holzforschung 61: 469-477.
22. Scholz, G., Krause, A., Militz, H. 2010a: Exploratory study on the impregnation of Scots pine sapwood (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) with different hot melting waxes. Wood Sci. Technol 44: 379-388.
23. Scholz, G., Militz, H., Gascon-Garrido, P., Ibiza-Palacios, M., Oliver-Villanueva, J., Peters, B., Fitzgerald, C. 2010b: Improved termite resistance of wood by wax impregnation, Int. Biodeter. Biodegr 64: 688-693.
24. Sidorova, E., 2008: Oil heat treatment of wood. In: Proceedings of the 4 meeting of the Nordic Baltic network in wood. Mat Sci and Engine, Pp 13–14.
25. Sun, Y.X., Liu, Y.X., 2007: Variation of density and shrinkage rate of popular sample compressed by rollers. China Wood Industry 21(6): 13-16.
26. Tjeerdsma, B.F., Militz, H., 2005: Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood. Holz als Roh- und Werkstoff 63: 102-111.
27. Xie, Y., Fu.,Q.,, Wang, Q., Xiao, Z., Militz, H., 2013: Effects of chemical modification on the mechanical properties of wood. European Journal of Wood and Wood Products 71: 401-416.
28. Yang. Z., Lv. B., Fu, Y.J., 2012: The Relationship between near infrared spectroscopy and surface color of eight rosewoods. Advanced Materials Research 479-481: 1772-1776.

Jing Qian, Zhenyu Wang, Jinpeng Li, Lijie Qu
Songlin Yi*, Zhengbin He
Beijing Forestry University
College of Materials Science and Technology
Key Laboratory of Beijing for Wood Materials
and Engineering
Beijing 100083
P.R.China
*Corresponding author: ysonglin@126.com