EVALUATION OF THE PHYSICAL-MECHANICAL PROPERTIES OF OSB PANELS (ORIENTED STRAND BOARD) WITH DIFFERENT TYPES OF ADHESIVES AND PARTICLE ORIENTATIONS INFLUENCE OF COCONUT FIBER WASTE AND RICE HUSK ASH ON GREEN CONCRETE

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ABSTRACT

Objective: The present study aimed to evaluate the quality of OSB (Oriented Strand Board) panels produced with different particle orientations and adhesive formulations.

Method: The panels were produced using strand particles of Pinus taeda, with a nominal density of 0.65 g/cm³ in two particle orientations (oriented and random) and three adhesive formulations (100% phenol formaldehyde, 100% tannin and 50% phenol formaldehyde + 50% tannin), distributed in six treatments. The tests were carried out according to the standards established by the EN 300 (2006) standards.

Results and conclusion: The results showed that using the mixture of the phenol and tannin adhesive had better results for the swelling, water absorption properties and the static bending. It was not possible to determine the best type of adhesive to be used, as the results showed an equivalence between the two types of adhesives used, as well as the mixture between them. It was observed that the use of mixtures with 50% of each adhesive can be used in the production process of OSB panels, allowing new alternatives of adhesives for the industries.

Research implications: This research investigates the possibility of using different types of natural adhesives in the manufacture of wooden panels, contributing to reducing the use of materials that are harmful to the environment and reducing costs in panel production, contributing to more sustainable production.

Keywords: Wood Panels, Tannin, Phenol-formaldehyde, Pine Taeda.

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AVALIAÇÃO DAS PROPRIEDADES FÍSICO-MECÂNICAS DE PAINÉIS OSB (ORIENTED STRAND BOARD) COM DIFERENTES TIPOS DE ADESIVOS E ORIENTAÇÕES DAS PARTÍCULAS

RESUMO

Objetivo: O presente estudo objetivou avaliar a qualidade de painéis OSB (Oriented Strand Board) produzidos com diferentes orientações das partículas e formulações de adesivos.

Métodos: Os painéis foram produzidos utilizando as partículas strand de Pinus taeda, com densidade nominal de 0,65 g/cm³ em duas orientações de partículas (orientada e aleatória) e três formulações de adesivo (100% fenol formaldeído, 100% tanino e 50% fenol formaldeído + 50% de tanino), distribuídas em seis tratamentos. Os ensaios foram realizados conforme os padrões estabelecidos pelas normas EN 300 (2006).

Resultados e conclusão: Os resultados demonstraram que utilizando a mistura do adesivo fenol e tanino houve melhores resultados para as propriedades de inchamento, absorção de água e flexão estática. Não foi possível determinar o melhor tipo de adesivo a ser utilizado, pois os resultados demonstraram uma equivalência entre os dois tipos de adesivos utilizados, bem como da mistura entre ambos. Observou-se que o uso de misturas com 50% de cada adesivo pode ser usado no processo de produção de painéis OSB, possibilitando novas alternativas de adesivos para as indústrias.

Implicações da pesquisa: Esta pesquisa investiga a possibilidade de uso de diferentes tipos de adesivos naturais na confecção de painéis de madeira, contribuindo para a diminuição de uso de materiais nocivos ao meio ambiente e redução dos custos na produção de painéis, contribuindo para uma produção mais sustentável.

Palavras-chave: Painéis de Madeira, Tanino, Fenol Formaldeído, Pinus Taeda.

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1 INTRODUCTION

Wood has great versatility and due to the great demand from the furniture sector (mainly) and civil construction, many products have been created in order to meet this great demand, also thinking about the best use of the raw material. Reconstituted wooden panels are an example of these products, produced from wood fragments, with the addition of synthetic resins, which act as binding agents for the components, manufactured according to the desired uses (ARAÚJO et al., 2019). These panels originated in Germany, during the Second World War, where there was a period of scarcity of good quality wood. In the 1960s, in the USA, new types of panels were developed, such as Medium Density Particleboard (MDP), Medium Density Fiberboard (MDF) and Oriented Strand Board (OSB).

Among the main types of reconstituted wood panels, oriented particle boards (Oriented Strand Board – OSB) stand out. OSB panels have the function of supporting the structure of walls, roofs, mezzanines, dry slabs, floor platforms and ceilings, and are also used in the manufacture of packaging and furniture (CHIROMITO et al., 2016). Above all, in its manufacture it is possible to control the dimensions, proportions and orientation of the particles in each of the layers of the panel. This control is essential to achieve greater resistance to bending and greater stiffness of the panel, which are largely attributed to the parallel orientation of the strands. (FPL 2010; Shmulsky e Jones, 2011). The stiffness of the panel is due to the orthotropic properties of the wood and the thickness of the layers (PLENZER et al., 2013). Furthermore, in the formation of the mattress, in a cross-layered structural composition, it has a strong influence on the static flexural resistance and dimensional stability of the panels. Some
compositions have been studied, such as 20/60/20 to 30/40/30, being face/core/face (CLOUTIER, 1998).

However, the type of adhesive, the quantity and composition of the adhesive mixture with additive, determine the properties and intended use of the panel. Since the type of adhesive is one of the most expensive elements in the production process, it is important to define the type and quantity of adhesive to be used (POBLETE, 2001; IWAKIRI et al., 2003). That is, the type of adhesive is considered an extremely important variable in the production process, as it involves technical and economic issues, as the resin represents around 30 to 60% of the costs and is directly related to the quality of the product. (BARROS FILHO, 2009).

Currently in Brazil, there is growing interest in the development of natural adhesives. Solt et al. (2019) found that the availability of tannin for adhesives may only be sufficient for a limited region (South America). It is obtained from several renewable sources, such as the bark of *Acacia mearnsii* and *mangium*, *Pinus radiata*, *Stryphnodendron adstringens*, *Eucalyptus* spp., *Anadenanthera*, *Pinus oocarpa*, *Ochroma pyramidale* (VITAL et al., 2004; CARNEIRO et al., 2009; FERREIRA et al., 2009; PAES et al., 2013; VIEIRA et al., 2014; CARVALHO et al., 2015; BARBIRATO et al., 2018). Natural or synthetic organic polymers are the main chemical compounds used in the production of adhesives (NASCIMENTO et al., 2015). However, during the panel production process, using urea-formaldehyde (UF) and phenol-formaldehyde (FF) resins, the curing of these adhesives causes the emission of toxic gases, with a strong odor and high chemical reactivity (HELLMEISTER, 2018). In this way, the search for vegetable resins appears as an alternative, acting as a less polluting material, above all reducing production costs and helping in the development of more sustainable products.

Some studies have demonstrated efficiency in the use of tannin in the production of panels, such as Ferreira et al. (2009), Silva et al. (2012), Carvalho et al. (2015), Hemmilä et al. (2017), Gonçalves et al. (2017), Santiago et al. (2018), compared to other commercial and natural adhesives and reduction in Formaldehyde emission, demonstrating its potential for use.

Therefore, considering the increasing rise of natural adhesives, as well as the strong influence of layer composition on the physical and mechanical properties of OSB panels, studies that evaluate these variables become important. In view of the above, the objective of this research was to evaluate the quality of OSB panels produced with different adhesives and layer compositions and their influence on the final properties of the panels.

### 2 MATERIAL AND METHODS

#### a. Material

The panels were produced using strand particles, coming from *Pinus taeda* wood, in a forest stand. The material was supplied by an OSB panel company, located in the Campos Gerais region, in the state of Paraná. To adhere the particles, two types of adhesives were used, both supplied by collaborating companies, these being phenol-formaldehyde and Tannin-formaldehyde.

Table 1 presents the types of adhesives, their characteristics and properties used in the production of the panels.

<table>
<thead>
<tr>
<th>Technical information</th>
<th>Type of adhesive</th>
<th>Paraffin Emulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phenol-formaldehyde</td>
<td>Tannin-formaldehyde</td>
</tr>
<tr>
<td>pH</td>
<td>11-12</td>
<td>6.60 – 6.90</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.23</td>
<td>1.29</td>
</tr>
<tr>
<td>Solid content (%)</td>
<td>52</td>
<td>45</td>
</tr>
<tr>
<td>Viscosity (Brookfield)</td>
<td>165</td>
<td>700</td>
</tr>
</tbody>
</table>
b. Production of OSL and OSB panels

The panels were produced with oriented particles and non-oriented particles, in a face/core/face composition of 20/60/20. Strand-type particles were used. In this way, the factors ‘type of adhesive’ was evaluated, being phenol-formaldehyde and Tannin-formaldehyde and ‘particle distribution’.

The nominal density of the panels was established at 0.65 g/cm³, with a thickness of 10 mm.

Table 2. Experimental model for panel production

<table>
<thead>
<tr>
<th>Panel type</th>
<th>Type of adhesive (%)</th>
<th>Particle distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phenol</td>
<td>Taninn</td>
</tr>
<tr>
<td>P1</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>P2</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>P3</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>P4</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>P5</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>P6</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Source: Authors (2023)

To panels manufacturing, the particles were first prepared, where they were subjected to drying in an oven with forced air circulation at 60 ± 5°C, until they reached humidity between 3 and 5%. After drying, they were placed in plastic containers and sealed, in order to maintain the moisture content.

After packaging the particles, the adhesives were applied, where the particles were first weighed in specific quantities and placed in a gluing machine adapted for applying the adhesives and paraffin emulsion, with the aid of a compressed air gun coupled to a compressor. The phenol-formaldehyde adhesive was applied at a proportion of 6% solids over the dry weight of the particles.

The formation of the particle mattress occurred manually, in order to distribute the particles in a forming box with dimensions of 500 x 500 mm. The particles were distributed randomly or in three layers and, when necessary, the particles were oriented with the help of a laboratory particle advisor, attached to the forming box.

After forming the particle mattress, cold pre-pressing took place for compaction. Next, the mattress was subjected to a hydraulic plate press with electrical heating, together with 10 mm thick limit bars, placed on opposite sides of the mattress, in order to delimit the thickness of the panel, at a specific pressure of 3.92 Mpa, at a temperature of 160°C, for a period of 10 minutes. The panel manufacturing process is illustrated in figure 1.
Figure 1. Panel manufacturing process, where (a) application of the adhesive; (b) formation of the particle mattress; (c) oriented particle mattress; (d) pressing
Source: Authors (2023)

c. **Determination of the physical-mechanical properties of the panels**

After manufacturing and acclimatizing the panels, test specimens were prepared and subjected to physical-mechanical tests. The tests followed the parameters established by the EN 300:2006 standard and complementary standards. The section sketch of the test specimens in the panels is illustrated in figure 2.
Figure 2. Sketch of the test specimens for evaluating properties. (1) Basic density at moisture content and equilibrium moisture content; (2) Traction perpendicular to the panel faces; (3): Static bending in a parallel direction; (4): Static bending in the perpendicular direction; (5): Water absorption and thickness swelling. Source: Authors (2023)

To evaluate the physical properties of the panels, basic density tests were carried out at equilibrium moisture content, moisture content, water absorption after 2 and 24 hours of immersion in water and thickness swelling after 2 and 24 hours of immersion in water (Table 3).

<table>
<thead>
<tr>
<th>Test</th>
<th>Symbol</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic density</td>
<td>BD</td>
<td>EN 300</td>
</tr>
<tr>
<td>Moisture content</td>
<td>MC</td>
<td>EN 312 (2003)</td>
</tr>
<tr>
<td>Water absorption after 2h of immersion</td>
<td>WA 2h</td>
<td>EN 300</td>
</tr>
<tr>
<td>Water absorption after 24h of immersion</td>
<td>WA 24h</td>
<td>EN 300</td>
</tr>
<tr>
<td>Thickness swelling after 2h of immersion</td>
<td>TS 2h</td>
<td>EN 300</td>
</tr>
<tr>
<td>Thickness swelling after 24h of immersion</td>
<td>TS 24h</td>
<td>EN 300</td>
</tr>
</tbody>
</table>

Source: Authors (2023)

In evaluating the mechanical properties, static bending tests were carried out in a direction parallel and perpendicular to the particles of the layers on the panel face (MOE and MOR) and tension perpendicular to the panel faces.
Six types of panels were produced, with three replications for each, conducted in a completely randomized design (DIC), using a 2x2 factorial scheme, evaluating two types of adhesives in two particle distributions (Table 2). Once the prerequisites of homogeneity of variances and normal distribution were satisfied, ANOVA was applied, with a 5% probability of error, for the main factors and their interactions. If there were significant differences for the factors, the Tukey test was performed to compare the means.

### 3 RESULTS AND DISCUSSIONS

d. **Physical properties of OSB panels**

The average values of the physical properties of the OSB panels are presented in Table 4. It was possible to observe a statistical difference between the average density values for the different types of panels produced. In this way, the values were adjusted using covariance to analyze the other properties of the panels.

<table>
<thead>
<tr>
<th>Table 4. Mechanical properties of the panel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test</strong></td>
</tr>
<tr>
<td>Static Bending</td>
</tr>
<tr>
<td>Internal bonding</td>
</tr>
</tbody>
</table>

**Source:** Authors (2023)

The nominal density of the panels was established at 0.65 g cm⁻³, however, the average values observed were lower, ranging from 0.59 to 0.63 g cm⁻³, which can be attributed to particle losses and adhesive in the panel production process. The average density values found for all treatments fit into the classification of medium density panels, as they presented values between the ranges of 0.55 to 0.75 g cm⁻³ and 0.60 to 0.80 g cm⁻³ established by standards NBR 14810-2 (2018) and ANSI A280.1 (1993), respectively. Similar results were reported by Gonçalves et al. (2017), which, when evaluating different values of compaction ratio, found average values of 0.64 to 0.80 g cm⁻³, and this variation occurred due to the reduction in urea-formaldehyde solids and also the variation in tannin in dust.

The average moisture content found was 11.4%, also showing a statistically significant difference between the types of panels, a fact attributed to the type of adhesive used. Panels produced with phenol (P1 and P2) presented the lowest values, while panels produced with tannin adhesive (P3 and P4) presented higher values, although they are within the range established by standard EN 312 (2003), which establishes values between 5 and 13%. These values were above those found by Gomes et al. (2020), which were 7.35%.

<table>
<thead>
<tr>
<th>Table 5. Average values of the physical properties of OSB panels.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
</tr>
<tr>
<td>P1</td>
</tr>
<tr>
<td>P2</td>
</tr>
<tr>
<td>P3</td>
</tr>
<tr>
<td>P4</td>
</tr>
<tr>
<td>P5</td>
</tr>
<tr>
<td>P6</td>
</tr>
<tr>
<td>CV Average (%)</td>
</tr>
</tbody>
</table>

**Note:** P: Panel; F: Phenol adhesive; T: Tannin adhesive; F+T: Phenol + Tannin; BD: Basic density; MC: Moisture Content; WA: Water absorption; TS: Thickness Swelling; CV: Coefficient of variation. Means followed by the same letter do not differ statistically from each other using the Tukey test, at a 5% error probability level.

**Source:** Authors (2023)
The average values for water absorption varied between 39.0 and 65.6%. It was observed that panels produced with tannin presented the lowest values for this property, and panels produced with phenol presented the highest values. These results corroborate those found by Gonçalves et al. (2017), who, in the production of particle board with the presence of 10 and 20% tannin, observed a reduction in water absorption values after 2 and 24 hours of immersion. Carvalho et al. (2015) observed values of 28% for this property when producing panels using barbatimão and acacia tannin.

For thickness swelling (TS), the average values found varied between 16.5 and 26.5%. It was observed that the panel produced with tannin and with particle orientation (P4) presented the lowest value for TS, although there was no statistical difference with the panel produced without particle orientation (P3). Comparing the average values of TS for the panels, with the EN 300 (2006) standard, which establishes values between 20 and 25%, it was observed that panels produced with phenol and particle orientation (P2) and panels produced with mixture of the two adhesives, but without particle orientation (P5), presented values above those allowed for OSB types I and II. Gonçalves et al. (2017), in the manufacture of particle boards using urea-formaldehyde with the addition of powdered tannin, observed values for TS that varied between 24.05 and 51.48%, above the values found in the present study, a fact that can be attributed to the characteristics of the adhesives.

Carvalho et al. (2015), in the production of OSB using Pinus oocarpa wood, with a density of 0.65 g/cm³ and commercial adhesives and tannin from barbatimão and acacia, found WA and TS values of 27% and 28%, respectively, these values higher than those found in the present study.

Afterwards, the Tukey test was performed to evaluate the effects of the adhesives on the physical properties of the panels. The values are presented in Table 5.

Table 5. Influence of the type of adhesive on the physical properties of OSB panels.

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>D (g/cm³)</th>
<th>MC (%)</th>
<th>WA (%)</th>
<th>TS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.61 a</td>
<td>10.4 a</td>
<td>62.8 c</td>
<td>25.6 b</td>
</tr>
<tr>
<td>T</td>
<td>0.60 a</td>
<td>11.7 b</td>
<td>54.7 b</td>
<td>23.1 ab</td>
</tr>
<tr>
<td>F + T</td>
<td>0.59 a</td>
<td>12.1 c</td>
<td>39.2 a</td>
<td>19.8 a</td>
</tr>
</tbody>
</table>

Note: F: Phenol adhesive; F+T: Phenol + Taninn; T: Taninn adhesive; MC: Moisture content; WA: Water absorption; TS: Thickness swelling. Means followed by the same letter do not differ statistically from each other using the Tukey test, at a 5% error probability level.

Source: Authors (2023)

From the results, it was possible to observe that the type of adhesive used in the manufacture of the panels significantly influenced the properties of moisture content, water absorption and swelling in thickness. This fact was observed by Iwakiri et al. (2012), who found that, as the resin content in the inner layer and outer layers increased, there were positive effects on the water absorption properties and thickness swelling of the panels.

For the properties of water absorption and thickness swelling, using the phenol-formaldehyde adhesive, the values found can be attributed to the difficulty in manufacturing the panels, which occurred manually, making handling difficult, resulting in an inefficient distribution of the adhesive over particles, contributing to the decrease in values and consequently in the quality of the final product. Lopes Júnior et al. (2021) found that the resin influenced the physical properties, when using castor bean polyurethane resin, it provided panels with lower absorption rates, making them more stable in terms of hygroscopicity.
e. Mechanical properties of OSB panels

The effect of using different types of adhesives on the mechanical properties of the panels can be observed from the average values presented in table 6.

Table 6. Average values for the mechanical properties of OSB panels

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adhesive</th>
<th>Orientation</th>
<th>Bend // (MPa)</th>
<th>Bend + (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>MOR</td>
<td>MOE</td>
</tr>
<tr>
<td>P1</td>
<td>F</td>
<td>Random</td>
<td>16.8 ab</td>
<td>1633.5 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.8 a</td>
<td>2075.2 ab</td>
</tr>
<tr>
<td>P2</td>
<td>F</td>
<td>Oriented</td>
<td>15.0 ab</td>
<td>1543.3 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.6 bc</td>
<td>1440.3 c</td>
</tr>
<tr>
<td>P3</td>
<td>T</td>
<td>Random</td>
<td>19.0 a</td>
<td>1861.0 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.9 bc</td>
<td>1596.8 bc</td>
</tr>
<tr>
<td>P4</td>
<td>T</td>
<td>Oriented</td>
<td>13.1 b</td>
<td>1491.0 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.8 c</td>
<td>1562.5 bc</td>
</tr>
<tr>
<td>P5</td>
<td>F + T</td>
<td>Random</td>
<td>17.9 a</td>
<td>1828.2 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.8 a</td>
<td>2156.0 a</td>
</tr>
<tr>
<td>P6</td>
<td>F + T</td>
<td>Oriented</td>
<td>15.88 ab</td>
<td>1872.1 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.2 ab</td>
<td>2162.1 a</td>
</tr>
<tr>
<td>CV Average (%)</td>
<td></td>
<td></td>
<td>19.6</td>
<td>18.4</td>
</tr>
</tbody>
</table>

Note: //: parallel; +: Randon orientation; F: Phenol adhesive; F+T: Phenol and Taninn; T: Taninn adhesive; MOR //: Modulus of rupture; MOE //: Modulus of elasticity; CV: Coefficient of variation. Means followed by the same letter do not differ statistically from each other using the Tukey test, at a 5% error probability level.

Source: Authors (2023)

Statistical analysis detected statistical differences in the values of static bending properties between the different types of panels produced, with the exception of the modulus of elasticity, in the parallel direction. The average values for the modulus of elasticity and modulus of rupture, in the parallel direction, varied between 1491.0 to 1872.1 MPa and 13.1 to 19.0 respectively. These values are below the minimum value required by standard EN 300 (2006). Cunha et al. (2014) found average values for MOE and MOR of 1740.67 to 2213.07 MPa and 11.66 to 15.42 MPa, respectively, similar to those found in the present work.

Comparing the values observed with the requirements established by standard EN 300 (2003), the average values for MOR in the perpendicular direction for panels P2, P3 and P4 met the classification requirements for OSB types I, II and III, while the panels P1, P5 and P6 classified as type IV. For MOE, panels P2, P3 and P4 were classified as OSB types I, II and III, with panels P1, P5 and P6 as OSB type IV. It was therefore observed that, for both properties, the treatment classifications were the same.

Carvalho et al. (2015), when producing OSB panels using Pinus oocarpa wood, with a density of 0.65 g cm$^{-3}$ and commercial adhesives and tanin from barbatimão and acacia, they observed average values for MOE and MOR in the parallel direction of 2986 and 15.1 MPa respectively. For the perpendicular direction, values of 1212 MPa for MOE and 11.7 MPa for MOR, values close to those found in the present study.

A decrease in the modulus of elasticity values of the panels was observed, a factor attributed to cracks inside the panels, in addition to bubbles and failure in the distribution of adhesives, which occurred during the manufacturing process. Ferro et al. (2019) in the production of hybrid panels, found the highest values of modulus of elasticity for OSB, since the longer particles used in its manufacture, in the direction parallel to the fibers, contributed to the increase in these values.

For the MOR property in the parallel direction, panels produced with a mixture of adhesives and with random distribution of particles showed higher values compared to panels with oriented particles. However, the panels produced without the mixture of adhesives showed no statistical difference between those with and without particle orientation. The orientation of particles with 20% in the parallel direction on each external face of the panel should improve the parallel MOR values, which did not occur in the present work.

The average values for the adhesive type factor, evaluated in the present work, are presented in table 6.
### Table 6. Average MOR and MOE values of OSB panels by type of adhesive used

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>MOR // (Mpa)</th>
<th>MOE // (Mpa)</th>
<th>MOR + (Mpa)</th>
<th>MOE + (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>15.9 a</td>
<td>1589.4 a</td>
<td>18.2 b</td>
<td>1757.7 a</td>
</tr>
<tr>
<td>T</td>
<td>16.8 a</td>
<td>1850.1 a</td>
<td>20.0 b</td>
<td>2163.5 b</td>
</tr>
<tr>
<td>F + T</td>
<td>16.03 a</td>
<td>1675.9 a</td>
<td>15.3 a</td>
<td>1757.7 a</td>
</tr>
</tbody>
</table>

**Note:** F: Phenol; F+T: Phenol and Tanin; T: Tanin adhesive; MOR: Modulus of rupture; MOE: Modulus of elasticity; //: Parallel; +: Perpendicular. Means followed by the same letter do not differ statistically from each other using the Tukey test, at a 5% error probability level.

**Source:** Authors (2023)

A statistical difference was observed for the MOE and MOR values in the perpendicular direction in the panels where the adhesives were mixed, when compared to the use of pure adhesives. For the other properties, no statistical differences were observed. This fact was also observed by Gonçalves et al. (2017) that, as the proportion of powdered tannin to particles bonded with urea-formaldehyde increases, the mechanical properties increased. Lopes Júnior et al. (2021) found variations in mechanical properties depending on the resin content used. Using castor bean polyurethane resin, they verified that the mechanical properties met the requirements of the EN 300/2002 standard for type 1 OSB boards, recommended for indoor environments. OSB panels produced with a density of 400 kg/m³ and 15% of castor oil polyurethane resin had better mechanical properties compared to the other treatments evaluated with lower density or lower resin content (BARBIRATO et al., 2018). The adhesively bonded faces and trapezoidal core performed well during mechanical characterizations, proving that castor oil polyurethane has potential for application as an adhesive (BARBIRATO et al., 2022).

### 4 CONCLUSION

Analyzing the results for the physical properties of the panels, it was observed that the mixture of phenol-formaldehyde and Tannin-formaldehyde adhesives provides minimum values recommended by current standards.

Regarding mechanical properties, it was not possible to determine the best type of adhesive to be used, as the results demonstrated an equivalence between the two types of adhesives used, as well as the mixture between the two.

It was also observed that the use of mixtures with 50% of each adhesive can be used in the OSB panel production process, enabling new adhesive alternatives for industries, since adhesives represent high production costs.

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### REFERENCES


BARROS FILHO, R. M. (2009). Painéis aglomerado a base de bagaço de cana-de-açúcar e resinas uréia formaldeído e melamina formaldeído (Dissertação de Mestrado). Curso de Engenharia de Materiais – Processos de Fabricação, Departamento de Engenharia de Materiais, Rede Temática em Engenharia de Materiais, Ouro Preto.


FERREIRA, E. S.; LELIS, R. C. C.; BRITO, E. O.; NASCIMENTO, A. M.; MAIA, J. L. S. 
Teores de taninos da casca de quatro espécies de pinus. *Floresta e Ambiente*, 

FERRO, F. S.; ALMEIDA, T. H. de; SOUZA, A. M. de.; ALMEIDA, D. H. de.; 
CHRISTOFORETO, A. L.; LAHR, F. A. R. Painel híbrido OSB/MDP de madeira Pinus taeda e 
resina poliuretana à base de óleo de mamona. *Ambiente Construído*, Porto Alegre, v. 19, n. 3, 

Forest Products Laboratory - FPL. (2010). Wood handbook—Wood as an engineering material. 
*General Technical Report FPL-GTR-190*. Madison, WI, USA.

RAMOS, W. Q. Caracterização física de painel tipo OSB de Eucalyptus spp. aglutinado com 
resina de policloreto de vinil (PVC) reciclado. Brazilian Journal of Animal and 

Chapas aglomeradas confeccionadas com ureia-formaldeído sob adição de tanino em pó. 

HELLMEISTER, V. Painel OSB de resíduo de madeira Balsa (Ochroma pyramidale). Tese (Doutorado em Engenharia e Ciência de Materiais) – Faculdade de Zootecnia e Engenharia de 
Alimentos, Universidade de São Paulo, Pirassununga, 2018.

HEMMILÄ, V.; ADAMOPOULOS, S.; KARLSSON, O.; KUMAR, A. Development of 
sustainable bio-adhesives for engineered wood panels - a Review. RSC Advances, 7 (61), 

IWAKIRI, S.; MENDES, L. M.; SALDANHA, L. K. Produção de chapas de partículas 
orientadas “OSB” de Eucalyptus grandis com diferentes teores de resina, parafina e composição 

aglomerados homogêneos e multicamadas de *Melia azedarach* (cinamomo) e *Pinus taeda* com 

LOPES JUNIOR, W.E.; BARBRARITA, G. H. A.; PAVEIS, M.; SORIANO, J.; FIORELLI, J. 
Avaliação do teor ótimo de resinas orgânicas para produção de painéis OSB de madeira Balsa 

PAES, J. B.; DINIZ, C. E. F.; LIMA, C. R.; BASTOS, P. M.; NETO, P. N. M. Taninos 
condensados da casca de angico-vermelho (*Anadenanthera colubrina var. cebil*) extraídos com 
soluções de hidróxido e sulfito de sódio. Revista Caatinga, Mossoró, v. 26, n. 3, p. 22 – 27, 

PLENZLER, R.; NIEWIADOMSKA, L.; MIELCAREK, P. Shear and bending properties of 


