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PHYSICAL-MECHANICAL PROPERTIES AND HEAT TRANSFER ANALYSIS OF OSB PRODUCED WITH PHENOL-FORMALDEHYDE AND ZnO NANOPARTICLES ADDITION

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ABSTRACT

Oriented Strand Board is a structural wood composite with applications that require good physical and mechanical performance. The addition of ZnO nanoparticles is an alternative that has been studied in order to improve the properties of Oriented Strand Board panels. However, there is no information about its effect Oriented Strand Board. The aim of this work was to evaluate the influence of the addition of zinc oxide nanoparticles in two different percentages (0,25 % and 0,50 %) on the physical-mechanical properties of Oriented Strand Board panels produced with phenol-formaldehyde resin and on the heat transfer during hot-pressing. Oriented Strand Board panels were produced and tested according to European Standards. The addition of ZnO nanoparticles improved the dimensional stability of the panel, reducing its thickness swelling, and also increased the screw withdraw strength. The heat transfer during hot-pressing increased the temperature more quickly on boards with nanoparticles addition; on the other hand the final temperature of the control treatment was higher.

Keywords: Material properties, Oriented Strand Board, *Pinus elliottii*. wood composite, zinc oxide.

INTRODUCTION

OSB (Oriented Strand Board) is produced with wood strands oriented in three layers, where the inner layer has its fibers arranged perpendicular to the others (Mendes *et al.* 2015). According to Bufalino *et al.* (2015), the main applications of OSB are: wood frame and steal frame construction systems, I-beams, roofs, walls and coverings.

OSB has its applications limited due to its low dimensional stability in contact with water, causing moisture absorption and high swelling in thickness (Mendes *et al.* 2013). The proposed method for reducing this problem is the addition of nanoparticles, which are also applied for increasing resistance against biodegradable agents (Uyup *et al.* 2019).

Nanoparticles are commonly applied as additives in different types of materials in order to modify their properties (Candan and Akbulut 2015). According to Valle *et al.* (2020), the addition of nanoparticles in adhesives for the production of wood boards should be the focus of current research projects which seeks improvement to the material's physical and mechanical properties.

Few studies about addition of nanoparticles in the composition of wood boards are currently available. Salari *et al.* (2013) used of 3 % of SiO_2 nanoparticles in urea-formaldehyde resin for the production of paulownia OSB and significantly improved its mechanical properties (MOE // - over 9 % and MOR // - over 19 %), thickness swelling (over 14 %) and formaldehyde emission.

The addition of 0,5 % ZnO nanoparticles in MDF (Medium Density Fiberboards) reduced swelling in thickness, moisture content and density of the boards (Silva *et al.* 2019a). When the same nanoparticles were added in particle boards, at a 1 % content, the physical and mechanical properties were also improved (reduction over 32 % in thickness swelling, increase over 33 % in MOE and over 28 % in MOR), as well as the heat transfer

(Silva *et al.* 2019b). According to Taghiyari and Nouri (2015) the addition of nanoparticles contributes to the formation of bonds between the wood fibers, improving the physical-mechanical properties of the composite.

Based on the observed improvements of wood-based composites due to the nanoparticle presence, the aim of this work was to evaluate the influence of the addition of zinc oxide nanoparticles in two different percentages (0,25 % and 0,50 %) on the physical-mechanical properties of OSB panels produced with phenol-formaldehyde resin and on the heat transfer during hot-pressing.

MATERIALS AND METHODS

The OSB panels were produced with *Pinus elliottii* strands and phenol-formaldehyde resin. The nominal dimensions of the boards were 42 cm x 42 cm x 13 mm, based on EN 300 (2006), and each panel was produced in three perpendicular layers following the proportions 30:40:30 based on its weight. Three treatments were performed: The control treatment, the T0,25 treatment with the addition of 0,25 % ZnO nanoparticles and the T0,50 treatment with the addition of 0,50 % ZnO nanoparticles, both in relation to the adhesive mass. The nanoparticles used were produced in the laboratory using the protein gel method, following the methodology of Silva *et al.* (2019a).

Wood planks were cut (see Figure 1A) and submitted to water treatment to reduce the production of fines and to avoid twisting of the strands due to low moisture content during the processing of the wood. The strands were produced in a disc chipper (see Figure 1B) with nominal dimensions of 10 cm x 2 cm x 0,7 mm and classified on 5 mesh sieves (see Figure 1C) for removal of fines.

The strands drying process followed two procedures: natural drying over plastic canvas and oven drying with forced air circulation over a time span of one day at 103 °C

± 2 ºC, as observed on Figure 1D and 1E, respectively. These two procedures were adopted to avoid a severe drying of the strands, which could cause its twisting and breaking. The initial moisture content (MC) of the strand was above 30 % and the target MC was 3 %.

The adhesive was prepared according to the dry weight of the particles. It was composed of 10 % phenol formaldehyde and 1 % water (see Figure 1F), with viscosity of 180 cP and density of 1125 $kg \cdot m^{-3}$. The nanoparticles (see Figure 1G) were added with the resin before spraying the mixture on the strands in a mixer-rotating drum (see Figure 1H).

During the mattress formation a thermocouple type K, as observed in Figure 1I, was added in the inner layer for data acquisition, the evaluation was performed during the pressing process using the National Instruments system. Before hot pressing, the panels went through a pre-pressing under a 0,4 MPa (see Figure 1J).

The pressing variables at the hot press (see Figure 1K) were: temperature of 180 ºC, pressure of 4 MPa and pressing cycle of 600 seconds divided into three cycles of 180 seconds of pressing and two intervals of 30 seconds, following Silva *et al.* (2019c) methods. After the pressing process, the boards were removed from the press (see Figure 1L) and placed in a room with constant temperature and humidity, in accordance with EN 300 (2006).

Figure 1: Production process of the boards. A: Wood processing; B: Wood chipping; C: Strands classification with 5 mesh shive; D: Natural drying of the strands; E: Oven drying; F: Preparation of the adhesive; G: Weighing of nanoparticles H: Mixer-rotating drum; I: Thermocouple type K; J: Pre-pressing; K: Hot pressing; L: Finished panel.

The physical tests were performed to determinate density (EN 1993d), moisture content (EN 1993c) and thickness swelling through water immersion for 24 hours (EN 1993b) of the boards. The mechanical tests performed were screw withdrawal (EN 320 2011), as well as the determination of the modulus of elasticity (MOE) and modulus of rupture (MOR) through static bending (EN 1993a). Figure 2 shows some of the stages of the tests performed.

Figure 2: Stages of the physical and mechanical tests.

The results of the physical and mechanical properties were evaluated through the analysis of variance (ANOVA) and the Tukey test with a 95 % family-wise confidence level, the linear regression analysis for each test was also performed, using the software R version 3.6.3. (2020).

RESULTS AND DISCUSSION

Figure 3 shows the chart of inner layer temperature during the hot-pressing cycle of the three treatments, the moving average method was applied to reduce the noise oscillation.

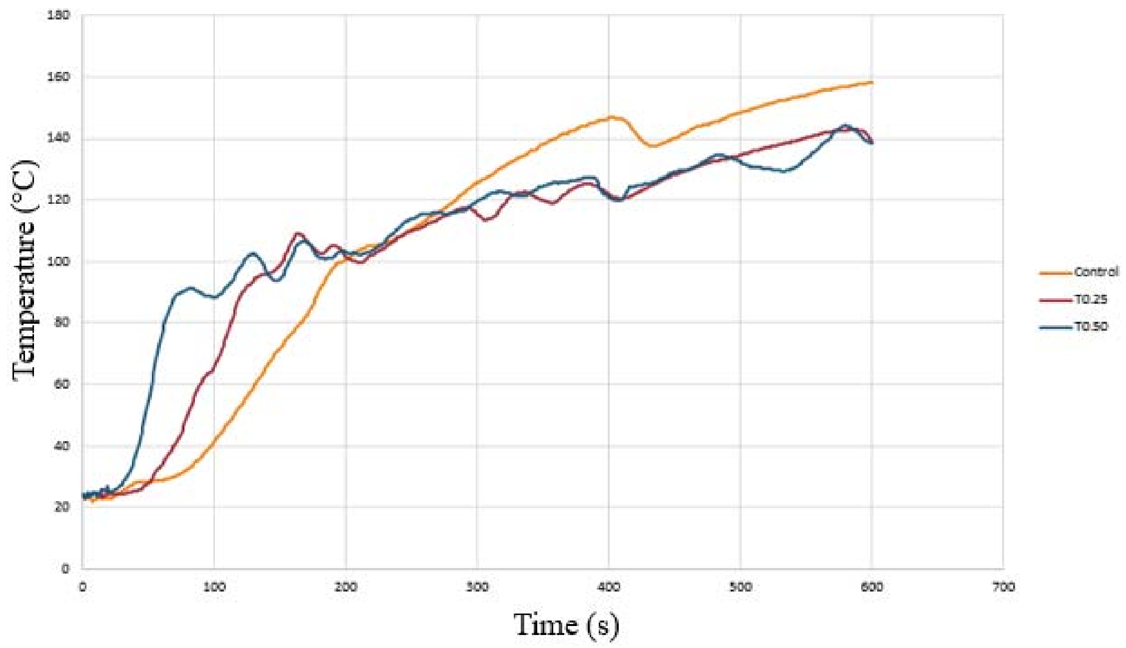

Figure 3: Inner layer temperature chart of the treatments performed.

As shown in the chart, treatments with the addition of nanoparticles increased the temperature more quickly in the beginning compared to the control treatment; however, the final temperature of the treatment without nanoparticles was higher. The addition of nanoparticles shows possible characteristics of a refractory material, inducing a slow heating with less oscillations.

The oscillations in the chart, mainly in treatments T0,25 and T0,50, occur due to the interference of nanoparticles. These oscillations were also observed by Silva *et al.* (2019b).

The mean values for the physical and mechanical properties followed by the analysis of variance results and linear regression equations were presented in Table 1, standard deviation is shown between parentheses; same letters on horizontal means no statistical difference among the mean values. The // symbol stands for outer layer parallel to strands.

Table 1: Result of physical-mechanical tests performed.

Test	Control	T0,25	T0,50
Density ($kg \cdot m^{-3}$)	835,64 A (102,28) *	691,56 B (94,85)	668,97 B (94,46)
	Density = 815,40 – 333,30 · Np%** adjusted R^2 = 30,85 %		
Moisture content (%)	7,95 A (3,33)	8,86 A (0,91)	9.26 A (0,85)
	M.C. = 8,047 + 2,598 · Np% adjusted R^2 = 4,76 %		
Thickness swelling (%)	57,95 A (15,70)	43,32 B (7,46)	40,21 B (7,33)
	T.S. = 56,03 – 35,48 · Np% adjusted R^2 = 29,04 %		
MOE // (MPa)	6391 A (1292)	6107 A (2810)	7959 A (549)
	MOE // = 6034,6 + 3136,7 · Np% adjusted R^2 = 6,55 %		
MOR // (MPa)	40,94 A (17.01)	41,91 A (21.86)	62,59 A (14.43)
	MOR // = 37,65 + 43,31 · Np% adjusted R^2 = 5,53 %		
Screw withdrawal (N)	1159,13 B (466,34)	1512,57 AB (798,04)	2155,94 A (562,51)
	S.W. = 1113 + 1963 · Np% adjusted R^2 = 26,78 %		

* Standard deviation

* *Np% = Percentage of nanoparticles

The addition of nanoparticles caused a significant reduction in the density of the board, the same situation was observed in Silva *et al.* (2019a), where the addition of 0,5 % ZnO nanoparticles on fiber boards reduced more than 8 %, while boards with 1 % ZnO reduced 21 %, both in relation to the control treatment.

This reduction also occurred in the thickness swelling test, which may have occurred due to the decreased of the density. The same occurred on Valle *et al*. (2020)

with particleboards produced with the addition of SiO_2 nanoparticles, with decreased the swelling over 40 %. However, the values found in all treatments for the thickness swelling test were higher than the maximum allowed in the EN 300 (2006) standard of 25 %.

The moisture content did not differ statistically between the treatments, as well as the MOE and MOR in the direction parallel to the fibers, where the boards are classified as OSB class of type 4, which are structural type materials for use in humid conditions. These properties were not influenced by boards density.

In the screw withdraw test, the performance of the panels with the addition of nanoparticles were superior. The performance of OSB panels with the addition of nanoparticles was superior to OSSB (Oriented Structural Straw Board) panels produced with soy straw and polyurethane resin based on castor oil studied by Silva *et al.* (2021), which ranged from 490 N to 1190 N.

In the tests that there was no significant difference between treatments (moisture content, MOE // and MOR //), the adjusted R^2 was low, as there is no relationship between the improvement of the property with the addition of nanoparticles.

CONCLUSIONS

Results presented visible effects of zinc oxide nanoparticles addition, which caused significant changes to the properties of the OSB.

ZnO nanoparticles increased heat transfer during the hot-pressing of the panel, as the temperature inside the mattress increased more quickly, however control treatment reached the highest temperature at the end of the process.

As for the physical properties, the nanoparticles reduced the density of the panel as well as its swelling in thickness. No significant changes in the moisture content of the boards were observed.

As for the bending stiffness and strength, there was no statistical difference between the treatments in the parallel direction of the external layer fibers. The result of face screw withdraw was superior in the treatments with nanoparticles. For future studies it is recommended the addition of paraffin to the adhesive, in order to reduce the swelling in thickness to reach standard requirements, as well as to identify possible interactions with the ZnO nanoparticles.

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