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Properties of Thermally Modified Woods by a Brazilian Process †

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Abstract: Thermal modification processes are strategies used to improve the properties of wood with an environmental liability when no chemicals are used. The Vap HolzSysteme®, developed in Brazil, promotes a thermal modification in wood when using an atmosphere saturated with water vapor thus ensuring a low oxygen content in the pressure system. To evaluate this process, samples of *Pinus taeda* and *Eucalyptus grandis* woods were treated in an industrial autoclave at a final cycle temperature of 160 °C. Consequently, the anatomical characteristics were maintained; however, equilibrium moisture, basic density, chemical composition, and mechanical properties were modified. Some modifications were different considering the wood species, mainly in their mechanical properties.

Keywords: *Pinus taeda*; *Eucalyptus grandis*; wood modification

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1. Introduction

Wood is a biological and heterogeneous material, with both hygroscopic and anisotropic behaviors. These characteristics give many variations to its technological properties when compared to more homogeneous materials, such as concrete and steel. Despite the adversities, wood has an excellent ratio of mechanical strength to specific mass, aesthetic uniqueness, thermal and acoustic insulation, and it is a renewable resource among other factors that keep it as one of the most used raw materials industrially [1].

There are processes capable of improving the properties of wood that can expand its use, such as chemical, surface, impregnation, or thermal modifications [2]. Among these, thermal modification stands out as it does not use any toxic chemical reagents and thus maintains the sustainable and renewable characteristics of wood. Briefly, the processes of thermal modification can be defined as the application of heat that results in a degradation and an alteration to the chemical components of the wood cell wall, which consequently has positive effects in improving the dimensional stability, a greater biological durability, less color variation, and greater hydrophobicity; however, thermal modifications can cause a decrease to some of the mechanical properties of wood [3].

The most popular thermal wood modification processes are "ThermoWood® Process" (Finnish origin), "Retification®" and "Le Bois Perdure®" (both of French origin), "Plato-Process®" (Dutch origin), "Oil-Heat-Treatment®" (of German origin), "WTT" (of Danish origin), and "Huber Holz" (of Austrian origin) [3]. In Brazil, the TWBrazil company developed a modification process called Vap HolzSysteme®, which uses saturated water vapor for the direct transfer of heat to the wood, simultaneously promoting a more efficient thermal modification and a reduction in the oxygen concentration in the system due to the saturation of the system with steam and without a final forced cooling step.

Thus, the objective of this research was to evaluate the wood characteristics of *Pinus taeda* and *Eucalyptus grandis* wood thermally modified by the Vap HolzSysteme®.

2. Material and Methods

Boards of *P. taeda* and *E. grandis*, made for decking, untreated and thermally treated, were donated by TW Brazil company. The thermal modification process was carried out at a final process temperature of 160 °C, in a saturated steam atmosphere with a decreased oxygen concentration in five stages: initial heating at 110 °C, 25 min at 110 °C; second heat 160 °C, 45 min at 160 °C; followed by natural cooling. The total duration of the thermal modification was 16 h, divided into two heating–cooling cycles of eight hours each.

The effects of thermal modification on the anatomy of wood (surface description), the wood's physical properties (equilibrium moisture, wood basic density, and shrinkage), the chemical composition of the wood (holocellulose content, total lignin content, and total extractive content), and the mechanical properties of the wood (static bending and hardness). All analyzes were performed with five replicates.

3. Results and Discussion

Figure 1 shows the microscopy of the heat-treated wood. The thermal modification did not cause any significant changes in the anatomical structure of the wood, with the only observable effect being a reduction in the cell wall in both species due to the thermal degradation of wood carbohydrates [4].

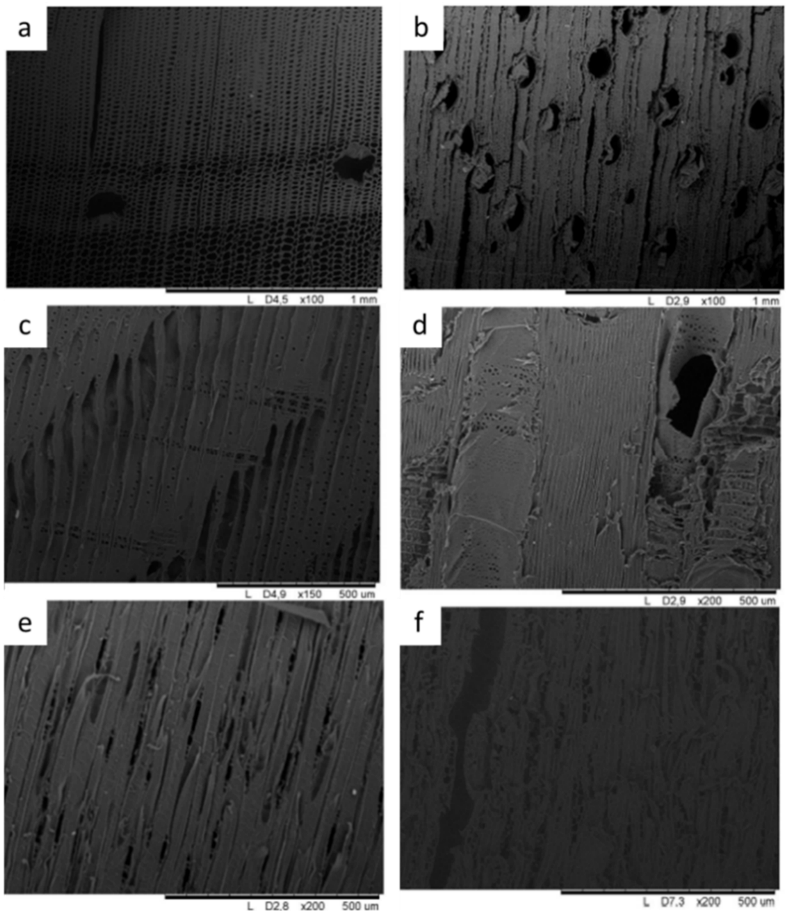

Figure 1. Microscopy of the heat-treated woods. (**a**) *P. taeda* cross section; (**b**) *P. taeda* radial section; (**c**) *P. taeda* tangential section; (**d**) *E. grandis* cross section; (**e**) *E. grandis* radial section; (**f**) *E. grandis* tangential section.

The comparison between heat-untreated wood and heat-modified wood, taken into consideration the physical properties, chemical composition, and mechanical properties of the wood is shown in Table 1.

Table 1. Wood characteristics of *Pinus taeda* and *Eucalyptus grandis* wood before and after the thermal modification.

Wood Property	UPW	TPW	UEW	TEW
Wood basic density, g cm^{-3}	0.53 a	0.41 b	0.67 a	0.56 b
Equilibrium moisture, %	11.47 a	9.76 b	11.43 a	10.11 b
Volumetric shrinkage, %	15.03 a	9.54 b	13.29 a	10.42 b
Longitudinal shrinkage, %	0.49 a	0.29 a	0.77 a	0.47 a
Radial shrinkage, %	6.61 a	4.26 b	4.84 a	4.03 a
Tangential shrinkage, %	8.56 a	5.24 b	8.16 a	6.21 b
Anisotropy of shrinkage	1.29 a	1.23 a	1.68 a	1.55 a
Holocellulose content, %	68.49 a	65.47 b	70.14 a	59.14 b
Total lignin content, %	27.97 b	30.51 a	22.08 b	30.07 a
Total extractives content, %	2.54 b	3.24 a	6.77 b	9.79 a
Flexural strength, MPa	82.26 a	54.19 b	104.87 a	53.94 b
Elastic modulus, MPa	9621.28 a	8488.40 a	14,219.60 a	11,623.45 b
Longitudinal hardness, Kgf	286.73 b	295.26 a	671.33 a	434.22 b
Radial hardness, Kgf	221.71 a	203.41 a	507.72 a	289.33 b
Tangential hardness, Kgf	264.19 a	213.05 b	340.17 b	563.72 a

(UPW) untreated *P. taeda* wood; (TPW) treated *P. taeda* wood; (UEW) untreated *E. grandis* wood; (TEW) treated *E. grandis* wood. Microscopy of the heat-treated woods. Means followed by different letters, considering the line, are different according to the Tukey ($p < 0.05$).

The basic density of all the evaluated wood was reduced significantly; this behavior is expected in thermally modified woods [5]. The decrease in the basic density values of the wood is associated with mass loss, which is due to the thermal degradation of wood carbohydrates [3]. A drop in equilibrium moisture was also observed, i.e., wood hygroscopicity is decreased by thermal modification. This phenomenon is also associated with the thermal degradation of carbohydrates, as there is a decrease in the hydroxyl groups that can form bonds with water via hydrogen bonds [4].

The exchange of water with the environment is the reason for the dimensional variations in the wood [4,5], with the loss of hydrophilic carbohydrates caused by the thermal degradation, a tendency of decreasing contractions was observed. The anisotropy of shrinkage is the main parameter used to verify the dimensional stability of wood [6] and is obtained by dividing the tangential shrinkage by the radial shrinkage. In the present work, the reductions in the anisotropy of shrinkage were not significant in both woods; however, it was possible to observe that the wood of *P. taeda* had less anisotropy of contraction and was therefore more dimensionally stable than that of *E. grandis*.

The thermal modification of wood significantly alters the chemical composition, degrading extractives and some cell wall components [4]. In the present work, the total extractive content and total lignin content increased significantly but the holocellulose content reduced. Due to the volatility of the extractives, these compounds were quickly eliminated from the wood; however, the thermal degradation of the carbohydrates produced new compounds, which were extractable in solvents, such as water, ethanol, and toluene. This caused an increase in the total extractive content of the wood [3,4]. Lignin is the component with the highest thermal stability, and it remains in the wood against the action of temperature [7], so its content increased in thermally treated wood.

The major problem of thermal modification is the consequent decrease in the mechanical properties of wood [3]. Negatively significant effects were found on the flexural strength of both species, on the elastic modulus of *E. grandis*, on the longitudinal and radial hardness of *E. grandis*, and on the tangential hardness of *P. taeda*; on the other hand, the longitudinal hardness of *P. taeda* wood and the tangential hardness of *E. grandis* increased. Heat-treated wood has its ability to exchange water reduced, so the low moisture content can make it more resistant to some mechanical stresses to the point of compensating for the negative effects of mass loss [8].

4. Conclusions

The change in wood anatomy, caused by the thermal modification process, was restricted to the reduction in cell walls.

The loss of mass caused a decrease in wood density and a drop in the equilibrium moisture for both species.

In general, heat treatment improved the dimensional stability of the wood, taking into consideration the shrinkages in each of the three directions of the wood separately; however, the anisotropy of contraction remained the same.

The main effects on the chemical composition of the wood were a decrease in the holocellulose content and an increase in the lignin content.

As expected, thermal modification resulted in a decrease of the mechanical strength properties of the wood; however, the opposite effect was observed in the longitudinal hardness of *P. taeda* and in the tangential hardness of *E. grandis*.

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References

1. Hill, C.; Kymäläinen, M.; Rautkari, L. Review of the use of solid wood as an external cladding material in the built environment. *J. Mater. Sci.* **2022**, *57*, 9031–9076. [CrossRef]
2. Hill, C. *Wood Modification*; Wiley: Hoboken, NJ, USA, 2006.
3. Esteves, B.M.; Pereira, H.M. Wood modification by heat treatment: A review. *BioResources* **2009**, *4*, 370–404. [CrossRef]
4. Lengowski, E.C.; Bonfatti Júnior, E.A.; Nisgoski, S.; Muñiz, G.I.B.; Klock, U. Properties of thermally modified teakwood. *Maderas Cienc. Tecnol.* **2021**, *23*, 1–16. [CrossRef]
5. Ozasahin, S.; Murat, M. Prediction of equilibrium moisture content and specific gravity of heat treated wood by artificial neural networks. *Eur. J. Wood Wood Prod.* **2017**, *76*, 563–572. [CrossRef]
6. Fu, Z.; Cai, Y.; Zhao, J.; Huan, S. The effect of shrinkage anisotropy on tangential rheological properties of Asian white birch disks. *BioResources* **2013**, *8*, 5235–5243. [CrossRef]
7. Poletto, M.; Zattera, A.J.; Santana, R.M.C. Thermal decomposition of wood: Kinetics and degradation mechanisms. *Bioresour. Technol.* **2012**, *126*, 7–12. [CrossRef] [PubMed]
8. Boonstra, M.J.; Van Acker, J.; Tjeerdsma, B.F.; Kegel, E.V. Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. *Ann. For. Sci.* **2007**, *64*, 679–690. [CrossRef]