UTILIZATION OF PINUS RESINATED *Oversize* FIBERS IN PRODUCTION OF PARTICLEBOARDS

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ABSTRACT – The objective of this study was to evaluate the technical feasibility of producing particleboard from *oversize* resin fibers in a reduced proportion of adhesive. It was used as raw material, *oversize* resin fibers discarded from the MDF (*Medium Density Fiberboard*) production process, *flake* particles of *Pinus* spp. derived from an MDP (*Medium Density Particleboard*) company's chipper and adhesive formed by the urea-formaldehyde resin and paraffin emulsion. The experiment consisted of five treatments, mixing particles and fibers in different proportions (100: 0%; 75: 25%; 50: 50%; 25: 75%; 0: 100%). Three panels were produced per treatment, with nominal density of 650 kg.m^{-3}, 8% resin and pressing cycle of 160ºC, 40 kgf.cm^{-2} for 8 minutes. The properties of the panels were evaluated by the procedures described in ASTM D-1047 (1993), DIN 53362 (1982) and ABNT / NBR 14810 (2013). The results showed that *oversize* resin fibers have potential for use in the sector, especially in quantities above 75%, a fact that was evidenced by the values found for dimensional stability and strength/stiffness. For internal adhesion, the increase in the number of fibers above 25% was not significant.

Keywords: Utilization of waste; MDF and MDP; Technological properties.

UTILIZAÇÃO DE FIBRAS OVERSIZE RESINADAS DE PINUS NA PRODUÇÃO DE PAINÉIS AGLOMERADOS

RESUMO – O objetivo do estudo foi o de avaliar a viabilidade técnica da produção de painéis aglomerados a partir de fibras oversize resinadas em proporção reduzida de adesivo. Como matéria-prima, foram utilizadas fibras *oversize* resinadas descartadas do processo produtivo do MDF (*Medium Density Fiberboard*), partículas *flake* de *Pinus* spp. derivadas do cepilhador de uma empresa de MDP (*Medium Density Particleboard*) e adesivo formado pela resina uréia formaldeído e pela emulsão de parafina. O experimento foi composto por cinco tratamentos, misturando partículas e fibras em diferentes proporções (100:0%; 75:25%; 50:50%; 25:75%; 0:100%). Foram produzidos três painéis por tratamento, com densidade nominal de 650 kg.m^{-3}, 8% de resina e ciclo de prensagem de 160ºC, 40 kgf.cm^{-2} por 8 minutos. As propriedades dos painéis foram avaliadas por meio dos procedimentos descritos na ASTMD 1047(1993), DIN 53362(1982) e ABNT/NBR 14810(2013). Os resultados demonstraram que as fibras oversize resinadas apresentam potencial para utilização no setor, principalmente, em quantidade acima de 75%, fato que foi evidenciado pelos valores encontrados para estabilidade dimensional e resistência / rigidez. Para adesão interna, o aumento da quantidade de fibras acima de 25% não foi significativo

Palavras-Chave: Aproveitamento de resíduos, MDF e MDP, Propriedades tecnológicas.

1. INTRODUCTION

Brazil is among the most advanced countries in the world in the manufacture of reconstituted wood panels, and is the country with the largest number of state-of-the-art factories. With continuous investments in technology / automation, the companies built versatile and modern industrial parks, installing new units, technologically updating existing ones, implementing new production lines and new printing, impregnation, coating and painting processes (ABIPA, 2014).

In the world, as raw materials for the production of panels, industrial wood waste, forestry waste, otherwise low-quality non-industrialized wood, wood from planted forests and direct recycling of wood are used (Pierre, 2010).

In Brazil, wood from planted forests, especially pine and, to a lesser extent, eucalyptus, is the main source of raw material, although the initial purpose of the world's first panel industries was to harness forest and industrial waste. The great acceptance of pine species is mainly due to their low density, which results in panels with high compaction ratio (Baldin et al., 2016).

The wood industry has great potential for industrial waste utilization, considering that the wood processing industry has, on average, a low utilization, around 40% (Brand, 2010). Hillig et al. (2009) state that, although waste is often used for some specific purposes, it can in many cases constitute a problem of environmental management regarding companies.

From the point of view of the production process, it is necessary to consider in the reconstituted panel industry the generation of waste and atmospheric emissions. The most important residues are the solids generated by the use of wood, whose proper management avoids the pollution of the soil, rivers and even the air. Furthermore, it allows financial return as they can be reused. Regarding atmospheric emissions, the major concern is related to the drying and pressing steps, given that the volatile gases present in the urea-formaldehyde adhesive are partly evaporated (Hedlund, 2013).

Thus, it is found that problems related to environmental issues, such as pollution and waste generation, are directly associated with production processes. The better use of raw materials, through processes that incorporate the concept of reverse logistics and the principles of environmental management, has been gaining importance in industries and research institutions, because in addition to environmental benefits, they bring economic advantages for companies (Weber and Iwakiri, 2015).

Specifically, the medium density fiberboard (MDF) industries generate, among so many waste products, oversize fibers (*oversize*) that do not fit the grain size used by the company. These fibers are removed from the process in the classification step, which occurs moments before the formation of the mattress. It should be noted that, until this stage of the process, the fibers had already received urea formaldehyde resin and paraffin emulsion, and after disposal, are directed to burning in the company's boiler.

In recent years, MDF companies have begun to look more closely at waste from *oversize* fibers, both in terms of the volume generated, which is not fully consumed by the boiler, and in terms of pollutant emissions and increase of the production cost. Thus, companies began to look for alternatives from universities and research centers, in order to add greater value to this waste, as in the manufacture of other products that serve the most diverse sectors, such as furniture.

To date, studies have only focused on the characterization of fibers and the effect of different particle sizes on the properties of the panels, as observed in the works of Wenderdel and Krug (2012), Sliseris et al. (2016) and Benthien et al. (2016). Nevertheless, the only study using the *oversize* fiber in reconstituted panels is that of França et al. (2016), who evaluated the possibility of using this raw material in MDP panels (*Medium Density Particleboard*), but with the application of an additional 12% of urea formaldehyde adhesive. This study obtained excellent results, especially in terms of increased dimensional stability and internal adhesion, however a large amount of resin (24%) was used, which, in industrial terms, significantly increases the cost of production.

The objective of this study was to evaluate the technical feasibility of producing particleboard panels from *oversize* resin fibers in reduced proportion of adhesive.

2. MATERIAL AND METHODS

2.1 Characterization and preparation of raw materials

The raw material was composed of oversize resin fibers, discarded from the MDF production process, *flake* particles of *Pinus* spp coming from MDP industries and adhesive formed by urea formaldehyde resin and paraffin emulsion.

The *oversize* fibers were collected during the classification step, in an equipment called *Stifter*. Afterwards, they passed through disintegrators and air ducts, being deposited in collection boxes. It should be noted that the fibers already had 12% psp (dry weight basis of particles) of urea formaldehyde resin and 0.5% psp paraffin emulsion in their structure, since these materials are incorporated after the process of defibration. Declassified fibers are usually burned in the company's boiler, along with other kinds of waste regarding the process.

The *flake* particles were collected after the logs passed through the scraper, which directly originated the raw material. These particles are used by the company to produce the central layer of MDP panels to provide rigidity and strength.

For complete particle / fiber adhesion and improved dimensional stability of the panels, 8% psp urea formaldehyde resin and 1% psp paraffin emulsion were applied. According to the company's technical bulletin, the resin had a 66% solids content, a 65s gel time and a 255 cps Brookfield viscosity, while the paraffin emulsion contained a 45% solids content.

As the particles and fibers were not reclassified in the laboratory, the only preparation process was drying in a forced air circulation oven at a temperature of 80ºC to a moisture content of 4 +/- 1%.

2.2 Experimental Plan

The experiment consisted of five treatments, which were characterized by the different percentages of *oversize* resin fibers in the panels, in order to determine the influence of this raw material on the technological properties of traditional particleboard. The treatments were denominated T1 (100% particles : 0% resin fibers *oversize*); T2 (75% : 25%); T3 (50% : 50%); T4 (25% : 75%) and T5 (0% : 100%). Three homogeneous panels were produced per treatment, with dimensions of 0.40 x 0.40 x 0.0155 m, density of 650 kg.m^{-3}, cold pre-press at 5 kgf.cm^{-2} for 10 minutes and final press cycle with temperature of 160ºC, pressure 40 kgf.cm^{-2} and time of 8 minutes.

2.3 Production of the panels

The resin and paraffin emulsion were independently applied to the particles / fibers by means of a spray gun, which was fixed within a rotating screw that rotated at a speed of 20 rpm to provide homogenization of the application. After the formation of the mattress, cold pressing was performed and then hot pressing in a hydraulic press. Afterwards, the panels were stored in a climate room, with a temperature of 20 +/- 2ºC and a relative humidity of 65 +/- 3%, until constant mass.

2.4 Technological testing

The panels were squared to the size of 0.37 x 0.37 m to avoid edge effects. Specimen dimensions and density, moisture content, water absorption, thickness swelling, and internal adhesion tests were based on the procedures of ASTM D-1047 (1993), while the static bending and screw withdrawal tests on DIN 53362 (1982) and ABNT / NBR 14810 (2013), respectively.

The compaction ratio was obtained by the relationship between panel density and wood density. For wood, the average value of 380 kg.m^{-3}, provided by the companies inspection and quality laboratories, was used. For spring back, the relationship between panel thickness after constant mass in the normal situation and after immersion in water for 24 hours was used.

2.5 Statistical analysis

Data were tested for the presence of *outliers* (*boxplot*), distribution normality (Shapiro-Wilk) and variance homogeneity (Levene). To circumvent the problem of data that did not comply with the assumptions for performing parametric statistics, a Box-Cox transformation was performed. Finally, the Analysis of Variance was applied, and in case of statistical difference, the Scott-Knott means comparison test at 95% probability. In addition to the traditional analysis, the mean values of each treatment were compared with the literature and the ABNT / NBR 14810 (2013), ANSI A208.1 (2009) and EN 312-2 (2003) standards.

Table 1 – Average values for the physical properties of the panels.
Tabela 1 – Valores médios para as propriedades físicas dos painéis.

Composition	Density (kg.m^{-3})	Compression Ratio	Thickness (mm)	Moisture Content (%)
Q1 ($P_{100\%}$ - $F_{0\%}$)	$602_{5.37}$ a	$1.58_{5.37}$ a	$16.75_{0.34}$ d	$10.03_{2.24}$ c
T2 ($P_{75\%}$ - $F_{25\%}$)	$586_{4.77}$ a	$1.54_{4.77}$ a	$16.18_{0.43}$ c	$09.53_{0.99}$ b
T3 ($P_{50\%}$ - $F_{50\%}$)	$586_{2.81}$ a	$586_{2.81}$ a	$16.13_{0.68}$ b	$09.41_{1.03}$ b
T4 ($P_{25\%}$ – $F_{75\%}$)	$582_{4.04}$ a	$1.53_{4.04}$ a	$16.05_{0.73}$ b	$09.18_{2.84}$ b
T5 ($P_{0\%}$ - $F_{100\%}$)	$580_{3.24}$ a	$1,53_{3.24}$ a	$15.66_{0.17}$ a	$08.74_{4.00}$ a
Average:	587	1,43	16.15	09.38

In witch: T: treatment, P: particle, F: fiber, subscript: coefficient of variation (%). Means followed by the same letter in the column do not differ statistically from each other.

Legenda: T: tratamento, P: partícula, F: fibra, subscrito: coeficiente de variação (%). Médias seguidas de mesma letra na coluna não diferem estatisticamente entre si.

3. RESULTS

Table 1 shows the average values of density, compaction ratio, thickness and moisture content, with their respective coefficients of variation, which are low, demonstrating homogeneity in the production of the panels.

The average density obtained was 587 kg.m^{-3}, with no significant difference between treatments. According to ABNT / NBR 14810 (2013) and EN 312-2 (2003), the panels of all treatments can be classified as medium density, as they are between 551 and 750 kg.m^{-3}, as proposed by the standards. Nonetheless, when referring to ANSI A208.1 (2009), which delimits values between 640 and 800 kg.m^{-3}, none of the panels has reached the minimum limit.

For compaction ratio, the mean values were above 1.3, which is the minimum proposed by Moslemi (1974) and Maloney (1993), to ensure a satisfactory contact area and sufficient densification; this results in quality panels with respect to dimensional stability and mechanical strength.

As for the thickness, after the acclimatization period, it was *observed* that as the percentage of oversize fibers increased (from 25 to 25%), the mentioned dimension decreased, reaching close to nominal (15.50 mm). Thus, there was a statistical difference between treatments, where the best was T5 and the worst was T1; the others presented intermediate values.

Through the moisture content values, it is possible to verify that all panels were below the equilibrium humidity of the climate room (12%). The justification for reducing hygroscopicity is related to the fact that the material has undergone the process of drying and pressing at high temperatures, in addition to the incorporation of resin and paraffin, which makes the panels less reactive to water (Weber and Iwakiri, 2015).

The average values of water absorption, thickness swelling and spring back, presented in Table 2, show clearly and significantly that the best treatment was T5 with 100% *oversize* fibers. It can also be seen that as the presence of this raw material in the panel is reduced, dimensional stability is impaired.

Table 2 – Average values for dimensional stability of panels.
Tabela 2 – Valores médios para estabilidade dimensional dos painéis.

Composition	AA (%)		IE (%)		Spring back(%)
	2 hours	24 hours	2 hours	24 hours	
Q1 ($P_{100\%}$ - $F_{0\%}$)	$82.39_{15.27}$ d	$103.9_{81.72}$ d	$18.77_{07.52}$ d	$25.21_{11.03}$ c	$22.95_{14.01}$ c
T2 ($P_{75\%}$ – $F_{25\%}$)	$41.06_{10.10}$ c	$77.2_{98.60}$ c	$11.66_{13.22}$ c	$19.95_{07.39}$ b	$21.09_{08.94}$ c
T3 ($P_{50\%}$ - $F_{50\%}$)	$12.65_{13.19}$ b	$54.0_{45.20}$ b	$09.03_{18.42}$ c	$19.51_{07.68}$ b	$18.92_{09.69}$ b
T4 ($P_{25\%}$ – $F_{75\%}$)	$11.7_{08.85}$ b	$34.7_{34.59}$ a	$06.11_{01.85}$ b	$18.35_{04.48}$ b	$17.45_{16.38}$ b
T5 ($P_{0\%}$ - $F_{100\%}$)	$07.4_{56.73}$ a	$32.39_{13.10}$ a	$03.60_{16.63}$ a	$16.83_{04.83}$ a	$06.90_{14.40}$ a
Average:	31,05	60.49	9,83	19,97	17,46

In witch: T: treatment, P: particle, F: fiber, AA: water absorption, IE: thickness swelling, subscript: coefficient of variation (%). Means followed by the same letter in the column do not differ statistically from each other.

Legenda: T: tratamento, P: partícula, F: fibra, AA: absorção de água, IE: inchamento em espessura, TNRE: taxa de não retorno em espessura, subscrito: coeficiente de variação (%). Médias seguidas de mesma letra na coluna não diferem estatisticamente entre si.

Table 3 – Average values for static flexion.
Tabela 3 – Valores médios para flexão estática.

Composition	Static Flexing (MPa)	
	MOE	MOR
Q1 (P$_{100\%}$ - F$_{0\%}$)	1367.28$_{7.85}$ b	09.59$_{21.12}$ d
T2 (P$_{75\%}$ – F$_{25\%}$)	1461.70$_{5.58}$ b	11.76$_{14.15}$ d
T3 (P$_{50\%}$ - F$_{50\%}$)	1504.90$_{8.37}$ b	15.61$_{08.29}$ c
T2 (P$_{75\%}$ – F$_{25\%}$)	1601.95$_{5.08}$ b	17.35$_{10.20}$ b
T5 (P$_{0\%}$ - F$_{100\%}$)	1667.75$_{5.70}$ a	19.30$_{17.45}$ a
Average:	1520.72	14,72

In witch: T: treatment, P: particle, F: fiber, subscript: coefficient of variation (%). EOM: modulus of elasticity, MOR: modulus of rupture. Means followed by the same letter in the column do not differ statistically from each other.
Legenda: T: tratamento, P: partícula, F: fibra, subscrito: coeficiente de variação (%). MOE: módulo de elasticidade, MOR: módulo de ruptura. Médias seguidas de mesma na coluna não diferem estatisticamente entre si.

Table 5 – Average values for screw withdrawal resistance.
Tabela 5 – Valores médios para resistência ao arrancamento de parafuso.

Composition	Screw Withdrawal (N)	
	Surface	Top
Q1 (P$_{100\%}$ - F$_{0\%}$)	1229.44$_{12.69}$ b	750.50$_{19.07}$ a
T2 (P$_{75\%}$ – F$_{25\%}$)	1232.55$_{11.06}$ b	760.18$_{15.68}$ a
T3 (P$_{50\%}$ - F$_{50\%}$)	1237.70$_{06.36}$ b	817.33$_{14.55}$ a
T4 (P$_{25\%}$ – F$_{75\%}$)	1241.00$_{09.48}$ b	825.60$_{12.40}$ a
T5 (P$_{0\%}$ - F$_{100\%}$)	1344.80$_{10.97}$ a	856.50$_{17.40}$ a
Average:	1259.10	802.02

In witch: T: treatment, P: particle, F: fiber, subscript: coefficient of variation (%). Means followed by the same letter in the column do not differ statistically from each other.
Legenda: T: tratamento, P: partícula, F: fibra, subscrito: coeficiente de variação (%). Médias seguidas de mesma na coluna não diferem estatisticamente entre si.

In Table 3, which shows the average values of stiffness and resistance in the static bending test, by modulus of elasticity (MOE) and rupture (MOR), it is observed that the best treatment was T5. The tendency of reduction of values followed what was found in dimensional stability. However, in this test, there was an inverse relationship with the compaction ratio, which is not generally found in other works; this can be explained by the large amount of adhesive (resin + paraffin) incorporated into the fibers / particles.

Mean values for internal adhesion, Table 4, ranged from 0.32 MPa to 0.40 MPa, for T1 and T5 treatments, respectively. Nevertheless, only the average value of T1 treatment differed statistically from the others, demonstrating that for this property, the increase in the amount of *oversize* fibers, with a large amount of adhesive, did not influence most treatments.
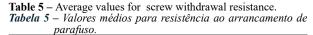
The values related to screw withdrawal resistance are presented in Table 5, which shows a statistical

Table 4 – Average values for internal bond.
Tabela 4 – Valores médios referentes à adesão interna.

Composition	Internal Bond (MPa)
Q1 (P$_{100\%}$ - F$_{0\%}$)	0.32$_{19.35}$ b
T2 (P$_{75\%}$ – F$_{25\%}$)	0.37$_{03.82}$ a
T3 (P$_{50\%}$ - F$_{50\%}$)	0.37$_{08.16}$ a
T4 (P$_{25\%}$ – F$_{75\%}$)	0,38$_{08.45}$ a
T5 (P$_{0\%}$ - F$_{100\%}$)	0.40$_{10.23}$ a
Average:	0,37

In witch: T: treatment, P: particle, F: fiber, subscript: coefficient of variation (%). Means followed by the same letter in the column do not differ statistically from each other.
Legenda: T: tratamento, P: partícula, F: fibra, subscrito: coeficiente de variação (%). Médias seguidas de mesma letra na coluna não diferem estatisticamente entre si.

difference only for the surface, where T5 was superior and not equivalent to the others.

4. DISCUSSION

Table 1, in addition to the statistical similarity between the treatments, shows that the nominal variable specified in the experimental plan was not obtained (650 kg.m^{-3}). This fact was also verified in other panel studies, such as Trianoski et al. (2011) with panels of *Pinus taeda*, nominal density of 750 kg.m^{-3} and real density of 680 kg.m^{-3}; Iwakiri et al. (2008), which produced *Pinus* spp particleboard with densities of 600 kg.m^{-3}, 700 kg.m^{-3}; 800 kg.m^{-3}; and 900 kg.m^{-3}, obtained 570 kg.m^{-3}, 640 kg.m^{-3}, 700 kg. m^{-3} and 780 kg.m^{-3}; and Grubert (2014) who worked with *oversize* fiber bundles, nominal density 650 kg.m^{-3} and real density 570 kg.m^{-3}.

Iwakiri et al. (2012) clarify that the difference between actual and nominal density can be attributed to operating conditions at the laboratory level, as it is a manual process, i.e. without automation and with low control regarding the precision of fiber distribution / particles at the time of mattress formation. Eleotério (2000) also points out that in the scattering of fibers / particles during pressing, mass dispersion occurs over a larger area than planned. The same author adds that another determining factor of this deviation may be related to panel swelling within a few tenths of a millimeter after pressure relief.

For thickness (Table 1), it is believed that the approximation of the nominal of the treatments with the highest fiber percentage is due to the smaller particle size, the high fiber flexibility and the amount

of adhesive present in the structure (company + laboratory), which eventually generating a void-free structure.

With respect to quantifying hygroscopicity, hot pressing reduces by 7% to 27% from the equilibrium humidity of the environment in which the panel is stored (Trianoski, 2010). In the present study, the reduction in moisture content was equivalent to that proposed by the author, with a range between 16% (T1) and 27% (T5).

Also referring to table 1, it is noted that the average values of moisture content ranged from 8.74 to 10.03% for T5 and T1 treatments, respectively, characterizing statistical difference between treatments. It is believed that the higher percentage of adhesive present in the T5 treatment may have caused waterproofing, thus reducing the susceptibility to moisture absorption. This can be proven by decreasing moisture content by increasing the percentage of *oversize* fibers in treatments.

Comparing the average values with the ABNT / NBR 14810 (2013) and ANSI A208.1 (2009) standards, which determine moisture content values between 5 and 13% and a maximum of 10%, respectively, all treatments met the specifications.

The better stability of the composite panels with higher percentage of *oversize* fibers (Table 2) is not linked to higher densification, as mentioned by several authors, considering that the panels with large amount of particles (T1 and T2) had numerically the best compression ratio values. Thus, it is believed that the best dimensional performance of the *oversize* fiber-rich treatments is due to the higher accommodation of the raw material, provided by the inclusion of smaller material and higher resin availability, which may have caused a physical barrier, with greater occupancy of the hygroscopic sites of the wood, making the mattress less reactive to water (Silva, 2006).

Regarding other studies for the water absorption variable, Iwakiri et al. (2005), who by using particles of *Pinus* spp. for the production of particleboard with nominal density of 650 kg.m^{-3}, found average values of 124.02% for 2 hours absorption and 126.52% for 24 hours. As for laboratory criteria and reference standards, it is found that the average values of treatments T4 and T5 were within the range established by the Forest Products Laboratory (1987) of 5% to 50%.

For thick swelling, it is believed that the largest amount of resin and paraffin previously incorporated in the production process of the MDF company, corroborated as an insulator, preventing the entry of water and consequently the swelling. Iwakiri et al. (2005) also obtained statistical differences in their particleboard panels with *Pinus* spp, whose values ranged from 15.19% to 25.09% for thickness swelling 2 hours and 16.77% to 29.99% for 24 hours, which are above those found in the present study.

França et al. (2016), also working with *Pinus* spp and oversize resin fibers but with 12% urea-formaldehyde resin, observed the same trend, where the panels formed by 100% particles showed a 24-hours swelling of 23.40% and for 100% fiber, 10.19%, which is a reduction of 56%.

Regarding the fulfillment of the quality standards criteria, it can be seen that in the 24 hours swelling, the panels of all treatments were in accordance with ANSI A208.1 (2009) which establishes a maximum value of 40%. However, in relation to ABNT / NBR 14810 (2013) which establishes a maximum swelling of 18%, only T4 and T5 treatments did not exceed what was established. Yet, according to EN 312-2 (2003), which establishes a maximum of 15%, no treatment has reached what was determined by the standard.

For MOE and MOR (Table 3), the increase in the average values of T1 to T5 treatments can be attributed to the large amount of fibers, the largest amount of resin available (applied in industry and the laboratory) and the greater accommodation of fibers inside the mattress and then the panel. França et al. (2016) also observed the same trend, where panels with 100% *Pinus* spp particles had MOE of 1623 MPa and MOR of 11.20 MPa, and with 100% fiber oversize, MOE 1967,46 MPa and MOR of 25,83 MPa.

Dacosta et al. (2005) found a similar fact in their work with particleboard (600 kg.m^{-3} nominal density) formed by *Pinus elliottii* shavings, where panels such as 4% resin achieved MOR and MOE values of 766.50 MPa and 8.76 MPa, respectively, with 8% resin 1071.10 MPa and 9.20 MPa and 12% 1078.60 MPa and 7.01 MPa. Similarly, Eleotério (2000) found mean values of MOR and MOE for MDF (600 kg.m^{-3}) of 10.69 and 1770 MPa (6% resin), 14.63 and 1990 MPa (8%), 18.49 and 2000 MPa (10%), 25.92 and 2740 MPa (12%) and 23.73 and 2670 MPa (14%).

Regarding the three studies cited, it is noted that the values found in the present study are higher than those of Dacosta et al. (2005) and lower than France et al (2016) and Eleotério (2000). Still, Trianoski et al. (2013) working with *Pinus taeda*, found 3332.44 MPa and 15.69 MPa for MOE and MOR, respectively, which are higher than the average values of the present work.

Comparing the mean values of MOE and MOR with ABNT / NBR 14810 (2013), which establishes minimum stiffness and resistance values of 1600 MPa and 11 MPa, only T4 and T5 treatments were classified. The same treatments were those that reached the established by EN 312-2 (2003), minimum of 1600 MPa for MOE and 13 MPa for MOR. As for ANSI A208.1 (2009), which establishes quality classes, M1 (1550 MPa, 10 MPa), again the treatments composed of 75% and 100% *oversize* fibers were those that reached the minimum values established by the standard. For the other classes (MS, M2 and M3i), no treatment presented compatible final mean values.

For internal bond (Table 4), Vital et al. (1974) state that the resistance generally increases with increasing density of the panels, but in the present study it is verified that there were two factors that had a greater influence, the inclusion of *oversize* fibers and the amount of resin (process + laboratory). Brito and Peixoto (2000) complement that panels made with material of smaller particle size have a greater resistance to internal adhesion, when compared to larger particle size. The authors also describe that smaller particle sizes are responsible for a better material uniformity and the formation of smaller internal spaces.

As shared values, mentions again França et al. (2016) working with the same raw material, but with higher resin content (12%), which increased among other properties, the internal adhesion resistance to values between 0.39 and 0.59 MPa, range that is superior to that found in the present work.

Comparing the results with the standards ABNT / NBR 14810 (2013) and EN 312 (2003), which set the minimum value of 0.35 MPa for the property, it is found that only T1 treatment composed of 100% particles did not reach the value determined by the standards. Comparing with the parameters of ANSI A208.1 (2009), which establishes in the quality classes

0.36 MPa (classes M1 and MS), 0.40 MPa (M2) and 0.50 MPa (M3i), one can classify T5 treatment panels as M-2, T2, T3 and T4 treatments as MS, whereas T1 treatment panels do not fall into any of the classes.

Sanches (2012) found lower mean values (Table 5) for screw withdrawal when working with *Pinus* spp particleboards manufactured in the laboratory and industry. Trianoski et al. (2011) obtained lower means for surface (1031.86 N), but higher for top (846.06 N), and Trianoski et al. (2013) obtained results superior to the average of the present work for both surface with 1372.32 N and for top 1251.80 N.

It was also observed that there was a statistical difference for the surface screw withdrawal, where the T5 treatment, consisting of 100% oversize fibers, was superior and statistically different from the others. Regarding the top screw withdrawal, there was no statistical difference between the treatments. It can be stated that the inclusion of the *oversize* fibers did not have any influence.

Comparing the results found with the parameters of ANSI A208.1 (2009), which determines a minimum load of 700 N for top and 800 N for surface in class MS, 800 N and 900 N in M2 and 900 N and 1000 N in M3i, three treatments met M2 (T3, T4, and T5) and two met MS (T1 and T2). As for ABNT / NBR 14810 (2013), it is noteworthy that all treatments reached the determined for surface pullout (1020 N), but for top screw withdrawal, treatments T1 and T2 did not reach the minimum value of 800 N.

5. CONCLUSIONS

In the properties related to dimensional stability and strength / stiffness of the panels, it was shown that the best treatments were T4 and T5 with a large amount of *oversize* resin fibers, 75% and 100%, respectively.

For internal bond, the increase in the amount of *oversize* resin fibers above 25% in the panel did not statistically change the mean values of treatments, demonstrating that the increase in resin and smaller particle size above a limit does not interfere with panel strength in the property mentioned.

The compaction ratio values did not present a positive relationship with the mechanical properties of the panels, as expected. This fact was due to the high

resin availability in the panels with lower compaction ratio, besides the presence of the smaller particle size material, which caused better fiber accommodation.

Resin *oversize* fibers (residue from the MDF panel manufacturing process) presented, in terms of technological properties, potential for use in the particleboard sector, especially when used in large quantities.

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