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The Effect of Post-Heat Treatment in MDF Panels

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This study was to evaluate the effect of post-heat treatment on the physical and mechanical properties of MDF (Medium Density Fiberboard) panels. Commercial MDF panels were produced in Brazil using Pinus wood and urea-formaldehyde (UF) adhesive. The post-heat treatments were carried in a factorial 3 x 2 (three temperatures of heat treatment - 200, 225 and 250 °C, and two times – 5 and 10 minutes), and a control treatment (without heat treatment). Subsequently, the physical and mechanical tests were performed. From the results it can be concluded that: 1) The most effective thermal post-treatment for improving the dimensional stability of the MDF was applied at 225 ° C and 10 min; 2) All the thermally treated panels revealed a significant decrease in the modulus of rupture and modulus of elasticity (MOR and MOE) to bending when compared with the control panels without post-heat treatment.

Keywords: *Physical and mechanical properties, Dimensional stability, Temperature and time of heat treatment, post-heat treatment, MDF panels*

1. Introduction

The furniture industry combines several production processes, including a variety of raw materials and final products. It is chiefly the result of the materials the furniture is composed of (wood, metal and other), as well as related to the uses for which they are destined[1,2].

The wood furniture, hold a significant percentage of the total industry production. It is segmented into two types: straight, having a smooth, with simple design of the straight lines using particleboard and plywood panels as the raw materials; and turned, combining more sophisticated finishing details, mixing both straight and curved shapes and utilizing whose main raw material is solid wood and panels Medium Density Fiberboard (MDF), which can be machined[3].

The MDF panels are produced by wood fiber bonding, utilizing synthetic adhesives and the combined action of temperature and pressure[4]. To obtain the fibers, the wood is cut into small chips which are subsequently comminuted by shredders[5]. The MDF panels has excellent machining conditions, both at the edges as in the faces. When the correct density and homogeneity are provided by the fibers, the MDF panel can be easily turned, carved and machined[6].

As already mentioned, this panel type widely use in the furniture sector, in particular, in front doors, drawer fronts and other more elaborate pieces[7]. However, for the employment of this panel in highly humid areas, improved dimensional stability is required, because this product will be in contact with water and / or water vapor on an every-day, in particular in bathrooms and kitchens, which involve the use of furniture made with MDF panels.

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Several possible alternatives have been proposed for improving the dimensional stability of the panels. They include heat treatment, which involves hemicellulose degredation, the most hygroscopic of the cell wall components, as well as the release of the compressive stresses formed during pressing[8,9].

A few studies have reported the influence of the heat treatment on the conventional particleboard, flakeboard, waferboard, MDF and OSB. They have shown promise, because normally the heat treatment of the previously consolidated panels enhances the dimensional stability and resistance to xylophagous attack[9-14]. However, heat treatment in the panels could also reduce the mechanical properties[10,15].

Thus, the aim of this study was to evaluate the effect of time and temperature level of post-heat treatment on the physical and mechanicals properties MDF panels, seeking to obtain a treatment that improves the dimensional stability of the panels with the least possible effect on the reduction of mechanical properties.

2. Material and Methods

2.1 Obtaining the material

Commercial MDF panels used were produced in Brazil using Pinus wood and urea-formaldehyde (UF) adhesive and with dimensions of 2.75 x 1.83 x 0.015 m (length, width and thickness, respectively). These panels were divided in smaller panels of 50 x 50 cm (length and width, respectively), and which were conditioned in a room at 22 ± 2°C temperature and 65 ± 5% relative humidity.

2.2 Post-heat treatment

The panels were heat-treated in a hydraulic press, with time, temperature and pressure control, as specified in Table 1.

Table 1: Type of heat treatment.

Treatment	Temperature (°C)	Time (Min.)
T1	200	5
T2		10
T3	225	5
T4		10
T5	250	5
T6		10
Control	-	-

The pressure used for the post-heat treatment was 0.5 kgf/cm² to promote good contact between the press platens and the panel to facilitate temperature conduction. A duration of 10 s was employed for closing the press, the press was kept closed for 5 or 10 min according to each treatment, and a subsequent 10-s duration was allowed to open the press. Three replicates for each treatment were performed.

2.3 Physical and mechanical properties

The panels after heat-treated were air-conditioned in a room with temperature of 22 ± 2°C and 65 ± 5% relative humidity.The test bodies were obtained by using a standard saw. The dimensions of the test bodies and test procedures used for the evaluation of the properties of apparent density, water absorption after 2 and 24 h (WA2h and WA24h), thickness swell after 2- and 24-h immersion (TS2h and TS24h), irreversible thickness swelling rate (ITS), and internal bond (IB) were according to the determinations of the ASTM D1037 [16] norm, while for the properties of the modulus of elasticity (MOE) and modulus of rupture (MOR) in static bending, the DIN 52362 [17] norm was adopted. The bulk density of the panels was calculated using the average density of each of the samples in determining the physical and mechanical properties.

2.4 Thermal property of the adhesive

The thermal thermogravimetric analysis (TGA) was performed using a Shimadzu DTG-60AH device in which 2mg of each sample was subjected to a heating rate of 20°C min^{-1} at an initial temperature of 30°C and final temperature of 600°C, under nitrogen flow. The analysis of differential scanning calorimetry (DSC) was done on a Shimadzu DSC apparatus 60A. It used 2 mg of sample, Heating rate of 25°C min^{-1} under nitrogen flow, at an initial temperature of 30°C and final temperature of 350°C. The analyzes were performed to assess the effect of post-heat treatment in the degradation property of the urea-formaldehyde adhesive, which may ultimately affect the final quality of the panel.

2.5 Statistical analysis

For statistical analysis of the data, the experiment was conducted in completely randomized design, in which the treatments were arranged in a 3 × 2 factorial arrangement (three temperatures of post-heat treatment - 200, 225 and 250°C, and two times - 5 and 10 minutes) and a control treatment (without heat treatment). For comparison between the panels that had undergone some treatment and the control panels, Dunnett's test at 5% significance was conducted. The Tukey test, also at 5% significance, was performed for the properties that showed significant interaction between the temperature and post-heat treatment time as well as for evaluating the bulk density, moisture and thickness of the panels.

3. Results and Discussion

3.1 Bulk density, moisture and thickness

In Table 2 it can be seen the average values of density, moisture and thickness of the post-heat treated panels.

For bulk density, only the panels subjected to heat treatment for 10 min., except only treatment at 200°C, differed statistically from the witness panels having lower mean values. According to Paul et al.[15] e Mendes et al.[9], the decrease in bulk density of the panels may be related to chemical degradation of some wood polymers, especially polyoses, and also the release of tensions of panels pressing.

Ayrilmis et al.[14] evaluated the dimensional stability of the commercial MDF with phenol-formaldehyde adhesive and heat post-treatment. The panels were thermally treated at temperatures of 175°C for 15 minutes, 200°C for 30 minutes and 225°C for 30 minutes. The authors recorded mean values of bulk density ranging from 780 and 810 kg m^{-3}, with a tendency for lowered values for the heat-treated panels, although it was not statistical difference between treatments.

Mendes et al.[9] studied the effect of the thermal treatment of a particulate strand at temperatures of 200 to 240°C, on the quality of the OSB, observed a significant reduction in the density panels. The authors also observed the direct effect of an increase in panel thickness on the decrease in the bulk density of the panels. This thickness in increase is due to the partial release of the compressive stress, which occurred just at the end of the pressing in panel production, a fact also observed in this study (Table 2).

The heat treatment at 250°C and 10 minutes showed the lowest average for moisture, differing significantly from the other treatments. while the control panels showed the higher mean value, differing significantly from the other

Table 2: Average values of bulk density, moisture and thickness of the MDF panels.

Treatment	Bulk Density ($kg.m^{-3}$)	Moisture (%)	Thickness (mm)
200°C 5’	630 (0.02) b	7.7 (0.2) c	15.66 (0.21) a
200°C 10’	630 (0.02) b	7.0 (0.2) b	15.86 (0.30) a
225°C 5’	650 (0.01) a	6.9 (0,1) b	15.68 (0.32) a
225°C 10’	600 (0.01) b	6.9 (0.2) b	15.74 (0.29) a
250°C 5’	657 (0.00) a	6.9 (0.02) b	16.05 (0.45) a
250°C 10’	627 (0.01) b	6.6 (0.1) a	15.68 (0.24) a
Control	680 (0.01) a	8.2 (0.07) d	15.25 (0.17) a

Means followed by the same letter in the column show no difference statistically by the Tukey test at the 5% significance level. The standard deviation values are given within the parentheses.

treatments. Also in relation to moisture, the treatments at 200°C in 10 minutes, 225°C in two times (5 and 10 minutes) and at 250°C in 5 minutes were statistically equal. All the average values for moisture content met the requirements of the NBR 15316-2[18] and EN 622[19] standards, defining the minimum humidity at 4% and a maximum of 11%.

3.2 Physical properties

Table 3 lists the average values of water absorption after two (AA2h) and after twenty-four hours (AA24h) for each of the treatments evaluated. Variations in the average values of the panels in relation to the panels without heat treatment are also shown.

Table 3: Average values water absorption values of the MDF after two and twenty-four hours of immersion.

Treatment	AA2h	Δ	AA24h	Δ
		%		
200°C 5’	7.5 (1.2) ns	-13.0	23.5 (1.4) ns	-26.0
200°C 10’	7.3 (0.4) ns	-18.2	22.8 (1.9) *	-28.0
225°C 5’	6,5 (0.8) ns	-24.7	20.0 (2.0) *	-36.8
225°C 10’	3.8 (0.6) *	-55.8	12.2 (1.7) *	-61.6
250°C 5’	16.8 (3.0) *	95.5	35.4 (4.7) ns	11.7
250°C 10’	22.9 (4.3) *	166.5	41.0 (5.0) *	29.2
Control	8.6 (1.9)		31.7 (6.0)	

* Differs statistically by Dunnett's test (α = 00:05) from the control treatment; ns does not differ statistically by Dunnett's test (α = 00:05) from the control treatment. Standard deviation values are given within parentheses.

It can be seen that only the panels heat-treated at 225°C for 10 min. and the panels heat-treated at 250°C in two stages (5 and 10 minutes) differed significantly of the panels without thermal treatment.

The heat treatment at 225°C and 10 min. improved the AA2h property, getting the lowest average, with decrease of -55.8%. However, the panels treated at 250°C in two stages, showed an increase in the AA2h, with increased of 95.5 and 166.5%, respectively.

For the AA24h property, only those panels treated at 200°C and 250°C at the time of 5 minutes, showed no statistical difference from the panels without thermal treatment. The other treatments revealed a reduction in this property, except for the treatment at 250°C and 10 minutes, which showed an increase of 29.2%.

Gonçalez et al.[20] studied the heat treatment of MDF panels at temperatures of 160 to 180°C and times of 15 and 30 minutes and observed a significant reduction in water absorption after 24 hours of immersion in the order of -65%. Ayrilmis et al. [14] evaluated the dimensional stability of the MDF post-heat treatment. The panels were thermally treated at 175°C for 15 minutes, 200°C for 30 minutes and 225°C for 30 minutes. The authors observed a reduction of the values for AA2h from -1.8 to -7.7% and AA24h reduction between -28.6 to -5.0%.

This decrease of the hygroscopicity is due to because reduced accessibility to the sorption sites and the formation of furfural polymers, resulto of the sugars degradation (hemicelluloses), which are less hygroscopic[21]. Winandy e Krzysik[13] conducted heat treated in fibers to produce MDF panels at temperatures of 180, 200 and 220°C and detected a reduction in the arabinan and galactan content, both components of the side chain of the hemicelluloses. The manana, a key component of main chain of hemicellulose, was also affected, although to a lesser degree. These authors purported that these changes in the hemicellulose appeared to lower the hygroscopicity of the fibers. This in turn inhibits moisture sorption, which could lead to water absorption, thickness swelling and influences the loss of mechanical properties.

Still in relation to the data obtained, it was observed interaction between the three temperatures (200 225 250°C) and the two times of use (5 and 10 minutes) for AA2h and AA24h properties as shown in Table 4.

On evaluation of the AA2h property using different times of thermal treatment (5 and 10 minutes) in each different temperature (200, 225 and 250°C), it was observed that at both times the treatment at 250°C statistically differed from the others, revealing the highest average value. For AA24h, in the time of 5 minutes was there any statistical difference observed only for the treatment at 250°C; however, for 10 minutes, all the treatments showed statistical diferences, in both cases with the highest values being obtained for those panels heated to 250°C.

In evaluation each temperature (200, 225 and 250°C) within each time (5 and 10 minutes), only for AA2h no statistical difference was recorded in temperature to 250°C, for AA2h was statistical difference only in temperature to 250 °C, increasing the average value with the addition of time of post-heat treatment. However, for AA24h only treatment at 225°C was statistically different from other

Table 4: Deployments of average values of water absorption after two and twenty-four hours based on the time and temperature of MDF.

Temperature (°C)	AA2h (%)		AA24h (%)	
	Time			
	5’	10’	5’	10’
200	7.5(1.2) bA	7.3(0.6) bA	23.5(1.4) bA	22.8(1.7) bA
225	6.5(0.4) bA	3.8(3.0) bA	20.0(1.9) bA	12.2(4.7) cB
250	16.8(0.8) aB	22.9(4.3) aA	35.4(2.0) aA	41.0(5.0) aA

Means followed by the same letter show no statistical difference by the Tukey test at 5% significance level. Lower case letters refer to the values of the columns while the capitals refer to the values of the lines.The standard deviation values are given within the parentheses.

treatments, reducing the average value with increasing heat treatment time.

The highest average values obtained for the panels thermally treated at 250°C, at both times, may be associated with the greater thermal depolymerization of the cellulose, occurs between the temperatures of 200 to 280 °C[22], and it is steeper from 240°C[23]. It is also associated with the fact that the urea-formaldehyde adhesive gets degraded at this temperature as shown in Figure 1, where the onset of the degradation of the adhesive at temperature 250°C is observed, which promotes the reduction of bonding between the particles, as well as enables greater thickness swelling (Table 5), resulting in an increase in the internal spaces within the panel and consequently greater water absorption capacity.

Table 5 shows the mean values of thickness swelling after two (IE2h) and after twenty-four hours (IE24h) and the rate of no return in thickness (TNRE) for each treatment tested. Variations in the average values of the panels in relation to the panels without heat treatment are also shown.

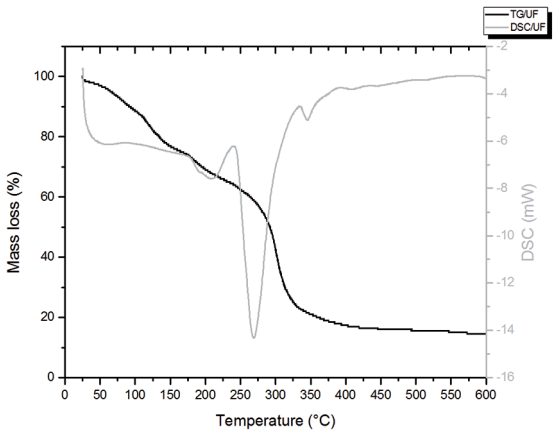

Figure 1: Mass loss of the urea formaldehyde adhesive as a function of temperature.

On evaluating the IE2h property, only those panels treated at 250°C and 5 min showed no statistical difference from the panels without heat treatment. Treatments at temperatures of 200 and 225°C at both times (5 and 10 minutes) reduced IE2h, ranging from -43.5 to -87.1%. While the treatment at 250°C for 10 minutes time, also differed statistically from the control panel,however, an increase of 82.3% in this property. Fact that associated with the thermal degradation of the urea-formaldehyde adhesive, as previously discussed (Figure 1).

For the IE24h and TNRE properties the treatments at 200°C in both heat treatments (5 and 10 minutes) and at 250°C in 10 minutes of time there was no difference statistically from the control panels. The panels treated at 225°C in two times (5 and 10 minutes) obtained reduction of -24.9 and -62.4% for IE24h and -35.3 and -72.1% for TNRE, respectively. The panels treated at 250°C and 5 minutes showed increases in these properties of 24.9 and 32.4%, respectively.

These smaller average values for thickness swelling and rate of no return in thickness, were observed mostly in the treatments applied at 225°C, are associated with two factors: 1) chemical modification of the panel surface; and 2) release of pressing tension[9]. On the issue of chemical modification, chemical degradation of the hemicellulose is the main mechanism, compound less stable thermally and more hygroscopic. At first the hemicelluloses are broken down into monomeric structures and subsequently dehydrated to aldehydes to form the furfural when derived from pentose and hydroxymethylfurfural when derived from hexoses, lowering the hygroscopic capacity of the material[24,25,13]. However, it can also be associated with an increase in the crystalline portions, which induces a decrease in the amorphous regions of the cellulose microfibrils[23-26].

In the case of release of pressing tensions, they develop during the panel production process, result of the fiber mattress compression, and then are retained in the consolidated panel by the action of the adhesive bond between the fibers, which are released when the panel is in contact with moisture and / or water. Practically, the heat treatment promovetes this release of pressing tensions, before the panels come into contact with moisture, which prevents partly the thickness swelling when in use[9].

The release mechanism of compressive stress is described by Del Menezzi[10], as the viscoelastic behavior of wood, mainly that of the lignin, that with the increased temperature applied to the panel, causes the matrix formed by the cross wood polymers have lower resistance to deformation, enables the internal stress to be released or minimized through a matrix rearrangement.

Also in relation to data, interaction was observed between temperatures (200, 225 and 250°C) and the two times of heat treatments (5 and 10 minutes). The deployments of the data for thickness swelling after two and twenty-four hours of immersion in water and the rate of no return in thickness are shown in Table 6.

For IE2h and IE24h, evaluated the times of 5 and 10 minutes within each temperature (200, 225 and 250°C). Note that in the time of 5 minutes only the treatment at 250°C differed significantly from the others, showing the highest average value. For the 10 minutes time period, the IE2h property, showed that three treatments were statistically different, with the lower value being obtained at 225°C and the highest at 250°C. For the 10 minute time, in the IE24h property, only the treatment at 225°C was statistically distinct from the others (200 and 250°C), revealing the lowest average value. In relaction of the TNRE, in two time periods (5 and 10 minutes), the three treatments showed statistical differences, with the highest value being observed for the temperature of 250°C and the lowest value being observed for 225°C.

On analyzing each temperature (200, 225 and 250°C) within each time (5 and10 minutes), there was significant effect for IE2h only when analyzed treatment at 250°C, the highest value was obtained at time 10 min. For IE24h, there was a difference between the treatment only at 225 °C temperatures, the lowest value being obtained at 10 min. For the TNRE, there was a significant effect of time at temperatures of 225°C and 250°C; at 225°C with increasing time there was a reduction of the mean value, while at the 250°C temperature the increase in the time gave a higher average value.

Thus, there is a generallly that the best post-heat treatment for improving the dimensional stability of MDF is at 225°C and time of 10 min. As it has been observed, post-heat treatment at higher temperatures is not indicated.

Ayrilmis et al.[14] evaluated the effect of heat treatment on the dimensional stability of the MDF made with phenol formaldehyde adhesive. The panels were thermally treated at 175°C for 15 minutes, 200°C for 30 minutes and 225°C for 30 minutes. The authors observed a decrease for IE2h in the order of 0.9 to 7.4% and for the IE24h in the order of -1.5% to -14.6.

Mohebby e Ilbeighi [27] evaluated MDF panels composed of industrial fibers and treated hydrothermally at 120, 150 and 180°C for a time of 0, 30 and 90 min. The MDF panels were produced with 0.70 g / cm^3 density, 10 mm thickness and a 3 MPa pressure pressing cycle, at 170°C and 10 minutes of time. The authors noted a decrease in the thickness swelling after two hours and twenty four hours (IE2h and IE24h) in response to the increase in temperature and time. For IE2h, the reductions observed were of the order of -4 to -38%, while for the IE24h the reductions were of the order of -10 to -36%.

According to ANSI A208.2[28], the maximum value of thickness swelling for the MDF panels in internal use applications is 10%. Thus, only those panels heat treated at 225°C, in two times, met this prerequisite. However, with the norm EN 622[19], which reveals a maximum of 12% for panels with a nominal thickness of 12 to 19 mm, only the

Table 5: Average values of the swelling thickness of the MDF after two and twenty-four hours of immersion and the thickness no return rate.

Treatment	IE2h	Δ	IE24h	Δ	TNRE	Δ
			%			
200°C 5’	3.5 (0.7) *	-43.5	11.3 (1.2) ns	-7.8	6.3 (1.0) ns	-7.4
200°C 10’	3.2 (0.6) *	-48.4	11.4 (1.1) ns	-6.9	5.6 (0.6) ns	-17.6
225°C 5’	2.4 (0.2) *	-61.3	9.2 (0.8) *	-24.9	4.4 (0.6) *	-35.3
225°C 10’	0.8 (0.3) *	-87.1	4.6 (0.5) *	-62.4	1.9 (0.6) *	-72.1
250°C 5’	7.2 (1.2) ns	16.1	15.3 (2.0) *	24.9	9.0 (1.3) *	32.4
250°C 10’	11.3 (2.2) *	82.3	13.8 (1.4) ns	12.65	7.4 (0.8) ns	8.8
Control	6.2 (1.0)		12.25 (0.4)		6.8 (0.4)	

* Differs statistically by Dunnett's test (α = 00:05) from the control treatment; ns does not differ statistically by Dunnett's test (α = 00:05) from the control treatment. The standard deviation values are given within parentheses.

Table 6: Deployments of average values of thickness swelling after two and twenty-four hours and the rate of no return in thickness based on the time and temperature of the thermal treatment of MDF.

Temperature (°C)	IE2h (%)		IE24h (%)		TNRE (%)	
	Time					
	5’	10’	5’	10’	5’	10’
200	$3.5^{(0.7)}$ bA	$3.2^{(0.3)}$ bA	$11.3^{(1.2)}$ bA	$11.4^{(0.5)}$ aA	$6.3^{(1.1)}$ bA	$5.6^{(0.6)}$ bA
225	$2.4^{(0.6)}$ bA	$0.8^{(1.2)}$ cA	$9.2^{(1.1)}$ bA	$4.6^{(2.0)}$ bB	$4.4^{(0.6)}$ cA	$1.8^{(1.3)}$ cB
250	$7.2^{(0.2)}$ aB	$11.3^{(2.2)}$ aA	$15.3^{(0.8)}$ aA	$13.8^{(1.4)}$ aA	$9.0^{(0.6)}$ aA	$7.4^{(0.8)}$ aB

Means followed by the same letter show no statistical difference by the Tukey test at 5% significance level. Lower case letters refer to the values of the columns while the capitals refer to the values of the lines.The standard deviation values are given within the parentheses.

panels treated at 200 and 225°C in two stages obtained the mean values below those stipulated by the standard.

3.3 Mechanical properties

Table 7 shows the mean values for the modulus of elasticity (MOE) and modulus of rupture (MOR) at static bending and internal bond for each of the treatments evaluated. The variations in the average values of the panels in relation to the panels without thermal treatment are also evident.

The mean values for the thermally treated panels, for MOR and MOE, were statistically distinct from the control panels, showing reductions of -10.3 to -20.9% for MOE and - 15.3 to -40.7% for the MOR. For the internal bond property, only treatments 200 and 225°C in five minutes of time did not show statistical difference from the control panels; however, all the other treatments showed a reduction in this property, in the order of -11.9 to -37 3%.

According Ayrilmis et al.[14] and Mendes et al.[9] the reduction of the MOE and MOR can be attributed in part to the fact that the heat treatment have caused mass loss during heating, as well as released the tensions of pressing, consequently decreasing the panel density, which relates positively to the mechanical properties of the panel[29,30]. However, Rowell[31] suggests a few depolymerization steps of the carbohydrates by the acids which are produced by the chemical degradation of the timber, a fact that acelerates the breakdown of the long chain carbohydrates to shorter chains. This depolymerization and reduction of the cellulose polymer can affect the MOE and MOR timber, and under acidic conditions at elevated temperatures, it can degrade via hydrolysis, and thus affect the resistance of the wood.

It is also observed that the decreasing trend of the MOE is less than the decrease of MOR, which was also observed by several authors[9,10,15,32].

Mohebby e Ilbeighi[27] evaluated panels composed of MDF fibers hydrothermally treated at temperatures of 120, 150 and 180°C for 0, 30 and 90 min. These panels were produced with 0.70 g / cm^3 density, 10 mm thickness and with a 3 MPa pressure pressing cycle, at 170°C in 10 min. The authors observed a reduction in the MOR, MOE and internal bond, as the temperature and time increased. For the MOR, the reductions observed were in the order of -6.3 to -25.0%, while for the MOE the reductions were approximately 9.1 to 20.5% and for the internal bond the reductis were in the order of -25.0 to -43.8%.

Jarusombuti et al.[33] evaluated the physical and mechanical properties of the MDF panels made with *Eucalyptus camaldulensis* wood fibers heat treated at three different temperatures (120°C, 150°C and 180°C) for 30 or 60 minutes using a laboratory autoclave. Regarding the mechanical properties, the authors observed a decrease of -9% to -25 for the modulus of elasticity (MOE), of -16 to -37% for the modulus of rupture (MOR) and -10 to -39% for the internal bond.

The EN 622[19] standard has a minimum requirement of 20 MPa for the MOR, 2200 MPa for the MOE and 0.55 MPa for the internal bond. The ANSI-A 208.2 [28] determines the minimum values of 24 MPa for the MOR, of 2400MPa for the MOE and 0.60MPa for internal bond. Thus, none of the treatments (including the panels not subjected to the heat treatment) responded to the minimum internal bond stipulated by the EN 622[19] and ANSI-A 208.2[28] standard. When considering the MOR, only the panels heat treatment at 250°C in 10 minutes did not meet the value set by the EN 622[19] standard, while that for the ANSI-A 208.2[28], treatments at 225°C and 10 minutes and 250°C in two times (5 and 10 minutes) did not meet this minimum requirement. Regarding the MOE, all the treatments met the minimum value stipulated by the two standards.

No interaction was observed between the temperatures and times used for the mechanical properties of the panels. Tables 8 and 9 show the average values of MOE, MOR and IB in function of temperature and time of post-heat treatment, respectively.

Table 8 shows, when the mechanical properties were measured in function of temperature, only the MOR property was observed to have different average values for the three temeratures (200, 225 and 250°C); a decrease in these values was noted as the temperature was increased to perform the heat treatment. The reason is that a greater reduction in the MOR values is associated with 250°C, besides the improved chemical degradation of wood at the beginning of thermal

Table 7: Average values of the modulus of elasticity and modulus of rupture in bending strength and internal bond of the MDF panels.

Treatment	MOE	Δ	MOR	Δ	Internal Bond	Δ
			MPa			
200°C 5’	2847.5 (112.1) *	-10.5	28.3 (0.05) *	-15.3	0.41 (0.03) ns	-11.9
200°C 10’	2630.1 (112.1) *	-17.4	25.5 (0.05) *	-23.7	0.33 (0.04) *	-28.2
225°C 5’	2853.7 (123.5) *	-10.3	26.5 (0.8) *	-20.7	0.36 (0.05) ns	-23.1
225°C 10’	2595.6 (49.3) *	-18.4	21.9 (1.6) *	-34.4	0.29 (0.03) *	-37.3
250°C 5’	2637.6 (70.0) *	-17.1	22.8 (0.3) *	-31.7	0.32 (0.07) *	-30.8
250°C 10’	2516.7 (27.2) *	-20.9	19.8 (2.0) *	-40.7	0.30 (0.09) *	-36.4
Control	3182.3 (38.0)		33.4 (1.07)		0.47 (0.03)	

* Differs statistically by Dunnett's test (α = 00:05) from the control treatment; ns does not differ statistically by Dunnett's test (α = 00:05) from the control treatment. The standard deviation values are given within parentheses.

Table 8: Average values of MOE, MOR and Internal Bond based on the temperature applied to the MDF

Temperature (°C)	MOE	MOR	Internal Bond
		MPa	
200	2738.8 (159.0) a	26.9 (1.6) a	0.37 (0.1) a
225	2724.7 (151.4) a	24.2 (2.7) b	0.33 (0.1) a
250	2577.1 (72.5) a	21.3 (2.1) c	0.31 (0.1) a

Means followed by the same letter in the column show no statistical difference by the Tukey test at 5% significance level. The standard deviation values are given within the parentheses.

Table 9: Average values for MOE, MOR and Internal Bond in function of the time of the heat treatment applied to the MDF.

Time (min.)	MOE	MOR	Internal Bond
		MPa	
5	2779.6 (123.6) a	25.9 (2.8) a	0.36 (0.1) a
10	2580.8 (89.1) b	22.4 (2.6) b	0.31 (0.1) b

Means followed by the same letter in the column show no statistical difference by the Tukey test at 5% significance level. The standard deviation values are given within the parentheses.

degradation of the urea-formaldehyde adhesive (Figure 1), fact that promoted reduction trend of the internal bond of the panels (Table 8) and consequently the loss of the MOR flexure resistance.

Regarding the evaluation of the mechanical properties as a function of time (Table 9), a statistical difference is seen between the values at 5 and 10 minutes for the three properties evaluated, showing a decrease in the average values with increasing heat treatment time.

4. Conclusions

The most effective thermal post-treatment for improving the dimensional stability of MDF was applied at the temperature of 225°C and time of 10 min. With this treatment smaller values were obtained for the AA2h, AA24h, IE24h and TNRE.

The thermal treatment at 250°C is not indicated for MDF made with urea-formaldehyde adhesive. This fact is due to the onset of thermal degradation of the adhesive and consequently increase in values of the physical and lower mechanical properties.

Only thermally treated panels at 225°C in two times (5 and 10 min) meet the IE24h maximum value stipulated by ANSI A208.2 (2002) standard. The panels treated at 200 and 225°C in two times (5 and 10 min) met the requirement of EN 622 (2006) standard for IE24h.

All the heat-treated panels revealed a significant decrease in the MOR and MOE in static bending when compared with the panels not subjected to thermal treatment. There was effect of temperature level only for the MOR propertywith the decrease in the average values according to the increased temperature levels. The effect of post-heat treatment time was also observed, with significantly decrease the properties of MOR, MOE and the internal bond with increase in the heat treatment time.

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