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Discarded Furniture Panels with Different Densities and Resin Contents

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Abstract

This study evaluated the quality of the particleboard produced with particles generated from mobile discharges with mixture of equal parts of industrial particles of *Pinus*. The material was collected and processed in the form of chips by a company specialized in waste recycling. The experimental plan consisted in producing panels with nominal density 0.55, 0.70 and 0.85 g/cm^3, and urea-formaldehyde resin of 8, 10 and 12%. The increased density and resin content contributed to improve the physical and mechanical properties of the panels. The panels produced with nominal density of 0.70 and 0.85 g/cm^3, and 10% resin content, showed better feasibility of using mobile discharges particles in a proportion of 50% mixture with particles of *Pinus* industrial production of particleboards.

Keywords: recycling, wood panel, mobile residues.

1. INTRODUCTION AND OBJECTIVES

The recycling of wood-based products is increasingly more important for the forest-based industry due to its positive impact on both the environment and the production chain of consumer goods. Such process involves collection, separation and cleaning, allowing fewer new products to be manufactured, saving raw material, inputs, and contributing to reduce energy consumption.

Zamarian et al. (2017) reported that wood waste from sources such as furniture production, packaging and demolition can be reprocessed in industrial grinders and processed into chips for use as raw material in the manufacture of new wood products. The grinding process is simple, efficient and inexpensive, being technically and economically interesting as a way to add value to waste, providing supplies to agglomerated panel industries.

The main source of wood for the production of agglomerated panels in Brazil comes from planted forests, with *Pinus* and *Eucalyptus* being the most used species (Iwakiri, Matos et al., 2012). Industries use wood in the form of thin logs from slabs or chips generated from reprocessing of sawmill and rolling mill residues. However, studies suggest that sawmill, as well as wooden construction discards and carpentry and woodworking residues, can also be reused as raw materials for reconstituted panels (Azambuja et al., 2018; Iwakiri, Vianez et al., 2012; Weber & Iwakiri, 2015). The use of residues of wood products at the end of their life cycle to produce agglomerated panels is not yet carried out in Brazil. In this context, the aim of this research was to produce agglomerated panels consisting of particles generated from furniture wastes and industrial *Pinus* particles, mixed in equal proportions, with different densities and urea-formaldehyde resin contents.

The use of furniture waste for the production of new agglomerated panels may favor the implementation of reverse logistics, provided for in environmental law 12.305, contributing to the reduction of urban waste and consumption of virgin timber from forest exploitation, favoring a better utilization of raw materials and providing greater added value to new products. The use of particles generated from the disposal of furniture for the production of agglomerated panels may also impact on the reduction of energy costs for particle drying,

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since materials from furniture discards have an equilibrium moisture content (10 to 12%) lower than that of virgin wood.

2. MATERIAL AND METHODS

The material used in this study was collected on the streets of the northeastern region of Curitiba and consisted of discarded furniture such as bedroom appliances, cabinets with drawers, table tops, doors and shelves. The material also contained metal and plastic fittings, as well as fasteners such as hinges, shelf supports, handles, nails, screws and staples. Pieces with swelling due to moisture, rot or damage from xylophagous agents were not excluded from the selection process. The material selected was dry, not exposed to weather variations and had no contact with organic waste, since it was collected on the same day of disposal.

The products used in the furniture were agglomerated panels, MDF, hardboard, plywood and solid wood, with different finishes such as paints, wood veneers, plastic laminates and BP (melamine film) and FF (finish foil) decorative papers.

All the material collected, without classification and quantification of the different raw materials, was processed in a grinder, equipped with an electromagnet for the removal of metals. The process was conducted twice for complete metal removal and chip reduction. All other components of discard pieces were ground but were not removed from the resulting material.

Industrial *Pinus* particles, urea-formaldehyde resin, paraffin emulsion and ammonium sulfate were also used as catalysts.

Both chips obtained from furniture discards and industrial *Pinus* particles were reprocessed twice in hammer mill using sieves with 18 and 12 mm meshes (Figure 1). After this procedure, particles were dried at medium moisture content of 3% and classified in sieves for the removal of fines.

The experimental plan consists of nine treatments, with three different densities and three resin contents (Table 1).

Experimental panels were produced with densities of 0.55, 0.70 and 0.85 g/cm^3 and dimensions of 500 × 500 × 13 mm (length, width and thickness). Urea-formaldehyde resin was applied in the amount of 8, 10 and 12% solids, basis dry weight of particles, and 1% paraffin emulsion. About 50% of furniture discards and 50% of industrial *Pinus* particles were used in the composition. Panels were pressed at temperature of 140 °C, specific pressure of 4.0 MPa and pressing time of 10 minutes. After panels were manufactured, they were conditioned in a climatic chamber with temperature of 20 ± 3 °C and relative humidity of 65 ± 5% until moisture content was stabilized.

The quality of panels was evaluated based on their physical and mechanical properties, in accordance to test procedures described in the ABNT NBR-14810-3: 2006 standard (ABNT, 2006b). The following properties were evaluated: water absorption and thickness swelling after 2 and 24 hours of immersion in water; elasticity and rupture modulus in static bending; perpendicular traction (internal bonding) to the surface of the panel; and screw pullout resistance on the surface and top of the panel.

Statistical analysis was performed according to a 3 (density) × 3 (resin content) factorial and means were compared using the Tukey test at 95% confidence level. The results of properties were compared with the requirements established by the EN 312: 2003 (EN, 2003) and NBR-14810-2: 2006 (ABNT, 2006a) standards.

Figure 1. Hammer mill sieves with respective furniture disposal particles: (a) 18 mm mesh and (b) 12 mm mesh.

Table 1. Experimental design.

Treatment	Density (g/cm³)	Resin content
T1 (ME55/R8)	0.55	
T2 (ME70/R8)	0.70	8%
T3 (ME85/R8)	0.85	
T4 (ME55/R10)	0.55	
T5 (ME70/R10)	0.70	10%
T6 (ME85/R10)	0.85	
T7 (ME55/R12)	0.55	
T8 (ME70/R12)	0.70	12%
T9 (ME85/R12)	0.85	

ME: panel density; R: resin content.

3. RESULTS AND DISCUSSION

3.1. Physical properties of panels

The mean water absorption values varied from 7.30% (T9) to 48.35% (T1) and from 23.32% (T9) to 90.82% (T1) after 2 and 24 hours of immersion in water, respectively. Panels produced with nominal density of 0.85 g/cm³ and 12% (T9) of resin presented a statistically equal mean in comparison to panels made with density of 0.85 g/cm³ and 10% (T6) resin content; in general, lower than the other treatments, for both absorption properties (Table 2).

Table 2. Average values of the physical properties of panels.

Treatment	AA 2h (%)	AA 24h (%)	IE 2h (%)	IE 24h (%)
T1 (ME55/R8)	48.35^{e} (22.96)	90.82^{d} (9.44)	6.61^{c} (19.78)	13.07^{c} (14.62)
T2 (ME70/R8)	23.23^{d} (36.76)	61.76^{c} (19.79)	5.25^{b} (28.01)	15.81^{d} (14.62)
T3 (ME85/R8)	12.66^{bc} (21.12)	44.60^{b} (13.51)	5.32^{b} (26.40)	18.00^{e} (13.07)
T4 (ME55/R10)	20.05^{d} (23.84)	61.76^{c} (18.07)	3.56^{a} (25.10)	10.48^{b} (15.13)
T5 (ME70/R10)	14.98^{c} (34.29)	40.17^{b} (28.85)	3.60^{a} (40.28)	11.95^{c} (13.96)
T6 (ME85/R10)	8.59^{ab} (22.50)	30.33^{a} (18.18)	4.01^{a} (19.75)	12.26^{c} (14.68)
T7 (ME55/R12)	21.08^{d} (38.81)	61.29^{c} (26.60)	3.40^{a} (32.02)	8.83^{a} (13.53)
T8 (ME70/R12)	12.65^{bc} (25.47)	39.69^{b} (18.07)	3.08^{a} (35.66)	9.15^{ab} (14.53)
T9 (ME85/R12)	7.30^{a} (17.54)	23.32^{a} (16.96)	3.51^{a} (35.73)	9.64^{ab} (18.90)

ME: panel nominal density; R: resin content; AA 2h and AA 24h: absorption of water after 2 and 24 hours of immersion; IE 2h and IE 24h: thickness swelling after 2 and 24 hours of immersion. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

Regarding thickness swelling, after 2 hours of immersion, panels produced with nominal densities of 0.55, 0.70 and 0.85 g/cm³, with 10 and 12% resin content (T4 to T9) presented means statistically equal to each other and lower than the other treatments.

As for thickness swelling after 24 hours of immersion, the mean values ranged from 8.83% (T7) to 18.00% (T3). Panels produced with density of 0.55 g/cm³ and 12% (T7) resin content presented statistically equal mean in comparison to panels made with nominal density of 0.70 (T8) and 0,85 (T9) g/cm³ and 12% resin content and lower than the other treatments.

All treatments met the maximum requirement of 8% for thickness swelling after 2 hours, according to NBR-14810 (ABNT, 2006a) and 18% for thickness swelling after 24 hours, as established by NBR-14810 (ABNT, 2014).

Compared with other studies found in literature, the absorption and swelling results obtained in this study were satisfactory. Trianoski et al. (2016) obtained for agglomerated panels made with *Pinus taeda* with nominal density of 0.70 g/cm³ and 8% of resin content, water absorption values and thickness swelling after 24 hours of 98.43% and 31.41%, respectively. In the study by Cunha et al. (2014), mean values for these properties ranged from 39.14% to 17.10% for three *Eucalyptus* species. Weber & Iwakiri (2015) found for panels produced with MDP and MDF processing residues in pure form or with different mixture percentages, with 6% and 10% resin content and nominal density of 0.80 g/cm³, absorption and thickness swelling after 24 hours of 57.41% and 32.26%. Azambuja et al. (2018) obtained for panels produced with 25% of construction and demolition waste particles mixed with *Pinus* particles, with 8% resin content and nominal density of 0.75 g/cm³, values of 52.94% and 16.12%, respectively.

The results show the favorable aspects of the use of furniture disposal particles in the production of new particulate panels due to the presence of paraffin in its original composition, which can positively influence the dimensional stability of panels produced. The increased presence of residual resin and paraffin of original panels contributed to the reduction of water absorption and thickness swelling of panels evaluated, corroborating studies by Weber & Iwakiri (2015) and Zamarian et al. (2017).

Table 3 shows the results of the factorial analysis of the effects of density on the physical properties of panels.

Both for water absorption after 2 hours and 24 hours of immersion, the increase in the nominal density of panels resulted in lower mean water absorption values, with statistically significant differences. This effect can be attributed to the greater compaction of particles in the panel, making it difficult for water to enter its closed structure.

Table 3. Mean values of water absorption and thickness swelling – effect of panel density factor.

Density (g/cm^3)	AA 2h (%)	AA 24h (%)	IE 2h (%)	IE 24h (%)
0.55	29.83^{c} (52.26)	71.29^{c} (26.02)	4.52^{b} (40.78)	10.79^{a} (21.83)
0.70	16.96^{b} (44.36)	47.21^{b} (31.15)	3.98^{a} (40.90)	12.30^{b} (26.68)
0.85	9.52^{a} (32.12)	32.75^{a} (31.45)	4.28^{ab} (32.56)	13.30^{c} (30.34)

AA 2h and AA 24h: water absorption after 2 and 24 hours of immersion; IE 2h and IE 24h: thickness swelling after 2 and 24 hours of immersion. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

Regarding thickness swelling, the results were different after 2 and 24 hours of immersion in water. For 2 hours of immersion, no direct effect of density on thickness swelling was observed. On the other hand, after 24 hours of immersion, the mean thickness swelling values were statistically higher for panels with higher nominal densities. Panels with higher density are composed of greater amount of wood particles that exert two concomitant effects on thickness swelling. The first is the hygroscopic swelling of wood particles and the second is the release of higher compression tensions generated during the pressing process. The increase in nominal density resulted in panels with lower water absorption and greater thickness swelling, corroborating studies by Melo & Menezzi (2010) and Trianoski et al. (2014).

Table 4 presents the results of the factorial analysis of the effects of resin content on the physical properties of panels.

Table 4. Mean of water absorption and thickness swelling values – effect of resin content factor.

Resin content (%)	AA 2h (%)	AA 24h (%)	IE 2h (%)	IE 24h (%)
8	28.08^{b} (60.94)	65.73^{b} (32.36)	5.73^{b} (26.47)	15.63^{c} (19.03)
10	14.54^{a} (43.21)	44.08^{a} (37.17)	3.73^{a} (29.33)	11.56^{b} (15.94)
12	13.68^{a} (55.80)	41.43^{a} (45.33)	3.34^{a} (34.57)	9.21^{a} (16.23)

AA 2h and AA 24h: water absorption after 2 and 24 hours of immersion; IE 2h and IE 24h: thickness swelling after 2 and 24 hours of immersion. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

The mean water absorption values after 2 and 24 hours of immersion indicate that the increase in resin content contributes to reduce thickness swelling. Panels produced with 10 and 12% resin content had averages statistically equal to each other and lower than panels produced with 8% resin content.

The same behavior was verified for thickness swelling, but with statistical difference among the three treatments with different resin contents for tests after 24 hours of immersion.

The results corroborate those reported by Melo (2013) and Weber & Iwakiri (2015), in which the application of a greater amount of resin increases the coating of particles and their waterproofing, reducing water absorption and, consequently, the hygroscopic swelling of wood.

3.2. Mechanical properties of panels

The mean elasticity modulus (MOE) values ranged from 4.024 MPa (T9) to 1.267 MPa (T1). Panels produced with nominal density of 0.85 g/cm^3 and resin content of 12 and 10% (T9 and T6), are statistically equal and higher than the other treatments (Table 5).

Table 5. Mean values of the mechanical properties of panels.

Treatment	MOE (MPa)	MOR (MPa)	LI (MPa)	APS (N)	APT (N)
T1 (ME55/R8)	1.267^{a} (18.31)	6.55^{a} (16.49)	0.53^{a} (14.26)	534^{a} (25.83)	550^{a} (28.01)
T2 (ME70/R8)	2.290^{b} (26.66)	12.16^{b} (29.76)	0.60^{abc} (10.08)	915^{b} (30.93)	907^{bc} (26.84)
T3 (ME85/R8)	3.298^{de} (12.64)	19.66^{d} (12.50)	0.68^{bcd} (9.89)	1.500^{c} (10.75)	1.524^{d} (13.11)
T4 (ME55/R10)	1.590^{a} (14.45)	8.33^{a} (16.70)	0.58^{ab} (18.15)	621^{a} (20.91)	623^{ab} (24.30)
T5 (ME70/R10)	2.870^{cd} (18.76)	16.18^{c} (19.87)	0.75^{def} (13.77)	1.093^{b} (22.05)	1.122^{c} (26.46)
T6 (ME85/R10)	3.677^{ef} (16.30)	21.38^{d} (16.36)	0.83^{f} (16.84)	1.526^{c} (17.38)	1.771^{de} (20.13)
T7 (ME55/R12)	1.412^{a} (22.83)	7.23^{a} (25.01)	0.63^{abc} (21.57)	608^{a} (17.89)	685^{ab} (22.54)
T8 (ME70/R12)	2.677^{bc} (11.82)	14.25^{bc} (12.92)	0.79^{ef} (19.86)	1.076^{b} (19.52)	1.172^{c} (19.79)
T9 (ME85/R12)	4.024^{f} (10.96)	22.00^{d} (12.69)	0.68^{cde} (13.38)	1.682^{c} (10.57)	1.861^{e} (12.05)

ME: panel nominal density; R: resin content; MOE: elasticity modulus; MOR: rupture modulus; LI: internal connection; APS: screw pullout resistance on the surface; APT: screw pullout resistance on the top. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

Except for panels produced with nominal density of 0.55 g/cm^3 and resin content of 8, 10 and 12%, all other treatments met the minimum requirement of 1.600 MPa established by the EN 312: 2003 standard (EN, 2003) for the elasticity modulus.

For the rupture modulus, mean values ranged from 22.00 MPa (T9) to 6.55 MPa (T1). Panels with density of 0.85 g/cm³ and resin content of 12, 10 and 8% (T9, T6 and T3) had higher mean values and were statistically equal. These panels, in addition to panels with nominal density of 0.70 g/cm³ and resin content of 10 and 12%, met the minimum requirement of 13 MPa, according to EN 312: 2003 (EN, 2003).

Compared to other data presented in the literature, Cunha et al. (2014) found, for panels made with three *Eucalyptus* species, mean values of 1.896 MPa and 12.90 MPa, respectively, for elastic and rupture modulus. Trianoski et al. (2016) obtained for *Pinus taeda* panels, mean MOE and rupture modulus (MOR) values of 1.751 MPa and 13.94 MPa. In the study by Weber & Iwakiri (2015), panels produced with MDP, plywood and MDF processing residues had MOE values of 1.185 MPa, 1.429 MPa and 1.129 MPa. MOR values obtained were 6.47 MPa, 6.88 MPa and 9.76 MPa, respectively. Azambuja et al. (2018) found for panels produced with 25% of particles obtained from construction and demolition waste mixed with *Pinus* particles, with 8% resin content and nominal density of 0.75 g/cm³, values of 1.144 MPa for MOE and 7.19 MPa for MOR.

According to the internal bonding results, panels with nominal density of 0.85 g/cm³ and 10% resin content (T6) presented statistically equal means in comparison to panels with nominal density of 0.70 g/cm³ and 12% (T8) and 10% resin content (T5), and higher in relation to the other treatments. The results obtained in this research were higher than the mean internal bonding values of 0.54 MPa, 0.48 MPa and 0.46 MPa, obtained by Weber & Iwakiri (2015) for panels produced with MDP, plywood and MDF processing residues, respectively.

All treatments reached the minimum requirement of 0.35 MPa as established by the EN 312: 2003 standard (EN, 2003).

Regarding screw pullout resistance, average values for panels produced with nominal density of 0.85 g/cm³ and resin content of 12% (T9) were higher than the other treatments and statistically equal to treatments of same nominal density and resin content of 8 and 10% (T3 and T6). These panels, together with panels produced with nominal density of 0.70 g/cm³ and 10 and 12% resin content, met the minimum requirement of 1.020 N established by the ABNT NBR-14810-2: 2006 standard (ABNT, 2006a).

For the screw pullout resistance on the top, treatment (T9), with nominal density of 0.85 g/cm³ and 12% resin content, was statistically equal to treatment of the same density and 10% resin content (T6), with the best results for the property. Except for panels produced with nominal density of 0.55 g/cm³ and resin content of 8, 10 and 12%, all other treatments met the minimum requirement of 800 N recommended by the standard (ABNT, 2006a).

The screw pullout resistance results obtained in this study were satisfactory in comparison to some references presented in literature. Trianoski et al. (2016) found for *Pinus taeda* panels of with density of 0.70 g/cm³, values ranging from 990 N to 1.137 N for the surface, and from 824 N to 1.042 N for the top of panels. Cunha et al. (2014) obtained for panels produced from wood of three *Eucalyptus* species with density of 0.70 g/cm³, screw pullout resistance values ranging from 915 N to 1.472 N for the surface, and from 1.042 N to 1.351 N for the top. In the study with panels of construction and demolition wood waste mixed with *Pinus* particles, Azambuja et al. (2018) found resistance values of 808 N and 758 N when pulling screws from the surface and top of panel, respectively.

Table 6 presents the results of the factorial analysis of the effects of density on the mechanical properties of panels.

Table 6. Mean values of the mechanical properties – effect of panel density factor.

ME (g/cm³)	MOE (MPa)	MOR (MPa)	LI (MPa)	APS (N)	APT (N)
0.55	1.423[a] (20.47)	7.37[a] (21.76)	0.58[a] (19.58)	588[a] (21.86)	619[a] (25.67)
0.70	2.612[b] (21.05)	14.20[b] (23.67)	0.71[b] (16.20)	1.028[b] (26.64)	1.067[b] (25.98)
0.85	3.666[c] (15.47)	21.02[c] (14.52	0.73[b] (17.18)	1.569[c] (13.79)	1.719[c] (17.38)

ME: density; MOE: elasticity modulus; MOR: rupture modulus; LI: internal connection; APS: screw pullout from surface; APT: screw pullout from top. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

It was observed that for both the MOE and MOR, the increase in the panel density resulted in an increase in the mean value of these properties, with statistically significant differences. The results corroborate studies by Dacosta et al. (2005), Iwakiri et al. (2008), Melo & Menezzi (2010) and Trianoski et al. (2014), where significant increases in mechanical properties were observed with increasing panel density.

Regarding internal connection, panels with density of 0.70 and 0.85 g/cm³ had means statistically equal to each other, but higher than panels with density of 0.55 g/cm³. Further compaction of particles during the pressing process may contribute to the increase of adhesion among particles.

Significant increase in the screw pullout resistance on surface and top of panels with increase in nominal density from 0.55 to 0.70 and 0.85 g/cm³ was obtained. Similar results were obtained by Iwakiri et al. (2008) and Trianoski et al. (2014) for these properties.

Table 7 presents the results of the factorial analysis of the effects of resin content on the mechanical properties of panels.

Table 7. Mean values of mechanical properties – effect of resin content factor.

TR (%)	MOE (MPa)	MOR (MPa)	LI (MPa)	APS (N)	APT (N)
8	2.285[a] (41.38)	12.79[a] (46.86)	0.60[a] (15.09)	983[a] (45.66)	993[a] (45.56)
10	2.712[b] (36.47)	15.30[b] (39.91)	0.72[b] (21.85)	1.080[ab] (40.35)	1.172[b] (46.88)
12	2.704[b] (42.00)	14.49[b] (44.61)	0.70[b] (17.71)	1.122[b] (42.38)	1.239[b] (42.66)

TR: resin content; MOE: elasticity modulus; MOR: rupture modulus; LI: internal connection; APS: screw pullout resistance on the surface; APT: screw pullout resistance on the top. Means followed by the same letter superscript in the same column are statistically equal by the Tukey test at 95% reliability.

The increase in resin content significantly affected mean values of the elasticity and rupture modulus only from 8% to 10%. No significant differences were found between panels produced with 10% and 12% resin content. Similar results were obtained for internal bonding and screw pullout resistance.

The results demonstrate the direct influence of the resin content on the mechanical properties of panels, but up to a certain level; therefore, aspects related to the benefit-cost ratio become an important factor in defining the amount of resin to be applied to particles. The positive effects of the resin content on the mechanical properties of agglomerated panels are also reported in the work of Dacosta et al. (2005) and Trianoski et al. (2014).

4. CONCLUSIONS

The increase in nominal density contributed to improve the physical and mechanical properties of panels.

The increase in resin content from 8 to 10 and 12% contributed to reduce water absorption and thickness swelling. On the other hand, the increase in the mechanical properties was only observed from 8 to 10% resin content. The increase in resin content from 10 to 12% did not interfere in the quality of panels produced, indicating the possibility of using 10% resin content due to the best benefit-cost ratio.

Panels produced with nominal density of 0.70 and 0.85 g/cm^3, and with resin content of 10%, presented better performance in relation to requirements of the NBR-14810-2: 2006 (ABNT, 2006a) and the EN 312: 2003 (EN, 2003) standards.

The results showed the feasibility of using particles generated from furniture discards, at proportion of 50% in the mixture with industrial *Pinus* particles to produce agglomerated panels.

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