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TECHNICAL PAPER

# INFLUENCE OF EXPOSURE TIME TO OPERATING TEMPERATURE ON SHEAR STRENGTH OF WOOD USED IN ROOF STRUCTURES

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**KEYWORDS**

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**ABSTRACT**

Wood is one of the main materials used in the constructing of covering structures (roofs) because of its versatility. Under this situation, due to solar radiation incidence, the temperature can exceed 60 °C and, such as other environmental conditions, influence the mechanical properties of the wood in use. The aim of this research was to study the influence of exposure time of the wood of four different hardwood species at a temperature of 60 °C on the shear strength parallel to fibers. The wood of the following species was used: Cupiúba (*Goupia glabra*), Eucalyptus (*Eucalyptus saligna*), Garapeira (*Apuleia leiocarpa*), and Jatobá Tamarindo (*Hymenaea* sp.). In order to investigate the effect of exposure time (0, 168, 456, 720, and 2160 hours) of the wood species in an oven (60 °C) on the values of shear strength in the direction parallel to fibers, an analysis of variance (ANOVA) was carried out at 5% significance level. According to the results, the time the wood was exposed to the operating temperature significantly influenced the shear strength in the direction parallel to fibers. In addition, all species showed a decrease in shear strength after 456 hours of exposure at a constant temperature of 60 °C.

## INTRODUCTION

Wood is one of the main materials used in the construction industry, either as a structural element (Almeida & Dias, 2016; Cavalheiro et al., 2016; Garcia et al., 2017), cover structures and roofs (truss) (Christoforo et al., 2011; Palludo et al., 2017) or as a support material for construction (shores, scaffolding, and formworks) (Calil Junior & Molina et al., 2010).

In Brazil, the wood used as structural elements in constructions has two different origins. The first origin is related to planted forests of exotic species of the genera *Pinus* (Lahr et al., 2017), *Eucalyptus* (Rodrigues et al., 2018), and *Corymbia* (Zangiácomo et al., 2014). The other group is represented by native species from different Brazilian biomes, mainly from the Amazon Forest (Steege et al., 2016; Almeida et al., 2017; Coral et al., 2017).

In Brazil, the standard ABNT NBR 7190 (1997) “Wood Structures Project” regulates the guidelines for projects and for carrying out laboratory tests to estimate the physical and mechanical properties of wood. It is important because it allows the rational use of this raw material in structures, considering the variability of the material and the need for attention related to its degradation in use (Macedo et al., 2014; Lahr et al., 2016a; Pigozzo et al., 2017).

Among the mechanical properties, shear strength parallel to fibers ($f_{v0}$) is of great importance because the wood presents fragile rupture in this situation, especially in the connections with metallic pins between elements of a truss (Calil Junior & Molina, 2010).

The degradation of wood in use may occur due to the attack of xylophagous organisms or their exposure to weather conditions of high humidity and temperature contents (Andrade Junior et al., 2014; Barcík et al., 2015; Brito et al., 2016; Matos & Molina, 2016; Teodorescu et al., 2017).

Studies conducted by Arruda et al. (2015), Lopes et al. (2014), Santos et al. (2014), Figueroa et al. (2015), Carrasco et al. (2016), and Pertuzzatti et al. (2018) aimed to study the effect of thermal treatments on the mechanical

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properties of wood and its coloration in order to provide a higher added value to it.

Other studies that deal with cases of structures in fire situations have been developed and are of interest because the degradation that occurs in constituent compounds of wood (lignin, cellulose, and hemicellulose) under these situations lead to loss of mass and strength, weakening the structure and putting at risk the people who use it (Moreno Junior & Molina, 2012; Moreno Junior et al., 2013).

The wood used in cover structures (roofs) can be exposed to different temperatures, reaching and even exceeding 60 °C (in times of high solar radiation), especially when metallic and fiber cement tiles are used (Coelho et al., 2017).

This research aimed to study the influence of exposure time of the wood of four different hardwood species at a temperature of 60 °C on the shear strength in the direction parallel to fibers.

## MATERIAL AND METHODS

This study was carried out with the hardwood species Cupiúba (*Goupia glabra*), Eucalyptus (*Eucalyptus saligna*), Garapeira (*Apuleia leiocarpa*), and Jatobá Tamarindo (*Hymenaea* sp.) obtained in sawmills and with a moisture content close to 12%, being properly stored at the Laboratory of Wood and Wood Structures (LaMEM), School of Engineering of São Carlos, University of São Paulo. The wood species used in this research are the most commercialized in São Carlos, SP, and therefore the most used in cover structures in this region.

The values of shear strength in the direction parallel to fibers ($f_{v0}$) of these four wood species were obtained according to the assumptions and methods of calculation of the Brazilian standard ABNT NBR 7190 (1997).

The factor investigated in this research was the exposure time of specimens in an oven at a controlled temperature of 60 °C, consisting of 0 (wood tested at ambient temperature and humidity, wood moisture content in the order of 12%, according to ABNT NBR 7190 (1997)), 168, 456, 720, and 2160 hours. Twenty-four determinations were obtained per wood species and six determinations were performed for the remaining four temperatures (168, 456, 720, and 2160 hours), totaling 192 determinations. The specimens of each experimental condition were manufactured in pairs, implying that possible differences in the results are explained only by the exposure time of the wood at a temperature of 60 °C, thus eliminating the intrinsic wood variability that could also affect the obtained results.

In order to investigate the effect of exposure time (0, 168, 456, 720, and 2160 hours) of the wood species in an oven (60 °C) on the values of shear strength in the direction parallel to fibers, an analysis of variance (ANOVA) at 5% significance level (α) was carried, consisting of the equivalence of means as null hypothesis ($H_0$) and non-equivalence (at least two) as alternative hypothesis ($H_1$). By the hypothesis formulation, a P-value equal to or higher than the significance level (0.05) implies accepting $H_0$, refuting it otherwise.

For ANOVA validation, the normality in the distributions of values of mechanical properties and homogeneity of variances of treatments were investigated with the Anderson-Darling (AD) and Bartlett (Bt) test, respectively, both at 5% significance level. According to the test formulation, a P-value higher than 5% implies that responses present a normal distribution and that the variances of treatments are equivalent, thus validating the ANOVA model.

When the time of exposure to a temperature of 60 °C was considered significant by ANOVA, the Tukey's multiple comparison tests (contrast test) was used to group the levels of the investigated factor. In the Tukey's test, the means in descending order are identified by the letters A, B, and C, where A is the highest mean, B the second highest mean, and so on. The levels of the investigated factor with equal letters present means statistically equivalent to a 95% confidence level.

## RESULTS AND DISCUSSION

Table 1 shows the mean values and coefficients of variation (CV) of the shear strength in the direction parallel to fibers for the four hardwood species and four experimental conditions.

TABLE 1. Values of shear strength in the direction parallel to fibers as a function of exposure time (h) at a temperature of 60 °C.

| | Stat. | 0 h | 168 h | 456 h | 720 h | 2160 h |
|---|---|---|---|---|---|---|
| Cupiúba | $f_{v0}$ (MPa) | 14.06 | 12.87 | 14.08 | 13.71 | 11.45 |
| | CV (%) | 12.84 | 24.23 | 17.47 | 21.87 | 29.22 |
| | Stat. | 0 h | 168 h | 456 h | 720 h | 2160 h |
| Eucalyptus | $f_{v0}$ (MPa) | 11.94 | 12.18 | 13.30 | 11.94 | 10.78 |
| | CV (%) | 22.83 | 23.18 | 37.19 | 23.36 | 27.57 |
| | Stat. | 0 h | 168 h | 456 h | 720 h | 2160 h |
| Garapeira | $f_{v0}$ (MPa) | 15.47 | 18.54 | 18.21 | 17.93 | 17.46 |
| | CV (%) | 13.39 | 8.60 | 14.81 | 10.57 | 10.10 |
| | Stat. | 0 h | 168 h | 456 h | 720 h | 2160 h |
| Jatobá Tamarindo | $f_{v0}$ (MPa) | 27.19 | 27.68 | 26.33 | 21.00 | 21.57 |
| | CV (%) | 22.95 | 29.08 | 24.32 | 39.56 | 41.76 |

Jatobá Tamarindo showed the highest mean value of shear strength under a condition without exposure at a temperature of 60 °C (0 hours) ($f_{v0}$ = 27.19 MPa) among the studied species. This value is in accordance with those determined by Lahr et al. (2016b) for lots of Jatobá from different Brazilian regions.

The mean value of $f_{v0}$ for Cupiúba was equal to 14.06 MPa with 0 hours of exposure at 60 °C, a value slightly lower than that determined by Almeida & Dias (2016). Jesus et al. (2015) determined mean value of $f_{v0}$ equal to 16.67 MPa at 12% moisture for Garapeira wood, which is higher than that obtained in our study (15.47 MPa).

Moura et al. (2012) and Lima et al. (2014) determined mean values of $f_{v0}$ equal to 16.16 and 12.70 MPa for woods of *Eucalyptus resinifera* and *Eucalyptus grandis*, respectively, both higher than that determined in this study for wood of *Eucalyptus saligna* (15.47 MPa). Müller et al. (2014) obtained a mean value of $f_{v0}$ equal to 11.41 MPa for *Eucalyptus benthamii*, which is lower than that determined in this study. For a temperature above 140 °C (heat treatment), the wood of *Eucalyptus grandis* presented loss of mass and shear strength (Moura et al., 2012).

Table 2 shows the results of ANOVA and validation tests regarding the mechanical property per wood species, where DF is the total degree of freedom and AD and Bt are the tests of normality and homogeneity of variances, respectively.

TABLE 2. Results of ANOVA and validation tests for shear strength in the direction parallel to fibers.

| Species | DF | Validation | | ANOVA |
|---|---|---|---|---|
| | | AD | Bt | |
| Cupiúba | 47 | 0.326 | 0.251 | 0.008 |
| Eucalyptus | 47 | 0.104 | 0.369 | 0.023 |
| Garapeira | 47 | 0.186 | 0.196 | 0.002 |
| Jatobá Tamarindo | 47 | 0.278 | 0.115 | 0.032 |

Table 2 shows that the distributions of $f_{v0}$ values for all wood species are normal and that the variances between treatments are homogeneous, validating the ANOVA model (P-value ≥ 0.05). The P-values of ANOVA for both values of shear strength in the parallel direction to fibers were lower than the considered significance level (0.05), implying an influence of exposure time on the samples at a temperature of 60 °C. Table 3 shows the results of the Tukey's multiple comparison tests (contrast test) and Figure 1 shows the results of graphs of the main effects.

TABLE 3. Results of the Tukey's test of the shear strength in the direction parallel to fibers ($f_{v0}$) of wood species.

| Species | Exposure time at a temperature of 60 °C (h) | | | | |
|---|---|---|---|---|---|
| | 0 | 168 | 456 | 720 | 2160 |
| Cupiúba | A | B | A | A | C |
| Eucalyptus | B | B | A | B | C |
| Garapeira | B | A | A | AB | B |
| Jatobá Tamarindo | A | A | A | B | B |

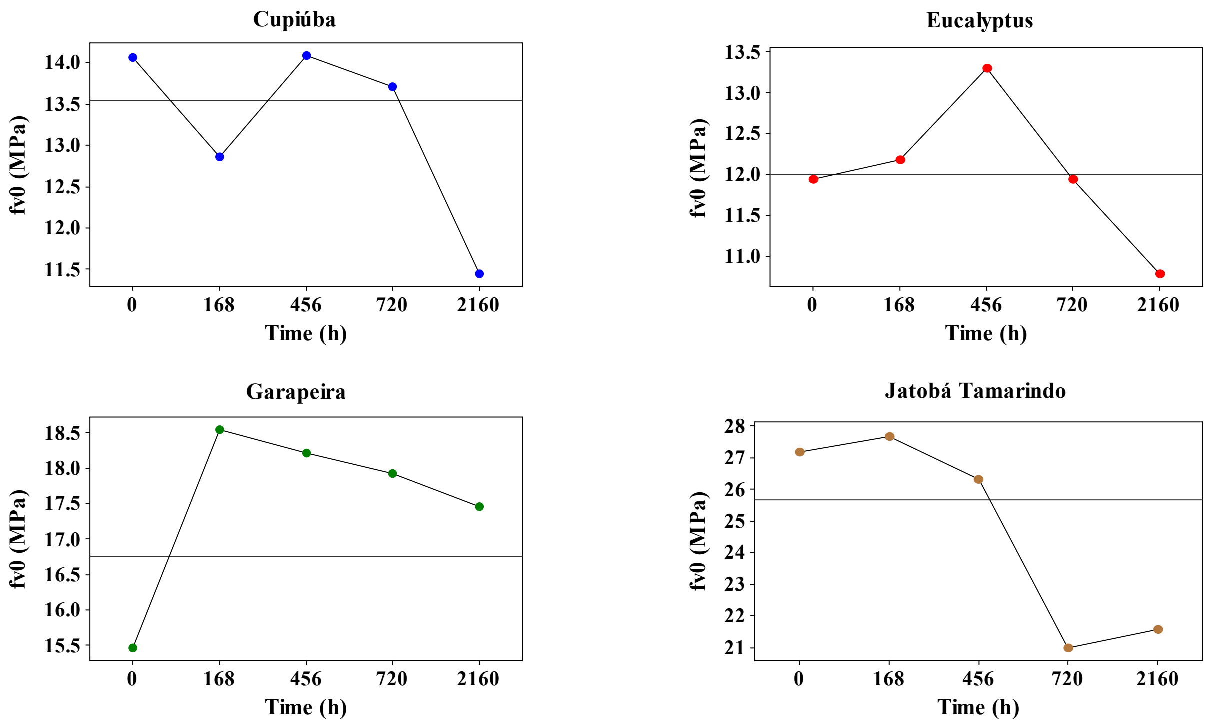


FIGURE 1. Graphs of the main effects of the factor exposure time on the values of shear strength in the direction parallel to fibers for the four evaluated wood species.

Figure 1 shows a decrease in the shear strength as the exposure time at a temperature of 60 °C increased, except for the Garapeira wood. In addition, each species had a different behavior as the exposure time at a temperature of 60 °C increased.

Garapeira was the only species that presented an $f_{v0}$ value at 2160 hours (17.46 MPa) higher than the mean value found for the wood at 0 hours of exposure. In addition, it also showed a decrease in shear strength from 168 hours in the oven. The increased shear strength in the first treatment stage can be explained by a possible effect of the initial drying of specimens.

After 456 hours of exposure at a temperature of 60 °C, all wood species showed a significant decrease in the mean value of shear strength (Table 3) due to the degradation of the constituent compounds of wood, which begin to show the degradation effects from 55 °C (Kollmann & Côté, 1968; Schaffer, 1973). According to Castro et al. (2015), Jatobá presents 31.88% of lignin, 12.78% of extractives, 0.36% of minerals, and 54.98% of holocellulose (cellulose plus hemicellulose).

## CONCLUSIONS

From the results obtained and discussed in this study, it is possible to conclude that:

- The time the wood is exposed to the operating temperature (cover structure), significantly influenced the shear strength in the direction parallel to fibers.
- Jatobá Tamarindo wood presented the highest value of shear strength among the studied species under the condition without exposure to temperature.
- Jatobá Tamarindo presented the highest shear strength among all combinations of exposure time and species when exposed at a temperature of 60 °C for 168 hours (27.68 MPa).
- All species presented a decreased shear strength after 456 hours of exposure at a constant temperature of 60 °C.

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