











Technological properties of particleboards produced using mixture of pines and bamboo

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ABSTRACT: *This paper aimed to evaluate the technological properties of particleboards produced with particles of unconventional species, bamboo of the species *Phyllostachys edulis*, and of the genus traditionally used by the sector for the production of the particulate panels in Brazil, *Pinus* spp. The bamboo splints of 3 years old were collected in Frei Rogério, Santa Catarina, being transformed into particles in a mill hammer, while the particles of *Pinus* spp. were collected from the industrial process of MDP production in Bonet Madeiras e Papéis Ltda Company in Santa Cecília, Santa Catarina. The company used eight-year-old logs of *P. taeda* and *P. elliottii* from the thinning process, without distinction of the species. The experiment was composed of five compositions with mixing the bamboo and wood particles in different proportions ((T1)100:0%; (T2)75:25%; (T3)50:50%; (T4)25:75%; (T5)0:100%). The panels were produced nominal density of 700 kg / m³ and pressing cycle of 160 °C and 40 kgf/cm² for 8 minutes. Results reporting physical and mechanical properties of panels were evaluated through Analysis of Variance and Tukey's Test at 95% probability. The results evidenced that bamboo particles presented potential for the production of particleboard. The most promising results were presented with the addition of 50% of bamboo in the panel composition (T3), mainly by means observed for dimensional stability, as for strength and stiffness. Values of internal bond presented significantly lower averages with the addition of more than 25% of bamboo.*

Key words: *species unconventional, reconstituted panels, properties.*

Propriedades tecnológicas de painéis de partículas produzidos com pinus e bambu

RESUMO: *Este estudo tem por objetivo avaliar as propriedades tecnológicas de painéis de madeira produzidos com partículas de bambu da espécie *Phyllostachys edulis*, e do gênero tradicionalmente utilizado pelo setor para a produção dos painéis particulados no Brasil, o *Pinus* spp. As varas de bambu com três anos de idade foram coletadas em Frei Rogério, no estado de Santa Catarina, Brasil, sendo transformadas em partículas em um moino. As partículas de *Pinus* spp. foram coletadas no processo produtivo da Empresa Bonet Madeiras e Papéis Ltda em Santa Cecília, Santa Catarina. A empresa utiliza toras provenientes do desbaste de reflorestamentos de *Pinus taeda* e *Pinus elliottii* com oito anos de idade, sem distinção de espécies. O experimento foi composto por cinco tratamentos com mistura das partículas de bambu e de madeira em diferentes proporções ((T1)100:0%; (T2)75:25%; (T3)50:50%; (T4)25:75%; (T5)0:100%). Os painéis foram produzidos com densidade nominal de 700 kg / m³ e ciclo de prensagem de 160 °C e 40 kgf/cm² por oito minutos. Os resultados para as propriedades físicas e mecânicas dos painéis foram avaliados por meio da Análise da Variância e do Teste de Tukey a 95% de probabilidade. Os resultados evidenciaram que o bambu apresenta potencial para a produção de painéis de partículas. O resultado mais promissor foi encontrado com a adição de 50% de bambu na composição do painel (T3), principalmente quanto a estabilidade dimensional e aos valores de resistência e rigidez. Os valores para ligação interna apresentaram-se significativamente menores com adição de mais de 25% de partículas de bambu.*

Palavras-chave: *espécies não convencionais, painéis reconstituídos, propriedades.*

INTRODUCTION

Medium Density Fiberboard (MDF), High Density Fiberboard (HDF), Medium Density Particleboard (MDP) and Oriented Strand Board (OSB) are the main reconstituted wood products made in Brazil. Risk of not supplying the demand for wood raw material to produce these panels is imminent. Considering that, MISKALO (2009) said that the logs are being

used for mechanical processing, with decreasing ages and giving signs of exhaustion of forest reserves.

In this context, MORAIS et al. (2015) pointed out that the globalized market requires the research for new materials to produce reconstituted panels, which should enable cost reduction, superior technical efficiency or equivalent to raw materials traditionally used by industry, and low environmental impacts. In addition, new raw materials as an

alternative to the most common species, such as *Pinus* spp. and *Eucalyptus* spp., is essential to sustain the market, making it even more promising (MISKALO, 2009).

Several alternative raw materials, also called unconventional raw materials, are being evaluated by researchers for a variety of purposes. Among them, the bamboo species, play an increasingly important role in reducing pressure on forest resources and are considered by many as the substitute for wood (MERA et al., 2014). According to MORAIS et al. (2015), the replacement of wood by bamboo species, or incorporation of these species into wood products has already occurred in countries such as China, Philippines and Colombia, since it is a lignocellulosic material with properties and quality like wood.

As a consequence of climatic characteristics, bamboo species of the genus *Phyllostachys*, such as *P. edulis* (Carrière) J. Houzeau, are the most recommended for plantations in Southern Brazil (BERNSEN et al., 2013). Only in China, *P. edulis* (Carrière) J. Houzeau plantations cover more than 3 million hectares which equivalent to 60% of all Chinese bamboo cover (HAN et al., 2009) and is being the genus of most important economic development (CHUNG, 2003).

Studies of the association between bamboo particles and wood particles of *Pinus* spp. for the production of particleboards are a reality in Brazil. However, the definition of the most suitable proportion between these materials is still little investigated (DE MELO et al., 2015).

The objective of this study was to evaluate the physical and mechanical properties of agglomerated panels produced with wood particles of *Pinus* spp. and bamboo *P. edulis*, in order to verify the technical viability of the species for the market segment.

MATERIALS AND METHODS

The particles of *Pinus* spp. used in the production of the panels particleboards were collected from the industrial process of MDP production in Bonet Madeiras e Papéis Ltda Company, located in Santa Cecília, Santa Catarina. The company used eight-year-old logs of *P. taeda* and *P. elliottii* from the thinning process, without distinction of the species.

The *P. edulis* were collected in Frei Rogério, Santa Catarina. The bamboo splints of 3 years old were transformed into particles in a mill hammer. Both *Pinus* spp and bamboo were classified

in oscillating screens and dried at the temperature of 80 °C in a forced air circulation oven, until reach moisture content of 4%. Prior to the production of the panels, 500 particles of *Pinus* spp and *P. edulis* were separated for determination of length, width and thickness size with a digital caliper. Measurement of these dimensions allowed the determination of the slenderness ratio by means of the ratio between length and particle thickness and the flatness ratio by the relation between width and thickness.

The study was conducted in order to produce homogeneous panels with mixed bamboo and wood particles in different proportions: 100% bamboo: 0% wood (T1(B₁₀₀W₀₀)); 75%:25%(T2(B₇₅W₂₅)); 50%:50% (T3(B₅₀W₅₀)); 25%:75% (T4(B₂₅W₇₅)) e 0%:100% (T5(B₀₀W₁₀₀)).

Panels were produced with dimensions of 40 X 40 X 1.55 cm and nominal density of 700 kg/m³, using 12 wt% of urea-formaldehyde resin and 1 wt% of paraffin emulsion in a pressing cycle of 8 minutes at 160 °C and 40 kgf/cm² of pressure.

Physical properties and internal bond of panels were determined by ASTM D1037 (1993), while static bending was determined by DIN 52362 (1982), and the resistance to screw withdrawal was determined by NBR 14810 (2013). For compression ratio and slenderness ratios, laboratory procedures were used, where the first variable was determined by the relation between the average density of the panels and the density of the wood / bamboo, while the second variable was obtained by the ratio between the thickness of the water absorption /swelling specimens in thickness after the stabilization in two points: after 24 immersion in water and before being submitted to this pre-treatment.

The density along the panel thickness was obtained using an X-ray densitometry IMAL, model DPX300, on randomly drawn specimens for each panel.

Results were first checked for normality and homogeneity of variances through the tests of Shapiro Wilk and Cochran. For the data that did not attend the normality / homogeneity of variances, it was used the data transformation of the Box-Cox type, making possible the accomplishment of the parametric statistical analysis. However, even with the transformation, some variables (moisture content and screw start) did not respond to the assumptions, and the nonparametric statistic was made using the Kruskal-Wallis test.

In the parametric statistic, was applied the analysis of variance and the Tukey's Test at 95% probability when necessary. The mean values

obtained were also compared with the parameters of the standards NBR 14810(2013), ANSI A208.1(2009), CS 236-66(1968), CSA 0437(1993) and EN 312-2(2003).

RESULTS AND DISCUSSION

Geometry of particles

The characterized bamboo particles were longer and thicker than the *Pinus* spp. particles. This feature was also observed by ARRUDA et al. (2011) in a study that related bamboo particles of the species *Guadua magna* and *P. taeda*. With this, the slenderness ratio reported for the particles of *Pinus* spp. was 59.5, which is 2.5 times higher than that of *P. edulis* (23.5).

Particles with low slenderness ratio usually resulted in poor properties of static bending and dimensional stability (KELLY, 1977). According to TRIANOSKI (2011), several factors influenced this ratio, especially the species, the type of equipment used to produce the chips and particles, and the thickness of the final product.

The flatness ratio of *Pinus* spp. was 15.9 and also higher than the bamboo particles (1.7), mainly due to the lower thickness of the wood particles. According to IWAKIRI et al. (2009), an increased flatness ratio will result in a better resin distribution condition due to a higher contact area of particles.

Physical properties

Mean values of the physical properties of the panels are shown in table 1, where is observed that there was statistical difference for density between the composition T1 and T4 / T5, and deviations that occurred in relation to the nominal density. In spite of the differences reported, panels

of all compositions were classified as of average density, according to the intervals established by the norms CS 236-66(1968), ANSI A208.1(2009), NBR 14810(2013) and EN 312-2(2003).

It is also noted that density values decreased when particles of *Pinus* spp are incorporated to the panels. This fact can be justified by the low density of *Pinus* spp, which consequently requires a larger volume of particles in the mattress and, according to MOSLEMI (1974), in a higher release of compression tension after the remove of the pressure in the hot-pressing step.

According to IWAKIRI (2005), the differences of the nominal density may be related to the specificities of the laboratory conditions, when compared to the industrial process, specifically referred to the distribution of the particles during the formation of the mattress, which eventually influences the difference of the density between treatments, within the same treatment and still within the same panel.

The observation of the density variation led to the determination of the density of each sample analyzed by its dimensional stability and mechanical properties. This density determination could be used as a variable during the application of the statistical tool.

The compaction ratio also showed a statistical difference between the treatments. The composite panels with the highest contents of *Pinus* spp. presented with the highest values of compaction ratio, showing an inverse relation to density. Thus, the average values shown in table 1 demonstrated that with the addition of bamboo particles in the panel composition, the compaction ratio tends to decrease. This is mainly due to the density of bamboo particles, which are higher than *Pinus* spp. The inversely

Table 1 - Mean values for density, compaction ratio and moisture.

| Treatment | -----Density (kg/m ³)----- | | Compaction ratio | Moisture(%) |
|---------------------------------------|--|--------------|--------------------------|----------------------------|
| | Panels | Raw material | | |
| 1 (B ₁₀₀ W ₀₀) | 716 a _(4,31) | 735 | 0.97 _{c(4,38)} | 10.54 _{b(1,92)} |
| 2 (B ₇₅ W ₂₅) | 701 ab _(5,63) | 666 | 1.05 _{c(5,73)} | 10.88 ab _(1,84) |
| 3 (B ₅₀ W ₅₀) | 691 ab _(7,87) | 597 | 1.15 _{bc(7,86)} | 11.41 a _(1,64) |
| 4 (B ₂₅ W ₇₅) | 670b _(5,77) | 528 | 1.26 _{b(5,74)} | 11.87 a _(1,36) |
| 5 (B ₀₀ W ₁₀₀) | 657b _(6,22) | 460 | 1.43 _{a(6,14)} | 12.67 a _(2,15) |
| Mean | 687 | 597 | 1.17 | 11.17 |

Means followed by the same letter in the same column do not statistically differentiate among themselves by the Tukey mean test at 95% probability. Values in parentheses indicate the coefficient of variation (%).

proportional relation between the wood density and the compaction ratio was also demonstrated by authors, such as IWAKIRI et al. (2012) in research on tropical species of different densities and CUNHA et al. (2014) which investigate the use of eucalyptus species particles with different densities and TRIANOSKI et al. (2013) which studied the addition of *Criptomeria japonica* to *Pinus* panels.

Panels produced with *P. edulis* particles presented compaction ratio values lower than the range of 1.3 to 1.6 recommended by MOSLEMI (1974) and MALONEY (1993). According to TSOUMIS (1993), a low compaction ratio may result in a low contact area between particles, impairing densification and quality of the panels. According to MENDES et al. (2002), to overcome the low compaction ratio reported in the panels with *P. edulis*, some process variables may be modified, such the increasing on the amount of adhesive, which will result in higher manufacturing costs.

Related to the moisture content, it is observed that all samples were below the equilibrium moisture content of the surround of 12%, except for treatment T5. WEBER and IWAKIRI (2015) explains that hygroscopicity is reduced by the transformation of the wood up to particle sizes, besides drying and hot-pressing process, which may contribute to the reduction of hygroscopic sites and lead to the loss of the water of constitution. The use of resin and paraffin emulsion also decreases the hygroscopicity of the panel (WU, 1999).

The difference of the equilibrium moisture content between the treatments can be attributed to the density of the panels. Some authors, such as KELLY (1977) and SILVA et al. (2006), says that panels with lower density values present a higher amount of empty spaces and higher moisture contents. This fact is evidenced in this study, where the treatments with higher densities presented lower equilibrium moisture, T1 with 10.54% and T2 with 10.88%.

Table 2 presents the data on the density profile of the panels, where there is no statistical difference between the treatments in the three different positions along the panel thickness. However, there is a higher density in the surface layers and a smaller in the central part, forming an "M" profile, which is characteristic of this type of reconstituted panel.

According to TRIANOSKI (2011) the difference between the maximum and minimum density for industrial panels must be between 20% and 35%. Therefore, it is possible to observe that the panels with the highest proportions of *P. edulis*

(T1 and T2) did not reach a minimum difference of 20%, while the other treatments remained within the range of 20% to 35%. This phenomenon was similar to the study conducted by MARINHO et al. (2013), on bamboo *Dendrocalamus giganteus fiberboards*, with a maximum and minimum density gradient greater than 20%.

Also, according to TRIANOSKI (2011), the difference between the maximum and minimum density value has direct relation with the density of the species. The species with higher density, the volume of particles is smaller to compose the mattress, so the surface layers become less malleable through a smaller plasticization, and less densification. At the same time, the central layer is more resistant to pressing, reducing the difference between the inside and the surface.

The mean values for water absorption and thickness swelling are shown in table 3, along with their coefficients of variation. Analyzing the results for water absorption after 2 hours of immersion in water, it is noticed that the mean values of the treatments decrease as the quantity of *Pinus* spp. increases.

After 24 hours, the reported results did not follow the same tendency of the 2 hour test, because the treatments that stood out were the intermediate ones, T3 and T2, with 43.59% and 50.55%, respectively.

The tendency to this behavior can be interpreted by the greater compatibility between the particles of bamboo and *Pinus* spp., recognizing this fact, the particles of smaller length (*Pinus* spp.) can be better accommodated along the more elongated particles (bamboo), assisting the dimensional stability.

However, MORAIS et al. (2015) verified in his study about the association between the wood of *Pinus taeda* and *Bambusa tuldooides*, lower water absorption in panels produced exclusively with bamboo particles when compared to those with bamboo and wood, but the authors reported that in the panels produced exclusively with wood particles the absorbed water was the lowest after 2 hours. The research of VITAL & HALENSEIN (1988), indicated that in the mixture between *Bambusa vulgaris* and wood of *Cecropia* sp. in particleboards with 10 wt% of resin, the absorption increased until the percentage of 33.3% of bamboo, decreasing the physical property with the increasing of particles up to 100%.

In relation to the standard quality parameters, only CSA 0437 (1993) is available for absorption in 2 hours and 24 hours, where it is verified that all treatments were above the recommended of 10% and 15%.

For the swelling after 2 hours of immersion in water, the statistical analysis showed that the

Table 2 - Mean values for density profile.

| Treatment | Density (kg/m ³) | | |
|---------------------------------------|------------------------------|--------------------------|--------------------------|
| | Uppermaximum | Minimum | Lowermaximum |
| 1 (B ₁₀₀ W ₀₀) | 707 a _(11,87) | 632 a _(10,26) | 697 a _(11,86) |
| 2 (B ₇₅ W ₂₅) | 736 a _(2,00) | 620 a _(1,38) | 723 a _(1,33) |
| 3 (B ₅₀ W ₅₀) | 764 a _(4,60) | 620 a _(2,23) | 759 a _(4,40) |
| 4 (B ₂₅ W ₇₅) | 799 a _(4,10) | 616 a _(5,45) | 797 a _(5,70) |
| 5 (B ₀₀ W ₁₀₀) | 814 a _(9,12) | 616 a _(2,27) | 813 a _(6,78) |
| Mean | 764 | 620 | 757 |

Means followed by the same letter in the same column do not statistically differentiate among themselves by the Tukey mean test at 95% probability. Values in parentheses indicate the coefficient of variation (%).

treatments formed by panels with particles of *P. edulis* and *Pinus* spp in the proportion of 25% of bamboo was the one that presented the greater coefficient. For 24-hour swelling, the tendency was repeated.

Only NBR 14810(2013) specifies minimum values of 8% for swelling in 2 hours, where it is observed that none of the treatments responded to the required standard. When comparing the values reported in the present study with the standards that establish limits for 24 hours swelling, it is verified that NBR 14810(2013) allowed an 18% maximum and only 2 treatments were within the specified, T2 and T3. While EN 312-2(2003) allowed 15% maximum and none of the results was satisfactory. However, taking as reference the standards ANSI A208.1 (2009) and CS 236-66(1968) with maximum values of swelling of 35% and 40% respectively, all treatments were within the pre-established limits.

Mechanical properties

The obtained values for mechanical properties of the panels are presented in table 4.

From the static bending test, were obtained the results of modulus of rupture (MOR) and modulus of elasticity (MOE). The best results for MOR were obtained in the T3 and T5 treatments, whereas the least expressive treatment was T1, which had statistical equivalence with T2 and T4. For the MOE variable, a statistical similarity among all the composite treatments was evidenced.

MOSLEMI (1974) reported that low density species originated panels with greater resistance to static bending, due to the possibility of a higher compaction ratio, which was evidenced in all panels of the study.

According to TRIANOSKI (2011), the values of MOR and MOE to the static bending are improved with the increase of the flatness ratio of the particles. IWAKIRI et al. (2009) also said that the flatness of the particles allowed the resin application process, the formation of the mattress and the area of contact between the particles. So, a high flatness ratio enabled a better resin distribution which will reflect on the variables of resistance and stiffness to the static bending.

Table 3 - Mean values for the water absorption and thickness swelling.

| Treatment | Water Absorption (%) | | Thickness Swelling (%) | |
|---------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| | 2 h | 24 h | 2 h | 24 h |
| 1 (B ₁₀₀ W ₀₀) | 34.83b _(18,45) | 59.02b _(8,80) | 10.78 ab _(12,23) | 22.04 ab _(14,13) |
| 2 (B ₇₅ W ₂₅) | 28.18 ab _(19,62) | 50.55 ab _(10,30) | 9.55 a _(15,18) | 17.06 a _(10,74) |
| 3 (B ₅₀ W ₅₀) | 25.05 ab _(33,20) | 43.59 a _(13,35) | 9.45 a _(25,41) | 16.80 a _(10,92) |
| 4 (B ₂₅ W ₇₅) | 22.86 a _(29,57) | 54.53b _(11,71) | 13.61b _(10,59) | 25.36b _(20,50) |
| 5 (B ₀₀ W ₁₀₀) | 22.07 a _(18,86) | 54.57b _(9,19) | 11.53 ab _(30,74) | 19.52 a _(23,26) |
| Mean | 26.60 | 52.53 | 1,98 | 20.16 |

Means followed by the same letter in the same column do not statistically differentiate among themselves by the Tukey mean test at 95% probability. Values adjusted by covariance for apparent density of 695 kg / m³. Values in parentheses indicate the coefficient of variation (%).

The referenced statements are observed for the MOR, where the best treatment was the T5 and the worse was the T1. It should be noted that the particles of *Pinus* spp. showed levels of flatness and slenderness ratio of 15.9 and 59.5, while *P. edulis* presented 1.7 and 23.5. Also, a coherent correlation between the variables was not verified for the modulus of rupture.

HIZIROGLU et al. (2005), studying the quality of particle panels produced with different proportions of *Eucalyptus camaldulensis* wood, rice straw and *Dendrocalamus asper* bamboo, verified a lower strength and mechanical stiffness on the panels with mixtures between species when compared to those produced only with one specie wood particles. This same fact was also observed in the present study.

For the MOR, it is observed through the comparison with the quality standards, that the treatment with 100% of particles of *Pinus* spp. (T5) and T3, produced with 50% of bamboo particles and 50% of *Pinus* spp., attended the specifications of NBR 14810 (2013) and of CS 236-66 (1968) of 11.0 MPa, whereas for EN 312 (2003) of 13 MPa, only the treatment T5 attended the established standard. In relation to ANSI A208.1 (2009), which classifies the product quality, it is verified that the T4 treatment was above the minimum required for class M1 of 10 MPa, T3 for the MS class of 11 MPa, and the T5 for the M2 class of 13 MPa.

Requirements of the national and international standards is repeated for MOE, in which only the treatment T5 attended to NBR 14810 (2013) and EN 312 (2003), which are at least 1600 MPa. The ANSI A208.1 (2009) classifications defined as M1 (1550 MPa) the T3 treatment and as MS (1700 MPa) the T5 treatment panels. Other standards were not attended.

The non-attendance at quality standards is also verified by several studies of wood panels made with different raw materials such as *Hymenobolium* sp./*Andira* sp., *Qualea* sp., *Nectandra* sp./*Ocoteasp*, *Cedrelinga cateniformis* and *Mezila urusitauba* in LONGO et al. (2015); *Pinus oocarpa* of SCATOLINO et al. (2013); *Pinus taeda* and *Greivilea robusta* of TRIANOSKI (2011) and *Pinus taeda*, *Eucalyptus saligna*, *Mimosa scabrella* and *Hovenia dulcis* of NAPOLI (2013).

The screw withdrawal was analyzed by the Kruskal-Wallis test (Table 4), which allowed to affirm that the treatment T2 was superior only in relation to treatment T4, were other treatments were equivalent for the top resistance. For the surface resistance, the same tendency is followed, with the better treatment consisting of 100% of *Pinus* spp. and the worst of 25% of *P. edulis* and 75% of *Pinus* spp.

The addition of 25% of bamboo decreased the capacity to hold the screws at the top and surface. However, after 25%, the increasing in the percentage of bamboo particles leads to an increasing of the property up to 75%, with a slight reduction on the panel produced with 100% of bamboo particles.

A similar behavior was observed by VITAL & HALENSEIN (1988), who reported the best results for screw withdrawal at the top with the addition of 33% of *Bambusa vulgaris* to the panels of *Cecropia* sp., produced with both 7% and 10% adhesive resin. For the screw withdrawal at the surface was observed the same tendency only with 7% resin, while with 10% resin the authors reported the best results for panels with 100% bamboo particles.

According to MOSLEMI (1974), panels produced with species of low density, presented an increasing in the properties of screw withdrawal however, this behavior was not evidenced in the

Table 4 - Mean values for the mechanical properties of panels.

| Treatment | MOR(MPa) | MOE (MPa) | -----Screw withdrawal(N)----- | | Internal bond (MPa) |
|---------------------------------------|-----------------------------|------------------------------|-------------------------------|-------------------------------|---------------------------|
| | | | Top | Face | |
| 1 (B ₁₀₀ W ₀₀) | 7.90 _c (38,24) | 1488.26 _a (31,62) | 1085.08 _{ab} (46,04) | 1287.25 _{ab} (27,33) | 0.36 _b (13,17) |
| 2 (B ₇₅ W ₂₅) | 9.85 _{bc} (29,58) | 1463.60 _a (16,24) | 1181.50 _a (30,58) | 1307.50 _{ab} (23,01) | 0.36 _b (26,35) |
| 3 (B ₅₀ W ₅₀) | 11.50 _{ab} (24,87) | 1595.62 _a (19,75) | 1105.08 _{ab} (13,34) | 1422.00 _a (18,51) | 0.37 _b (25,47) |
| 4 (B ₂₅ W ₇₅) | 10.80 _c (13,03) | 1481.54 _a (16,65) | 804.42 _b (24,89) | 1099.17 _b (13,58) | 0.41 _a (30,35) |
| 5 (B ₀₀ W ₁₀₀) | 14.41 _a (20,66) | 1745.90 _a (19,03) | 1105.83 _{ab} (27,06) | 1313.50 _{ab} (18,10) | 0.46 _a (25,58) |
| Mean | 10.89 | 1554.98 | 1056.38 | 1285.88 | 0.39 |

Means followed by the same letter in the same column do not statistically differentiate among themselves by the Tukey mean test at 95% probability. Values adjusted by covariance for apparent density of 695 kg/m³. Values in parentheses indicate the coefficient of variation

homogeneous panels, whereas that the panel with particles of *Pinus* spp. are statistically like panels with bamboo particles.

The high results for screw withdrawal of surface in relation to the top is due to the fact that the screw is fixed into the inner layer of the panel and; therefore, depends on the densification of the layer and where the minimum panel density is reached, resulting in a low resistance to the screw withdraw in this region (WEBER, 2015). Another factor that determines this difference is that the top screw is adhered to the entire thickness of the panel, which attains the entire density of that dimension. This fact was verified in the present study, by means of the averages of the surface screw withdrawal, which are higher than the top.

In general, the quality of particleboards with the mixture between the bamboo and the wood of *Pinus* spp. were satisfactory, whereas all treatments were higher than the minimum of 800 N and 1020 N for top and surface resistance required by NBR 14810 (2013). All were classified, according ANSI A 208.1 (2009), in which the T4 treatment was classified as M2 (800 N) and all others in M3i (900 N), the highest quality classification of the standard. For the surface, the classification of the standard indicated that all treatments were qualified as M3i (1000 N).

The mean values of internal bond of the panels shown in table 4 indicated that the best treatment was T5 and the less expressive were T1, T2 and T3, while the T4 treatment presented an intermediate value.

According to WONG et al. (1998), the perpendicular tension is affected by the uniformity of the density gradient of the panel, where smaller minimum values of the density profile may become to damage the analyzed mechanical property, which is due to the rupture that occurs at the weakest point in the thickness direction. However, the minimum density value of the panels (Table 2) did not present statistical differences among themselves, which corroborated the variation of the property in panels which did not have a direct relation to the species.

In comparison to the quality standards, it is verified that the average results of internal bond of panels with *P. edulis* particles were higher than the minimum of 0.35 MPa required by NBR 14810 (2013) and EN 312 (2003) standards; however, none has reached the value determined by CS 236-66 (1968) which is 0.48 MPa. According to the classification of ANSI A208.1 (2009), the panels of the treatments T1, T2 and T3 are classified as MS, since they reached a

minimum of 0.36 MPa and the others are classified in M2 with 0.46 MPa.

CONCLUSION

The panels presented low compaction ratio, except for panels formed with 100% of *Pinus* spp. particles.

The analysis of the density profile showed that the surface layers were more densified than the inner layer. However, there was no significant difference between the panel profiles.

In the properties related to dimensional stability, it was observed that the combination of 50% of bamboo particles and 50% of wood particles (treatment T3) presented the best result.

The average values reported for the mechanical properties showed statistical equivalence in the modulus of rupture of static bending between treatments T3 and T5, formed by the proportions of bamboo and wood of 50:50% and 0:100%, and screw withdrawal among all treatments, except for T4(25:75%), which was lower. For perpendicular tension, the addition of bamboo particles in the panels resulted in decreased mean values.

The bamboo particles of *Phyllostachys edulis* presented technical feasibility for its use in the particleboard industry segment. However, there is a need of adjustments in the process for the treatments meet the current quality standards, such as the preparation of the raw material, mainly referred to the particle size distribution.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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