

Effect of Thermal Treatment on Machining Properties of *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis* Woods

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Abstract

The thermal treatment of wood (or thermal rectification) is an alternative process to add value to wood. The thermally treated wood acquires colors similar to those observed in tropical woods, better resistance to fungi and weathering, higher dimensional stability and lower hygroscopicity. This material is, therefore, suitable for outdoor and indoor-wet uses that do not involve high mechanical stresses. Nowadays, however, little information is available on the effect of thermal treatments on the machining and finishing properties of treated woods. In this work, relatively low-valued woods (*Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*) underwent a variety of thermal rectification treatments. Thermal treatments were performed in presence or absence of oxygen. For treatments in presence of oxygen, maximum temperatures of 140°C, 160°C and 180°C were applied. For treatments in absence of oxygen, a maximum temperature of 200°C was also included. The aptitude of thermal treated wood for machining and finishing processes will be assessed through knife planing, sanding, and varnishing tests. For knife planing tests, three rake angles will be tested (15°, 20°, and 25°). Surface quality of planed surfaces was evaluated as a function of the incidence of machining defects, and uniformity of surface texture. Three sanding programs were tested (80, 100, and 100-120 grit). The quality of sanded surfaces was assessed by means of roughness and wetting tests. In planing tests, the surface quality was significantly higher in thermal treated samples than in control samples. The lowest mechanical strength in thermally treated samples allowed deeper penetration of abrasive grains during sanding, which resulted in increased roughness in thermally treated samples. The increase in the maximum treatment temperature caused a significant increase in wetting time, which corroborates that thermal treatment reduces wood hydrophilic properties. This latter effect should result in worse adhesion properties in thermally treated woods. Further studies are needed to evaluate the behavior of coating films applied on thermally rectified wood surfaces.

Keywords: thermal treatment, thermal rectification, planing, sanding, *Eucalyptus*, *Pinus*

Introduction and Background

Tropical woods often present excellent physical, mechanical, machining, and appearance properties, being highly valued in markets all over the world. However, the supply and availability of tropical wood species is declining, and prices are rapidly rising. In this scenario, the industrial use of fast-growing added-value alternative commercial species should be made technically feasible.

Impregnation with heavy metals is currently the most usual practice to enhance wood resistance to microorganisms. However, these preservative products are highly hazardous to environment and humans, as they may contaminate groundwater and soil. Due to their high toxicity, many of these heavy metal-based products have already been banned in several countries in North-America and Europe. In this context, there is a need for research on alternative clean technologies for wood preservation.

In North-America and Europe, outdoor wood sidings are increasingly being replaced by other materials requiring less maintenance practices, as aluminum and vinyl. In Brazil, in turn, house outdoor finishing is rarely composed of wood. Similarly, outdoor wood furniture has increasingly being replaced by plastics and metals. It is noted, thus, the need for new competitive wood materials and processes for the market of outdoor products.

The thermal treatment of wood (or thermal rectification) is an alternative process to add value to wood. The thermally treated wood acquires colors similar to those observed in tropical woods, better resistance to fungi and weathering, higher dimensional stability, and lower hygroscopicity. This material is, therefore, suitable for outdoor and indoor-humid uses that do not involve high mechanical stresses.

The increase in dimensional stability of thermally rectified wood is associated with the decrease in its hygroscopicity. During heating, the most hydrophilic polysaccharides (hemicelluloses) volatilize, reducing the availability of free hydroxyl groups, whereby water molecules would usually adhere. It is also mentioned the increase in lignin proportion, which improves the hydrophobic properties of the thermally treated material. Thus, species with higher hemicelluloses content might present a substantial increase in hydrophobicity after treatment. In addition to hydrophobic character, the densification of lignin chain is another factor to explain the increased resistance to fungi in thermally rectified woods. The thermal treatment has also the property of inhibiting the installation and development of microorganisms by eliminating essential nutrients (Duchez and Guyonnet 1998).

Little information is available on the effect of thermal treatments on the machining and finishing properties of treated woods. This work evaluated the effect of three rake angles in peripheral planing, and three sanding programs on the surface quality of *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis* treated with four levels of thermal rectification.

Material and Methods

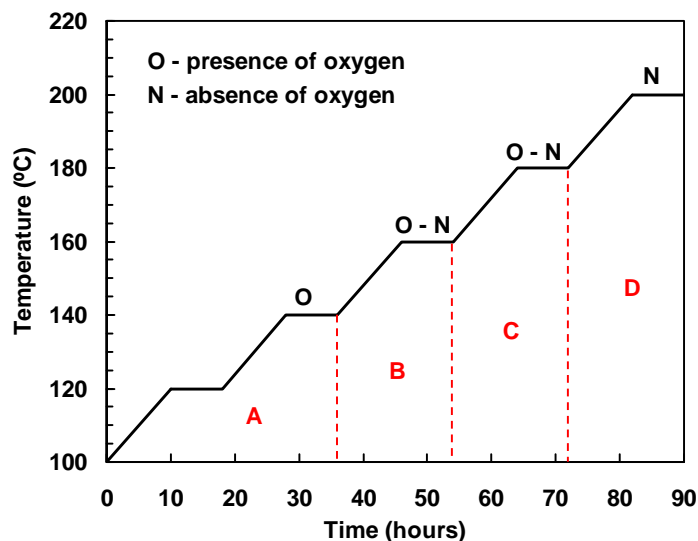
Testing Materials

Eucalyptus grandis and *Pinus caribaea* var. *hondurensis* woods were selected for this study, as they present relatively fast growing rates and low market values, in comparison to commercial tropical woods. Both species are very representative of silvicultural activity in Brazil. Commercial air-dried flat-sawn sapwood boards were stored until they reached 10% (*E. grandis*) and 12% (*P. caribaea* var. *hondurensis*) equilibrium moisture contents (EMC). The boards were cut into 80 mm by 600 mm oriented-grain samples. These samples were freshly planed to a thickness of 50 mm. Groups of seven sections from each species underwent a thermal treatment. The average basic densities of the boards were 532 kg/m³ and 394 kg/m³, for *E. grandis* and *P. caribaea* var. *hondurensis*, respectively.

Thermal Treatments

Thermal rectifications were performed in the LQCE (Laboratório de Química, Celulose e Energia – Laboratory of Chemistry, Pulp and Energy) of the Department of Forest Sciences at ESALQ-USP (Escola Superior de Agricultura “Luiz de Queiroz”, University of São Paulo). The boards were thermally treated in an electrical resistance oven, equipped with a system for air circulation, with a nominal chamber volume of 0.45 m³. A rate of heating of 0.033°C/minute was applied. This heating rate is in compliance with those recommended by Deglise and Magne (1987) and Graham et al. (1984). The maximum temperatures (140°C, 160°C, 180°C, and 200°C) were chosen based on previous studies by Vovelle and Mellottee (1982), and Crow and Pickles (1971). Samples were oven-dried until 0% humidity, and the oven was set at 100°C prior to starting treatments. The thermal treatment programs are illustrated in Figure 1.

Figure 1. Thermal treatment programs (A = 140°C; A + B = 160°C; A + B + C = 180°C; A + B + C + D = 200°C). Note that treatments over 160°C were performed in presence or absence of oxygen. 200°C treatment was only performed in absence of oxygen, to avoid the risk of fire.



Peripheral Planing Tests

In the first stage of this experiment, boards were peripherally knife planed using a conventional cabinet planer working at a feeding rate set to achieve 20 knife marks per 25 mm of length. Freshly sharpened non-rectified knives were installed in the cutterhead. The other two knives were kept in the cutterhead to avoid vibration but were disabled. Three rake angles (15°, 20°, and 25°) were tested. Planing was carried out parallel to the grain with a cutting depth of 1.20 mm. Surface quality was assessed by careful visual and tactile inspections: surface smoothness, texture uniformity, and the occurrence of machining defects (torn and fuzzy grain) were evaluated. All planed samples were ranked by their surface conditions: grades varied from 1 (worst) to 10 (best). Surface quality of planed surfaces was expressed in terms of the global ranking.

Sanding Tests

In the second stage of the experiment, boards were submitted to three sanding programs: 60-80 grit, 80-100 grit, and 100-120 grit. All sanding steps were performed with open-coat paper-backed aluminum oxide sandpapers coated with anti-static zinc stearate. Sanding was carried out along the grain with cutting depths of 0.50 mm (80-grit and 100-grit), and 0.32 mm (120-grit). The quality of sanded surfaces was assessed by roughness and wetting tests. Roughness measurements were carried out with a portative stylus-contacting type roughness meter. The pick-up travel length and cut off length were set to 15 mm and 2.5 mm, respectively. Measurements were performed at 0.5 mm/s. Roughness parameters were calculated as an average of five consecutive cut off lengths for each pick up travel length. The roughness average (R_{aL}) was measured across the grain, according to ISO 4287-1 (1984). Wetting tests consisted of recording the time taken to complete surface wetting by 5- μ l distilled water droplets (wetting time). The values of R_{aL} and wetting time were significantly correlated with surface adhesion properties in previous works by de Moura and Hernández (2005, 2006).

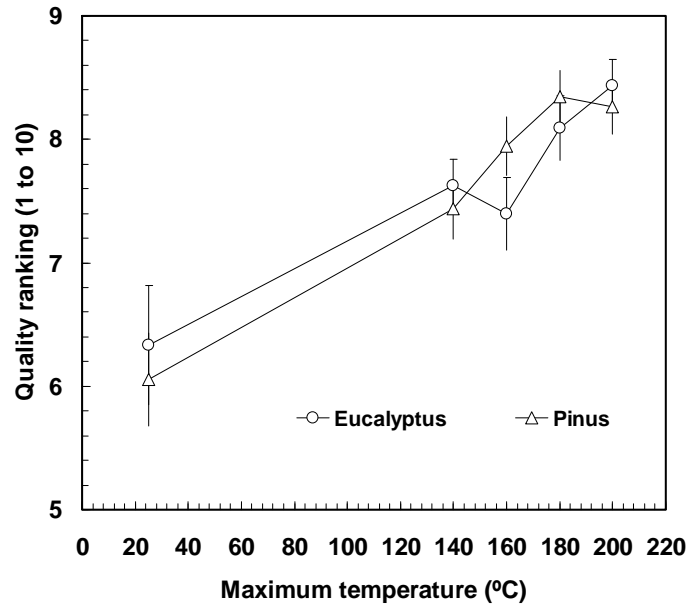
Results and Discussion

Peripheral Planing

In general, surface quality ranking was similar for *Pinus* (7.55) and *Eucalyptus* (7.46) (all independent variables pooled). The presence of oxygen in thermal treatment had no significant effect on quality of machined surfaces.

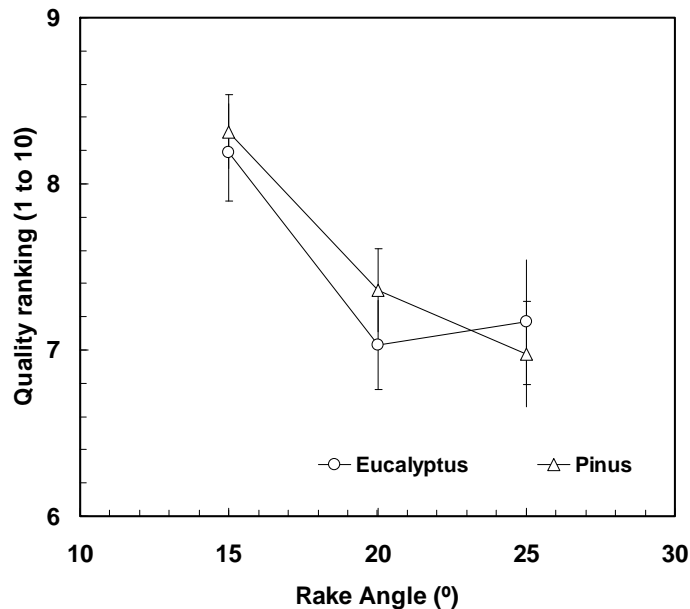
For all species and rake angles tested, thermally treated wood presented better surface appearance after peripheral planing. Quality ranking was improved by increasing the maximum temperature in thermal treatment (Figure 2). Thermally treated wood has shown to be less resistant to cut, and less prone to machining defects, as torn and fuzzy grain. In addition, the treated samples presented more uniform surface texture after planing, in comparison to non-treated samples. The thermal treatment is also likely to optimize the EMC of wood for planing.

Figure 2. Surface quality ranking for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of maximum temperatures in thermal rectification (rake angles pooled)



The most uniform and smooth surfaces were obtained with the 15° rake angle (8.25), while the other two rake angles tested (20°, 7.20; 25°, 7.07) produced similar surfaces, with significantly inferior quality (Figure 3). The original rake angle of knife planer is 25°. For both species studied, knife adaptation to obtaining 15° rake angle should significantly increase quality in planing, decreasing the occurrence of machining defects, and simplifying subsequent sanding operations.

Figure 3. Surface quality ranking for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of rake angles in peripheral planing (maximum temperatures pooled)



Sanding

Similar R_{aL} was observed in *Pinus* (8.53 μm) and *Eucalyptus* (8.94 μm) sanded surfaces (all independent variables pooled). For both species, the wood mechanical strength decreased as the maximum temperature of treatment increased. Thus, for samples treated at the highest temperatures, abrasive grains could further penetrate the surface, due to the lowest surface mechanical strength. Therefore, the highest R_{aL} were observed on surfaces treated at the highest temperatures, as shown in Figure 4.

As expected, the 80-grit sandpaper produced the roughest surfaces (10.94 μm , R_{aL}), compared with 100- (7.78 μm , R_{aL}), and 120-grit (7.48 μm , R_{aL}) sandpapers (Figure 5). The use of the 120-grit sandpaper, however, did not significantly decrease surface roughness.

The wetting time was significantly lower on *Pinus* (130 seconds) than on *Eucalyptus* (474 seconds) sanded wood. This difference in wettability can be associated with larger lumen diameter of conifer tracheids, which could enhance liquid penetration and spreading by capillarity, and chemical composition of wood. This first evaluation suggests that *Pinus* surfaces might have better adhesion properties than those of *Eucalyptus*.

The thermal rectification considerably increased surface hydrophobicity. This was observed by the increase in wetting time as the maximum temperature of treatment increased (Figure 6). This effect was even more pronounced for maximum temperatures higher than 160°C. Such behavior is mainly associated with volatilization of hydrophilic components of wood (hemicelluloses) during heating.

Figure 4. Surface roughness average (R_{aL}) for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of maximum temperatures in thermal rectification (grit sizes pooled)

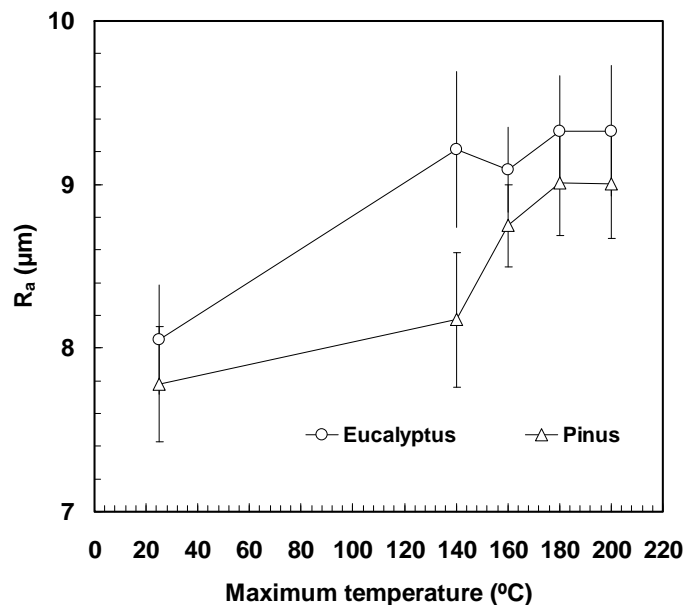
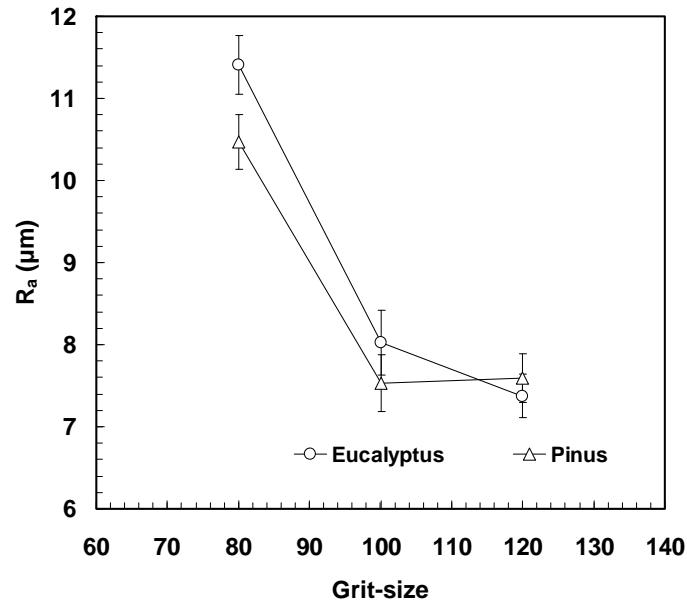


Figure 5. Surface roughness average (R_a) for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of final grit sizes in sanding (maximum temperatures pooled)



The wetting time had a defined pattern as a function of grit size: 80-grit sanded surfaces presented the fastest wetting (252 seconds), followed by 120- (295 seconds) and 100-grit (359 seconds) sanded surfaces (all independent variables pooled). For both species, the wetting time was higher after 100-grit sanding (Figure 7). These results indicate that sanding with 80-grit sandpaper could render the best results in terms of surface adhesion properties, in addition to provide stronger mechanical bonding for coating films, due to increased roughness.

The presence of oxygen in thermal treatment caused no significant effect on roughness and wetting of sanded surfaces.

Conclusions and Recommendations

Thermally rectified samples of *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis* presented enhanced surface quality in planing tests with three rake angles. In general, the 15° rake angle provided the best planing results for all species and thermal treatments studied. Knife adaptation to obtaining 15° rake angle should significantly increase quality in planing, decreasing the occurrence of machining defects, and simplifying subsequent sanding operations.

The increase in the maximum treatment temperature caused a significant increase in wetting time, which corroborates that thermal treatment reduces wood hydrophilic properties. This latter effect should result in worse adhesion properties in thermally treated woods. Further studies are needed to evaluate the behavior of coating films applied on thermally rectified wood surfaces.

The presence of oxygen in thermal treatment had no significant effect on quality of machined surfaces. However, the use of nitrogen to remove oxygen from the thermal treatment chamber should be a good practice to reduce the risk of fire, and allow reaching higher temperatures in future experiments.

Figure 6. Surface wetting time for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of maximum temperatures in thermal rectification (grit sizes pooled)

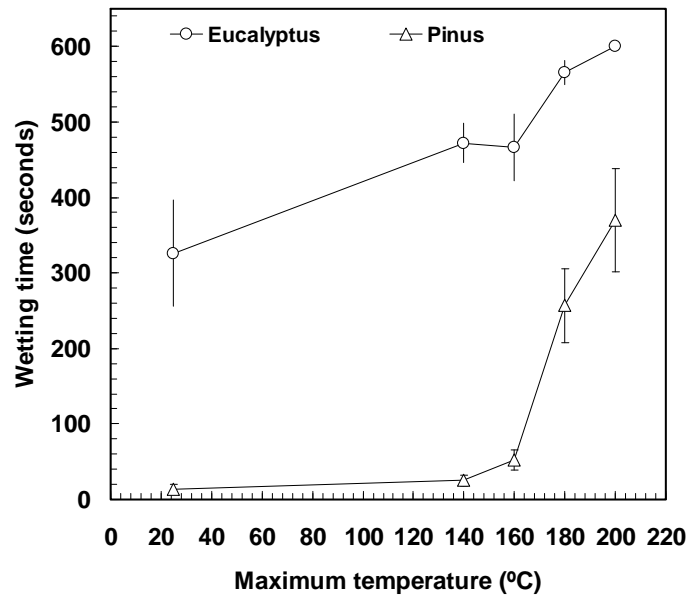
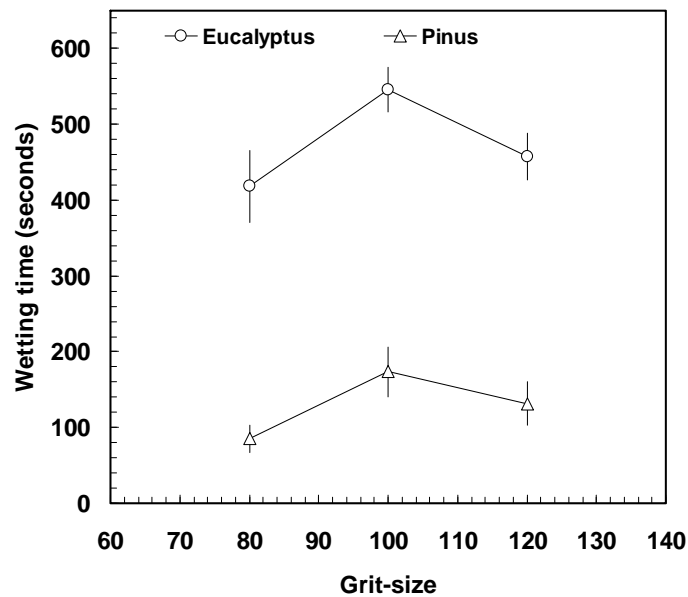


Figure 7. Surface wetting time for *Eucalyptus grandis* and *Pinus caribaea* var. *hondurensis*, as a function of final grit sizes in sanding (maximum temperatures pooled)



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Acknowledgments

The authors acknowledge financial support from FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo), *Pinus* samples from A W Faber Castell S.A. (São Carlos, Brazil – Eng. Eliane Fiorentini), technical support from SENAI (Serviço Nacional de Aprendizagem Industrial “Mário Henrique Simonsen”, Piracicaba, Brazil – Prof. José Francisco Bis), Madeireira Uliana Ltda (Tietê, Brazil – Mr. Antônio Carlos F. Uliana and M.Sc. Lis Rodrigues Uliana), Adriana Maria Nolasco, and Udemilson Luís Ceribelli.