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Properties of Thermally Modified Woods by A Brazilian Process [†]

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

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

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1. Introduction

Wood is a biological and heterogeneous material, with hygroscopic and anisotropic behavior, these characteristics give many variations in 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, it is a renewable resource, among other factors that keep it as one of the raw materials most used 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 reagent, maintaining the sustainable and renewable characteristic of wood. Briefly, the processes of thermal modification can be defined as the application of heat that results in degradation and alteration in the chemical components of the wood cell wall, having as positives effect the improvement in dimensional stability, greater biological durability, less color variation, and greater hydrophobicity, but they can cause a decrease in some wood mechanical properties [3].

The most popular thermal wood modification processes are "ThermoWood® Process" (Finnish origin), "Retification®" and "Le Bois Perdure®" (both 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 in the direct transfer of heat to the wood, promoting, simultaneously, a more efficient thermal modification and reduction of the oxygen concentration in the system due to the saturation of the system with steam, without a final forced cooling step.

Thus, the objective of this research was to evaluate wood characteristics of *Pinus taeda* and *Eucalyptus grandis* woods thermal 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 final process temperature of 160 °C, in saturated steam atmosphere with decreased oxygen concentration in five stages: initial heating at 110 °C, 25 minutes at 110 °C, second heat until 160 °C, 45 minutes at 160 °C, and natural cooling. The total duration of the thermal modification was 16 hours, divided in two heating-cooling cycles of eight hours each.

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

3. Results and Discussion

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

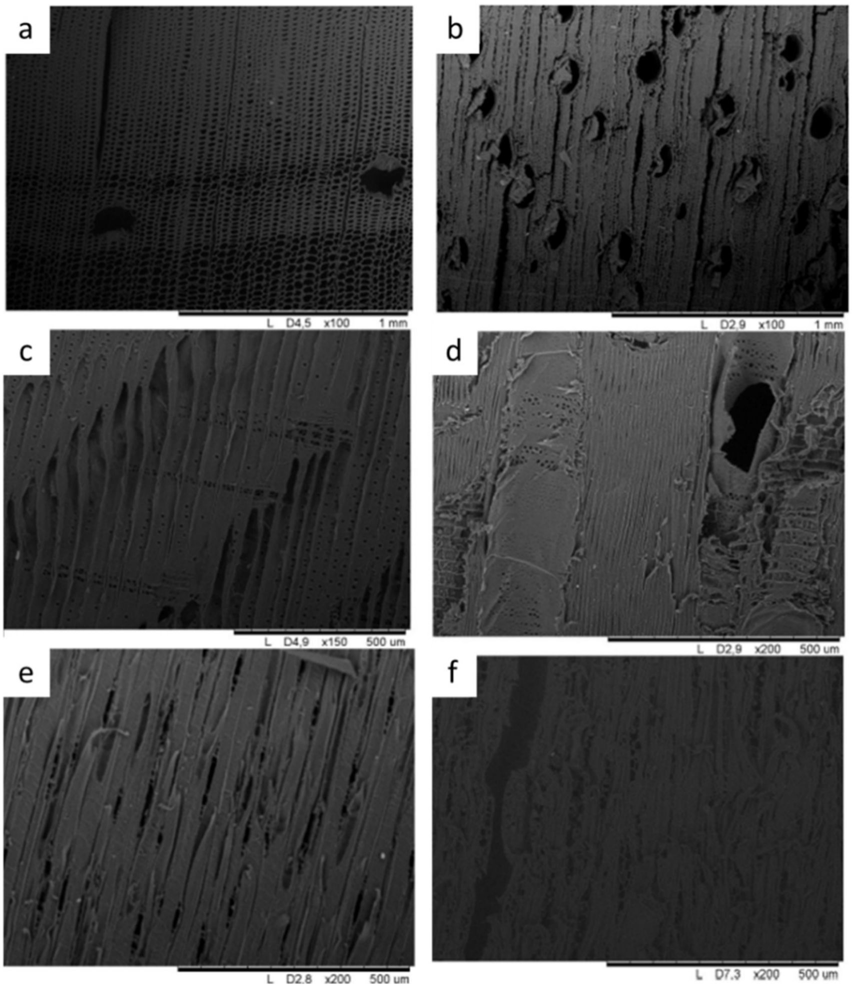

Figure 1. Microscopy of the heat-treated woods. (**a**) *P. taeda* cress section; (**b**) *P. taeda* radial section; (**c**) *P. taeda* tangential section; (**d**) *E. grandis* cress section; (**e**) *E. grandis* radial section; (**f**) *E. grandis* tangential section.

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

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

Wood property	UPW	TPW	UEW	TEW
Wood basic density, g cm^{-3}	0.53a	0.41b	0.67a	0.56b
Equilibrium moisture, %	11.47a	9.76b	11.43a	10.11b
Volumetric shrinkage, %	15.03a	9.54b	13.29a	10.42b
Longitudinal shrinkage, %	0.49a	0.29a	0.77a	0.47a
Radial shrinkage, %	6.61a	4.26b	4.84a	4.03a
Tangential shrinkage, %	8.56a	5.24b	8.16a	6.21b
Anisotropy of shrinkage	1.29a	1.23a	1.68a	1.55a
Holocellulose content, %	68.49a	65.47b	70.14a	59.14b
Total lignin content, %	27.97b	30.51a	22.08b	30.07a
Total extractives content, %	2.54b	3.24a	6.77b	9.79a
Flexural strength, MPa	82.26a	54.19b	104.87a	53.94b
Elastic modulus, MPa	9621.28a	8488.40a	14219.60a	11623.45b
Longitudinal hardness, Kgf	286.73b	295.26a	671.33a	434.22b
Radial hardness, Kgf	221.71a	203.41a	507.72a	289.33b
Tangential hardness, Kgf	264.19a	213.05b	340.17b	563.72a

(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. Different letters in the same species means significant difference by the F-test at 5 % of probability.

The basic density of all evaluated woods reduced significantly; this behavior is expected in thermally modified woods [5]. The decrease in wood basic density values is associated with mass loss due to 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 hydroxyl groups capable of forming bonds with water by 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 thermal degradation, a tendency of decreasing contractions was observed. The anisotropy of shrinkage is the main parameter 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* has less anisotropy of contraction and therefore is 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 are quickly eliminated from the wood, however the thermal degradation of carbohydrates produces new compounds extractable in solvents such as water, ethanol, and toluene, and this causes 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 in 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].

3. Conclusions

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

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

In general, the heat treatment improved the dimensional stability of the wood considering the shrinkages in the three directions of the wood separately, on the other hand the anisotropy of contraction remained the same.

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

As expected, the thermal modification proved decrease on mechanical strength properties of the woods, but opposite effect was observed in the longitudinal hardness of *P. taeda* and in the tangential hardness of *E. grandis*.

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