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PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD FROM *Eucalyptus grandis* PRODUCED BY UREA FORMALDEHYDE RESIN WITH SiO_2 NANOPARTICLES

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KEYWORDS

thickness swelling, wood-based products, adhesives.

ABSTRACT

The use of nanoparticles appears to be a feasible option for improving the quality of a range of wood-based products. Studies show that they can improve both the physical and mechanical properties of wood and wood-based products. This preliminary study aimed to analyze the influence of SiO_2 nanoparticles on the physical and mechanical properties of wood particleboard. To this end that, panels were produced without the addition of SiO_2 nanoparticles and with the addition of 4% by mass of the urea formaldehyde adhesive used for its production. The results showed that panels produced with the nanoparticles 42% reduction in thickness swelling of the panel. Therefore, the dimensional stability of the panels without decreasing mechanical properties, even when used in small proportions.

INTRODUCTION

Nanoparticles have been the object of study in wood and wood-based products in order to improve some of their physical and mechanical properties. results have been obtained when using these nanoparticles as additives in resins used in the consolidation of wood panels, especially urea formaldehyde resin.

In the work carried out by Rangel et al. (2017), *Eucalyptus urophylla* particleboards were produced with two density variations. Medium-density particleboards did not present satisfactory results in terms of physical properties, but produced good results with regards to mechanical properties when compared to normative values. On the other hand, high-density panels met both physical and mechanical normative requirements. The authors concluded that eucalyptus wood can be used to produce particleboards.

Urea formaldehyde resin has been widely used in the wood-based panel industry for over 100 years. Urea formaldehyde resins have advantages over other adhesives, such as easy handling, low cost, and good performance in wood panels (Lubis et al., 2017). This superior performance in panel production is due to its high reactivity and cost-effective properties. Its disadvantages include low moisture resistance and high emission of formaldehyde. Nowadays, this technology offers the possibility of using additives such as nanoparticles, which have large surface areas and can incorporate new or even modify important properties of the resins, such as reactivity. SiO_2 nanoparticles incorporated in urea formaldehyde resin have been reported to be an option for improving the mechanical properties of this resin (Roumeli et al., 2012).

Thickness swelling is another factor of wood-based panels that have been studied in order to decrease its occurrence. Iwakiri et al. (2012) produced homogeneous and multi-layered particleboards with *Melia azedarach* and *Pinus taeda* wood by varying the resin content. It was verified that the increase in resin content improved the particleboard performance in terms of water absorption and thickness swelling. One option is to explore the solutions that nanotechnology can offer. The small size of nanoparticles allows them to penetrate deep into the wood, effectively modifying the surface chemistry, resulting in an increased protection against moisture (Mantanis & Papadopoulos, 2010).

Taghiyari & Bibalan (2013) incorporated copper nanoparticles into the particles of wood particleboard, which resulted in an improvement in heat transfer during the hot-pressing process, consequently reducing the

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pressing time. Furthermore, the addition of nanoparticles improved the modulus of elasticity (MOE) of the panels and decreased water absorption, which is an important factor for improving the dimensional stability of the panel.

In the study by Mantanis & Papadoulos (2010) with medium density particleboard (MDP), oriented strandboard (OSB), and medium density fiberboard (MDF), the nanotechnological compound SurfaPore^{TM} W, which contains three different sizes of nanoparticles, was added to this compound as a nano-emulsion of paraffin. The results showed a significant reduction in the thickness swelling of panels treated with the nano-emulsion of paraffin.

The study of wood-based panels has gained prominence in recent years, specifically with the goal of improving the physical and mechanical properties of panels. Different materials have been incorporated into the panels where reinforcements such as fibers and special resins can be highlighted, in addition to different treatments, in order to improve some of its properties.

In a study on the use of low-density wood residues and two variations of polyurethane resin, Christoforo et al. (2015) demonstrated the efficiency of these new adhesives in the production of wood particulate panels, both in terms of physical and mechanical performance. The authors have proven that the addition of these new constituents as reinforcement, or even as another adhesive, has improved the overall properties of the panels.

Ferreira et al. (2017) carried out heat treatment in plywood and obtained an improvement in dimensional stability without decreasing the mechanical properties. Silva et al. (2019) studied the addition of ZnO nanoparticles to eucalyptus particleboards, and the results showed that homogenous heat distribution occurred during the pressing stage, which improved physical properties, decreasing the 24 h swelling from 22.2% to 14.9%, and the 24 h absorption from 30.29% to 21.0%. Moreover, the modulus of rupture (MOR) values increased from 11.3 MPa to 14.5 MPa, and the modulus of elasticity (MOE) increased from 1880 MPa to 2510 MPa.

Kumar et al. (2013) studied the use of aluminum oxide nanoparticles mixed with urea formaldehyde resin in the production of MDF. The results showed that the addition of these nanoparticles improved heat transfer during the curing stage, thus reducing the pressing time. This also influenced the physical and mechanical properties of the fiberboard by enhancing its MOR, MOE, and thickness swelling.

Christoforo et al. (2016) evaluated the mechanical properties of particulate panels of *Pinus* wood and polyurethane resin reinforced with laminated composites in an epoxy matrix, and obtained results much higher than the normative specifications in static flexural tests for MOE and MOR determination.

Nanoparticles have also been a good alternative for increasing wood-based product biodeterioration resistance by fungi. This can be observed in the study by Taghiyari et al. (2014), who used silver and copper nanoparticles, which showed a large decrease in the growth of fungal colonies exposed to particleboard treated with nanoparticles.

In the study performed by Zeki & Akbulut (2015), wood particleboards were reinforced with nanoparticles of SiO_2, Al_2O_3, and ZnO at loading levels of 0%, 1%, and 3%. The authors concluded that the use of nanomaterials for the reinforcement of panels affected the physical-mechanical performance, indicating feasibility in the use of these materials as reinforcements in wood particleboards.

Nosáľ & Reinprecht (2017) added zinc oxide nanoparticles to melamine-formaldehyde resin used to impregnate coating papers in panels. The objective of the use of the nanoparticles was to improve the properties of the panels against the attack of bacteria and molds, which was improved by up to 50%.

Rangavar & Hoseiny (2015), when treating particleboard with urea-formaldehyde resin and copper nanoparticles, an increase in the MOR value (12.41 MPa) of the treated panels (6% of nano-copper) with respect to the control panels (11.05 MPa) and it was. The best internal bonding result was obtained for panels treated with 8% nano-copper (0.32 MPa).

Based on the foregoing information, this preliminary study aimed to evaluate the influence on the physical and mechanical properties of wood particleboards by adding SiO_2 nanoparticles in the urea formaldehyde adhesive used in the production of these boards.

MATERIAL AND METHODS

In this study, particleboards were produced with *Eucalyptus grandis* particles and urea formaldehyde adhesive. SiO_2 nanoparticles that were 30 nm in length were added to the adhesive. These nanoparticles were characterized in earlier studies (Goveia et al., 2011). However, panels without the addition of nanoparticles were also produced. Four panels of each type were produced with measurements of 420 mm × 420 mm × 13 mm.

Initially, *Eucalyptus grandis* wood was processed using a laboratory chipper with four knives to produce chips. These chips were then converted into particles using a Wiley mill (Thomas Scientific). Subsequently, the particles were passed through in a sieve shaker, where particles of 9, 16, 35, and 60 mesh were obtained.

For the formation of the mattress, 1330 g of particles was used per panel. The core layer was made using 1000 g of 9- and 16-mesh particles in equal proportions. Each of the two outer layers was made using 165 g of 35- and 60-mesh particles, in equal proportions.

The adhesive used contained 10% of urea formaldehyde resin based on the particle dry weight, 2% water, and 1% catalyst (ammonium sulfate) for the outer layers, and 8% of urea formaldehyde resin based on the particle dry weight, 2% water, and 1% catalyst for the core layers. The nanoparticles were added to the adhesive in a proportion of 4% relative to the urea formaldehyde resin weight.

Firstly, the adhesive was mixed with the particles until complete homogenization was achieved. Then, the blend was placed in the forming box and compressed to obtain the mattress (Figure 1a). Following compaction, the forming box was removed (Figure 1b), and the mattress was subjected to hot-pressing for 10 min (3 cycles of 180 s with two intervals of 30 s between them) at a temperature of 160 °C and pressure of 40 kgf cm^{-2} in a hydraulic press (Figure 1c).

(a) (b) (c)

FIGURE 1. Production of the particleboards: (a) forming box, (b) particle mattress, and (c) hot-pressing.

The panels were placed in a climatic chamber until the completion of the resin curing process for 72 h, at a relative humidity of 60% and temperature of 25 °C. Four panels were produced with the addition of nanoparticles and four without the addition of nanoparticles, in order to obtain the samples necessary to perform characterizations according to the normative document.

The following tests were carried out for physical and mechanical characterization of the panels: thickness swelling for 24 h (EN 317 – 2000), moisture content (EN 322 – 2000), bulk density (EN 323 – 2000), perpendicular tension or internal bonding (EN 319 – 2000), and static bending (EN 310 – 2000) in order to determine the modulus of rupture (MOR) and modulus of elasticity (MOE).

The results were analyzed via a hypothesis test, i.e., the t-distribution test at a 5% significance level, using the R software version 2.12.2.

RESULTS AND DISCUSSION

Table 1 shows the mean and standard deviation of the physical tests performed.

TABLE 1. Results of physical tests.

Situations	Density (kg m^{-3})	Moisture Content (%)	Thickness Swelling (%)
0% SiO_2-Nano	867a[1]	6.9a	62a
	(9%)[2]	(7%)	(29%)
4% SiO_2-Nano	866a	6.5a	37b
	(14%)	(10%)	(24%)

[1] Means followed by the same letter were not significantly different at a 5% significance level.
[2] Values in parentheses show the coefficient of variation.

The density and moisture content values were statistically equal at a significance level of 5%. The panels produced may be classified as high-density panels according to EN 1058 (2003), which ranked medium density particleboard as being between 500 and 800 kg m^{-3}.

The average values of thickness swelling were high; however, for dry conditions including for use in furniture, EN 312 has no normative limitation. These results may be caused by the absence of paraffin emulsion in the manufacturing process because it increases the dimensional stability of the panel or the lower amount of resin in the core layer. An alternative for improving the performance of thickness swelling further is the addition of a nano-emulsion of paraffin, as performed by Mantanis & Papadopoulos (2010). However, paraffin was not used in the present study to only analyze the influence of SiO_2 nanoparticles on the thickness swelling of the particleboard.

However, it is important to note that the addition of nanoparticles decreased the thickness swelling in the panel by 42%. This result was markedly different as it produced a significant difference at the 5% significance level. Therefore, the addition of the nanoparticles in the adhesive increased the dimensional stability of the panel.

Roumeli et al. (2012) found that swelling ranged from 27.07% to 28.41% in MDP treated with silica nanoparticles, while 29.63% swelling occurred in untreated MDP. Thus, as observed in this study, this characteristic was improved.

Table 2 shows the mean and standard deviation of the results of the mechanical tests of static bending and perpendicular tension.

TABLE 2. Results of mechanical tests.

Situations	Static Bending		Perpendicular Tension
	MOR (MPa)	MOE (MPa)	(MPa)
0% SiO_2-Nano	12.4a[1] (30%)[2]	1937a (34%)	0.63a (46%)
4% SiO_2-Nano	12.3a (25%)	2400a (26%)	0.79a (48%)

[1] Means followed by the same letter were not significantly different at a 5% significance level.
[2] Values in parentheses show the coefficient of variation.

The addition of SiO_2 nanoparticles showed no significant difference in the modulus of rupture (MOR) of the panel at a significance level of 5%. EN 312 (2003) specifies a minimum MOR value of 13 MPa for panels with thickness ranging between 6 and 13 mm to be suitable for use in dry conditions, including furniture (P2). The results of this study were close to the values required by the standard thresholds.

A study by Taghiyari & Bibalan (2013) investigating the addition of copper nanoparticles in MDP panels resulted in MOR values between 11.55 and 12.19 MPa, similar to those presented in this work. In another study by Roumeli et al. (2012), using SiO_2 nanoparticles in MDP panels, resulted in MOR values between 14.52 and 15.09 MPa, i.e., 18.5 % higher than those obtained in this work.

The modulus of elasticity (MOE) also showed no significant difference at a significance level of 5%. EN 312 (2003) specifies a minimum MOE value of 1800 MPa for panels with thickness ranging between 6 and 13 mm for use in dry conditions, including furniture (P2). The values obtained in this study were above those required by the EN, especially for the panels produced with SiO_2 nanoparticles.

From static bending results, adding SiO_2 nanoparticles to the adhesive did not change the MOR and MOE of the particleboard because they were statistically equal.

Regarding the perpendicular tension test, the addition of nanoparticles also showed no significant difference at a significance level of 5%. In EN 312 (2003), the minimum perpendicular tension should be 0.40 MPa. The results of this study were higher than the minimum required by the standard.

Taghiyari & Bibalan (2013) used copper nanoparticles in the treatment of MDP panels and found a value of 0.48 MPa for the perpendicular tension. Kumar et al. (2013) treated MDF with aluminum oxide nanoparticles and determined values for perpendicular tension to be 0.89 MPa. Roumeli et al. (2012) treated MDP panels with SiO_2 nanoparticles and obtained a perpendicular tension value of 0.72 MPa. Therefore, the results obtained in this study were within the values found in the literature.

Thus, the addition of SiO_2 nanoparticles did not influence the perpendicular tension particleboard.

CONCLUSIONS

Based on the results of this preliminary study, the addition of SiO_2 nanoparticles to urea-formaldehyde-based adhesive increased the resistance to thickness swelling of the particleboard by 42%, thereby improving the dimensional stability of the panel. However, the absence of paraffin emulsion impaired the results.

Likewise, there were no changes in the mechanical properties of the panels as the addition of SiO_2 nanoparticles did not alter the properties of MOR, MOE, and perpendicular tension.

Therefore, adding SiO_2 nanoparticles to the adhesive used to produce wood particleboards is a good option for improving the dimensional stability of the panels without decreasing its mechanical properties, even when used in small proportions, as demonstrated in this study.

Future studies should investigate the effects of adding higher percentages of SiO_2 nanoparticles as well as adding a paraffin emulsion mixed with the adhesive and nanoparticles.

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