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Scientific Article

# HYBRID PANELS PRODUCED WITH PARTICLES AND VENEERS OF PINE WOOD IN DIFFERENT COMPOSITIONS

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## ABSTRACT

Hybrid wood panels can be produced with different particle or veneer sizes, forest species or even mixtures of synthetic materials, with the aim of reusing wood particles and generating new products. The present study aimed to verify the production process of hybrid panels formed with particles and veneers of *Pinus taeda* wood and urea–formaldehyde resin. The panels were produced in four different compositions, with a nominal density of 0.65 g/cm³, and their quality was evaluated through their physical and mechanical properties. The addition of veneers in the traditional particleboard system increased the density of the hybrid panels and improved the mechanical properties. The properties of the MOR and MOE in static bending and screw withdrawal were favored using veneers on the panel faces. The internal bonding of the panels was not affected by their composition. The addition of veneers to the particleboard improved the dimensional stability of the panel.

**Keywords:** Urea–formaldehyde; Particleboard; plywood

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# PAINÉIS HÍBRIDOS PRODUZIDOS COM PARTÍCULAS E LÂMINAS DE MADEIRA DE PINUS EM DIFERENTES COMPOSIÇÕES

**RESUMO** – Painéis híbridos de madeira podem ser produzidos com diferentes dimensões de partículas ou lâminas, espécies florestais ou até mesmo em mistura com materiais sintéticos, com o intuito do reaproveitamento de partículas de madeira e a geração de novos produtos. O presente trabalho teve como objetivo estudar o processo de produção de painéis híbridos, formados com partículas e lâminas de madeira de *Pinus taeda* e a resina ureia-formaldeído. Os painéis foram produzidos em quatro distintas composições, com densidade nominal de 0,65 g/cm³, avaliando sua qualidade por meio de suas propriedades físicas e mecânicas. Verificou-se que a adição de lâminas no sistema tradicional conferiu aos painéis híbridos maior densidade e melhores propriedades mecânicas. As propriedades de MOR e MOE em flexão estática e arrancamento de parafuso, foram favorecidas pelo uso de lâminas nas faces do painel, sendo que a resistência de ligação interna não foi alterada pela composição dos painéis. Constatou-se que a adição de lâminas ao painel de partículas melhorou a sua estabilidade dimensional.

**Palavras-Chave:** Ureia-formaldeído; Partículas; Compensado

## 1. INTRODUCTION

Currently, Brazil is among the leading producers of pulp, paper and wood panels worldwide. With an area of 9.5 million hectares of reforestation, the Brazilian forestry sector is responsible for 91% of all wood produced for industrial purposes and 6.2% of the country's industrial GDP and is also one of the segments with the greatest potential to contribute to the construction of a green economy (Mata Nativa, 2019).

The wood panel industry is highly important to the Brazilian economy, especially because of the new technologies dynamics associated with the generation of income and employment in the furniture and construction sectors (Vieira et al., 2012). This fact is due to the continuous investments in technology and automation of companies in production processes, in addition to best practices and forestry operations.

The use of wood panels in the domestic market increased by 14.6% in 2021 due to the large increase in sales of products that provide a home office environment. MDP sales total 3.2 million cubic meters in the year, an increase of 13.1% (IBÁ, 2022). According to the ABIMCI (2021), pine plywood exports account for 3.4 million cubic meters, confirming the trend of a gradual increase in the last decade.

Among the reconstituted wood panels, MDP is especially suitable for the furniture and joinery industry, especially in the production of residential and commercial furniture with straight lines (IBÁ, 2017). These panels consist of wood particles and resin and are consolidated under pressures of 3-4 MPa and an adequate temperature for curing the resin, which, in the case of urea–formaldehyde, can vary between 160°C and 180°C (Silva et al., 2020).

Plywood is made up of several layers of wood veneers, usually in odd numbers and varying in species and thickness, which are glued together via a combination of adhesive, catalyst, extender, pressure and temperature. The panel is assembled via the cross-lamination method, which consists of gluing layers at right angles to the adjacent layer (Lengowski et al, 2019). The pressure commonly used in the production process of this panel varies between 0.88 and 1.47 MPa, and pressing is performed at a temperature of 110°C when urea-formaldehyde resin is used (Bednarczuk et al., 2017; Tavares et al., 2020).

For the manufacture of wood panels, as well as other forest products, wood of the genus *Pinus* is the main raw material used, as it is also associated with the genus *Eucalyptus*, the main forest cultivated in Brazil with large plantations (BNDS, 2018). In 2021, pinus forests presented an average annual increment of 29.7 m³/ha, which is an expression of the influence of several factors, such as genetic improvement and soil fertility programs, nursery plant nutrition and the mechanization of plantations that were previously semi mechanized (IBÁ, 2021).

In recent years, much research has

been carried out on the development and characterization of new wood-based products with greater applicability, highlighting hybrid wood-based panels for increasing the lightness, stiffness and strength of wood in their applications. The first applications of hybrid panels were in the aerospace industry and later in the automotive and naval industries, and their use is on the rise today; for example, in Germany, the company Lopezpanel has been introducing houses with this type of panel, which stand out for their lower cost, faster construction and thermal insulation (CEPREVEN, 2018; Lopezpanel, 2021).

The manufacture of hybrid panels consists of the use of wood fibers or other resistant material in the outer layers and inner layer wood particles, which generally have a lower density and resistance than the species used in the adjacent layers, both of which are joined by an adhesive (Macedo et al., 2019). The hybrid panel receives this name for covering different dimensions of wood particles and species, with the possibility of including synthetic and natural materials in the same panel (Ferro et al., 2019).

The strength of these hybrid panels can be much greater than that of a traditional panel formed from the same material and of the same density. The use of synthetic materials in combination with wood was reported by Macedo et al. (2016) when producing OSB with bioriented polypropylene particles (BOPP) and by Bednarczuk et al. (2019) through MDP panels with the addition of tire rubber shavings.

Studies that portray the use of wood veneers and particles in the manufacture of hybrid panels are scarce and are limited to the production of structural panels. Macedo et al. (2019) produced hybrid panels with Pinus sp. veneers and particles and castor oil-based resin at 14%, adopting the parameters of 340 g/m2 adhesive weight on the veneers, a pressure of 4 MPa, a temperature of 100°C and a pressing time of 10 minutes. The authors reported that such panels had superior properties to those of commercially produced plywood and OSB panels, which was partly attributed to the adhesive used.

In view of the above, research aimed at the development of alternative construction models to those traditionally used in the reconstituted panel industry is of fundamental importance, providing technological innovation from new products within an economically viable and sustainable context. Thus, the present study aims to verify the potential of hybrid panels by evaluating their physical and mechanical properties.

## 2. MATERIAL AND METHODS

For the manufacturing of hybrid panels, industrial *Pinus taeda* wood veneers of 1.2 mm thickness and wood particles of sliver type were used in the inner or out layer, and urea-formaldehyde resin with 66.5% solids content, 8.2 pH, 324 cPs Brookfield viscosity, 40 s gel time and 1.30 g/cm³ density were used for bonding. The particles and the resin were also used to produce the particleboard, which was used as a control.

In general, for plywood panels, veneers between 1.2 and 2.5 mm are produced (Santos and Pinto Jr., 2021); thus, the minimum veneer thickness of 1.2 mm was used, as it represented 12% of each veneer of the nominal thickness of the particleboard used as a control.

The wood veneers with a density of 0.36 g/cm³, classified according to the NBR ISO 2426-2 standard (ABNT, 2006) and which fell into quality class E, were taken to the oven with air circulation at a temperature of 100°C, where they remained for 30 minutes until they reached a moisture content of 5%. A moisture content of 5% for the wood veneers was adopted, considering that it is the maximum moisture content allowed in the particleboard production process.

For the characterization of wood particles, their geometry was evaluated by means of the slenderness index, particle size and bulk density. The particle size consisted of weighing *Pinus taeda* particles in a proportion of 100 grams, with four repetitions. A sieve shaker was used, with a sequence of six sieves (4, 6, 8, 10, 12 and 16 mesh) that were shaken for a period of 10 minutes. The density and slenderness indices of the particles were measured by means of a sample average with 100 repetitions of each property analyzed.

The production of hybrid panels with dimensions of 40 × 40 cm, a thickness of 13.2 mm and a nominal density of 0.65 g/cm³ was configured in a DIC experiment in which four compositions of particles and veneers were tested. The experimental design was designed to test the inclusion of one, two

Revista ÁRVORE
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and three wood veneers of the same species in a particleboard and verify the influence of these inclusions on the properties of the panels. Three repetitions were chosen because they are common in studies carried out with plywood or particleboard, totaling twelve panels (Table 1).

The *Pinus taeda* wood particles of the sliver type obtained in industry were classified in the laboratory by means of Tyler series sieves with 8, 14 and 30 mesh or 2.380, 1.410 and 0.595 mm mesh opening sizes, respectively, for the panel's manufacture. The material that passed through the 8-mesh sieve and was retained in the 30-mesh sieve was sent to the oven with air circulation at a temperature of 60°C for 24 hours until it reached a humidity of 3%.

**Table 1.** Experimental design

**Tabela 1.** Delineamento experimental

| Panel | Composition | Repetitions |
|---|---|---|
| 1 | 100% particles | 3 |
| 2 | particles/veneer/particles | 3 |
| 3 | veneer/particles/veneer | 3 |
| 4[1] | veneer/particles/veneer/particles/veneer | 3 |

(1) Face veneers in the direction perpendicular to the core veneer.

(1) Lâminas de capa em direção perpendicular à lâmina de miolo.

For bonding the particles, urea–formaldehyde resin was used in the proportion of 10% solids in relation to the dry weight of the particles, 1% paraffin was used to reduce hygroscopicity, and 2% ammonium sulfate was used as a catalyst to accelerate the curing time. The application of the adhesive, paraffin and catalyst to the particles was performed via an air compressor and an applicator gun.

The glue beat of the urea–formaldehyde resin, formulated in a proportion of 40 parts by weight of resin, 30 parts of wheat flour, 30 parts of water, 1% on the weight of the ammonium sulfate catalyst resin and 25% of the solids content, was applied manually in the grammage of 160 g/m² in simple line on the veneers (Iwakiri, 2005).

After the resin was applied to the particles and veneers, the panel was assembled (Figure 1) in a forming box with dimensions of 40 × 40 cm, and then, the plate was pressed with electric heating where it remained for a period of 10 minutes, with a specific pressure of 4 MPa and a temperature of 160°C. After being pressed, the panels were acclimatized to an

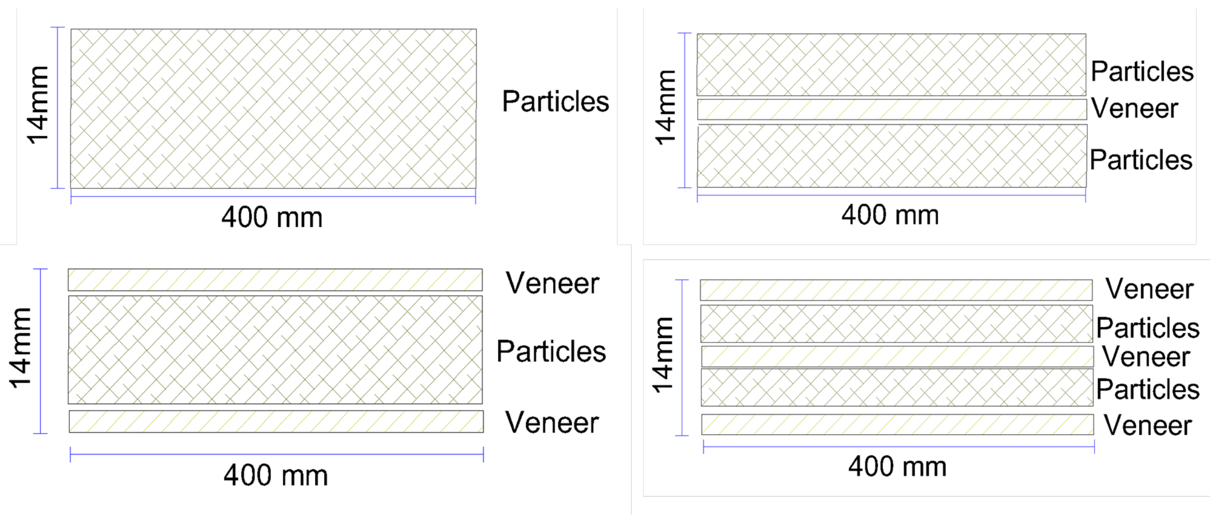


**Figure 1.** Hybrid panel assembly schematic. (no scale)

**Figura 1.** Esquema de montagem do painel híbrido. (sem escala) environment with a temperature of 20°C and 65% relative humidity.

After the acclimatization period of the panels, they were sent to make the samples according to the recommendations of the standard NBR 14810-2 (ABNT, 2013) to perform the following physical and mechanical tests: density, moisture content, water absorption and thickness swelling after periods of 2 and 24 h of water immersion (WA2; WA24; TS2; TS24), static bending in the parallel and perpendicular directions to the veneer face to determine the modulus of elasticity (MOEPa and MOEPe) and modulus of rupture (MORPa and MORPe), perpendicular strength to the panel surface to verify the internal bond (IB) and screw withdrawal (SW). The panel thicknesses were also determined, and the densification degree of the particles in the panel structure was interpreted by means of the compaction ratio. The mechanical tests were carried out on the universal testing machine EMIC DL 30000.

The average values of the panels' physical–mechanical properties were subjected to statistical analysis to verify the composition influence. Thus, the values obtained for the compaction ratio and physical–mechanical properties of the hybrid panels were subjected to the following statistical tests: the Kolmogorov–Smirnov test to analyze the data normality; the Levene test to analyze the homogeneity of variances; once the normality and homogeneity of variances were proven, analysis of variance (ANOVA) was applied; if the hypothesis of equality was rejected by ANOVA, the means were compared via the Tukey test at the 5% probability of error level.

## 3. RESULTS

The average values of the characteristic slenderness index and bulk density were 18.29 and 0.47 g/cm³, respectively. The average density values of the panels were significantly different, ranging from 0.66 g/cm³ to 0.72 g/cm³ (Table 2), highlighting that the addition of veneers provided better dimensional stability to the panels.

For the moisture content, a statistically significant difference was found between the panel means, ranging from 10.47% to 12.04%.

**Table 2.** Average values of the physical properties of hybrid papers produced from different compositions of *Pinus taeda* wood

**Tabela 2.** Valores médios das propriedades físicas dos painéis híbridos produzidos nas diferentes composições com madeira de *Pinus taeda*

| Panel | Composition | Thickness (mm) | Density (g/cm³) | Moisture content (%) | Compaction ratio | Water absorption | | Thickness swelling | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 2 h (%) | 24 h (%) | 2 h (%) | 24 h (%) |
| 1 | 100% Particles | 10.28 d | 0.66 b | 10.47 c | 1.26 b | 21.79 b | 51.85 b | 9.72 b | 19.73 b |
| 2 | Particles/ Veneer/ Particles | 11.16 c | 0.72 a | 10.67 c | 1.41 a | 16.03 a | 41.07 a | 3.57 a | 18.78 b |
| 3 | Veneer/ Particles/ Veneer | 12.18 b | 0.71 ab | 11.51 b | 1.44 a | 17.14 a | 33.13 a | 6.38 a | 11.01 a |
| 4 | Veneer/ Particles/ Veneer/ Particles/ Veneer | 13.78 a | 0.71 ab | 12.04 a | 1.38 a | 22.83 b | 40.32 a | 5.48 a | 14.14 a |

Notes: Means followed by the same letter in the same column do not differ statistically according to Tukey's test at a 5% probability of error.

Nota: Médias seguidas pela mesma letra na mesma coluna não diferem estatisticamente pelo teste de Tukey a 5% de probabilidade de erro.

These values are in accordance with the 5% to 13% recommended for MDP panels (ABIPA, 2013) and the up to 12% recommended for plywood panels (ABIMCI, 2009). For the water absorption properties, the average values obtained ranged from 16.03% to 22.83% and 33.13% to 51.85% after 2 and 24 hours of immersion in water, respectively. For both tests, a statistically significant difference between the means was found, highlighting that the hybrid panels presented lower water absorption after 24 hours of immersion than did the 100% particleboard.

The average values for thickness swelling after 2 and 24 h of immersion in water ranged from 3.57% to 9.72% and 11.01% to 19.73%, respectively, with a statistically significant difference between the means of the panels. These values meet the recommended maximum thickness swelling of 8% after 2 hours of water immersion for the standard NBR 14810-2 (ABNT, 2013) and a maximum of 40% for a period of 24 hours according to ANSI A 208.1 (ANSI, 2009).

The mechanical properties analyzed revealed statistically significant differences between the compositions of the panels (Table 3).

**Table 3.** Average values of the mechanical properties of hybrid panels produced from *Pinus taeda* wood with different compositions

**Tabela 3.** Valores médios das propriedades mecânicas dos painéis híbridos produzidos com madeira de *Pinus taeda* em diferentes composições

| Painel | Composition | SW (N) | IB (MPa) | MORPa (MPa) | MOEPa (MPa) | MORPe (MPa) | MOEPe (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | 100% Particles | 1034.86 c | 0.35 b | 10.09 c | 2329.00 c | 10.40 b | 2410.21 b |
| 2 | Particles/Veneer/ Particles | 1706.42 b | 0.59 a | 15.61 c | 2874.39 c | 13.33 ab | 2148.02 b |
| 3 | Veneer/Particles/ Veneer | 1955.23 ab | 0.58 a | 60.35 a | 9478.36 a | 15.66 a | 2956.54 a |
| 4 | Veneer/Particles/ Veneer/Particles/ Veneer | 2250.78 a | 0.49 ab | 33.09 b | 6561.06 b | 14.78 a | 2170.93 b |

KEY: SW–Screw withdrawal; IB–internal bonding; MORPa–parallel modulus of rupture in static bending; MOEPa–parallel modulus of elasticity in static bending; MORPe–perpendicular modulus of rupture in static bending; MOEPe–perpendicular modulus of elasticity in static bending. Notes: Averages followed by the same letter in the same column do not differ statistically according to the Tukey test at a 5% probability of error.

CHAVE: SW – Arrancamento de parafuso; IB - ligação interna; MORPa – módulo de ruptura paralelo em flexão estática; MOEPa – módulo de elasticidade paralelo em flexão estática; MORPe – módulo de ruptura perpendicular em flexão estática; MOEPe – módulo de elasticidade perpendicular em flexão estática. Nota: Médias seguidas pela mesma letra na mesma coluna não diferem estatisticamente pelo teste de Tukey a 5% de probabilidade de erro.

## 4. DISCUSSION

The long and thin particles of *Pinus taeda* resulted in a slenderness index that was greater than that reported by Sozim et al. (2019), which was 13.63 for the same species. The contact area between the particles plays an important role in the characteristics of the panels, which is measured by the slenderness index, which is directly related to the panel's mechanical properties and the resin consumption. Therefore, this index influences the quality and finish of the panels, so there is a need to observe the particles homogeneity in the process (Iwakiri, 2005a).

All panels presented values higher than the quality standards described by the ABIPA Technical Report (2013), which are 0.60 g/cm³ to 0.65 g/cm³ for MDP and 0.47 g/cm³ to 0.54 g/cm³ for plywood, as recommended by the ABIMCI (2002).

The panel density is related to its thickness, which differs across the panels produced with the veneer's addition. The return in thickness, on the other hand, is influenced by internal bonding because at the end of the panel's pressing cycle, they may suffer an increase in thickness because of the tension suffered and their release by the wood in this final pressing process (Iwakiri, 2005a).

One of the variations in the manufacturing process corresponds to the panel thickness, a fact proven by the static analysis for this property, since there was an increase in thickness with the addition of the veneers in the particleboard. The panel with tree veneers presented the greatest average thickness (13.78 mm), whereas the panel with 100% particles (10.28 mm) presented the smallest average thickness.

The appropriate compaction ratio to produce particleboard should be in the range of 1.3 (Iwakiri, 2005b). Thus, the average values ranging from 1.26 to 1.44 obtained in this study are in accordance with the recommended values.

Nuryawan et al. (2020), when manufacturing hybrid plywood panels with nanoparticles of palm residues, obtained 24-hour test values ranging from 20% to 40% water absorption, and this property increased with the addition of nanoparticles. Research by the authors confirmed that the higher the value of water absorption is, the weaker the wood-based panel becomes. Them noted that several factors can influence water absorption properties, such as the fiber load, area of exposed surfaces, diffusivity, and void content. In this research, it was observed that with the addition of veneers, there was a reduction in water absorption, which was attributed to the panel pressing process where the compaction of pores wood occurred.

An examination of the thickness swelling property together with the water absorption of the panels revealed that the addition of veneers to the particleboard improved its dimensional stability. Natalli (2020) obtained MDP panels produced from byproducts of the pine wood industry and glued them with urea-formaldehyde; the thickness swelling after 24 hours of immersion in water ranged from 19.34% to 44.38%, and for water absorption, the values ranged from 13.61% to 20.35%. The thickness swelling values were lower than those reported in this research.

In the study carried out by Lima et al. (2018) with MDP panels produced with urea-formaldehyde and *Eucalyptus* spp. wood residues, the authors reported 8.58% for two hours and 13.81% for 24 hours of thickness swelling for the panels pressed for 10 minutes under a pressure of 4 MPa. These values are lower than those of the panel with 100% particles but compared with the panel produced with two veneers and particles in the inner layer, it presented higher values for both immersion periods. In the present study, when the properties of density and water absorption were compared, it was found that denser panels had lower water absorption.

Iwakiri et al. (2005), studying different densities of MDP panels (0.6 and 0.8 g/cm³) and resin contents (6% and 8%), reported results ranging from 15.32% to 66.59% for water absorption and from 8.57% to 25.62% for thickness swelling, whereas less dense panels with higher resin contents (0.6 g/cm³ and 8%) presented the best results.

In this research, the panels with veneers presented the best results, except for water absorption of the panels with three veneers for 2-hour and thickness swelling of the panels with one veneer for 24-hour. The greater water absorption after two hours of immersion was attributed to the greater number of veneers in the panel, as plywood panels generally have greater water absorption than those observed in this study (Bednarczuk et al., 2017; Tavares et al., 2020). On the other hand, the 24-hour thickness swelling of one veneer panel was statistically similar to that of the 100% particle panel because of the small thickness of the veneer in the center of the panel.

The addition of wood veneers to the panel composition improved the modulus of rupture and modulus of elasticity obtained for the static bending test in the parallel and perpendicular directions. These panels meet the requirements of NBR 14810-2 (ABNT, 2013) for nonstructural panels intended for indoor use under dry conditions, which establish minimum strength values of 11 MPa, 1800 MPa and 0.40 MPa for the MOR, MOE and IB, respectively.

The American marketing standard ANSI A 208.1 (ANSI, 2009) was established for medium-density panels (0.60 to 0.85 g/cm³), with a minimum required value of 11 MPa for MOR and 1700 MPa for MOE. In the present study, all the hybrid panels produced obtained an average value higher than that recommended by the referred standards for the mechanical properties, highlighting that the panel made with two veneers and particles in the inner layer reached a value of 60.35 MPa for the parallel MOR, resulting in an increase in resistance six times greater than the referred standards.

The addition of veneers to the panels

Revista ÁRVORE
ISSN 1806 – 9088

increased their mechanical properties; however, for the MOR and MOE under static bending, in the parallel and perpendicular directions, the average values of the panel with only one veneer in the center did not differ statistically from those of the panel with 100% particles.

For static bending, the increase in strength and stiffness provided by a reinforcement depends on its position in relation to the neutral axis, as both the MOR and MOE are calculated considering the moment of inertia of the cross section (Isleyen and Kesik, 2021; Davis et al., 2012). On the other hand, for screw withdrawal and internal bonding, the panel strength increased regardless of the position and number of reinforcement veneers.

Ferro et al. (2018) reported that longer particles, such as those used in the manufacture of OSB in the outer layers of a hybrid panel, contribute to higher values of MOR and MOE, which can be attributed to the greater values of mechanical properties in the direction parallel to the wood fibers.

In this study, all the hybrid panels produced with the addition of veneers presented MOEPa and MORPa properties greater than the 1886.61 and 12.03 MPa values reported by Iwakiri et al. (2010), who studied *Pinus taeda* panels made with 8% urea-formaldehyde and a density of 0.68 g/cm³. This difference can be explained by the contribution of the hybrid panel cover veneers, which contribute to the increase in strength in the direction parallel to its fibers, as described in the paper by Tavares et al. (2020). Another factor that directly influences this property is the applied pressure, which is directly linked to the density of the panel (Saldanha and Iwakiri, 2009).

Nurhazwani et al. (2015) reported average values of 15.30 MPa and 2650 MPa, corresponding to the strength and stiffness analyzed in hybrid bamboo and rubber panels through static bending tests. These values are lower than those obtained in this study for hybrid panels produced with the addition of veneers analyzed via static bending tests in the parallel direction.

Silva et al. (2017), when producing hybrid panels made with sugarcane bagasse and *Pinus taeda* fibers, obtained similar results to those of the panel with 100% particles obtained in this study for the static bending test in MOR and lower results for the MOE. The average values reported by the authors were 11 MPa and 1089 MPa for the MOR and MOE, respectively.

The averages obtained for the modulus of rupture and modulus of elasticity of the hybrid panels with the addition of two or three veneers for the static bending test in the parallel direction met the minimum requirements of 31 MPa and 5192 MPa specified by the ABIMCI Technical Catalog (2002) for laminated panels. Notably, the panel with the addition of two veneers presented results twice as high as those required by the standard.

For the internal bonding of the panel, a statistically significant difference was found between the 100% particleboard panel and the compositions of the panels with added veneers. This can be explained by the interference of the veneers in the transfer of heat and pressure to the inner layers of the panel. Therefore, it was not necessary to carry out the glue line shear test, which would be recommended for assessing the bonding between veneers in a plywood panel, as the perpendicular tensile test was sufficient, since the specimens did not break at the glue line between the veneer cover and the core particles.

The ANSI A208.1 standard (ANSI, 2009) establishes that the internal bond for medium-density MDP panels should range from 0.31 to 0.50 MPa, depending on the purpose of the panel. The NBR 14810-2 standard (ABNT, 2013) has a value of 0.40 MPa. This shows that the panels produced with 100% particles met the requirements of the ANSI standard but did not meet the NBR standard, emphasizing that panels made with the addition of veneers can be used for a variety of purposes, such as cladding and acoustic insulation for homes and the manufacture of furniture.

In relation to the studies presented in the literature, Sozim et al. (2019) reported average internal bond values of 0.62 MPa for particleboard panels made from *Pinus taeda*, which are close to the values reported in this study for panels with added veneers.

Dacosta et al. (2005) reported that for MDP panels made from Pinus elliottii mechanical processing waste, with a nominal density between 0.60 and 0.70 g/cm³ and a pressure of 3 MPa, the internal bond values of the panels ranged from 0.09 to 0.23 MPa. In contrast, the lowest value obtained in this study was 0.35 MPa. Dacosta (2004), when producing panels using wood shavings with urea-formaldehyde resin, reported values of 0.20 and 0.22 MPa for the internal bond test. These values were lower than those reported in this study with the results of panel 1, without the addition of veneers.

For the screw withdrawal test, the addition of veneers led to an increase in panel strength compared with 100% particleboard panels. As the number of veneers in the panel increased, greater resistance was obtained. The hybrid panels met the ANSI A 208.1 standard (ANSI, 2009), which recommends minimum values between 550 and 1000 N for surface screw withdrawal strength for low- and medium-density particleboards.

Trianoski et al. (2016), when producing pine particleboards with the incorporation of *Grevillea robusta* at a nominal density of 0.80 g/cm³ and urea-formaldehyde resin, reported surface screw withdrawal strength values between 990 and 1137 N, values close to those found for 100% particleboards, which resulted in 1034.86 N.

Dugani et al. (2019) made hybrid plywood using coconut fibers, jabon (*Anthocephalus cadamba* Miq.) veneers and urea-formaldehyde resin and found lower values than those obtained in this study for the screw withdrawal test, with values ranging from 747.40 to 982.4 N. They also verified that the increase in the panel density caused an increase in the strength of the screw withdrawal test. In this research, a lower density was verified in the panels produced with only particles, and they were also the panels with a lower strength of screw withdrawal. In terms of this property, panels with three veneers obtained the best results.

## 5. CONCLUSION

Compared with the addition of panels made with only particles, the addition of veneers to the panels led to an improvement in dimensional stability. For the water absorption and thickness swelling tests, the panel with the addition of two veneers showed better results.

For the mechanical properties, an increase in strength and stiffness to static bending was obtained mainly in the parallel direction for the hybrid panels, where the panel with the addition of two veneers obtained an increase in strength of six times in relation to the 100% particleboard.

The addition of one or more veneers to the panel composition increased the internal bonding means compared with those of the particleboard, but the number of veneers did not significantly influence the mean values.

The mechanical properties obtained met the minimum requirements established by the NBR 14810-2 standard for nonstructural medium density particleboard for internal use, by ANSI A208.1 and by the ABIMCI and ABIPA technical catalogs.

Among the compositions studied, the addition of two veneers to the face of particleboard provided better gains in the physical and mechanical properties analyzed, emphasizing that the use of one or three veneers was not very efficient, resulting in increased production costs.

## 6. ACKNOWLEDGEMENTS

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## AUTHOR CONTRIBUTIONS

Mustefaga E.C.: conceptualization, methodology, experimental, data analysis, writing, review; Sozim C.L.S.: data analysis, review, editing; Bednarczuk E.: experimental, review, editing; Barbosa A.V.: writing, review, editing. Hillig E.: conceptualization, funding, supervision, review.

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