EFFECTS OF TEMPERATURE AND PRESSURE TIME IN THE MANUFACTURE OF PARTICLEBOARDS

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Received for publication: 13/06/2017 - Accepted for publication: 28/02/2019

Resumo

Efeitos da temperatura e tempo de prensagem na manufatura de painéis aglomerados O objetivo deste trabalho foi avaliar os efeitos de três diferentes temperaturas e tempos de prensagem, próximas às condições industriais, sobre as propriedades de painéis experimentais produzidos em laboratório. Os painéis foram produzidos com densidade nominal de 0,70 g/cm³, com 8% de resina ureia-formaldeído e prensados à temperatura de 180, 200 e 220ºC e tempo de 2, 4 e 6 minutos. Os painéis foram produzidos com densidade nominal de 0,70 g/cm³, com 8% de resina ureia-formaldeído e prensados à temperatura de 180, 200 e 220ºC e tempo de 2, 4 e 6 minutos O aumento no tempo de prensagem não afetou de forma significativa as propriedades físicas dos painéis, porém melhorou as suas propriedades mecânicas. Já o aumento na temperatura de prensagem afetou de forma negativa as propriedades mecânicas dos painéis.

Palavras-chave Parâmetros de prensagem; propriedades dos painéis; transferência de calor.

Abstract

The objective of this work was to evaluate the effects of three different temperatures and pressing times, near of industrial conditions, on the properties of experimental panels produced in the laboratory. The objective of this work was to evaluate the effects of three different temperatures and pressing times, near of industrial conditions, on the properties of experimental panels produced in the laboratory. The objective of this work was to evaluate the effects of three different temperatures and pressing times, near of industrial conditions, on the properties of experimental panels produced in the laboratory. The increase in the pressing time did not significantly affect the physical properties of the panels but improved their mechanical properties. The increase in the pressing temperature reduced the mechanical properties of the panels.

Keywords: Press parameters; properties of the panels; heat transfer.

INTRODUCTION

The pressing process is considered the most critical stage for the production of particleboards, since their final properties are directly related to pressure, temperature and time levels established in the press according to the production plan.

The main function of the temperature during the pressing process is to accelerate the polymerization of the resin distributed between wood particles. In this step, the densification of the material occurs by a mechanical process of deformation by bending and compression until the final thickness, a heating of the material and consequently a chemical process that leads to curing of the resin (MALONEY, 1993).

The pressing temperature is defined according to the type of resin used (KELLY, 1977; MARRA, 1992). The heat transfer rate occurs from the surface layers to the center of the panel, where in the first moments of pressing, steam formation occurs on the faces of the mattress, then, plasticizing the wood and facilitating its compression until it reaches the ultimate thickness. Albuquerque and Iwakiri (2016) report that when using urea-formaldehyde resin, temperature above 93° C in the core of the panel for 15 seconds is enough for curing.

The press temperature directly affects the productivity of a manufacturing unit, since higher press temperatures result in a shorter panel pressing time (IWAKIRI, 2005). In general, with increasing temperature, the mechanical properties tend to increase. However, Wilcox (1953), using a pressing temperature of 240° C, found a considerable decline in the flexural strength of the panels, as a result of the degradation of the crystalline structure of the cellulosic chain. Additionally, Suleiman (1999) argues that, in addition to changing physical behavior, too high temperatures affect heat conduction capacity.

The pressing time is the time elapsed between the moment of consolidation of the particleboard to the final thickness of the panel and the opening time of the press plates (MOSLEMI, 1974). According to Marra (1992), the pressing time must be sufficient for the interior of the panel to reach the temperature required for polymerization of the resin. In addition, the author reports that the pressing time exerts significant influence on the properties of the panels, thickness control and surface quality.

According to Albuquerque and Iwakiri (2016), the pressing time depends mainly on the heat transfer efficiency, the panel thickness, the temperature, the moisture distribution in the mattress, and generally can be defined at about 6 to 12 seconds per mm thickness of the panel. Moslemi (1974) states that the reduction in the time of consolidation of the panels is economically desirable, as they imply higher productivity as well as reduction in energy consumption, nevertheless, the decrease in the pressing time also results in the reduction of resistance properties.

On the one hand, agglomerated panel industries employ temperatures of 200 to 220° C and pressing time, or, press factor, of 6 to 12 seconds per mm of panel thickness. On the other hand, at the laboratory level, temperatures of 140 to 160° C, specific pressure of 4 MPa and pressing time of 8 minutes, are usually employed for panels with resin-based bonding of urea-formaldehyde resin and thickness of 15 mm. Therefore, there are different pressing conditions, even considering the small dimensions of experimental panels.

Thus, the objective of this study was to evaluate the effects of three different temperatures and pressing times near of industrial conditions on the properties of experimental panels produced in the laboratory.

MATERIAL AND METHODS

In order to perform this research, industrial particles of *Pinus* were collected from an agglomerated panel industry in the metropolitan region of Curitiba, Paraná State, Brazil. The particles were reprocessed in a hammer mill, dried at a medium humidity content of 3%, and classified in a 0.6 mm mesh screen to remove "thins".

The experimental panels were produced with nominal density of 0.70 g / cm³ and dimensions of 50x38x1,30 cm, with 8% of urea-formaldehyde resin and 1% of paraffinic emulsion. The panels were pressed with three different times and press temperatures, simulating the industrial conditions, being 2, 4 and 6 minutes and 180, 200 and 220º C, respectively. The experimental design is presented in Table 1. The applied pressure was 4.0 MPa and three panels were produced per treatment, totaling 27 panels.

Table 1. Experimental design
Tabela 1. Delineamento experimental

Treatment	Temperature (° C)	Pressing time (min)
T1 - 180/2	180	
T2 - 200/2	200	2.
T2 - 220/2	220	
T4 - 180/4	180	
T5 - 200/4	200	4.
T6 - 220/4	220	
T7 - 180/6	180	
T8 - 200/6	200	6.
T9 - 220/6	220	

After pressing, the panels were squared and conditioned in a climatic chamber at a temperature of 20 ±° C and relative humidity of 65± 3%, until stabilized at a mean humidity content of 12%.

For the evaluation of the physical-mechanical properties, five specimens of each panel were tested for density, five for static bending, five for internal bond, and five for water absorption and thickness swelling after 2 and 24 hours of immersion in water. In this way, the tests were based on the procedures described in standards EN 323 (2002), EN 310 (2002), EN 319 (2002) and EN 317 (2002), respectively. The results of the tests of modulus of rupture, modulus of elasticity and internal bond were compared with the requirements of standard EN 312-3 (P3) for panels destinated for interior use (including furniture) in dry conditions, with a thickness of more than 13 mm.

The statistical stablishment was in a factorial arrangement (3x3), being three times and three temperatures. For the statistical analysis of the results, it was applied Grubbs tests to identify outliers, Shapiro Wilks for data normality, Bartllet for homogeneity of variance, ANOVA and Tukey for averages comparison. All to 95% reliability in the statistical package Sthatgraphics.

FLORESTA, Curitiba, PR, v. 49, n. 3, p. 383 - 390, jul/set 2019
Iwakiri, S. *et.al.*
Electronic ISSN 1982-4688
DOI: 10.5380/rf.v49 i3.53238

RESULTS

Physical properties of the panels

Table 2 shows the mean density results, water absorption and thickness swelling after 2 and 24 hours immersion in water.

Table 2. Averages of the physical properties of the panels.
Tabela 2. Valores médios das propriedades físicas dos painéis.

Treatment	Density ($g.cm^{-3}$)	WA2h (%)	WA24h (%)	TS2h (%)	TS24h (%)
T1 - 180°C/2 min	0.685 a (5.90)	18.65 ab (21.10)	59.16 c (13.33)	6.75 ab (16.07)	21.21 bc (9.48)
T2 - 200°C/2 min	0.673 a (4.95)	20.00 ab (21.89)	70.05 a (9.80)	6.82 ab (19.08)	23.71 ab (12.56)
T3 - 220°C/2 min	0.675 a (6.10)	22,43 a (14.75)	66.66 ab (7.46)	8,35 a (18.44)	26,26 a (9.26)
T4 - 180°C/4 min	0.679 a (5.64)	16,66 b (22.58)	65.23 ABC (10.10)	5.84 c (33.47)	23.64 ab (14.16)
T5 - 200°C/4 min	0.683 a (5.63)	19.36 ab (15.37)	62,80 bc (10.44)	7.22 ab (16.06)	23.78 ab (16.25)
T6 - 220°C/4 min	0.687 a (6.05)	19.09 ab (12.28)	59.26 c (6.10)	7.18 ab (16.25)	24.23 ab (9.42)
T7 - 180°C/6 min	0.684 a (6.96)	19,87 b (23.25)	61,00 bc (9.25)	7.20 ab (19.91)	24.45 ab (8.80)
T8 - 200°C/6 min	0.692 a (7.53)	17,10 b (18.87)	60,65 bc (9.43)	7,67 a (22.46)	23.67 ab (12.12)
T9 - 220°C/6 min	0.701 a (6.56)	19.31 ab (13.97)	50.83 d (9.17)	7,61 a (18.53)	18.65 c (18.16)

WA2h: water absorption after 2 hours; WA24h: water absorption after 24 hours; TS2h: thickness swelling after 2 hours; TS24h: thickness swelling after 2 hours.
Averages followed by the same letter in the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

The density averages ranged from 0.673 $g.cm^{-3}$ for the panels T2 (200°C/2 min) at 0.701 $g\ cm^{-3}$ for the T9 panels (220°C/6 min). There were no significant differences between treatments.

The WA2h averages ranged from 16.66% for T4 panels (180°C/4 min) to 22.43% for T3 panels (220°C/2 min), the averages being statistically different from each other. The T4 panels (180ºC/4 min) had a statistically lower average in relation to the T3 panels (220ºC/2 min) and the same in comparison to the other treatments.

For the WA24h, the averages varied from 50.83% for T9 panels (220ºC/6 min) to 70.05% for T2 panels (200ºC/2 min), being the averages statistically different between themselves. The T9 panels (220ºC/6 min) presented a statistically lower average compared to all other treatments.

The TS2h averages ranged from 5.84% for T4 panels (180°C/4 min) to 8.35% for T3 panels (220°C/2 min), the averages being statistically different from each other. The T4 panels (180ºC/4 min) presented a statistically lower average compared to all other treatments.

For TS24h, the averages ranged from 18.64% for T9 panels (220°C / 6 min) to 26.26% for T3 panels (220°C/2 min), the averages being statistically different from each other. The T9 panels (220ºC/6 min) had a statistically equal average in relation to T1 panels (220ºC / 2 min) and the same average in comparison to the other treatments.

Table 3 shows the effects of pressing time on water absorption and swelling in thickness after 2 and 24 hours of immersion in water.

Table 3. Effects of pressing time on the physical properties of the panels.
Tabela 3. Efeitos do tempo de prensagem sobre as propriedades físicas dos painéis.

Time	WA 2h (%)	WA 24h (%)	TS 2h (%)	TS 24h (%)
2min.	20,36 a (20.46)	65.29 a (12.24)	7,31 a (20.39)	23,73 a (13.55)
4min.	18,45 b (17.36)	62.30 a (10.23)	6,81 a (21.91)	23,89 a (13.22)
6min.	18,22 b (17.56)	57.57 b (12.28)	7,48 a (20,11)	22,31 a (16.99)

Averages followed by the same letter in the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

The results of the factorial analysis indicated that there was influence of the pressing time on the average values of WA2h and WA24h. No significant differences were found for TS2h and TS24h for different pressing times of the panels.

Table 4 shows the effects of pressing time onWA2h, WA24h, TS2h and |TS24h.

Table 4. Effects of pressing time on the physical properties of the panels.
Tabela 4. Effect of pressing time on the physical properties of panels.

Temperature	WA 2h (%)	WA 24h (%)	TS 2h (%)	TS 24h (%)
180°C	17.88 b (21.03)	61.64 ab (11.48)	6.65 b (23.45)	23.08 a (12.34)
200°C	18.85 ab (19.71)	64.59 a (17.57)	7.23 ab (19.62)	23.72 a (13.49)
220°C	20.29 a (15.56)	59.10 b (13.59)	7.71 a (18.13)	23.15 a (18.05)

Averages followed by the same letter in the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

The results of the factorial analysis presented in Table 4 showed that, except for the TS24h, there was influence of the pressing temperature on the average values of WA2h and WA24h and TS2h.

Mechanical properties of panels

Table 5 shows the average results of modulus of rupture, modulus of elasticity and internal bond.

Table 5. Averages of the mechanicals properties of the panels.
Tabela 5. Resultados médios das propriedades mecânicas dos painéis.

Treatment	MOR (MPa)	MOE (MPa)	IB (MPa)
T1 - 180°C/2 min	11.68 a (7.41)	1.987 ab (9.78)	0,62 b (13,94)
T2 - 200 ° C/2 min	8.71 c (14,00)	1.711 ab (14.75)	0.38 c (14.55)

Electronic ISSN 1982-4688
DOI: 10.5380/rf.v49 i3.53238

T3 - 220 ° C/2 min	7.88 c (14.04)	1.648 b (14.23)	0.35 c (20.34)
T4 - 180°C/4 min	11.73 ab (8.76)	1.877 ab (13.72)	0.70 ab (17.34)
T5 - 200 ° C/4 min	10,65 b (8.47)	1.849 ab (10.39)	0.69 ab (20.87)
T6 - 220 ° C/4 min	8.44 c (15.52)	1.769 ab (15.98)	0.45 c (17.12)
T7 - 180°C/6 min	11.48 ab (11.12)	1.870 ab (16.99)	0,74 a (13.61)
T8 - 200°C/6 min	12.31 a (12.86)	1993 a (12.11)	0.73 ab (19.05)
T9 - 220 ° C / 6 min	10,54 b (15.01)	1.702 b (16.98)	0.73 ab (13.79)

MOR: modulus of rupture; MOE: modulus of elasticity; IB: internal bond; averages followed by the same letter in the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

The average values of MOR ranged from 7.88 MPa for T3 panels (220 C/2 min) to 12.31 MPa for T8 panels (200°C/6 min), the averages being statistically different from each other. The T8 panels (220ºC /6 min) had a statistically equal average in relation to the T1 panels (180ºC/2 min), T4 (180ºC/6 min) and superior mean in comparison to the other treatments.

The average values of MOE ranged from 1.993 MPa for T8 panels (220°C/6 min) to 1.648 MPa for T8 panels (200°C/2 min), the averages being statistically different from each other. The T8 panels (220ºC /6 min) had a statistically equal average in relation to the T3 panels (220ºC/2 min), T9 (220ºC/6 min) had superior average in comparison to the other treatments.

The average values of IB ranged from 0.35 MPa for T3 panels (220°C/2 min) to 0.74 MPa for T7 panels (180°C/6 min), the averages being statistically different from each other. The T7 panels (180ºC/6 min) presented a statistically equal average in relation to the T4 panels (180ºC/4 min), T5 (200ºC/4 min), T8 (220ºC/6 min) and T9 (220ºC/6 min) had superior average in comparison to the other treatments.

Table 6 shows the effects of pressing time on MOR, MOE and IB.

Table 6. Effects of pressing time on the mechanical properties of the panels.
Tabela 6. Efeitos do tempo de prensagem sobre as propriedades mecânicas dos painéis.

Time	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**
2min.	9,46 b (20.70)	1875 a (15.02)	0.45 c (30.95)
4min.	9,73 b (18.83)	1813 a (14.29)	0,61 b (26.97)
6min.	11,16 a (15.07)	1807 a (16.12)	0,73 a (15.22)

Averages followed by the same letter in the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

Except for the MOE, the results of the factorial analysis indicated that there was influence of the pressing time on MOR, MOE and IB.

Table 7 shows the effects of pressing time on MOR, MOE and IB.

Table 7. Effects of pressing time on the mechanical properties of the panels.
Tabela 7. Efeitos da temperatura de prensagem sobre as propriedades mecânicas dos painéis.

Temperature	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**
180°C	11,63 a (13.97)	1.911 a (13.26)	0,68 a (16.56)
200°C	10,52 b (16.89)	1.848 a (12.64)	0.60b (33.06)
220°C	9.22 c (18.80)	1.720 b (15.19)	0.51 c (35.10)

Averages followed by the same letter of the same column are statistically the same by the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

The presented results of the factorial analysis in Table 7 indicated that it had influence of the pressing temperature on MOR, MOE and IB.

DISCUSSIONS

Small reductions in the density averages obtained for the panels were observed in respect to the nominal density calculated to 0.700 $g.cm^{-3}$. However, these differences were not statistically significant. The small reductions observed in the density of the panels produced can be attributed to the loss of material during the formation of the panels and return in thickness after hot pressing followed by packaging.

Additionally, the increase in the pressing time resulted in a reduction of WA2h and WA24h. The effects of the pressing times were not found for TS of the panels.

There was no uniform influence of the pressing temperature on the WA results. The temperature rises from 180 to 220°C increased WA2h, but there was a reduction in WA24h. However, for TS2h, lower values were obtained for lower temperatures, nonetheless, the effect of temperature was not found for TS24h.

The results of WA and TS obtained in this study were satisfactory when compared to some references presented in literature on particleboards of species from forest plantations, produced in the laboratory. Naumann *et al.* (2008) found for particleboards of *Eucalyptus urophylla*and *Schizolobium amazonicum,*WA24h values of 97.2% and 117.9%, respectively; Iwakiri *et al.* (1996) found for particleboards of *Pinus taeda*and *Eucalyptus dunnii*, WA24h of 75.04% and 80.05%, respectively; and Trianoski *et al.* (2016) found for panels produced with a mixture of *Pinus taeda* with *Grevilea robust*, values of 22.44 to 31.41% for WA24 h. With respect to TS24h, Naumann *et al.* (2008) found for panels of *Eucalyptus urophylla* and *Schizolobium amazonicum*, 30.50% and 35.09%, respectively; While Iwakiri *et al.* (1996) found for panels of *Pinus taeda* and *Eucalyptus dunnii* values of 30.50% and 35.09%; and *Trianoski et al.* (2016) found for panels produced with a mixture of *Pinus taeda* and *Grevilea robust*, values from 66.26 to 98.43% for TS24h.

Moreover, the increase in pressing time contributed to improve the results of MOR and IB, nevertheless did not significantly affect the MOE results. Regarding the effects of the pressing temperature, the best results of mechanical properties were obtained for panels produced with lower temperatures. Therefore, the results confirm the theories presented by Wilcox (1953) and Suleiman (1999), in which high press temperatures can contribute to the degradation of the crystalline structure of the cellulosic chain and affect the conductivity of heat, damaging the mechanical resistance of the panels.

Regarding the normative requirements of EN 312-3: 2003, all the treatments met the minimum values established for the MOE and IB whose values are respectively 1,600 MPa and 0,35 MPa. Regarding the MOR, no treatment met the minimum requirement of 13 MPa.

The results of WA and TS obtained in this research were satisfactory when compared to some references presented in literature on particleboards of species from forest plantations produced in the laboratory. In this way, Trianoski *et al.* (2011) found for particleboards produced with wood of *Acrocarpus fraxinifolius*, *Melia azedarach* and *Toona ciliata*, values of IB of 1.50 MPa, 1.88 MPa and 1.64 MPa, respectively. In turn, Colli *et al.* (2010) found for particleboards produced with *Schizolobium amazonicum* an average value of 0.22 MPa. While Naumann *et al.* (2008) found for particleboards produced with timber of *Eucalyptus urophylla and Schizolobium amazonicum* values of 4.26 MPa and 13.96 MPa for MOR, and of 696 MPa and 1,873 MPa for the MOE, respectively. Yet, Trianoski *et al.*(2011) found for particleboards produced with timber from *Acorncarpus fraxinifolius*, *Melia azedarach* and *Toona ciliata* MOR averages of 18.19 MPa, 18.56 MPa and 19.83 MPa, and MOE averages of 2.134 MPa, 2.191 MPa and 2.427 MPa, respectively for the three species studied; Finally, Trianoski *et al.* (2016), for the panels produced with a blend of *Pinus taeda* and *Grevilea robust*, values of MOR and MOE in the range of 7.67 to 13.85 MPa and 1.381 to 1.635 MPa were found, respectively.

CONCLUSIONS

The increase in the pressing time contributed to the reduction of the water absorption of the panels, however, did not significantly affect the swelling results in thickness. Regarding the temperature, the results indicated the possibility of pressing the panels with a lower temperature of 180ºC.

In addition, the increase in the pressing time resulted in higher values of flexural strength and perpendicular traction of the panels.

Furthermore, the increase in the pressing temperature adversely affected the mechanical properties of the panels, confirming the theories presented in the literature that high press temperatures can contribute to the degradation of the crystalline structure of the cellulosic chain and affect the heat conduction capacity, damaging the mechanical strength of the panels.

Based on the results obtained, it can be stated that the best combination of temperature and pressing time is 180°C and 6 minutes. To improve the results of swelling in thickness and resistance to static bending, which did not meet the normative requirements of EN 312-2003, a small increase in resin content is recommended.

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