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Thermal treatment effect on physical and mechanical properties of MDF panels

Rosane Betina WANDSCHEER[1*], Jaqueline BRESSAN[1], Rafael Rodolfo de MELO[1],
Daiane Cristina de LIMA[1], Talita Dantas PEDROSA[2], Mayra Daniela FERREIRA[3]

[1] Instituto de Ciências Agrárias e Ambientais, Universidade Federal de Mato Grosso, Sinop, Mato Grosso, Brasil.
[2] PPG em Ciências Ambientais, Universidade Federal de Mato Grosso, Sinop, Mato Grosso, Brasil.
[3] PPG em Ciências Florestais Ambientais, Universidade Federal de Mato Grosso, Cuiabá, Mato Grosso, Brasil.
* E-mail: rosane.lrv@gmail.com

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ABSTRACT: The purpose of this study was to evaluate the effect of heat treatment on MDF panels, aiming mainly to improve their dimensional stability. The panels were obtained from the local market and were manufactured using as raw material *Eucalyptus* sp. and synthetic urea-formaldehyde resin. Twenty-five samples were used in the tests, which were subdivided into different groups for the thermal treatment in an oven and submitted to temperatures between 160 and 180 °C during a period between 6 and 12 min. We also evaluated the performance of the control samples, i.e., those that have not undergone any treatment. After the treatment, samples were produced for physical tests (density, water absorption - at 2 and 24 h, thickness swelling, residual and hygroscopic swelling - at 2 and 24 h) and mechanical tests (static bending and screw withdrawal resistance). For the physical tests after the treatment, the sample dimensions were reduced to 15 x 15 x 1.5 cm thick, and for the mechanical tests they were sawn in dimensions of 7.5 x 42 x 1.5 cm thick. The results of the physical properties showed that the treatments used did not increase the dimensional stability. The mechanical properties were also not affected by the heat treatment.

Keywords: wood panels, thermal rectification, dimensional stability.

Efeito do tratamento térmico sobre as propriedades físicas e mecânicas de painéis MDF

RESUMO: O objetivo deste trabalho foi avaliar o efeito do tratamento térmico em painéis de MDF, visando principalmente à melhoria de sua estabilidade dimensional. Os painéis foram obtidos junto ao comércio local, fabricados com matéria-prima *Eucalyptus* sp. e resina sintética ureia-formaldeído. Foram utilizadas vinte e cinco amostras para os ensaios, sendo estas subdivididas em diferentes grupos para o tratamento térmico em estufa utilizando as temperaturas de 160 e 180 ^{o}C, por um período de 6 e 12 min. Juntamente, avaliou-se o desempenho de amostras testemunhas, ou seja, as quais não foram submetidas a nenhum tipo de tratamento. Após o tratamento, foram produzidas amostras para os ensaios físicos (massa especifica, absorção de água – às 2 e 24 h, inchamento em espessura, residual e higroscópico – às 2 e 24 h) e mecânicos (flexão estática e resistência ao arrancamento de parafusos). Para os ensaios físicos após o tratamento, as amostras foram reduzidas as dimensões de 15 x 15 x 1,5 cm em largura, comprimento e espessura e, para os ensaios mecânicos foram serradas nas dimensões de 7,5 x 42 x 1,5 cm em largura, comprimento e espessura. Os resultados das propriedades físicas indicaram que os tratamentos utilizados não proporcionaram aumento na estabilidade dimensional. As propriedades mecânicas também não foram afetadas pelo tratamento térmico.

Palavras-chave: painéis de madeira, termorretificação, estabilidade dimensional

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1. INTRODUCTION

MDF is the abbreviation for Medium Density Fiberboard. MDF panels are widely accepted in the Brazilian market of furniture manufacturing and related areas, which is due, among other features, to its excellent workability in machining and surface finishing process (IWAKIRI, 2005). In this segment of the national wood processing, there is a growing trend in using eucalyptus in the production of MDF panels (BELINI et al., 2008), which is produced basically by mixing the wood fibrous elements with a synthetic adhesive which are then pressed under heat action. As it happens with the wood, wood panels have hygroscopicity, i.e., when it comes into direct contact with water or high moisture, it swells because of the very hygroscopic nature of the material or as a result of the release of the stresses imposed to the panel during the pressing process of the wood, thus causing dimensional changes to the panel. Hence the use of treatments aimed at reducing the panels. There are several types of treatments that can be used to improve the dimensional stability of the wood and wood panels, among them stands out the heat treatment, also known as thermal rectification (DEL MENEZZI, 2004; MELO, 2013). The heat treatment of panel wood comes as a technique that can be used to improve the employability of the wood and wood products, especially those considered problematic from a technological point of view. Therefore, this study aimed to evaluate the effect of the heat treatment on MDF panels in order to improve its dimensional stability.

2. MATERIALS AND METHODS

2.1. Raw material

The study was conducted at the Wood Technology Laboratory of the Federal University of Mato Grosso, Campus of Sinop. It was used two MDF panels obtained from the local market, produced with *Eucalyptus sp.* and a synthetic resin made of urea formaldehyde, with a size of 160 cm x 280 cm and 1.5 cm thick. From these panels, twenty-five subsamples with 42 cm x 42 cm through the panel thickness (1.5 cm) were taken, each forming a sampling unit. The samples were divided randomly among the treatments for the tests. For the production of the different thermal treatments, the subsamples were randomly selected from groups of five as shown in the Table 2. In order to compare the effect of these treatments to the panel, considering the control samples, they were taken to a forced air circulation oven (Figure 1), where treatments were performed using temperatures of 160 ° C and 180 ° C with 6 and 12-minute treatment times.

Figure 1. Forced circulation oven and samples ready for heat treatment.

2.2. Experiment evaluation

In order to evaluate the quality of the samples submitted to the different treatments, physical tests (moisture content, density, water absorption, thickness swelling, hygroscopic and residual swelling) and mechanical tests (static bending and screws pullout resistance) were performed. It was adopted the recommendations of the standard D 1037 of the American Society for Testing and Materials - ASTM (1998). For the physical tests after the treatment, samples were reduced to the dimensions of 15 cm wide x 15 cm long x 1.5 cm thick, and for the mechanical tests they were sawn in dimensions of 7.5 wide x 42 x long 1.5 cm thick (Figure 2).

2.3. Density and moisture content

Before and after the thermal rectification treatment, the dimensions and the weight were subtracted from the equilibrium moisture content. These data were then used for calculating the apparent density (Equation 1) and the equilibrium moisture content (Equation 2) for each sample.

$$\mathrm{Da}\left(\mathrm{g\ cm^{-3}}\right)=\frac{\text{Mass to the equilibrium moisture content (g)}}{\text{Volume equilibrium moisture content (cm}^{3}\text{)}} \quad (1)$$

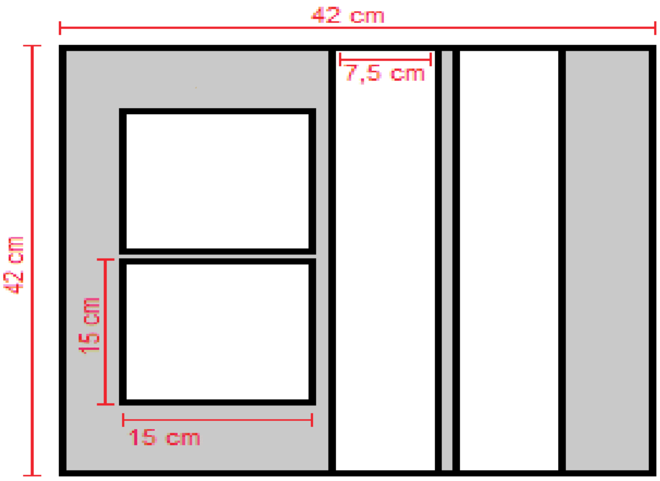

Figure 2. Plate cutting model for the making of the specimen.

$$\mathrm{EMC}(\%)=\frac{\text{Mass balance of moisture} - \text{Dry mass}}{\text{Mass balance of moisture}}\times 100 \quad (2)$$

2.4. Dimensional stability

For measuring the stability, the samples were marked five points which were used for calculating the thickness at different times by using a dial indicator. Additionally, the size and the mass of each of the samples in each of the steps were taken. All these parameters were taken before and after soaking the samples in water for periods of 2 and 24 hours. This information was used to determine the thickness of the swelling at 2 and 24 hours after soaking (Equation 3) and the water absorption also at 2 and 24 hours after soaking (Equation 4).

$$\mathrm{TS}(\%)=\frac{\text{Thickness final average} - \text{Initial average thickness}}{\text{Initial average thickness}}\times 100 \quad (3)$$

$$\mathrm{WA}(\%)=\frac{\text{Final average weight} - \text{Massa initial average}}{\text{Massa initial average}}\times 100 \quad (4)$$

2.5. Residual swelling and hygroscopic swelling

After the soaking tests in water were performed, the samples were acclimated for a period of 45 days (Figure 3) and their size and weight were measured again to determine the residual swelling (Equation 5) and the hygroscopic swelling (Equation 6).

$$\mathrm{RS}=\frac{\mathrm{to}-\mathrm{ti}}{\mathrm{ti}}\times 100 \quad (5)$$

$$\mathrm{HS}=\mathrm{TS}-\mathrm{RS} \quad (6)$$

where: RS = residual swelling (%); ti = initial thickness before soaking (mm); and to = the thickness observed after acclimating the samples (mm); HS = hygroscopic swelling (%); TS = thickness in swelling (%).

2.6. Static bending

For the bending test, the panels Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were determined. The tests were performed on a universal testing machine with a load capacity of 300 KN. The gap between the

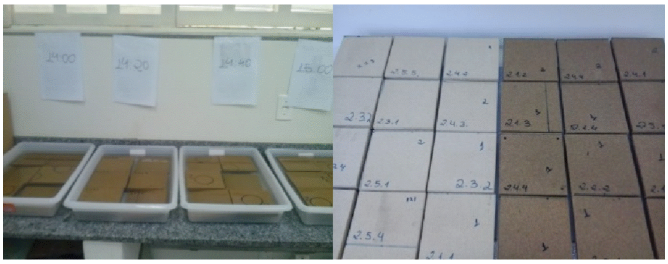

Figure 3. Sample soaked in water for a period of 2 and 24 hours and after soaking in water for acclimating process.

supports used was 24 times the thickness and the load application speed was approximately 5 mm/min (Figure 4) (ASTM D - 1037, 1998).

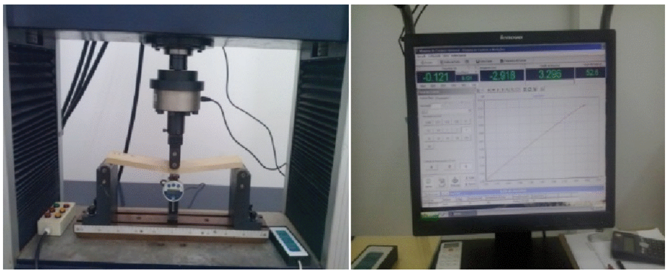

Figure 4. Flexure test carried out on the universal testing machine.

2.7. Screw withdrawal strength

In order to assess the screw withdrawal strength, it was used the same specimens in which the bending tests were performed. After the samples broke, the two sides were then glued together one under the other, which produced a new sample with approximate dimensions of 21 cm long x 7.5 cm wide x 3.0 cm thick (Figure 5).

In the samples produced, a drilling was performed across the thickness by using a drill of 3.2 mm of diameter with a drilling machine. In this hole, screws of 3.5 mm of diameter, 2.54 cm long and with 16 threads/inch were introduced up to 2/3 of its length. Subsequently, tests were conducted in the universal testing machine, which obtained the maximum pullout resistance of the bolts by using the approximate speed of 3 mm/min (ASTM D1037 - 1998).

Figure 5. Gluing of the bonded samples, insertion of the screws and performing of the screw withdrawal strength test.

2.8. Analysis of the results

The results obtained for the parameters: density (before and after the treatment), water absorption (2 and 24 hours), thickness of swelling (at 2 and 24 hours), residual swelling, hygroscopic swelling, flexure and screws pullout strength for the different treatments were evaluated through the analysis of the variance with the subsequent comparison by the Tukey test using the significance of 5%. The program used was ASSISTAT.

3. RESULTS AND DISCUSSION

3.1. Physical Properties of the Panels

3.1.1. Density

The results of the apparent density of the MDF varied in the range of 0.59 to 0.64 g cm^{-3} before the treatment and 0.59 and 0.64 g cm^{-3} after the treatment (Table 1), which classifies them, according to the AMERICAN NATIONAL STANDARD ANSI/A1-208-01 (1993), in the low density category (less than 0.64 g cm^{-3}). There was no significant difference among the treatments. The results are favorable, since there were no losses in density. Therefore, the temperature and/or the duration of the treatments caused no reduction in density.

Table 1. Mean variation in the density of the MDF panel samples before and after the heat treatment.

Treatment (min-°C)	Before (g cm^{-3})	After (g cm^{-3})
0-0	0.60 Aa	0.60 Aa
6-160	0.61 Aa	0.62 Aa
12-160	0.62 Aa	0.62 Aa
6-180	0.65 Aa	0.64 Aa
6-180	0.59 Aa	0.59 Aa

The values with the same letter – capitals on the columns or lowercase in the lines – do not differ statistically among themselves as performed by the Tukey test (significance of 5%).

3.1.2. Water absorption

The results obtained in the water-soaking test at 2 hours and 24 hours are shown in the Figure 6. It was noted a statistically significant difference among the treatments. The treatment that used a temperature of 180 ºC for twelve minutes was the one that resulted in the highest percentage of water absorption.

Del Menezzi (2004), though, when comparing the temperatures of 220 ° C and 190 ° C, noted that the treatment that used the higher temperature reduced the absorption of water, i.e., resulted in a further improvement in the properties related to the dimensional stability as compared to the treatment that used the lowest temperature. Therefore, the opposite result in

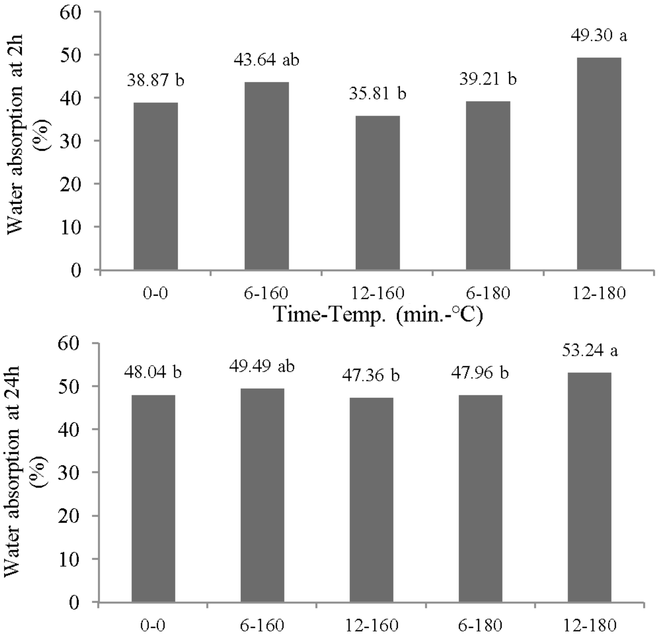

Figure 6. The mean values for the water absorption tests after 2 hours and 24 hours of soaking found for the different treatments assessed.

this study may be due to a loss of the quality in the adhesive bond used in the manufacturing of the panels, which might not have supported the temperatures that were used. For the remaining cases, there were no significant difference, a result that persisted after 24 hours of soaking. According to the United States Department of Agriculture - (USDA 2010), medium density fiberboard (0.60 to 0.80 g cm^{-3}) should present water absorption lower than 50% after soaking. Among the treatments evaluated, only the treatment that used the temperature of 180ºC for 12 minutes time has not reached the requirements presented by this legislation.

3.1.3. Thickness swelling

The mean thickness swelling values (ST) for 2 hours and 24 hours after soaking are shown in the Figure 7. According to the above data, it was observed a significant difference among treatments for both 2h and 24h time. The treatment that showed the best performance, with smaller ST values in both times, was the one that used the temperature of 160 ° C for a 6 minutes time.

Regarding the thickness in swelling after 24 hours, it can be seen that the treatments 6-180 and 12-180 showed no statistical difference, which indicates that higher temperatures affects the swelling of the panels. Xiangquan (1997), however, when evaluating two temperatures (190 and 220 ° C) and five times of thermal post-treatment (5, 10, 15, 20 and 25 minutes) in chipboard panels found that the swelling of the panels decreased as the time and temperature of the treatment were increased. Del Menezzi (2004) attributed this decrease to the release of the compressive stress and to a decreased hygroscopicity caused by the heat treatment, which resulted in an improved dimensional stability of the panels.

This finding showed by Xiangquan (1997) is observed in the present work only in the time of 2 hours, in the treatment 12-180, where there was a reduction in the ST with the increasing of the time and the temperature, and therefore the use of treatments with larger temperatures in order to obtain more satisfactory results in improving the dimensional stability of the panels is recommendable.

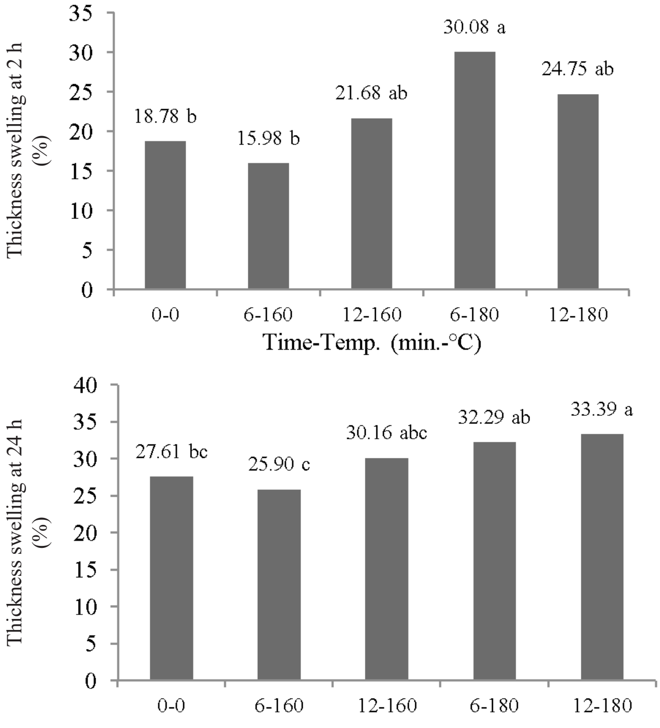

Figure 7. Mean values for thickness swelling after 2 and 24 hours soaking found for the different treatments assessed.

The values obtained for thickness swelling did not exceeded the maximum value accepted by ANSI A 208.1 (1993), which establishes a maximum value of 35%.

3.1.4. Residual and hygroscopic swelling

The results for the residual swelling statistical analysis showed no significant differences (Figure 8). The hygroscopic swelling values for the treated samples were significantly higher than those for the control samples, and that may have been caused by the big release of tension of the treated material. This result is similar to that found by Arruda (2012) when he evaluated the influence of the thermomechanical treatment of Amescla blades (*Trattinnickia burseraefolia*) over plywood physical and mechanical properties.

Another factor that possibly contributed to the largest water absorption and swelling values in both thickness and hygroscopic tests was the type of material used in the manufacturing of the panels. Haselein (1989) also found it difficult to work with *Eucalyptus grandis* and phenolic resins for the production of particle boards, since the panels produced presented poor bonding and excessive swelling. Niekerk; Pizzi (1994) pointed out that the extractives present in this species promote a rapid decrease in adhesive pH during the production process, which in turn makes it difficult to glue.

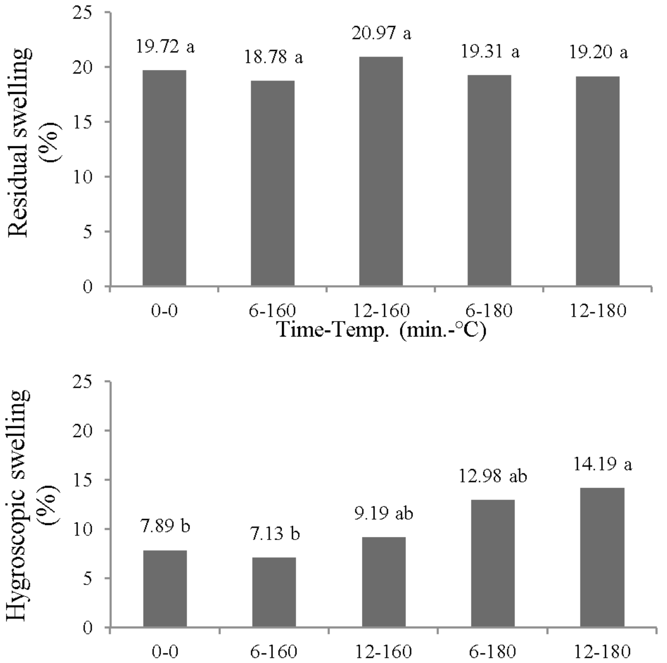

Figure 8. Mean values found for the residual swelling and hygroscopic swelling obtained for the different treatments evaluated.

3.2. Mechanical properties of the panels

3.2.1. Static bending

The findings for the statistical analysis of the modulus of rupture and the modulus of elasticity showed no significant differences among the treatments (Figure 9). The tests showed MOR values above the norm ANSI/A 208.1/93 (ANS, 1993), that establishes 12.5 MPa as the minimum value. Similarly, the

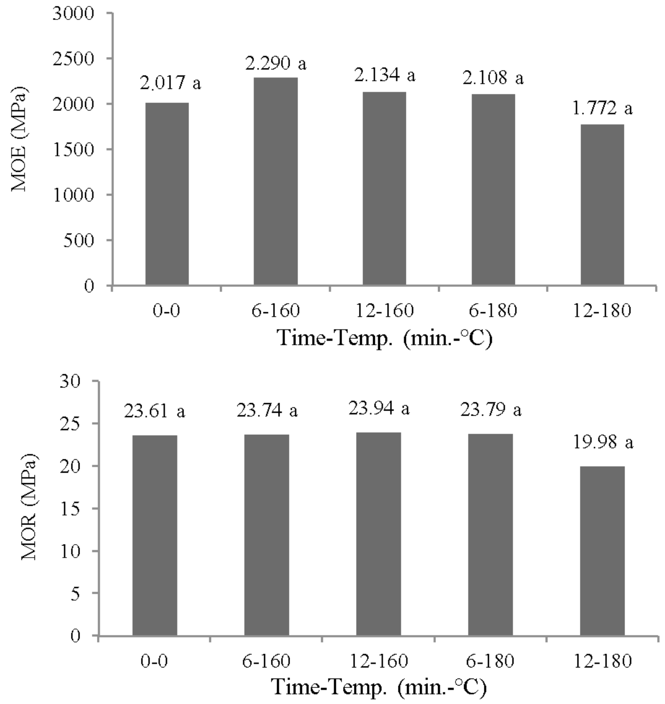

Figure 9. Mean values for the modulus of elasticity (MOE) and modulus of rupture (MOR) found for the different treatments assessed.

MOE showed values above the minimum required by the USDA standard (2010), which sets 1.700 MPa as the minimum value for the sale of MDF.

Through these values, it can be observed a negative correlation between water absorption in 2 and 24 hours with the rupture and elasticity modules. The treatment 12-180 showed the highest values for water absorption in the two times and the lower one for the static bending tests. Eleotério et al. (2000) also observed a negative correlation between the MOE and MOR and water absorption of plywood, thus corroborating our findings. Protásio et al. (2012) reports that the larger the water absorption of the chipboard panels produced from *Eucalyptus grandis* is, the lower will be the rupture and the elasticity modules, as well as the mechanical quality of the panels.

3.2.2. Screw withdrawal strength

We can see in the Figure 10 the mean values obtained for the bolts pullout strength (BP) among the different treatments. It was verified that the treatment 6-160 was the one that provided the lower screw withdrawal strength with a resistance of 807.4 N, while the treatment 12-160 was the one that provided the largest resistance with a value of 897.1 N. However, it was observed that there was no significant difference in the screw withdrawal strength for the different treatments used.

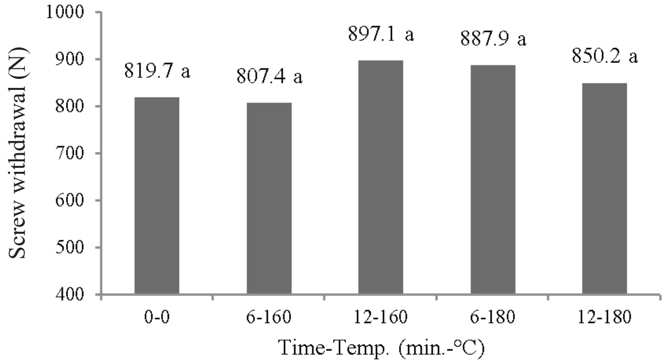

Figure 10. Mean values for the screw withdrawal resistance found for the different treatments evaluated.

Okino et al. (2007), while conducting thermal post-treatment with a temperature of 190 ° C and a 12-minute period in OSB panels made with urea-formaldehyde adhesive and *Cupressus glauca* Lam wood, concluded that the mechanical properties (MOR and screw withdrawal) were not affected by heat treatment.

The mean screw withdrawal strength was higher than the minimum stipulated by ANSI/A 208.1 (1993), which requires a resistance value equal to or over 550 N in low-density plates.

4. CONCLUSIONS

The thermal treatments did not improve the physical properties of the panels. In some cases, it was observed that the use of the temperature caused a reduction in the MDF stability.

As to the mechanical properties, regardless of the temperature and the time used, it was not verified any significant influence on the strength of the MDF panels.

Therefore, it is recommended the use of treatments that combines different times and temperatures from those evaluated in this study in order to analyze the feasibility of using heat treatment as a tool for improving the properties of the panels.

5. ACKNOWLEDGMENTS

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