Effects of Thermal Treatment before Plane Sanding on the Surface Quality of *Corymbia citriodora* Wood

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Wood sanding is one of the most expensive processes in the woodworking industry, and little is known about the factors that influence the final quality of wooden parts. For this reason, studies involving different wood treatments, such as thermal treatment, have been developed to produce better surface qualities. The objective of this work was to verify the influence of thermal treatment of the wood species *Corymbia citriodora* before the sanding process on the surface quality of the wood pieces. The surface finishes of the sanded natural and heat-treated wood were compared. Sanding was performed using two sandpaper grades, 80 mesh and 120 mesh, with abrasive grains of aluminum oxide. The sanding process was performed by flat horizontal sanding parallel to the fibers. Six specimens were used for each sandpaper grade. Initially the specimens were heat-treated at 120 °C, 160 °C, and 200 °C for 2 h, and then they were subjected to sanding. For the analysis of the surface quality of the wood pieces, the average roughness was used. From the obtained results, it was concluded that the heat treatment considerably reduced the roughness of the wood for both sandpaper grit sizes, and it facilitated the final finishing of the wood pieces.

Keywords: Sanding process; Heat treatment; Superficial finishing; Roughness (R_a)

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INTRODUCTION

Sanding improves the surface of wood, and this process is essential when a wood piece needs to go through a later stage of varnishing or painting. A good sanding process ensures a better penetration and uniformity of the varnish or paint products applied on the wood material (Hendarto *et al.* 2004). The wood sanding process is difficult to characterize and analyze because of the random nature and distribution of grains in the sandpaper. In the case of sanding heterogeneous materials, such as wood, the complexity of the process increases and many conditions must be considered (Saloni *et al.* 2010). There are several methods for sanding wood, such as horizontal and vertical flat sanding, but little is known about the effect of wood treatment, such as heat treatment, on the wood sanding quality.

The heat treatment of wood provides a method for controlled degradation of wood material. This process normally occurs in the absence of oxygen or air and promotes the decomposition of the chemical constituents, mainly hemicellulose. Changes in the properties will occur according to the temperature used during treatment (Rodrigues 2009; Navi and Sandberg 2012).

During heat treatment, an increase in the cellulose crystallinity occurs in the wood because of the degradation of the amorphous regions and reorganization of the cellulose molecules (Bhuiyan *et al.* 2000; Wikberg and Maunu 2004; Yildiz and Gümüşkaya 2007). However, Poubel *et al.* (2013) reported a noteworthy reduction in the crystalline cellulose content starting at 220 °C. Because the cellulose crystallinity is considered to be the main factor responsible for the resistance of wood fiber, this resistance decreases when the degree of polymerization of the cellulose decreases (Sweet and Winandy 1999).

Polyoses (hemicelluloses) begin to degrade at a temperature above 190 °C. Thus, hemicellulose degradation begins before cellulose degradation. This is because of the lower thermal stability of hemicelluloses compared with that of cellulose caused by their amorphous structure (Yildiz *et al.* 2006; González-Peña *et al.* 2009; Kačíková *et al.* 2013). With the degradation of hemicellulose, the cell wall absorbs less water because of a decrease in OH groups (hydroxyls); thus, a reduction in the swelling and retraction of the wood occurs, which implies a greater dimensional stability (Gündüz *et al.* 2008).

Molina and da Silva (2012) studied the effects of thermal treatment on the resistance and rigidity properties of *Eucalyptus citriodora* wood. In their work, wood samples were heat-treated at 160 °C, 180 °C, 200 °C, 220 °C, and 240 °C with a heating rate of 0.033 °C/min. The variables analyzed were the compressive strength parallel to the fibers, compressive modulus of the elasticity parallel to the fibers, modulus of resistance of the wood to flexion, flexural modulus of elasticity, tensile strength parallel to the fibers, and shear parallel to the wood fibers. The results showed that there was no substantial evidence that heat treatment affects the stiffness of the wood samples. However, a notable decrease in the material strength was reported.

Araújo (2010) found that the Janka hardness values of various wood species were not improved much by heat treatment. Moura and Brito (2008) also studied the effects of heat treatment of *Pinus caribaea* var. *hondurensis* and *E. grandis* on the mechanical and finishing properties. The heat treatments were done in the presence and absence of oxygen at 140 °C, 160 °C, 180 °C, and 200 °C. The heat-treated samples were sanded with grit sizes of 80 mesh, 100 mesh, and 120 mesh. According to these authors, there was a decrease in the mechanical wood properties, and there was a higher penetration of the abrasive grains during sanding. The mean roughness in this study increased substantially in the heated-treated samples.

Salca and Hiziroglu (2014) studied the influence of heat treatment on the hardness and roughness of four wood species: *Alnus glutinosa* L., *Quercus falcata* Michx., *P. taeda* L., and *Liriodendron tulipifera* L. The treatments were performed at 120 °C and 190 °C with exposure times of 3 h and 6 h. The authors concluded that the heat treatment improved the surface quality of all of the wood species, but the hardness decreased. According to Ibach (2010), all thermally treated timber samples can be glued or painted and can also be used to manufacture furniture, floors, doors, window components, and other products.

There are few reports available that have studied the effect of heat treatment on the surface quality during the sanding process. Therefore, it was important to analyze the influence of wood heat treatment before sanding to evaluate the surface quality of the wood through the roughness (R_a).

EXPERIMENTAL

Preparation of the *Corymbia citriodora* Samples

The samples were prepared from *Corymbia citriodora* wood, with a density of 959.1 kg/m^3 at a 12% moisture content and a basic density of 731.7 kg/m^3. The basic density was determined according to ABNT NBR 11.941 (2003), in which the density values were obtained with Eq. 1,

$$d_b = \frac{m_3}{(m_2 - m_1)} \quad (1)$$

where d_b is the basic density of wood in g/cm³; m_3 is the mass of the oven dried sample at (105 ± 2) °C, in grams (g); m_2 is the mass of the vessel with water and immersed sample, in grams (g); and m_1 is the mass of the container with water, in grams (g). The volume of the sample corresponds to the volume of the displaced water, which in turn is equal to the mass difference $(m_2 - m_1)$, considering the water density as one gram per cubic centimeter (g/cm³).

The *C. citriodora* wood was purchased at a sawmill in the city of Bauru (Brazil) and was obtained from large trees with a minimum diameter of 50 cm and age of approximately 35 years. The samples were produced in the Wood Processing Laboratory at São Paulo State University (UNESP, Itapeva, Brazil). The dimensions of the samples used were 54 mm × 30 mm × 23 mm (length × width × thickness).

The research was conducted using a horizontal sander that was driven pneumatically with an automatic testing system. The wood samples were sanded parallel to the grain. Sandpaper made of aluminum oxide with two different grit sizes (120 mesh and 80 mesh) was used at a cutting speed of 11 m/s and specific pressure of 1 kgf/cm^2 (98.1 kPa).

Heat Treatment and Wood Sanding

For the preparation of the wood samples for heat treatment, 36 samples were placed in a climatic chamber to stabilize the moisture content to 12%. Afterwards, the samples were placed in the kiln for the heat treatment, and the heating was started at a rate of approximately 1.8 ° C/min until the desired treatment temperature was reached. The samples were then left for 2 hours at the temperature reached, and soon after, the kiln was switched off until it cooled to room temperature. Three temperatures of 120 °C, 160 °C, and 200 °C were employed (Almeida *et al.* 2013). Twelve samples were heat-treated at each temperature.

The sanding process was conducted on the heat-treated samples. These samples were placed with their surfaces sanded parallel to the grain in a flat sander, using an automatic feed system with two different sandpaper grit sizes (80 and 120 mesh). Additionally, 12 control samples with a 12% moisture content were sanded at room temperature. After sanding the samples, their surfaces were evaluated six times by measuring their R_a values in the direction perpendicular to the grain using a roughness meter.

Measurement of the Average Roughness

The roughness parameter obtained was from the mean R_a values. This was the best fit to the surface finishing of the wood samples because of their anatomy. The sampling length was set at 2.5 mm (cut-off), as was suggested by ABNT NBR ISO 4287 (2002). The measuring course with the 2.5-mm cut-off was 12.5 mm, which resulted in an average of five measurement values being acquired. The range adopted in the rugosimeter was 300 μm. To measure the surface roughness, a roughness meter (Surtronic 25+, Taylor Hobson, La Roca del Vallés, Spain) with a cone-spherical diamond-like measuring stem and radius of 2 μm was used.

Data Evaluation

For the evaluation of the results, a full cross-factorial design (2 × 4) was used, where the first factor was the sandpaper grit with two mesh levels (80 mesh and 120 mesh), and the second factor was the heat treatment with four temperatures (control, 120 °C, 160 °C, and 200 °C). The data were analyzed with an analysis of variance (ANOVA) using the software R (version 3.3.1, *Statistical Computing*, Vienna, Austria). Multiple Tukey comparison tests between the grit size and heat treatment temperature were done using Tukey's honest significant difference test.

RESULTS AND DISCUSSION

Table 1 shows the general and marginal averages, as well as the standard deviations and errors of the surface roughness values for the various heat treatment temperatures and sandpaper grit sizes. Table 1 also gives the results of the ANOVA.

Table 1. Surface Roughness Values under Various Conditions of Sanding of the *C. citriodora*

Factor		Number of Samples	Average Roughness (μm)	Standard Deviation	Standard Error	Coefficient of Variation (%)
Sandpaper Grit Size	Temp. (°C)					
80	Control	6	7.45	0.659	0.269	8.8
	120	6	7.33	0.698	0.285	9.5
	160	6	7.23	0.383	0.156	5.3
	200	6	8.27	0.712	0.291	8.6
120	Control	6	6.27	0.403	0.165	6.4
	120	6	5.27	0.446	0.182	8.5
	160	6	5.47	0.546	0.223	10.0
	200	5	6.82	0.850	0.380	12.5
Marginal Average Roughness (μm) for Each Factor Level						
80 mesh		120 mesh	Control	120 °C	160 °C	200 °C
7.57		5.96	6.86	6.30	6.35	7.54
ANOVA and SV		DF	SS	MS	F	P (> F)
Sandpaper		1	32.11	32.11	87.68	7.69e-12
Temperature		3	11.26	3.75	10.25	3.44e-05
Residues		42	15.38	0.37	-	-
Total		46	58.75	-	-	-

SV: source of variation; DF: degrees of freedom; SQ: sum of squares; MS: mean square; The F and P values are expressed at significance levels of α = 5%.

There was no interaction between the sandpaper grit size and heat treatment temperature (P value = 0.316) at a 5% significance level, as is shown in Fig. 1.

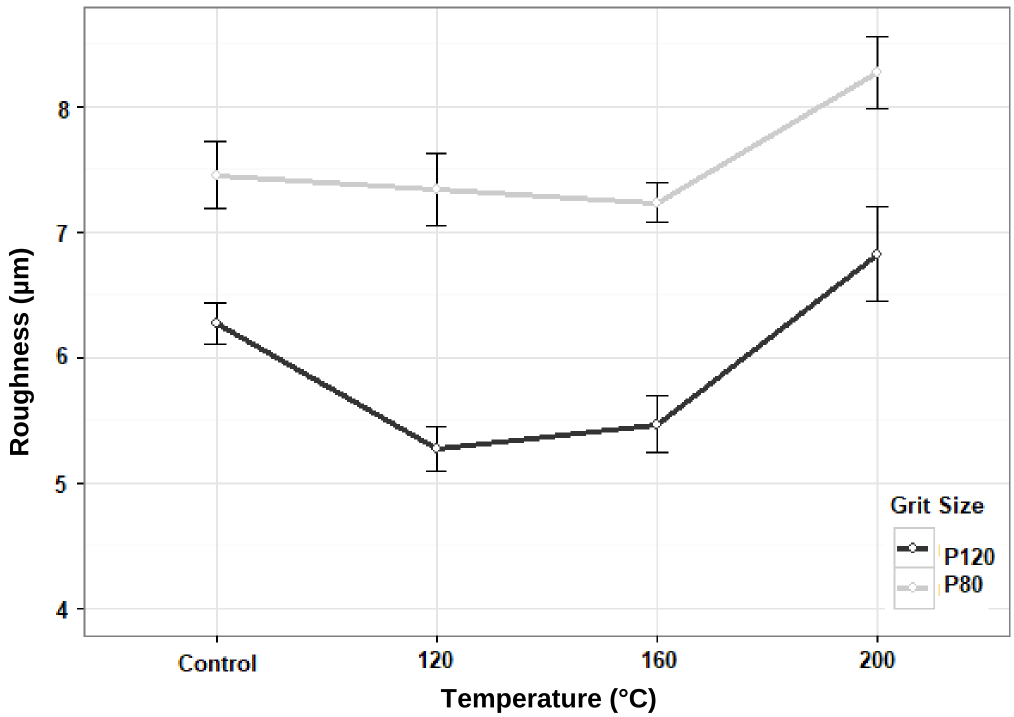

Fig. 1. Graph of the interaction between the roughness and heat treatment temperature for different grit sizes

While analyzing the main effects, significant differences were found between the two sandpaper mesh sizes (P value = 7.69 e-12) and between the three temperatures (P value = 3.44 e-05). Figure 2 shows the distribution of the data for the sandpaper grit sizes and heat treatment temperatures. The gray dots represent the average values for each factor level.

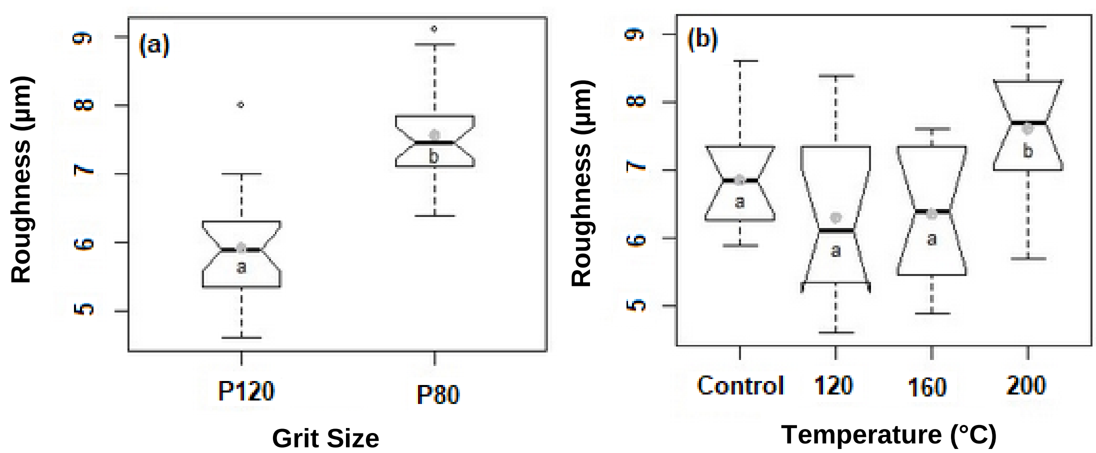

Fig. 2. Distribution of the average roughness of the *C. citriodora* samples for different (a) sandpaper grit sizes and (b) heat treatment temperatures; different letters represent significant differences between the groups (P value < 0.05); gray dots are the average values

It was found that there were no significant differences between the temperatures of 120 °C and 160 °C compared with the control samples. However, these three levels had significantly lower roughness values when compared with those obtained at 200 °C. The sandpaper mesh size of 80 and the temperature of 200 °C had the highest roughness values for this wood species and differed significantly from the other studied levels.

This result was explained by the work of Molina and da Silva (2012), who studied the effects of heat treatment on the strength and stiffness of *E. citriodora*, and noted a significant reduction in the material strength. Thus, it was inferred that the heat treatment caused the decrease in the wood resistance, and consequently the 80-mesh grit size pulled more material and produced higher roughness values.

Figure 3 shows a bar graph of the roughness as function of the temperature for both sandpaper grit sizes. The differences in the roughness values were large between the sandpaper grit sizes for the control and treated samples. Each bar contained the standard deviation for each combination of the sandpaper grit size and temperature with confidence intervals of 95%.

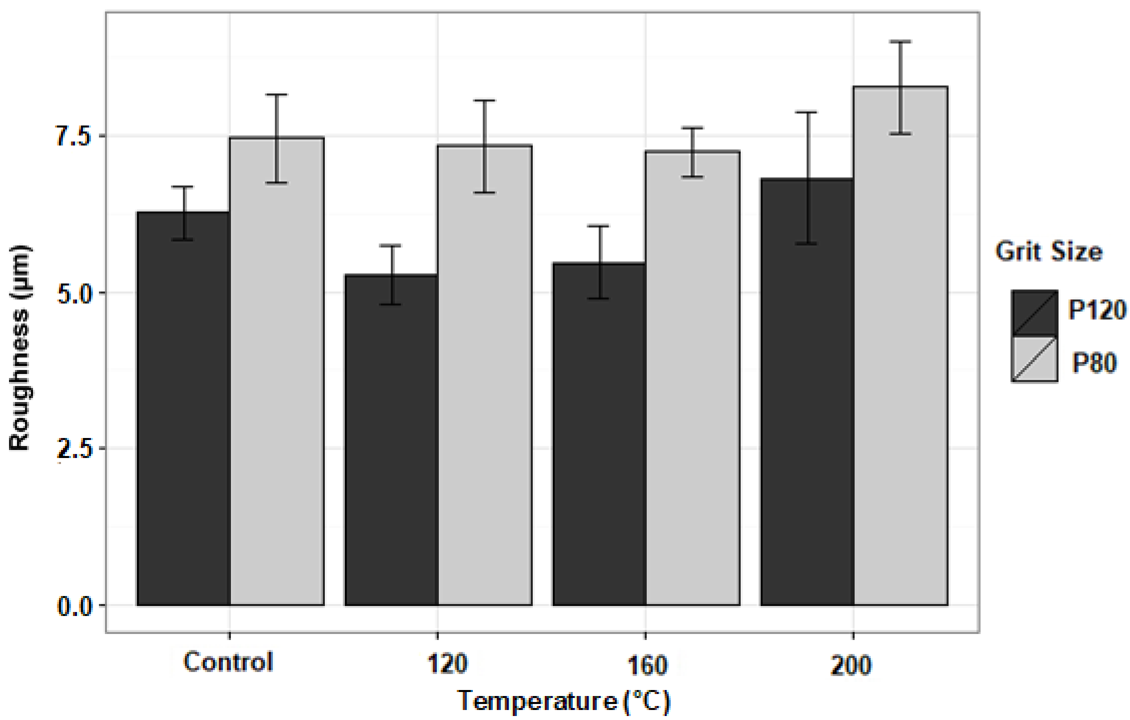

Fig. 3. Bar chart with standard deviations of the roughness as a function of the heat treatment temperature for different sandpaper grit sizes

CONCLUSIONS

1. The best surface finish of the *C. citriodora* samples was obtained with the 120-mesh sandpaper grit size at lower temperatures. However, a significant increase in the roughness of the wood samples was observed for both sandpaper mesh sizes after heat treatment at 200 °C.

2. This study showed that heat treatment at temperatures up to 160 °C did not decrease the wood surface quality. Therefore, up to this temperature, the benefits from heat treatment, including the best wettability, resistance to fungi and insect attack, and others, can be obtained without losing the wood surface quality after sanding.

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