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**Articles**

# Physical-mechanical performance and heat transfer analysis of OSB with ZnO nanoparticles

## Desempenho físico-mecânico e análise de transferência de calor em painéis OSB com nanopartículas de ZnO

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## ABSTRACT

The use of nanotechnology has been growing in the last decade due to its different properties when compared to macro-scale material. In the wood composites area, nanoparticles are used in order to reduce its hygroscopicity and improve its protection against decay. The aim of this work was to evaluate the physical-mechanical performance and heat transfer inside OSB (Oriented Strand Board) produced with pine wood and castor oil (Ricinus communis L.) polyurethane adhesive with addition of zinc oxide nanoparticles in two different percentages (0.25 and 0.50%) and compare them with the control treatment). The tests performed were density, moisture content, swelling in thickness, static bending and screw withdraw, according to European standards. At the end of the tests, a statistical analysis was performed, through the ANOVA test, with a 5% significance level to verify whether there was difference between the means. The properties of the studied panels were not influenced by the addition of nanoparticles, due the small amount of nanoparticles added. In heat transfer, the panels without the addition of nanoparticles reached a higher temperature compared to treatments with nanomaterial, however, none reached the desired temperature of 100°C. The panels produced attended the class 1 of OSB panels, except in swelling in thickness.

**Keywords**: Wood composite; Physical-mechanical characterization; *Pinus elliottii*

## RESUMO

O uso da nanotecnologia tem sido crescente na última década, devido às suas propriedades diferenciadas quando comparada ao material usado em macro escala. Na indústria de painéis, as nanopartículas são utilizadas com o intuito de reduzir sua higroscopicidade, assim como melhorar as propriedades físico-mecânicas. O objetivo do presente trabalho foi avaliar o desempenho físico-mecânico e a transferência de calor no interior de painéis OSB (*Oriented Strand Board*) produzidos com madeira de *Pinus elliotti* Engelm e resina poliuretana à base de óleo de mamona (*Ricinus communis* L.) com adição de nanopartículas de óxido de zinco em dois diferentes teores (0,25% e 0,50%) e compará-los com o tratamento de controle. As propriedades determinadas foram densidade, teor de umidade, inchamento em espessura, resistência à flexão estática e arrancamento de parafuso, seguindo as orientações de normas europeias. Ao fim dos ensaios, foi realizada a análise estatística, através da ANOVA, com nível de 5% de significância para verificar se houve diferença significativa entre as médias. As propriedades físico-mecânicas dos painéis estudados não foram influenciadas pela adição de nanopartículas nas porcentagens avaliadas, sendo explicada pela diminuta quantidade de nanopartículas adicionadas. Na transferência de calor, os painéis sem adição de nanopartículas alcançaram uma temperatura superior em relação aos tratamentos com nanomaterial, entretanto, nenhum atingiu a temperatura desejada de 100°C. Os painéis produzidos atenderam a classe 1 de painéis OSB, exceto no inchamento em espessura.

**Palavras-chave**: Compósito de madeira; Caracterização físico-mecânica; *Pinus elliottii*

## 1 INTRODUCTION

The OSB panel (Oriented Strand Board) is composed of three layers of wood strands oriented perpendicular to each other, bonded under the influence of pressure, temperature, and adhesive addition. According to Mendes, Mendes, Protásio, Oliveira, Carvalho and Farrapo (2015), the main applications of this type of panel include walls, floors, furniture, ceilings, beam components, and packaging.

OSB has structural properties; however, a limiting factor for its use is its low dimensional stability when exposed to water or humidity. According to Uyup, Khadiran, Husain, Salim, Siam and Hua (2019), one way to address this issue is the incorporation of nanoparticles.

The utilization of nanoparticles has rapidly increased in recent years due to their unique properties, such as surface area, nanoscale size, reactivity, charge, and shape (Bundschuh; Filser; Lüderwald; Mckee; Metreveli; Schaumann; Schulz; Wagner, 2018). Nanoparticles find applications across various fields.

In the forestry sector, the addition of nanoparticles has been studied in wood (Salla; Pandey; Srinivas, 2012; Filpo; Palermo; Rachiele; Nicoletta, 2013), MDF panels (Silva; Ferreira; Favarim; Silva; Silva; Azambuja; Campos, 2019a), and particleboard panels (Silva; Lima; Chahud; Christoforo; Lahr; Favarim; Campos, 2019b; Silva; Lima; Campos; Favarim, 2021a). The addition of nanoparticles to wood panels results in improved mechanical properties, greater dimensional stability, enhanced thermal process efficiency, and an easy and cost-effective implementation (Roumeli; Papadopoulou; Pavlidou; Vourlias; Bikiaris; Paraskevopoulos; Chrissafis, 2012; Silva; Lima; Campos; Favarim, 2021a). However, very little has been studied about the incorporation of nanoparticles into OSB panels.

Another material gaining ground in the panel industry is castor oil-based polyurethane resin (*Ricinus communis* L.). According to Cravo, Sartori, Fiorelli, Balieiro and Savastani Junior (2015), this resin demonstrates suitable performance to replace other commercial resins in panel manufacturing. Paes, Nunes, Lahr, Nascimento and Lacerda (2011) suggest that this adhesive, in addition to being derived from a renewable and abundant raw material in Brazil, poses no risks to humans or the environment.

Christoforo, Nascimento, Panzera, Ribeiro Filho and Lahr (2016) add that castor oil-based polyurethane resin offers advantages such as handling at room temperature, resistance to ultraviolet radiation, and high mechanical and water resistance.

Therefore, the aim of the current study was to evaluate the influence of zinc oxide nanoparticles on the properties of density, moisture content, thickness swelling, static bending strength, and screw withdrawal strength of OSB panels produced with castor oil-based polyurethane resin.

## 2 MATERIALS E METHODS

The OSB panels were produced with *Pinus elliottii* strands from trees from the region of Ribeirão Branco, state of São Paulo, donated by the company Vale do Cedro and polyurethane resin based on castor oil AGT 1315 from the company Imperveg bicomponent (pre- polymer and polyol), with a solids content of 100% and that does not release toxic vapors.

The nominal dimensions of the panels produced for this study were 42 cm x 42 cm x 1.3 cm (length x width x thickness, respectively), based on the EN 326-1 (1994) standard. Each panel was produced with three perpendicular layers, following the proportions of 30:40:30 based on mass.

Two treatments were carried out: the first with the addition of 0.25% of nanoparticles in relation to the adhesive mass, denoted as PU0.25%, and the second with the addition of 0.50%, denoted as PU0.50%. These treatments were compared with the control treatment, which had no nanoparticle addition, denoted as PU0.0%.

The nanoparticles were produced in the laboratory using the protein sol-gel method, following the methodology of Silva, Ferreira, Favarim, Silva, Silva, Azambuja and Campos (2019a). This protein sol-gel method is a derivative of the conventional sol-gel method, simplified by using lower-cost reagents and not requiring complex chemical processes, ensuring good results.

Metal ion salts were added to a solution containing gelatin. In this process, the introduction of a crystal nucleus occurs within a polymeric matrix, creating a network with “dangling” ions. Later, during the burning process, there is sufficient energy input for the formation of the desired material.

Next, the material was calcined at 550°C for 3 hours. X-ray and micrographs of the nanoparticles were then obtained, with the latter being performed by dispersing the sample as powder on a double-sided carbon tape without the need for gold coating.

The panel manufacturing process began with cutting the wood planks and immersing them in water to reduce the production of fines and prevent chip twisting during fabrication. The strands were produced by a disk chipper with nominal dimensions of 10 cm x 2 cm x 0.7 mm (length x width x thickness, respectively).

Afterwards, the chips were dried in the open air, classified in a 5-mesh sieve and dried in an oven at 103°C until constant mass (Figure 1A). The adhesive amount used was 10% in relation to the dry mass of the strands, and the ratio between the two adhesive components was 1:1 (Figure 1B). The nanoparticles, as shown in Figure

1C, were mixed with the adhesive and applied manually, followed by homogenization using a glue spreader (Figure 1D).

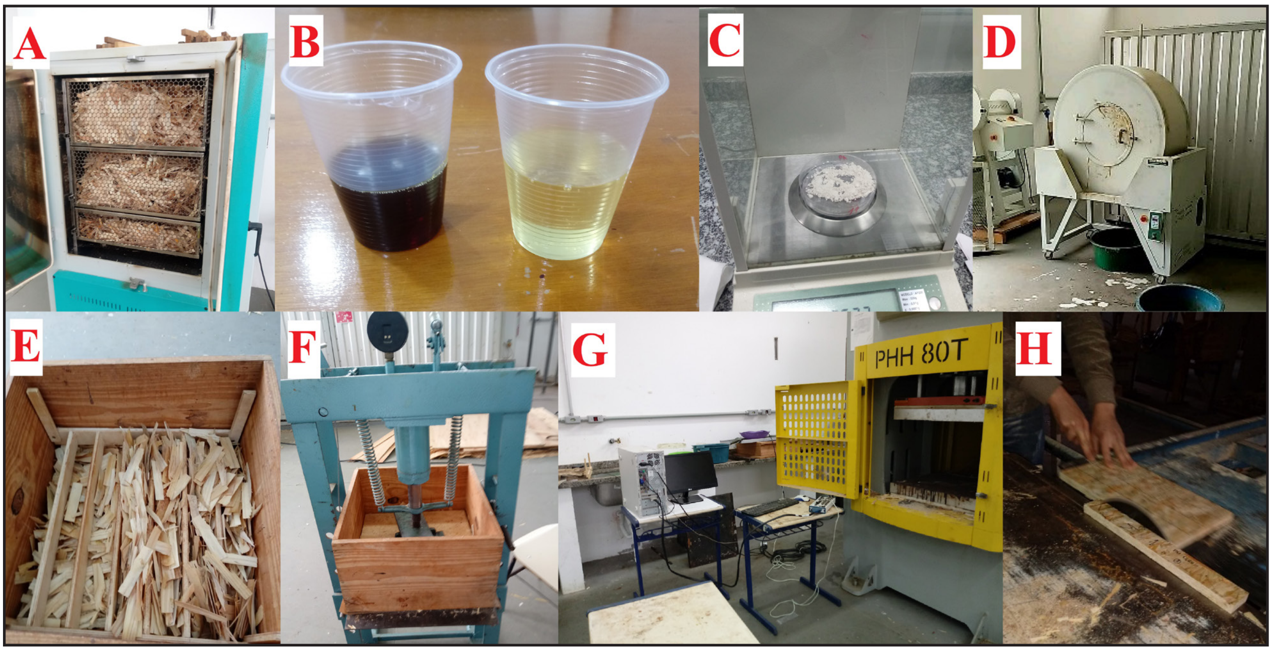
During the mattress assembly (Figure 1E), a type K thermocouple was inserted inside the panels for temperature acquisition, which was evaluated during the pressing process using the National Instruments DAQ system.

Before panel pressing, a pre-pressing step was performed for 5 minutes at a pressure of 0.1 MPa (Figure 1F).

The pressing variables were: a temperature of 100°C, a pressure of 4 MPa, and a pressing time of 10 minutes, divided into three pressing cycles of 3 minutes and two pressure relief cycles of 30 seconds each (Figure 1G).

After pressing, the panels were placed in a controlled temperature and humidity environment and then sectioned, as illustrated in Figure 1H, following the EN 326-1 (1994) standard. Figure 1 shows some stages of the panel manufacturing process.

Figure 1 – Steps of OSB production

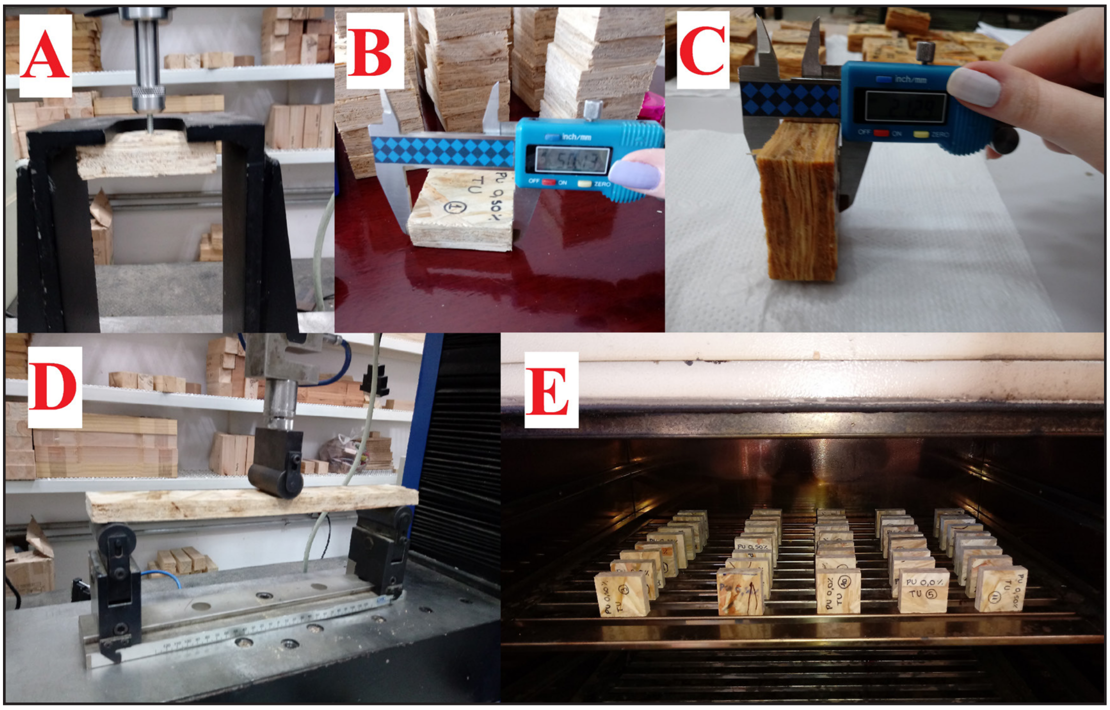



Source: Authors (2021)

In where: A is oven drying of *Pinus elliotti* strands, B polyurethane adhesive, where the dark component is the pre-polymer (on the left) and the light component the polyol (on the right), C ZnO nanoparticles inside the petri dish, D gluing machine, E mattress formation, F pre-pressing stage, G pressing and data acquisition and H cutting the samples.

The physical-mechanical tests performed were: density (EN 323/1993), moisture content (EN 322/1993), 24-hour thickness swelling (EN 317/1993), screw withdraw resistance on the face (EN 320/2011) and determination of the modulus of elasticity (MOE) and modulus of ruptue (MOR) to static bending in the parallel and perpendicular directions of the panel (EN 310/1993), the screw withdraw test was not carried out at the top, since the thickness of the panel was less than 15 mm. Figure 2 shows the performance of some test steps.

Figure 2 – Physical and mechanical testing of OSB




Source: Authors (2021)

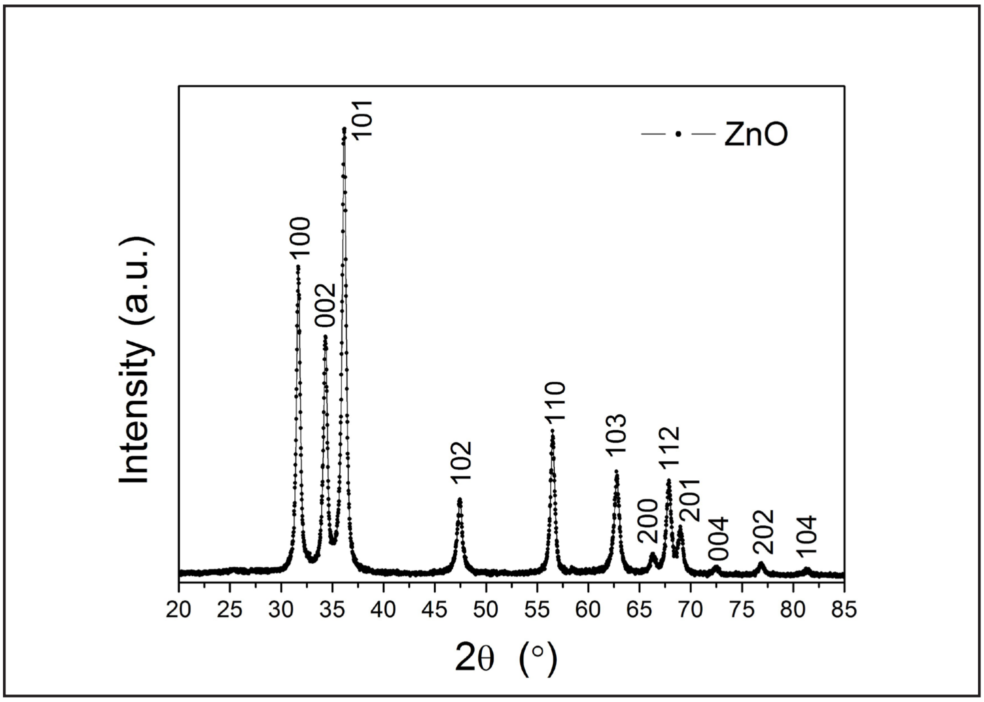
In where: A screw withdraw test, B density test, C swelling in thickness test, D static bending test and E moisture content test.

At the end of the tests, statistical analysis was performed at a 5% significance level to verify whether there was a significant difference between the means, through ANOVA, linear regression analysis was also performed for each test, using the R software version 4.1.1. (2021).

## 3 RESULTS AND DISCUSSIONS

The protein sol-gel technique has proven to be highly effective in synthesizing ZnO nanoparticles, utilizing low-cost reagents and lower calcination temperatures compared to traditional methods. The X-ray diffraction pattern of the ZnO nanoparticles, as well as the crystallographic plane associated with each peak, is illustrated in Figure 3. The presence of narrow and well-defined peaks indicates that the synthesis resulted in a single-phase material with good crystallinity. A comparison of the results with the JCPDS (Joint Committee on Powder Diffraction Standards) standards reveals a compact hexagonal wurtzite structure, consistent with the JCPDS 36-1451 standard. The crystallite size was estimated from the line width of the first 5 diffractogram peaks using the Scherrer equation, yielding an estimated value of 22 nm.

Figure 3 – X-ray diffraction graph of nanoparticles

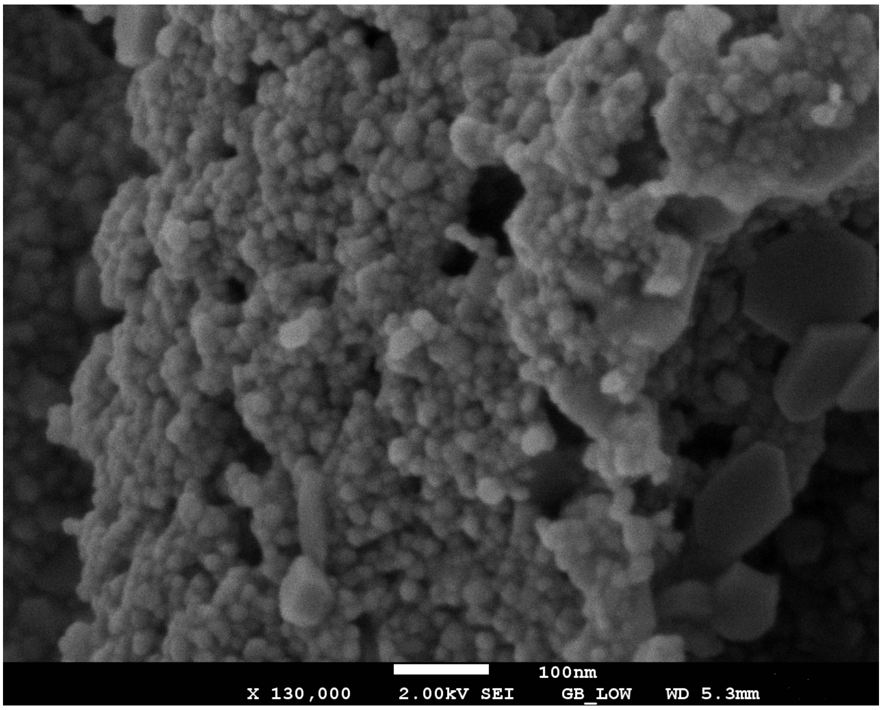



Source: Authors (2021)

Figure 4 shows the micrograph of the nanoparticles. It is evident that well-defined grains are present, without a predominant shape and with a wide range of sizes, ranging from 10 nm to structures close to 70 nm, with an average size of 19 nm when excluding the large plates presented in the lower corner. This result aligns with the X-ray diffraction analysis, which estimated a size of 22 nm.

Mantanis and Papadopoulos (2010) suggest that the reduced size of the nanoparticles used is crucial for deep penetration into the wood, altering its surface and enhancing moisture resistance.

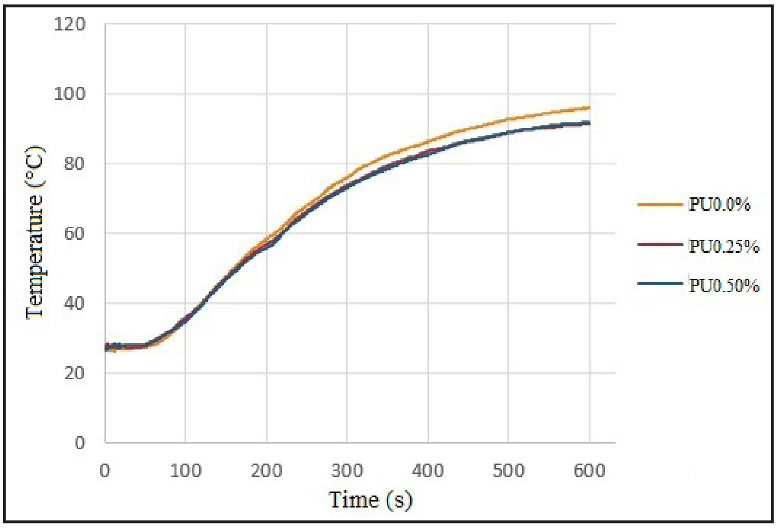
Figure 4 – Nanoparticles micrograph




Source: Authors (2021)

Figure 5 shows the temperature variation graph during the pressing of the panels in the control and two treatments, where the moving average method was applied for noise reduction.

Figure 5 – Changes in the middle layer temperature during OSB pressing




Source: Authors (2021)

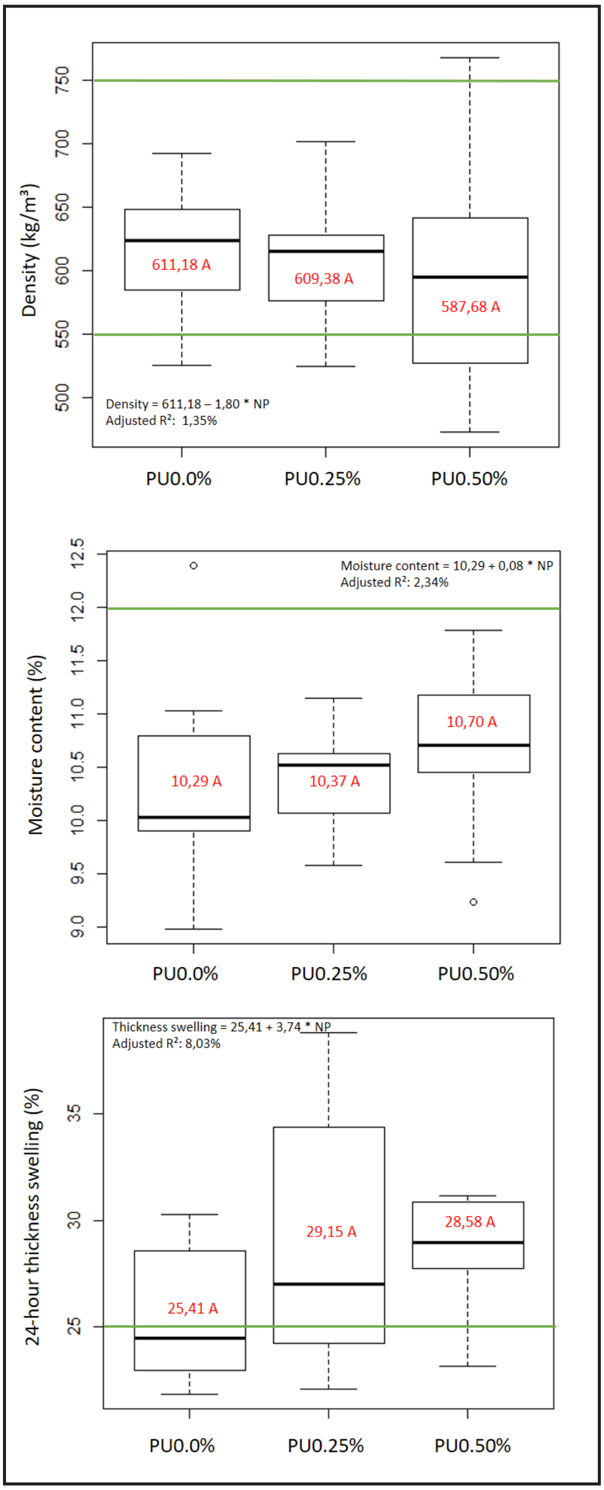
In where: PU0.0% the control treatment, PU0.25% the treatment with the addition of 0.25% of nanoparticles and PU0.50% the treatment with the addition of 0.50%

As observed, at the beginning of the pressing, all three treatments exhibited similar behaviors. However, starting around three minutes into the pressing process, the treatment without the addition of nanoparticles began to show a rise in temperature compared to the others, which persisted until the end of the pressing.

A similar phenomenon occurred in the MDP panels studied by Silva, Lima, Campos and Favarim (2021a) with the addition of nanoparticles of copper and aluminum oxides, attributed to the refractory effect. This effect does not allow uniform curing of the resin, since part of the thermal energy does not access the interior of the panel and is retained at the edges, compromising the attainment of the correct curing temperature for the applied time.

Figure 6 presents the results of the physical tests for the two treatments and the control.

Figure 6 – Results of the physical tests of the OSB panels of Pinus elliottii produced with ZnO nanoparticles




Source: Authors (2021)

In where: The mean, and statistical analysis, where equal letters indicate that there is no significant difference between the treatments at a 5% significance level. The horizontal line indicates the normative limits. NP means the percentage of added nanoparticle

For the density test, the ABNT NBR 14810-1 (2013) standard indicates that panels with densities between 550 and 750 kg/m³ are considered of medium density, and the tested specimens fit within this range.

Although there was no statistically significant difference, there is an observed trend of decreasing density with an increasing percentage of nanoparticles. A similar phenomenon was observed by Lima, Silva, Ferreira, Morais, Bertolini, Barreiros, Azambuja, Caraschi, Favarim and Campos (2022) when adding aluminum nanoparticles to Pinus spp. OSB panels with phenol-formaldehyde resin. This reduction in density can be attributed to the refractory effect, which leads to a faster curing of the adhesive in some parts of the panel, preventing complete compaction.

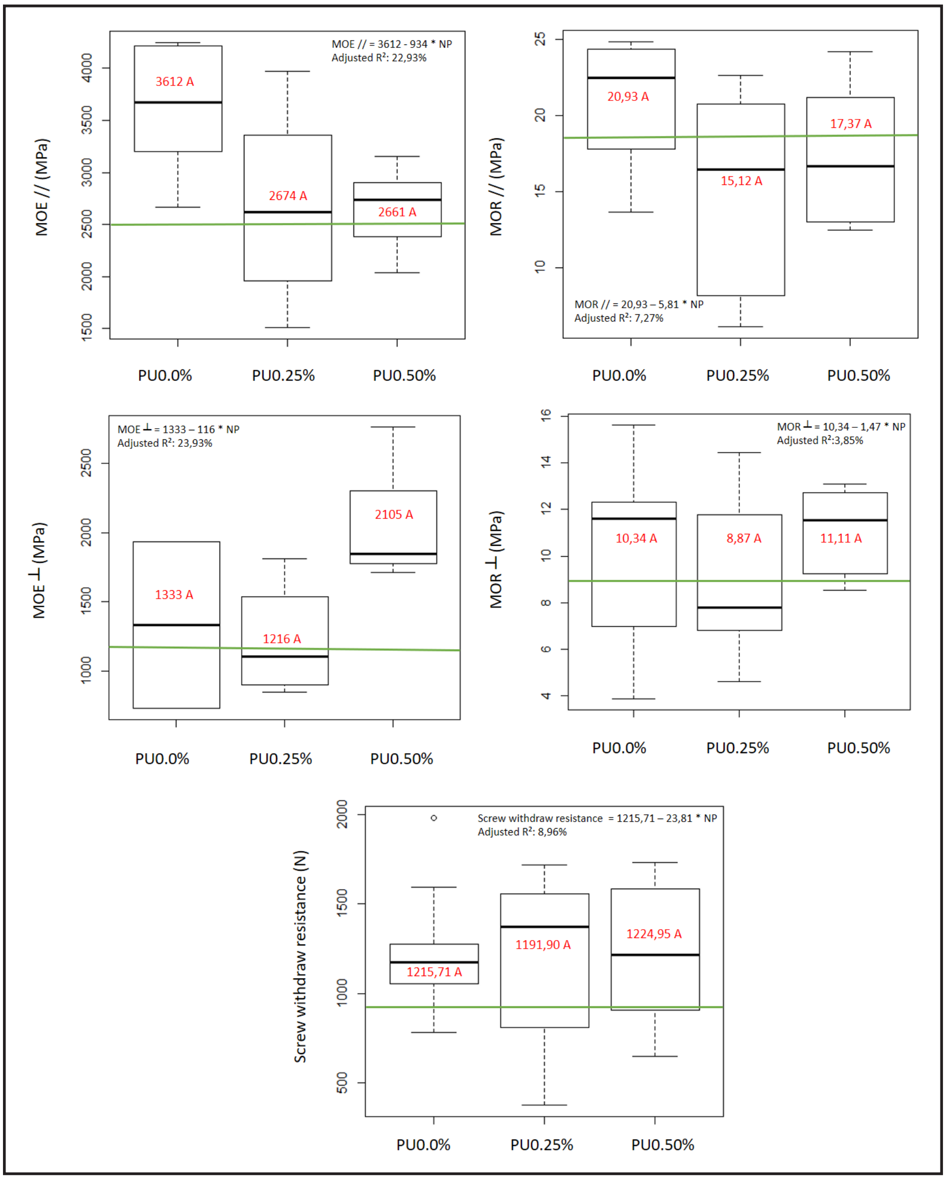
The moisture content values for the tested panels, both in the control and the two treatments, remained below the 12% threshold established for commercial panels (Arauco, 2023). These results are consistent with those found by Antunes, Rios, Cunha, Terezo, Archer, Flórez, Vieira and Buss (2019) for waferboard panels made from Pinus taeda wood and phenol-formaldehyde resin, where the density was also higher, and the moisture content similar to those obtained in the present study.

The EN 300 (2006) standard sets a limit of up to 25% thickness swelling for Type 1 OSB panels after 24 hours of water exposure. The analyzed treatments exceeded this value, which can be attributed to the high porosity resulting from the reduction in panel density.

Figure 7 presents the results of the mechanical tests for the three treatments.

In the static bending test, both in the parallel (//) direction to the orientation of the strands in the outer layers and in the perpendicular (⊥) direction, the treatments fit within the class of Type 1 OSB, as specified in the EN 300 (2006) standard. The normative limits are 2500 MPa for MOE //, 18 MPa for MOR //, 1200 MPa for MOE ⊥, and 9 MPa for MOR ⊥. The Type 1 OSB panel class encompasses non-structural panels for indoor use in dry environments.

Figure 7 – Results of the mechanical tests of the OSB panels of *Pinus elliottii* produced with ZnO nanoparticles




Source: Authors (2021)

In where: The mean, and statistical analysis, where equal letters indicate that there is no significant difference between the treatments at a 5% significance level. The horizontal line indicates the normative limits. NP means the percentage of added nanoparticle

The ANSI A208.1 (2016) standard specifies a minimum value of 900 N for screw withdrawal strength for medium-density panels. All the tested treatments exceeded this value. The results obtained were also superior to those reported by Silva, Silva, Ferreira, Fiorelli, Christoforo and Campos (2021b) for OSSB panels produced with soy straw and polyurethane resin.

In MDF panels produced by Silva (2018) with zinc oxide nanoparticles, the mechanical properties were adversely affected by the addition of the nanomaterial due to increased resin viscosity. In the present study, after the addition of nanoparticles to the adhesive, the viscosity of the adhesive increased slightly, but this did not affect the mechanical performance of the panel in all analyzed properties.

In all conducted tests, there was no statistically significant difference at a 5% significance level between the treatments. This can be attributed to the small quantity of nanoparticles added to the panel, as the percentage was relative to the adhesive mass. Additionally, none of the treatments reached the temperature of 100°C inside the panel, which hampered adhesive curing and prevented the attainment of structural mechanical properties.

## 4 CONCLUSIONS

The panels produced can be classified as Type 1 panels, as specified in the EN 300 (2006) standard, for non-structural use in dry environments, except for performance in contact with water.

The addition of zinc oxide nanoparticles did not alter, at a 5% significance level, the physical-mechanical performance of the OSB panels. This can be explained by the minimal amount of nanomaterial added.

Heat transfer within the panels was higher in the treatment without the addition of nanoparticles, likely due to the refractory effect of the metallic oxide. However, none of the treatments reached the desired temperature of 100°C. In future work, it is suggested to add nanoparticles only to the inner layer of the OSB panel to avoid interference with heat transfer at the beginning of the pressing process.

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