WOOD RESEARCH doi.org/10.37763/wr.1336-4561/70.4.567579
e-ISSN 2729-8906
70(4): 2025 567-579 pp.

COMPARATIVE STUDY ON THE HEAT TREATMENT OF *DALBERGIA LATIFOLIA* ROXB. WOOD UNDER ATMOSPHERIC PRESSURE AND VACUUM CONDITIONS

YANG ZHENG, MENGQING KE, CHENYANG CAI,
XIAOZHONGYANG,HONGHAI LIU
NANJING FORESTRY UNIVERSITY
PEOPLE'S REPUBLIC OF CHINA

(RECEIVED AUGUST 2025)

ABSTRACT

This study comparedatmospheric heat treatment (AHT) and vacuum heat treatment (VHT)of *Dalbergia latifolia*Roxb. at 180°C for 6 hto improve dimensional stability. Through multiple tests, it analyzed their effects on the wood. Results showed VHT caused milder chemical changes, preserving hydroxyl and lignin structures while AHT severely degraded hemicelluloses. VHT led to lower weight loss 0.45% vs 1.25%, better dimensional stability with a greater reduction in radial swelling 0.84% vs 1.34%, higher mechanical strength (modulus of rupture: 118.22 MPa vs 95.83 MPa; modulus of elasticity 9361.50 MPa vs 8558.34 MPa), and a smaller color change *ΔE**: 9.79 vs 18.65. Overall, VHT can balance performance improvement and minimize damage to the wood's structure and aesthetics.

KEYWORDS: Heat treatment, hygroscopic property, dimensional stability, mechanical characteristics.

INTRODUCTION

Dalbergia latifolia Roxb. wood, a precious rosewood, is a key material for high-end furniture and handicrafts because of its excellent physical properties and unique grain (Hill 2007). However, resource scarcity, high cost, and its tendency to warp and crack in harsh indoor conditions (Wang and Chen 2014; Wang and Yang 2024) limit its widespread use and cause economic losses. Improving its dimensional stability and durability while keeping its features is a crucial challenge.

Modification technology can enhance wood performance and stability (Tjeerdsma et al. 1998; Yang et al. 2025; Yang et al. 2021). Heat treatment (HT) is a common method. It modifies wood by controlling temperature and duration (Esteves and Pereira 2009; Yildiz et al. 2006), improving dimensional stability (Xue et al. 2022), decay resistance, insect-proof ability, and changing wood color.

Conventional atmospheric HT uses inert gases to keep oxygen below 5% and transfers heat mainly through gas convection (Candelier et al. 2013; Aydemir and Gündüz 2009). Vacuum HT operates at sub - atmospheric pressures (0 - 10 kPa), reduces oxygen to near - trace levels (<0.1%), and transfers heat through direct contact (Cao et al. 2022). Thermal modification restructures cell-wall polymers. Hemicellulose deacetylates above 160°C, reducing hygroscopicity by 40-60% but weakening mechanical strength (Wang et al. 2022). Cellulose recrystallizes, enhancing dimensional stability and tensile strength (Candelier et al. 2013). Lignin forms hydrophobic cross-links, improving decay resistance (Yang et al. 2015). These changes increase dimensional stability (anti-swelling efficiency increased by 50-70%) and reduce equilibrium moisture content (Tjeerdsma et al. 1998). Micro-checks in cell walls increase wood permeability (Manohara et al. 2025; Hao et al. 2018).

Both atmospheric and vacuum HT cause similar chemical changes in wood. Vacuum HT can better suppress oxidative degradation due to near-zero oxygen (Cao et al. 2022), potentially reducing discoloration. Differences in mechanical properties and dimensional stability between the two are often minor (Aydemir and Gündüz 2009; Salca and Hiziroglu 2014). Both can worsen pre-existing defects (Yang and Liu 2021; Zhu and Yang 2025). The initial lighter color from vacuum HT may become less distinct over time (Esteves et al. 2008).

Although vacuum HT parameters for *Dalbergia latifolia* have been optimized (Liu et al. 2025), a comparison between vacuum and atmospheric HT for this wood is lacking. This study aims to compare their effects on the physical, mechanical properties, dimensional stability, and color of *Dalbergia latifolia* wood and identify vacuum HT's advantages to promote its application.

MATERIALS AND METHODS

Experiment material

In this study, conventionally kiln-dried heartwood boards of *Dalbergia latifolia Roxb*. provided by Dong Cheng Furniture Co., Ltd. were utilized. The kiln-dried moisture content (MC) and density of these boards were 9.75% and 0.83 g/cm³, respectively. The boards were processed into two types of specimens. According to the dimensional requirements of standards of GB/T 1927:2021, GB/T 1934.2:2009, GB/T 1936:2009, we have set the test of 20×20×20 mm (L×T×R), and the other type had dimensions of 300 mm (L)×20 mm (T)×20 mm (R). Subsequently, these specimens were divided into two groups for HT under atmospheric pressure and vacuum conditions. There were 9 replicates in two types of specimens.

Equipment and instruments

A vacuum HT device was developed by Dongcheng Furniture Co., Ltd., China. This device integrates electrothermal plate heating and vacuum control technology, featuring rapid heating, easy control, energy efficiency, and environmental friendliness. The vacuum HT device consists of a kiln body, vacuum, heatingand cooling system (Liu et al. 2025). Other equipment employed includes: atemperature and humidity controlling chamber (DF-HS-408, Nanjing DEFO, Nanjing Defu Test Equipment Co., Ltd.); a drying oven (DHG-9053BS-II, Shanghai Xinmiao Instrument Co., Ltd.); an electronic balance (FA2004, Shanghai Precision Instrument Co., Ltd., with a precision of 0.001 g); a vernier caliper (CD-20CPX, Mitutoyo, Japan Mitutoyo Co., Ltd., with a precision of 0.01 mm); a Fourier infrared spectrometer (Alpha 2, Bruker Science and Technology Ltd., Beijing); a universal mechanical tester (CMT4204, Shanghai Sundown Instrument Manufacturing Co., Ltd.).

Heat treatments under atmospheric pressure and vacuum conditions

Previous studies have shown that the optimal parameters for *D. latifolia* after vacuum heat treatment (VHT) were determined to be 180°C, 20 kPa, and 6 h (Liu et al. 2025). In this study, the same temperature and duration (180°C/6 h) were employed for atmospheric heat treatment (AHT) to facilitate a direct comparison. The specific treatment conditions are shown in Tab. 1. Specimens of two different dimensions used for AHT were first oven-dried to a completely dry state. Subsequently, the initial measurements of the oven-dry mass, tangential and radial dimensions, and color were taken. Then, put the specimen on the metal wire mesh tray and conduct heat treatment in a drying oven at 180°C under normal pressure for 6 h. The steps are the same as those of VHT.After AHT, the subsequent measurements were carried out in the same way as for VHT. The data for the control (untreated) group and the VHT group were sourced from a previous study (Liu et al. 2025).

Tab. 1: Procedures and corresponding temperature, pressure and time for VHT and AHT.

Condition	Stages	Initial time(°C)	Target time(°C)	Heating time (h)	Heating rate (°C/h)	Treating time (h)	Cooling time (h)	Cooling rate (°C/h)	Pressure (kPa)
VHT	Heating	-	180	5	30	-	-	-	20
	Heattreatment	-	180	-	-	6	-	-	20
	Cooling	180	-	-	-	-	11	10	20
AHT	Heating	-	180	5	30	-	-	-	-
	Heattreatment	-	180	-	-	6	-	-	-
	Cooling	180	-	-	-	-	11	10	-

Infrared spectroscopy testing

The wood for infrared spectroscopy testing was prepared from the central part of the 20 mm (L)×20 mm (T)×20 mm (R) specimens. Before testing, it was crushed into wood powder with a mesh size of 80-100 and then mixed with KBr to make thin disks. These disks were subsequently placed in a sample cell. Infrared spectra were acquired in the range of 400-4000 cm^{-1}, with a spectral resolution of 4 cm^{-1} and 16 scans were accumulated.

Weight loss ratio and oven-dry density

After HT, the weight loss ratio (WLR) of the specimens was calculated using Eq. 1:

$$WLR=\frac{m_0-m_\mathrm{h}}{m_0} \quad (1)$$

where: m_0 and m_h- the oven-dry mass before and after AHT, respectively, g.

The oven-dry densities of the control, VHT and AHT wood was calculated using Eq. 2:

$$\rho_0=\frac{m_0}{v_0} \tag{2}$$

where: ρ_0 - the oven-dry density, g/cm³; m_0 - the oven-dry mass, g; v_0 - the oven-dry volume, cm³.

Equilibrium moisture content (EMC) after moisture absorption

All oven-dried specimens measuring 20 mm (L)×20 mm (T)×20 mm (R) were then uniformly placed in a temperature and humidity controlling chamber at a temperature of 25°C(±2°C) and a relative humidity (RH) of 65% (±5%). The mass and dimensions were measured every 3 h within the first 24 h, and then the measurement intervals were gradually extended. When the mass of the specimens became constant after approximately 434 h, the test was stopped. The equilibrium moisture content (EMC) of the specimens was calculated as:

$$EMC=\frac{m_e-m_0}{m_0} \tag{3}$$

where: m_e and m_0 - the mass of the specimens after and before moisture absorption, resp., g.

Moisture content of wood after water uptake

The specimens mentioned above were dried once more after moisture absorption to obtain their oven-dry mass and dimensions. Subsequently, each specimen was placed individually into a beaker filled with distilled water. During the initial phase of the experiment, the mass of the specimens was measured every 3 h within the first 24 h. After that, the intervals between measurements were gradually lengthened. Eventually, the water uptake process lasted approximately 66.5 h. In accordance with the GB/T 1934.1-91, the moisture content (MC) of the specimens after water uptake was calculated using Eq. 4:

$$MMC=\frac{G_e-G_0}{G_0} \tag{4}$$

where: MMC- the moisture content after 66.5 h water uptake, %; G_e - the mass after water uptake, g; G_0 - the oven-dry mass of specimens before water up-take, g.

Swelling of specimen during moisture absorption and water uptake

In accordance with the GB/T 1934.2:2009, the swelling ratio during the processes of moisture absorption and water uptake was computed using Eq. 5:

$$S_{t,r}=\frac{L_e-L_0}{L_0} \tag{5}$$

where: $S_{t,r}$ - the tangential and radial swelling ratio, %; L_e - the tangential or radial dimensions after moisture absorption or water uptake, mm; L_0 - the tangential or radial oven-dry dimensions of specimens, mm.

Modulus of rupture and modulus of elasticity of wood

In line with the GB/T 1936.1:2009 and GB/T 1936.2:2009, the three-point bending method was employed to measure the modulus of rupture (MOR) and modulus of elasticity

(MOE). Prior to the experiments, all specimens sized 300 mm (L) × 20 mm (T) × 20 mm (R) were oven-dried. Then, mechanical tests were carried out on a universal testing machine. The MOR and MOE of the specimens were calculated using Eq. 6 and Eq. 7, respectively.

$$MOR=\frac{3P_{max}l}{2bh^2} \tag{6}$$

$$MOE=\frac{23Pl^3}{108bh^3f} \tag{7}$$

where: P_{max} - the maximum load at failure, N; l - the span between the two supports, mm; b - the width of the specimen, mm; h - the height of the specimen, mm; P - the difference between the upper and lower loads, N; f - the deformation of the specimen between the upper and lower loads, mm.

Color measurement

The surface color of the 300 mm (L) × 20 mm (T) × 20 mm (R) specimens was measured at the same position before and after HT. The CIE L*, a*, b* chromaticity values were determined, and the color change ΔE* due to vacuum HT was calculated using Eq. 8:

$$\Delta E^*=\sqrt{\left(\Delta L^*\right)^2+\left(\Delta a^*\right)^2+\left(\Delta b^*\right)^2} \tag{8}$$

where: ΔL^*, Δa^*, and Δb^* - the changes in lightness, green-redness, and blue-yellowness before and after HT, respectively.

RESULTS AND DISCUSSION

Effect of heat treatment on the chemical composition

Fig. 1 shows the comparative FTIR spectra of control, VHT, and AHT wood. Spectral analysis reveals chemical changes due to different heat - treatment environments.The broad 3400 cm^{-1} peak (O–H stretching) was most intense in the Control, less so in VHT (red curve), and least intense in AHT (blue curve), indicating more hydroxyl - group depletion under atmospheric conditions. The C–H stretching peak (around 2900 cm^{-1}) was stable in all spectra, showing aliphatic C–H bonding stability. In the 1730 - 1740 cm^{-1} region (C=O stretching), the VHT peak was less intense than the Control's, and the AHT peak was nearly at the baseline. This aligns with deacetylation under low oxygen (Hakkou et al. 2005) and oxidative degradation in air. Peaks for lignin's aromatic skeletal vibrations (1600 cm^{-1} and 1510 cm^{-1}) gradually decreased. They were weaker in VHT than the Control and much weaker in AHT, suggesting lignin structure modifications, possibly oxidative degradation or inter - unit linkage cleavage, especially in air (Sivonen et al. 2002). The 1022 cm^{-1} band (mainly C–O stretching in cellulose/hemicelluloses) also decreased in intensity after VHT and AHT, most notably in AHT. These changes are consistent with glycosidic - bond hydrolysis and polysaccharide - matrix reorganization (Akgül and Korkut 2012). Overall, the spectral trends in Fig.1 (progressive attenuation of peaks at 3400 cm^{-1} (O–H), 1738 cm^{-1} (C=O), ~1600/1510 cm^{-1} (aromatic C=C), and 1022 cm^{-1} (C–O) from Control to VHT to AHT) show that heat treatmentsignificantly alters wood chemistry. The changes are more significant under atmospheric conditions than in vacuum processing. These chemical transformations likely play a key role in determining the material’s physical properties and application performance.

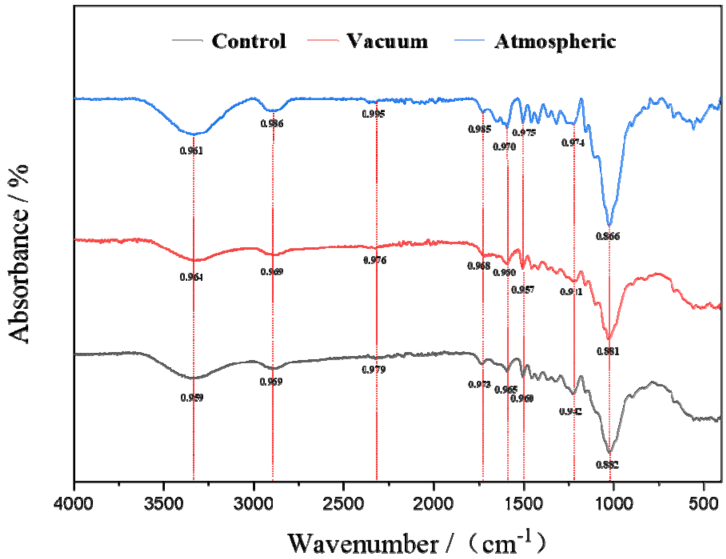

Fig. 1: FTIR of control, vacuum and atmospheric heat-treated wood.

Weight loss ratio and absolute dry density

Fig. 2a compares wood weight-loss ratios after VHT and AHT at 180°C for 6 h. VHT causes only 0.45% weight loss, while AHT leads to 1.25% reduction. The vacuum in VHT reduces oxygen, suppressing thermal oxidative degradation, the main weight-loss cause. In AHT, cellulose and hemicellulose decompose via free radical chain reactions in an aerobic environment, producing CO_2 and CO (Kong et al. 2019). VHT's vacuum system quickly removes pyrolysis volatiles like aldehydes and acids, preventing their retention in wood pores. In AHT, retained volatiles absorb heat, catalyze secondary degradation (e.g., hemicellulose acetyl-group hydrolysis), and break polymer chains. Fig. 2b shows oven-dry density changes. VHT wood density drops to 0.75 g/cm³, while AHT wood is 0.83 g/cm³.

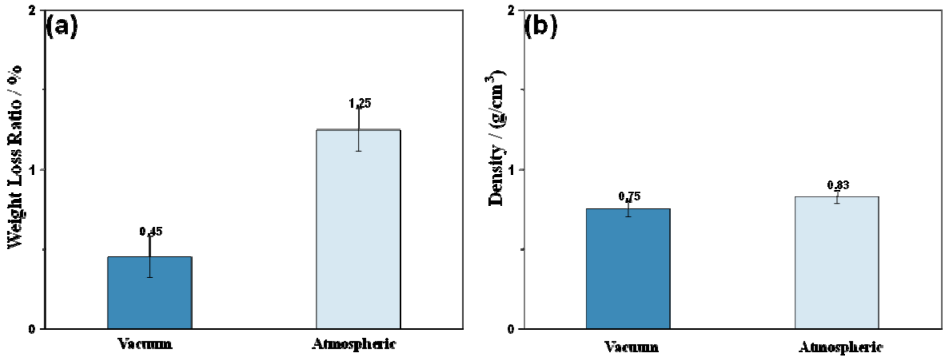

Fig. 2: Effects of different heat treatments on (a) weight loss ratio (b) density of wood.

The lower VHT density indicates better quality. In AHT, accumulated volatiles swell cell walls at high temperatures. After cooling, cell cavities collapse as volatiles escape, causing a false density increase due to structural damage. In VHT, continuous volatile removal keeps the cell-wall skeleton intact. The density decrease results from molecular-chain thermal breakage (Kubovský et al. 2020). In conclusion, VHT's oxygen-deficient environment inhibits degradation, and volatile removal eliminates secondary catalysis. VHT reduces the weight-loss ratio and maintains wood microstructure stability, outperforming AHT. Its low weight loss and controllable density change make it superior for material-property preservation.

Moisture absorption and water uptake characteristic

The MC of the control, VHT and AHT wood during moisture absorption and water uptake are presented in Figs.3a and 3b, respectively. The moisture absorption is rapid in the early stage (0-24 h) and then slows down. Samples reach the EMC after 434 h. The EMC values are 9.75 ± 0.9% for the control group, 5.17 ± 0.4% for the VHT group, and 7.60 ± 2.66% for the AHT group. These values represent decreases of 46.97% and 22.05% compared to the control group, respectively. In contrast, the water uptake of these woods is significantly faster than moisture absorption throughout the whole process. After 66.5 h, the MC of the control group is 41.39% ± 10.59%, while those of VHT and AHT are 29.28% ± 3.08% and 23.85% ± 0.70%, respectively, showing reductions of 29% and 42%. Compared with the MC during moisture absorption, AHT wood exhibits the lowest MC during water uptake. This is because, as shown in previous studies (Candelier et al. 2013), the water uptake capacity of wood is more complex than its moisture absorption capacity.

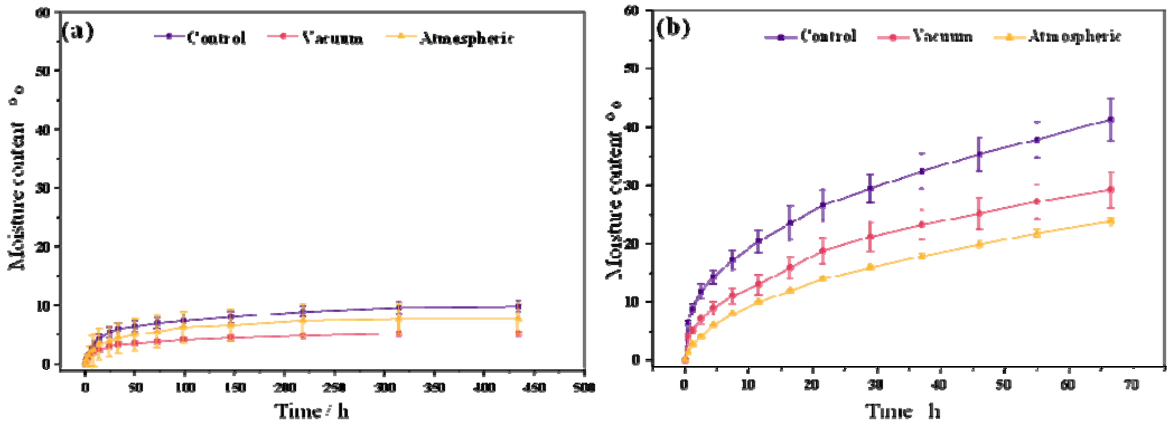

Fig. 3: Changes of moisture content of control, vacuum and atmospheric heat treated wood in (a) water absorption and (b) water uptake process.

Impact of heat treatment on the dimensional stability

Figs. 4a and 4b show radial and tangential swelling. Wood swells as cell-wall bound water increases, but HT-treated wood swells much less, especially tangentially. Radially, final swelling of control, VHT, and AHT wood is 1.97%, 0.84%, and 1.34% respectively, with VHT and AHT decreasing by 57.36% and 31.98% vs. control. Tangentially, VHT and AHT decrease final swelling by 60.83% and 59.35%. VHT is more effective for dimensional stability, especially radially, as HT reduces EMC by 29.26% - 42.38% and lignin forms cross-links (Wikberg and Maunu 2002). Figs. 4c and 4d show similar swelling curves during water uptake, faster than moisture absorption. HT wood swells significantly less in both directions. Initially, VHT wood swells more than AHT, later less. Radially, final swelling of control, VHT, and AHT is 4.19%, 2.43%, and 3.05% respectively, with VHT and AHT decreasing by 42.00% and 27.21% vs. control. Tangentially, VHT and AHT decrease swelling by 49.4% and 43.01%. VHT has a higher water - uptake ratio. In early stages (R < 25 h, T < 50 h), VHT has a higher swelling ratio, later similar to AHT ($p < 0.05$).

These results confirm VHT is more effective in controlling wood's dimensional stability during water uptake. Thermal treatment enhances stability by reducing hygroscopicity and forming dense layers and cross-links. VHT, with higher intensity, modifies cell-wall components better, suppressing swelling (Papadopoulos 2019).

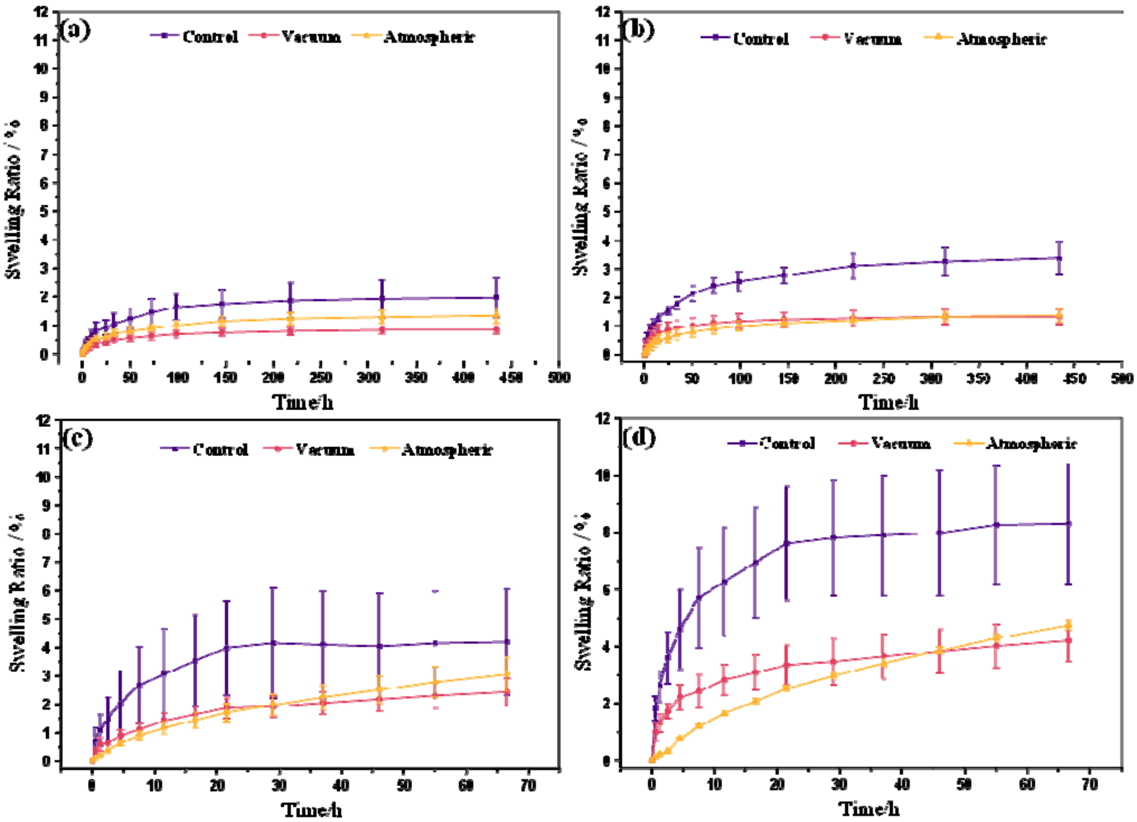

Fig. 4: Changes of swelling ratio in radial (a) and (b) tangential direction during moisture absorption process of control, VHT and AHT wood; swelling ratio in radial (c) and (d) tangential direction during water up take process of control, VHT and AHT wood.

Effect of heat treatment on the modulus of rupture and modulus of elasticity

Figs. 5a and 5b show MOR and MOE of control, VHT, and AHT wood. The untreated control had the best MOR (168.60 MPa). VHT (118.22 MPa, 29.85% lower) and AHT (95.83 MPa, 43.19% lower) saw significant drops, likely due to treatment - induced structural changes (Esteves and Pereira 2009). The MOE also decreased. The control had 11374.79 MPa, VHT 9361.50 MPa (17.69% decrease), and AHT 8558.34 MPa (24.75% decrease), possibly due to hemicellulose pyrolysis (Xing et al 2016). The MOR reduction rate (43.19%) was much higher than MOE's (24.76%), in line with wood mechanics (Guo et al. 2023). The MOE difference between VHT and AHT (803.16 MPa) was larger than MOR's (22.39 MPa), suggesting pressure affects micromechanics more. VHT better preserves wood's mechanical properties.

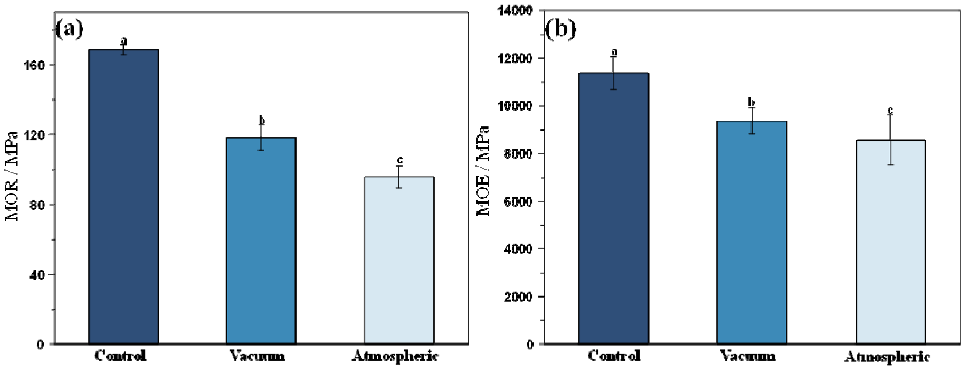

Fig. 5: The (a) MOR and (b) MOE of the control, vacuum and atmospheric heat-treated wood.

Effect of heat treatment on the color of wood

Fig.6 depicts the effects of HT on wood color parameters. After HT, the negative values of *Δa** indicate a slight shift towards a greenish hue (Yang et al. 2021; Liu et al.2017). Similarly, negative *Δb** values suggest a bluish tone, which is in contrast to the typical thermal yellowing trends. This might be attributed to the oxidation of lignin. The negative *ΔL** values confirm a reduction in brightness (darkening), presumably resulting from surface carbonization. The positive ΔE* values, which represent a significant overall color change, demonstrate pronounced chromatic shifts. After HT, *Δa**, *Δb**, *ΔL**, and *ΔE** exhibited similar trends of change. However, the changes in these parameters for VHT wood were significantly lower than those for AHT wood, indicating that VHT is more effective in maintaining the original color of the wood. The presence of oxygen in AHT likely accelerates oxidative reactions, thereby amplifying the color alterations.

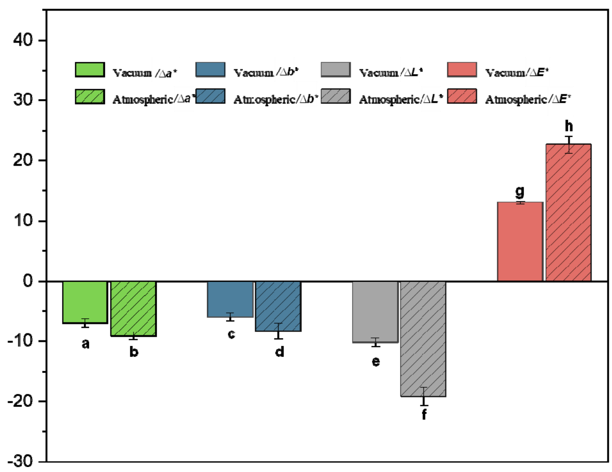

Fig. 6: The effect of heat treatment on wood color: (a) red-green difference, (b) yellow-blue difference, (c) brightness difference, (d) total color difference.

CONCLUSIONS

This study compared the effects of vacuum heat treatment (VHT) and atmospheric heat treatment (AHT) on *Dalbergia latifolia* wood. The key findings are as follows:*(1)*VHT resulted in lower weight loss (0.45% compared to 1.25% for AHT) and less density reduction (0.75 g/cm³ compared to 0.83 g/cm³), thereby minimizing the oxidative degradation of wood components.*(2)*AHT showed lower water uptake (23.85% compared to 29.28% for VHT), while VHT achieved a more significant reduction in equilibrium moisture content (*EMC*) (46.97% compared to 22.05% for AHT). VHT outperformed AHT in suppressing swelling, reducing radial hygroscopic swelling by 57.4% (compared to 32.0% for AHT) and water-induced swelling by 42.0% (compared to 27.2% for AHT). VHT demonstrated superior moisture resistance (lower *EMC*) and dimensional stability (57% less hygroscopic swelling), while AHT was more effective in reducing water uptake.*(3)*VHT maintained higher mechanical integrity, with the modulus of rupture (*MOR*) (118.22 MPa) and modulus of elasticity (*MOE*) (9361.50 MPa) exceeding those of AHT (95.83 MPa and 8558.34 MPa respectively).*(4)*AHT caused severe degradation of chemical groups, while VHT led to milder alterations and less color change (ΔE^*=12.3 compared to 18.6 for AHT).In conclusion, VHT provides a well-balanced approach for wood modification. Its low-oxygen environment reduces chemical degradation, improves dimensional stability, minimizes the loss of mechanical strength, and preserves the color, making *Dalbergia latifolia* wood more suitable for high-value wood applications.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China Grant No. 32301521, 31870545 and 31570558).

REFERENCES

1. HILL, C.A. (2007): Wood modification: chemical, thermal and other processes. John Wiley & Sons, 45-76.
2. XU, W. & YANG, C. (2014): The research about protection and restoration of ancient round fans in the palace museum. Journal of Gugong Studies, 11(01),479-488.
3. WANG, X. & YANG, L. (2024): Effect of freezing and freezing-thawing pretreatment on wood properties and drying characteristics of *Eucalyptus urophylla× E. grandis*. Wood Material Science & Engineering, 1-7.
4. TJEERDSMA, B.F., BOONSTRA, M., PIZZI, A., TEKELY, P. & MILITZ, H. (1998): Characterisation of thermally modified wood: molecular reasons for wood performance improvement. Holz alsRoh-und Werkstoff, 56(03), 149-153.

5. YANG, L., LIU, X., LI, T., & LI, J. (2025). Influence of temperature and vacuum level on the drying rate, moisture content distribution, wood color and drying stress of rubberwood in vacuum drying. *Wood Material Science & Engineering*, 1-7.
6. YANG, Y.Q., XU, W., LIU, X. & WANG, X.D. (2021): Study on permeability of *CunninghamiaLanceolata* based on steam treatment and freeze treatment. Wood Research, 66, 721-731.
7. ESTEVES, B.M. &PEREIRA, H.M. (2009): Wood modification by heat treatment: a review. BioResources, 4(01), 370-404.
8. YILDIZ, S., GEZER, E.D. & YILDIZ, U.C. (2006): Mechanical and chemical behavior of spruce wood modified by heat. Building and Environment, 41(12), 1762-1766.
9. XUE, J., XU, W., ZHOU, J., MAO, W. & WU, S. (2022): Effects of high-temperature heat treatment modification by impregnation on physical and mechanical properties of poplar. Materials, 15(20), 7334.
10. BRITO, F.M.S., PAES, J.B., DA SILVA OLIVEIRA, J.T., ARANTES, M.D.C. & DUDECKI, L. (2020): Chemical characterization and biological resistance of thermally treated bamboo. Construction and Building Materials, 262, 120033.
11. SRINIVAS, K. & PANDEY, K.K. (2012): Effect of heat treatment on color changes, dimensional stability, and mechanical properties of wood. Journal of Wood Chemistry and Technology, 32(4), 304-316.
12. ROWELL, R.M., IBACH, R.E., McSWEENY, J. & NILSSON, T. (2009): Understanding decay resistance, dimensional stability and strength changes in heat-treated and acetylated wood. Wood Material Science & Engineering, 4(1-2), 14-22.
13. 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(04), 401-416.
14. KAYMAKCI, A. & BAYRAM, B.C. (2021): Evaluation of heat treatment parameters' effect on some physical and mechanical properties of poplar wood with multi-criteria decision-making techniques. BioResources, 16(3), 4693.
15. ZHU, J. & YANG, L. (2025): Progress in the study of dry shrinkage deformation and drying stress of raw bamboo. BioResources, 20(1), 2304-2320.
16. YANG, L. & LIU, H. (2021): Study of the collapse and recovery of *Eucalyptus urophydis* during conventional kiln drying. European Journal of Wood and Wood Products, 79(1), 129-137.
17. WANG, D., FU, F. & LIN, L. (2022): Molecular-level characterization of changes in the mechanical properties of wood in response to thermal treatment. Cellulose, 29(06), 3131-3142.
18. CANDELIER, K., DUMARÇAY, S., PÉTRISSANS, A., PÉTRISSANS, M., KAMDEM, P. & GÉRARDIN, P. (2013):Thermodesorption coupled to GC-MS to characterize volatiles formation kinetic during wood thermodegradation. Journal of analytical and applied pyrolysis, 101, 96-102.
19. YANG, L., JIANG, T., LIU, H. & LI, K. (2015): Effects of different drying treatments on preservation of organic compounds in *Dalbergia bariensis* wood. Bioresources, 10(4).

20. MANOHARA, T.N., BALAKRISHNA, S.M. & SURESH, H.S. (2025): Genomic insights of *Dalbergia latifolia* (Indian rosewood): applications in conservation and beyond. Trees, 39(2), 39.
21. HAO, Y., PAN, Y., DU, R., WANG, Y., CHEN, Z., ZHANG, X. & WANG, X. (2018): The influence of a thermal treatment on the decay resistance of wood via FTIR analysis. Advances in Materials Science and Engineering, 2018(1), 8461407.
22. CAO, S., CHENG, S. & CAI, J. (2022): Research progress and prospects of wood high-temperature heat treatment technology. BioResources, 17(02), 3702.
23. YANG, L., HAN, T., LIU, Y. & YIN, Q. (2021): Effects of vacuum heat treatment and wax impregnation on the color of *Pterocarpus macrocarpus* Kurz. Bioresources, 16(1), 954-963.
24. AYDEMIR, D. & GÜNDÜZ, G. (2009): The effect of heat treatment on physical, chemical, mechanical and biological properties of wood. Bartn Orman FakültesiDergisi (15), 71-81.
25. SALCA, E. A. & HIZIROGLU, S. (2014): Evaluation of hardness and surface quality of different wood species as function of heat treatment. Materials & Design (1980-2015), 62, 416-423.
26. HE, L., ZHANG, T., RUAN, Z., ZHAO, Y., HE, Z., YI, S. (2023): Effect of high-temperature heat treatment on color and dimensional stability of three tropical hardwoods. Chinese. Journal of Wood Science and Technology,37(02):25-34.
27. LIU, H., ZHENG, Y. & KE, M. (2025): Study on the effects of vacuum heat treatment on the physical, mechanical, and chemical properties of *Dalbergia latifolia*Roxb wood. Wood Material Science & Engineering, 1-11.
28. HAKKOU, M., PÉTRISSANS, M., ZOULALIAN, A. & GÉRARDIN, P. (2005): Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polymer Degradation and Stability, 89(01), 1-5.
29. SIVONEN, H., MAUNU, S.L., SUNDHOLM, F., JMS, S. & VIITANIEMI, P. (2002): Magnetic resonance studies of thermally modified wood. Holzforschung, 56(06), 648-654.
30. AKGÜL, M. & KORKUT, S. (2012): The effect of heat treatment on some chemical properties and colour in Scots pine and Uludağ fir wood. African Journal of Biotechnology, 7(21), 2854-2859.
31. KONG, F., ZOU, C., WANG, Y., SHAO, H., SUN, L., XU, L., YE, J. & JIN, W. (2019) Effect of heat treatment on chemical composition and physico-mechanical properties of wood. Forestry Machinery & Woodworking Equipment, 47(01): 9-16.
32. KUBOVSKÝ, I., KAČÍKOVÁ, D., & KAČÍK, F. (2020). Structural changes of oak wood main components caused by thermal modification. *Polymers*, *12*(02), 485.
33. CANDELIER, K., DUMARÇAY, S., PÉTRISSANS, A., GÉRARDIN, P. & PÉTRISSANS, M. (2013): Comparison of mechanical properties of heat treated beech wood cured under nitrogen or vacuum. Polymer Degradation and Stability, 98(09), 1762-1765.
34. WIKBERG, H. & MAUNU, S.L. (2004): Characterisation of thermally modified hard-and softwoods by 13C CPMAS NMR. Carbohydrate Polymers, 58(4), 461-466.

35. PAPADOPOULOS, A.N. (2019): Advances in wood composites. Polymers, 12(01), 48.
36. XING, D., LI, J., WANG, X. & WANG, S. (2016): In situ measurement of heat-treated wood cell wall at elevated temperature by nanoindentation. Industrial crops and products, 87, 142-149.
37. GUO, X., ZHOU, F., DENG, S. & DONG, C.(2023): Study on the static-bending properties of surface-reinforced wood with asymmetric fibers. Forests, 14(12), 2454.
38. YANG, L. & JIN, H. (2021): Effect of heat treatment on the physic-mechanical characteristics of *Eucalyptusurophylla*STBlake. Materials, 14(21), 6643.
39. LIU, X.Y., TIMAR, M.C., VARODI, A.M. & SAWYER, G. (2017): An investigation of accelerated temperature-induced ageing of four wood species: colour and FTIR. Wood Science and Technology, 51(02), 357-378.

YANG ZHENG[1,2], MENGQING KE[2], CHENYANG CAI[1,2], XIAOZHONG YANG[3], HONGHAI LIU[1,2*]
NANJING FORESTRY UNIVERSITY
[1]JIANGSU CO-INNOVATION CENTER OF EFFICIENT PROCESSING AND UTILIZATION OF FOREST RESOURCES
[2]COLLEGE OF FURNISHINGS AND INDUSTRIAL DESIGN
NANJING 210037, CHINA
[3]JIANGSU TE WEI ER SI NEW MATERIALS CO., LTD
SUQIAN, 223700, CHINA
*Corresponding author: liuhonghai2020@njfu.edu.cn