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ORIGINAL ARTICLE – Forest Products Science and Technology

Effect of CCB Treatment and Alternative Adhesive Content on Physical and Mechanical Performance of Particleboards

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Abstract

The present study aimed to characterize medium density particleboard manufactured with CCB treated particles of *Pinus* sp. wood specie and alternative mixed vegetal oil-base bicomponent polyurethane resin. For this, three different resin concentrations (10 %, 12 % and 15 %) were used in combination with the presence or absence of the CCB preservative, resulting in six distinct treatments. The particleboards were produced according the Brazilian Standard – NBR and evaluated according European standards – EN. The results met the requirements of NBR and EN. The technical feasibility of making panels with those materials used were proved and the quality of the product according to its performance were verified, indicating the possibility to use alternative bicomponent polyurethane resin from mix vegetal oil. Statistical analysis demonstrated that adhesive and preservative factors and the interaction between them were significant on physical and mechanical properties.

Keywords: Wood panels, *Pinus*, CCB preservative, polyurethane resin.

1. INTRODUCTION AND OBJECTIVES

Brazil is the country with the highest number of wood species (8715 wood species) and the country with the largest vegetal cover, being across 58% of its territory (493,5 million hectares) (Beech et al. 2017; Steege et al. 2016). Wood physical and mechanical properties are close to properties of other well-known construction materials, such as concrete and steel. Also, energy consumption to manufacture timber is low when compared with cement and steel (Ramage et al. 2017a; Souza et al. 2018).

To enable wood use on severe conditions of biological attacks (Bayatkashkoli et al. 2016; 2017), it is necessary to treat wood to provide protection and enhance its lifespan. The preservative treatments available are chromated copper arsenate (CCA), which is widely used on timber for houses (Ferro et al. 2016; Freeman et al. 2003) and considered toxic due to element arsenic, which is carcinogenic (Vidal et al.

2015); and chromium copper boron (CCB) (Almeida et al. 2019; Ferro et al. 2016), less toxic than CCA and bring better mechanical properties to wood (Bertolini et al. 2013).

Observing the elevated amount of residue during timber manufacture process and the demand for residue reuse, wood based engineered products, such as medium density particleboard (MDP) and oriented strand board (OSB) panels is an alternative for use of this material in civil construction. These products displays low density, renewable materials, mechanical properties compatible for structural use and use on furniture and use for structural purpose on buildings (Araujo et al. 2018; Bufalino et al. 2015; Fink et al. 2018; Ramage et al. 2017b).

MDP panels are defined as wood particles and resin consolidated under pressure and temperature (Ferro et al. 2014b; Kollmann et al. 1975; Nemli et al. 2001). The final product is more homogeneous than timber, where oriented fibers and natural imperfections affect their mechanical properties (Paes et al. 2011).

The resin is one of the main components on panel production due the physical and mechanical properties that it provides, which may grant different performances varying chemical composition and concentration on particle mixture. The use of urea-formaldehyde adhesive is common due its low cost, quick cure process and color development, but its use leads to the emission of formalin gas, toxic to mankind health. (Barbirato et al. 2018; Carvalho et al. 2014; Mantanis et al. 2018; Muttil et al. 2014; Silva et al. 2016; Zhou and Pizzi 2014).

So, an alternative to reduce the use of urea-formaldehyde adhesive is the use of alternative resin, such as castor oil based polyurethane bicomponent resin, a natural and renewable material, which is not aggressive for environment and human being, used on several researches on literature (Barbirato et al. 2018; Younesi-Kordkheili and Pizzi 2018; Zau et al. 2014).

However, castor oil has several applications, such as human implants, tissue scaffolds, coatings, fibers, foams (Das et al. 2017; Guo et al. 2017; Kunduru et al. 2015; Mendes et al. 2018; Shirke et al. 2015), more noble applications than the use on wood panels. Considering other applications listed and its manufacture elevated cost of castor oil (Das et al. 2017), an alternative is the use of mixed vegetal oil, composed of natural oils from several sources, including castor oil.

Observing the literature, it can be highlighted the studies of MDP panel treated with preservative using castor oil polyurethane resins of Paes et al. (2011) and Bertolini et al. (2013). Also, it was observed on literature any research of MDP panel made with wood particle treated with CCB preservative using mixed vegetal oil-based polyurethane resin.

Aiming to contribute to the study of use of wood residue treated with CCB preservative on MDP using bicomponent polyurethane resin of mixed vegetal oil, the present research intended to characterize medium density particleboard manufactured with CCB treated particles of *Pinus* sp. wood specie and alternative mixed vegetal oil-base bicomponent polyurethane resin.

2. MATERIALS AND METHODS

For panel manufacture, it was used wood particles of *Pinus* sp. treated with CCB preservative under pressure and without preservative of the *Pinus* sp. wood specie. For CCB treatment, the particles were carried to industrial plant for preservative treatment. Panels were manufactured in the Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering (SET), São Carlos Engineering School, University of São Paulo, São Carlos, Brazil.

The moisture of wood particles was close to 10% and size ranged between 0.8 and 2.8 mm. The dry mass of panels was defined 640 g per each panel, with dimensions of 280 mm × 280 mm × 10 mm (width x length x thickness). The bicomponent mixed vegetal oil polyurethane resin is composed by mix vegetal oil-based polyol (1.0 $g.cm^{-3}$) and an isocyanate pre-polymer (1.24 $g.cm^{-3}$), provided by Kehl® industry. The resin components were disposed on the proportion 1:1 of each component (Ferro et al. 2014a). To evaluate the behavior of bicomponent resin on panels, it was produced several panels with different adhesive content. Also, the investigated factors of physical and mechanical properties on wood panels consisted on the use of preservative CCB [Pre] or not and adhesive content [Ad] (10 %, 12 % and 15 %), which resulted on six different experimental treatments, as disposed on Table 1. A total of five (5) panels were produced for each treatment, totalizing 30 panels. CCB preservative retention were not informed by industry, alleged industrial secret.

The resin was homogenized on particles mechanically on a mixer and, displaced on the mold for a manual compaction under pressure of 0.01 MPa. The panel was placed on hydraulic press to the final pressing under pressure of 3.50 MPa and temperature of 100°C during 10 minutes on press. Panels underwent a 72-hour cure process and panels were squared (Figure 1a and 1b).

The panels were characterized evaluating their physical and mechanical properties, such density (ρ); thickness swelling after 2 hours (IE-2h) and after 24 hours (IE-24h), water absorption after 2 hours (Abs-2h) and after 24 hours (Abs-24h), modulus of rupture (MOR), modulus of elasticity

(MOE), normal tensile strength (TP), surface bolt pullout test (RAPf) and top bolt pullout test (RAPt), characterized as the Brazilian Standard ABNT NBR 14810 (ABNT 2018).

For MOR and MOE evaluation on static bending, it was produced proof test of dimensions 50 mm × 250 mm × 10 mm (width x length x thickness) containing 15 specimens per treatment, totalizing 90 specimens. From these specimens were extracted the smaller proof test, with dimensions 50 mm × 50 mm × 10 mm (width x length x thickness) to evaluate physical and mechanical properties, resulting in eight specimens on the determination of each physical and mechanical property, resulting 552 experimental determination.

Table 1. Experimental delimitation.

Treatment [Tr]	Wood particles mass (g)	Adhesive content (%)	Adhesive mass (g)	Preservative
1	640	10	64.0	CCB
2	640	10	64.0	Without (Sem)
3	640	12	76.8	CCB
4	640	12	76.8	Without (Sem)
5	640	15	96.0	CCB
6	640	15	96.0	Without (Sem)

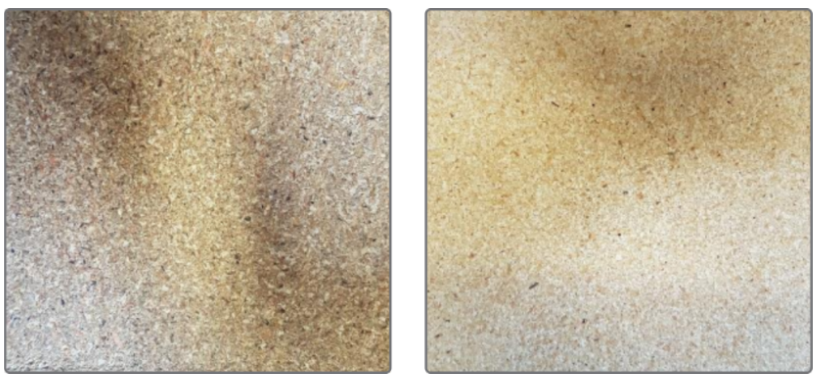


Figure 1. Squared panel with CCB treated wood particles (a) and untreated wood particles (b)

To evaluate the experimental results, it was performed an analysis of variance (ANOVA) along the Tukey test. Normality (Anderson-Darling test) and residue homogeneity tests were carried out at 5% significance level. In this case, ANOVA consist in verify the influence of adhesive and preservative factors, also its interaction. Tukey test is applied to analyze the difference between mean values, i.e., the mean values for each treatment are statistically distinct, even when the values are not the same. From this analysis, it is verified the influence of each parameter evaluates and its significance as well determine which treatment obtained the best performance.

Regression models (Equation 1) based on ANOVA (α – 5 % significance level) were used to relate physical and mechanical properties in function of two evaluated factors, enabling investigate model significance, isolated factors and its interaction as the treatment that led to the extreme properties' values.

$$Y = \beta_0 + \beta_1 \cdot \mathrm{Ad} + \beta_2 \cdot \mathrm{Pre} + \beta_3 \cdot \mathrm{Ad} \cdot \mathrm{Pre} + \varepsilon \quad (1)$$

On Equation 1, Y denotes the dependent variable (physical and mechanical properties), β_i consist on the adjusted coefficients by the Least Square Method and ε is the random error and the quality of the adjustment measured by the coefficient of determination (R^2).

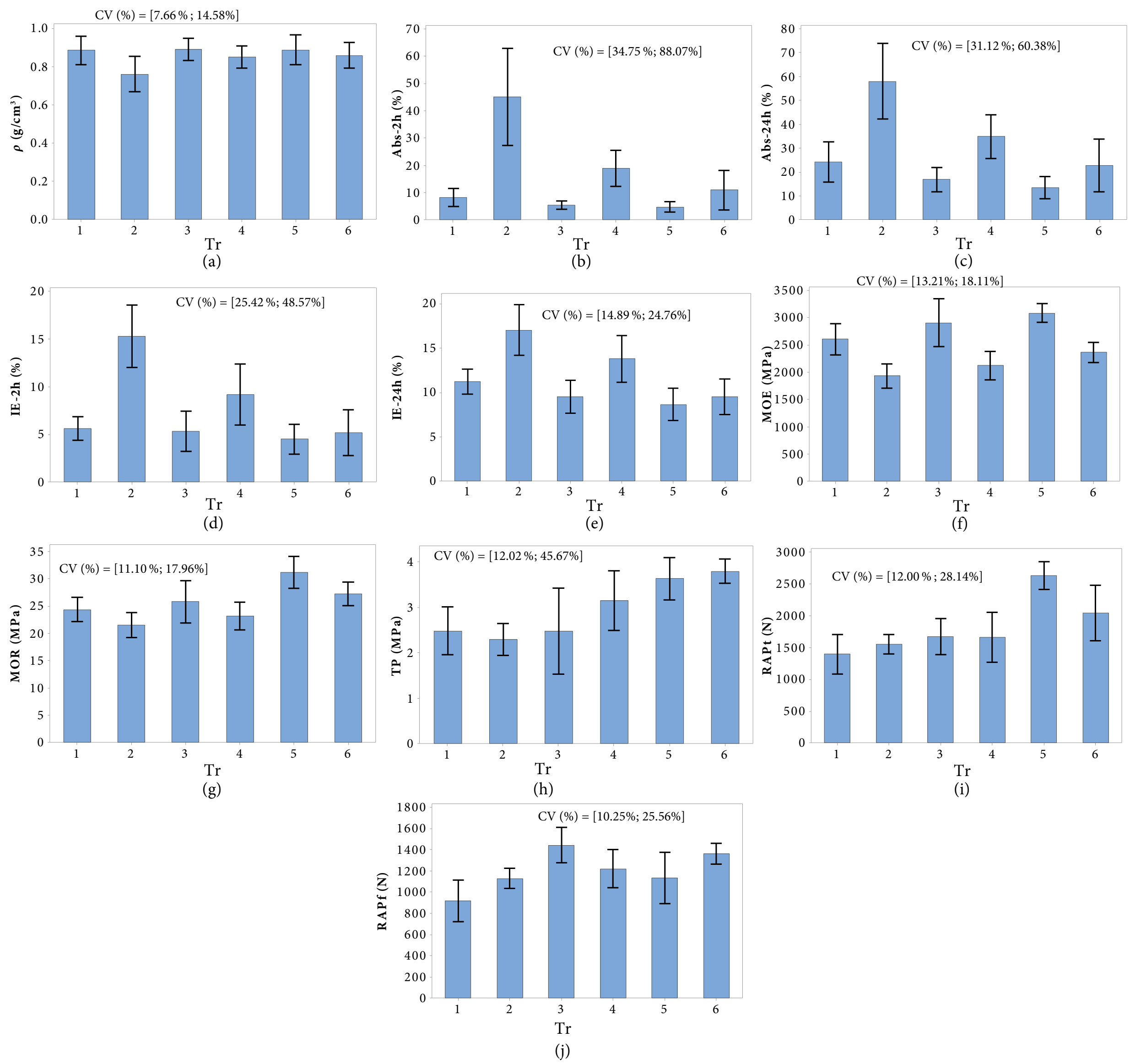
Also, Tukey test (α – 5 % significance level) was performed to analyze the differences on adhesive contents (10 %, 12 % and 15 %), considering that ANOVA of the regression model do not judge, if significant, the difference between 10 %, 12 % and 15 % adhesive content on physical and mechanical properties.

3. RESULTS

Figure 2 presents the mean values, mean confidence interval (CI – 95 % confidence), coefficient of variation (CV) maximum and minimum values of physical and mechanical properties of panels, respectively. Treatment – [Tr].

The regression models obtained to estimate physical and mechanical properties of wood panels are presented on Equations 2 to 11, with the factor underlined considered significant by ANOVA (5% significance level).

Considering the regression models, it can be pointed out that all models were considered significant by ANOVA (p-value < 0.05), and it implied that, even the great variability on results, which reflected on adjustment quality, the models captured the behavior tendency between estimated properties and the evaluated factors.



Where: density (ρ); thickness swelling after 2 hours (IE-2h) and after 24 hours (IE-24h), water absorption after 2 hours (Abs-2h) and after 24 hours (Abs-24h), modulus of rupture (MOR), modulus of elasticity (MOE), normal tensile strength (TP), surface bolt pullout test (RAPf) and top bolt pullout test (RAPt).

Figure 2. Results of physical properties of wood panels of treatments [Tr] - ρ (a), Abs-2h (b), Abs-24h (c), IE-2h (d), IE-24h (e), MOE (f), MOR (g), TP (h), RAPt (i), RAPf (j).

$$\rho(\mathrm{g/cm^3}) = 0.599 + 0.018 \cdot \mathrm{Ad} + 0.28 \cdot \underline{\mathrm{Pre}} - 0.018 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [R^2 = 20.55\%] \tag{2}$$

$$\text{Abs- 2 h}(\%) = 105.3 - 6.51 \cdot \underline{\mathrm{Ad}} - 91.0 \cdot \underline{\mathrm{Pre}} + 5.84 \cdot \underline{\mathrm{Ad} \cdot \mathrm{Pre}} \quad [R^2 = 62.52\%] \tag{3}$$

$$\text{Abs- 24 h}(\%) = 122.4 - 6.80 \cdot \underline{\mathrm{Ad}} - 78.5 \cdot \underline{\mathrm{Pre}} + 4.71 \cdot \underline{\mathrm{Add}} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 62.06\%] \tag{4}$$

$$\text{IE-2h } (\%) = 34.04 - 1.961 \cdot \underline{\mathrm{Ad}} - 26.12 \cdot \underline{\mathrm{Pre}} + 1.735 \cdot \underline{\mathrm{Ad} \cdot \mathrm{Pre}} \quad [\mathrm{R}^2 = 64.21\%] \tag{5}$$

$$\text{IE-2h } (\%) = 31.94 - 1.498 \cdot \mathrm{Ad} - 16.02 \cdot \mathrm{Pre} + 1.001 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 61.38\%] \tag{6}$$

$$\mathrm{MOE(MPa)} = 1079 + 85.8 \cdot \underline{\mathrm{Ad}} + 643 \cdot \underline{\mathrm{Pre}} + 6.7 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 68.72\%] \tag{7}$$

$$\mathrm{MOR(MPa)} = 9.60 + 1.167 \cdot \underline{\mathrm{Ad}} + 0.28 \cdot \underline{\mathrm{Pre}} + 0.233 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 54.21\%] \tag{8}$$

$$\mathrm{RAPt\ (N)} = 513 + 100.4 \cdot \underline{\mathrm{Ad}} - 1730 \cdot \mathrm{Pre} + 152.2 \cdot \underline{\mathrm{Ad}} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 55.63\%] \tag{9}$$

$$\mathrm{RAPf(N)} = 661 + 47.0 \cdot \underline{\mathrm{Ad}} + 128 \cdot \mathrm{Pre} - 16.3 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 42.10\%] \tag{10}$$

$$\mathrm{TP(MPa)} = -0.55 + 0.29 \cdot \underline{\mathrm{Ad}} + 0.43 \cdot \mathrm{Pre} - 0.051 \cdot \mathrm{Ad} \cdot \mathrm{Pre} \quad [\mathrm{R}^2 = 52.63\%] \tag{11}$$

3.1. Density

From Equation 2, density was affected significantly only by the use of preservative CCB, which contributed on the rise (6.02 %) of the value of this property. Figure 3 illustrate the main effects of density in function of preservative factor.

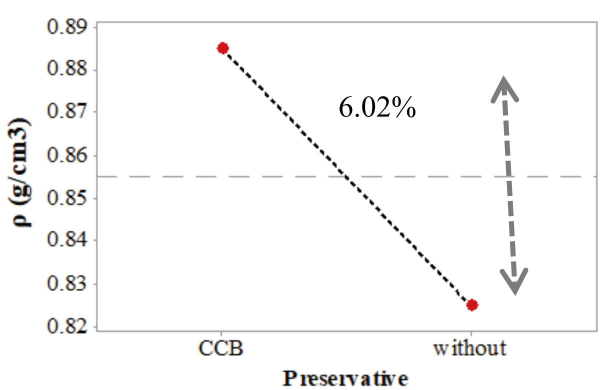


Figure 3. Main effects of preservative factor on panel density values.

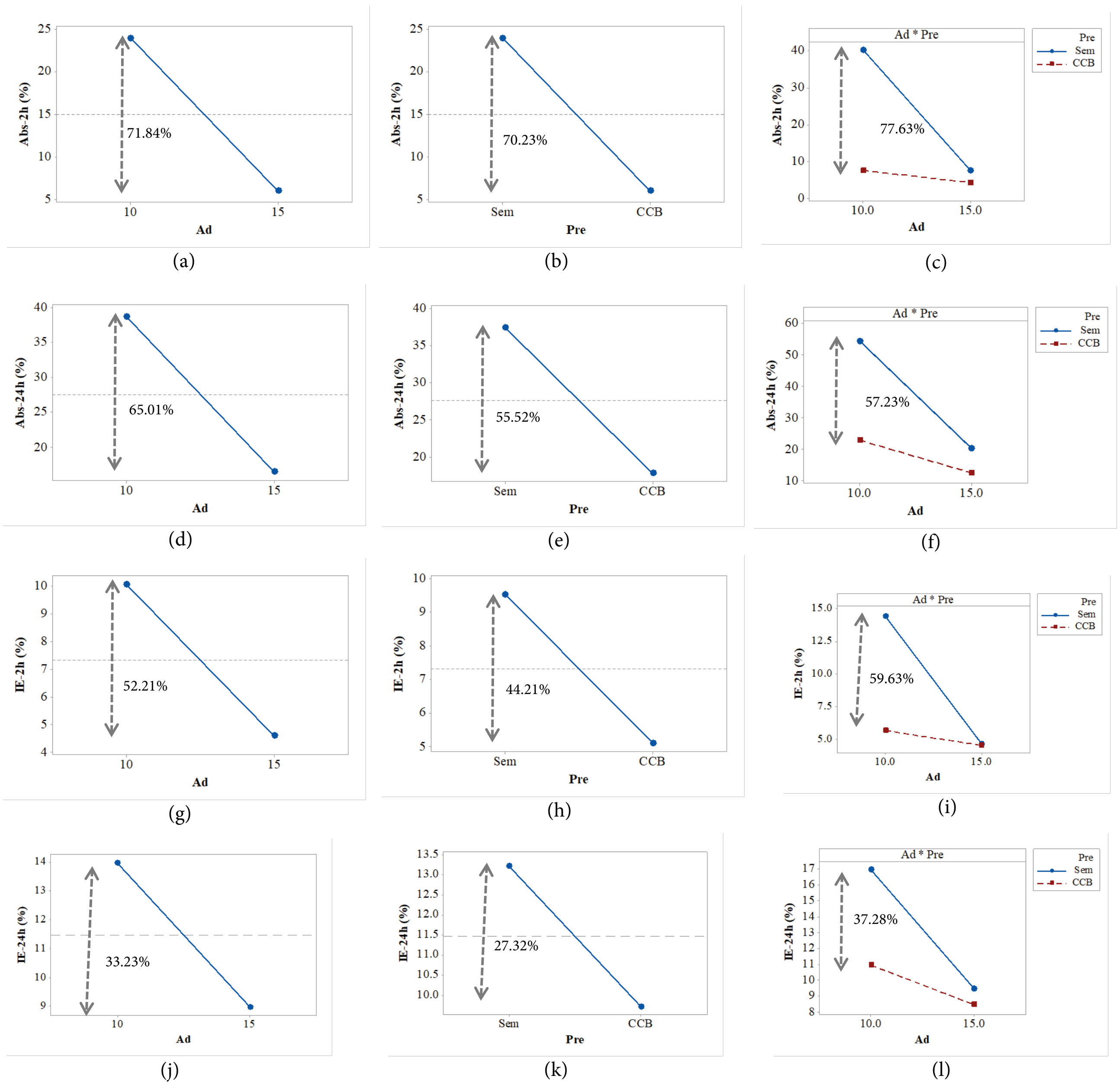
The CCB treatment enabled a major compaction of the material. On treatments with wood without preservative (control), the mean thickness was 5.3 % higher than CCB treated panels and the volume of those panels are slightly higher. This difference may be caused by a greater stability of CCB treated panels after press when compared with untreated wood particle panels.

3.2. Water absorption and thickness swelling

From Equation 3 and 4, the individual factors and the interaction between themselves influenced significantly water absorption values after 2 hours in water and after 24 hours. The use of 15 % adhesive content reduced water absorption in 71.84 % [Abs-2h] (Figure 4a) and 65.01 % [Abs-24h] (Figure 4d). The inclusion of CCB reduced 70.23 % [Abs-2h] (Figure 4b) and 55.52 % [Abs-24h], and the interaction with 10% adhesive content with CCB provided a value of 77.63 % [Abs-2h] and 57.23 % [Abs-24h] lower than the condition with 10 % resin content and without preservative content (Figure 4c and Figure 4f).

From Equations 5 and 6, individual factors and the interaction between factors contributed significantly for thickness swelling after 2 hours and 24 hours. The 15 % adhesive content granted a reduction of 52.21 % [IE-2h] (Figure 4g) and 33.23 % [IE-24h] (Figure 4j) when compared with 10 % adhesive content. The inclusion of CCB reduced 44.21 % [IE-2h] (Figure 4h) and 27.32 % [IE-24h] (Figure 4k) when compared with untreated wood particle panels. The interaction between factors considering 10 % adhesive content and CCB treated wood panel provided a value 59.63 % [IE-2h] (Figure 4i) and 37.28 % [IE-24h] (Figure 4l) lower when compared with 10 % adhesive content and untreated wood particle panel.

Observing the results, the adhesive content and the preservative treatment were influent on the obtained values. It can be explained by the hygroscopic property of polyurethane resin and the CCB preservative may explain the reduction on thickness swelling.

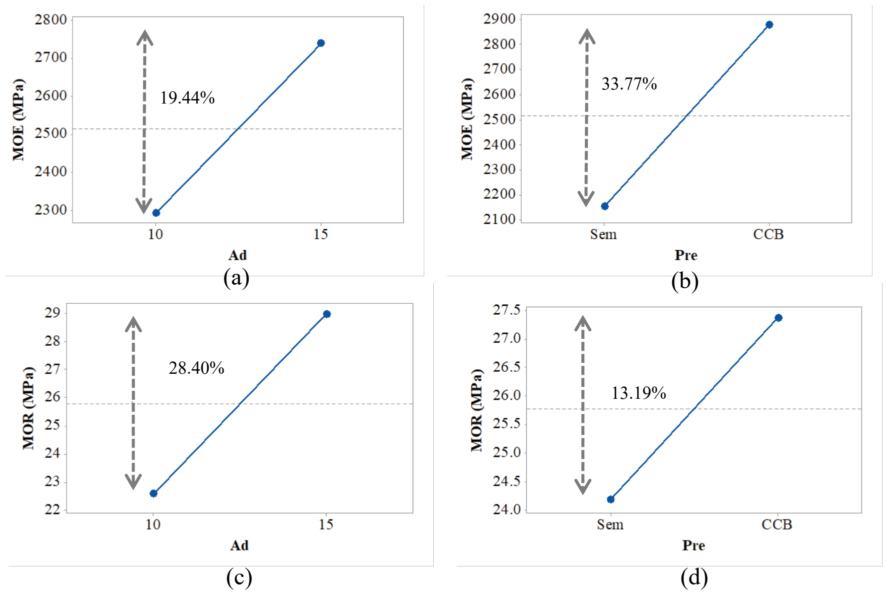


Where: thickness swelling after 2 hours (IE-2h) and after 24 hours (IE-24h), water absorption after 2 hours (Abs-2h) and after 24 hours (Abs-24h).

Figure 4. Main effects on water absorption after 2 hours in function of adhesive content (a), use of preservative (b) and interaction between factors (c) and after 24 hours in function of adhesive content (d), use of preservative (e) and interaction between factors (f) and main effects on thickness swelling after 2 hours in function of adhesive content (g), use of preservative (h) and interaction between factors (i) and after 24 hours in function of adhesive content (j), use of preservative (k) and interaction between factors (l).

3.3. Modulus of elasticity and modulus of rupture

From Equation 7 and 8, only individual factors affected significantly the values of MOE and MOR on static bending. The use of 15% adhesive content elevated in 19.44% MOE in relation of 10% resin content (Figure 5a) and 28.40% MOR in relation of 10% content (Figure 5c). The inclusion of CCB preservative elevated in 33.77% MOE when compared with wood particles without preservative treatment (Figure 5b) and increased in 13.19% the MOR in relation of untreated particles (Figure 5d).



Where: modulus of rupture (MOR), modulus of elasticity (MOE).

Figure 5. Main effects on Modulus of Elasticity in function of adhesive content (a), use of CCB preservative (b) and on Modulus of Rupture in function of adhesive content (c), use of CCB preservative (d).

The results of Tukey test (5% significance level) of adhesive content factor (Ad) on MOE values resulted in: 10% - B; 12% - B; 15% - A; evidencing that 10% and 12% adhesive content imply on equivalent property values for MOR and MOE. Thus, the economical adhesive content is 10%, considering the statistical performance presented. Analyzing the results, CCB treatment provided an expressive mechanical performance, when compared with resin content increase. Otherwise, on MOR, the adhesive content was more significant than CCB treatment. The increase on adhesive content from 10% to 12% was not interesting due its statistical equivalence on rupture.

3.4. Screw pullout test

According Equation 9, the adhesive factor (Ad) and the interaction between adhesive and CCB preservative (Ad·Pre) affected significantly the values of RAPt. The use of 15 % adhesive content promoted an increase of 62.45 % when compared with 10% adhesive content (Figure 6a). Considering the interactions, 10 % resin content and no preservative treatment resulted in RAPt values 15.89 % higher when compared with the same adhesive content and wood particles treated with CCB, however it was not significant for Tukey test. For 15 % adhesive content, such behavior was inverse, with mean values of RAPt for CCB treated panels 27.36 % superior to untreated panels.

Tukey test results (5 % significance level) of adhesive content factor on RAPt values resulted in: 10 % - B; 12 % - B; 15 % - A; showing that 10 % and 12 % adhesive content mean in equivalent property values. Statistical analysis demonstrated the great influence of adhesive factor, being major contributor to the increase of RAPt strength on top bolt pullout test.

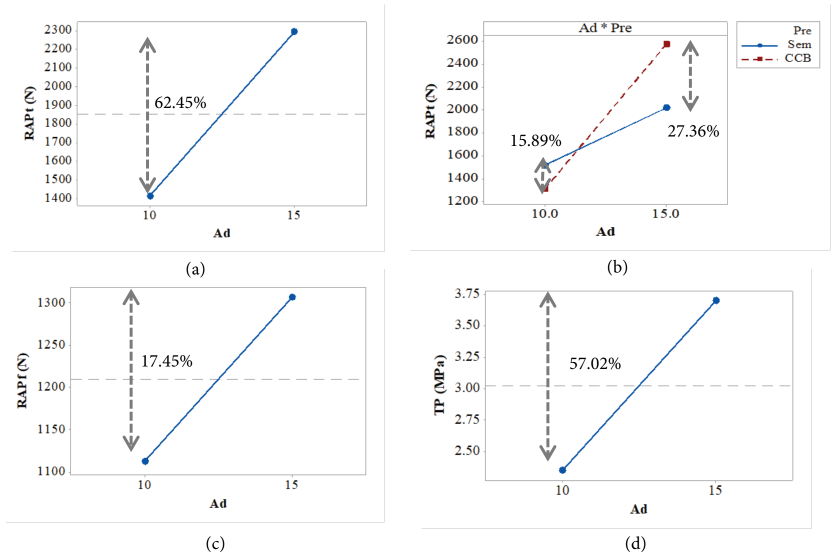
Analyzing Equation 10, only adhesive factor (Ad) affected significantly strength values of RAPf. The use of 15 % adhesive content elevated in 17.45 % when compared with the use of 10 % adhesive content (Figure 6c).

Tukey test results (5 % significance level) of adhesive factor (Ad) on RAPf values resulted in 10 % - B; 12 % - A; 15 % - A, demonstrating that 12 % and 15 % content represent equivalent property values.

From Equation 17, only the adhesive factor (Ad) affected significantly the values of normal tensile strength, and the same did not occur with the preservative factor and also with the interaction of both factors. The use of 15 % of adhesive promoted an increase of 57.02 % in relation to the use of 10 % (Figure 6d).

Tukey test results (5 % significance level) of adhesive factor (Ad) on TP values resulted in 10 % - B; 12 % - A; 15 % - A, demonstrating that 12 % and 15 % content represent equivalent property values.

For the normal tensile strength test, the CCB preservative was not significant as a factor which may influence on this property. Only the increase in adhesive content was effective in increasing the strength, but the equivalence of 12 % and 15 % of adhesive was observed for this property.



Where: normal tensile strength (TP), surface bolt pullout test (RAPf) and top bolt pullout test (RAPt).

Figure 6. Main effects on top bolt pullout test in function of adhesive content (a) and interaction between factors (b), surface bolt pullout test in function of adhesive content (c) and on surface bolt pullout test in function of adhesive content (d).

4. DISCUSSION

Observing the results displayed on Figure 2, the CCB preservative increased physical and mechanical properties of wood panels, corroborating the result obtained by Ferro et al. (2016). Other researches showed the CCB preservative do not influence physical and mechanical properties of wood engineered properties (Almeida et al. 2019; Bertolini et al. 2019). The use of CCB preservative, use of higher adhesive content and the interaction between these factors led to an improvement on panel performance, increasing dimensional stability, reducing the values of physical properties and enhancing mechanical properties, as showed on the statistical analysis already presented. It may happened due to a larger density obtained by the panels using vegetal based PU resin and the CCB treatment

The results obtained in the present research were compared with the standardized requisites disposed on NBR 14810 (ABNT 2018), American National Standards Institute - ANSI A208.1 (ANSI 2009), Commercial Standard - CS 236-66 (ANSI 1968) and EN 312 (EN 2003). The requisites are disposed on Table 2.

Table 2. Standard requisites for wood particle panels.

Standard Requisites											
Standard		ρ (g/cm3)	Abs-2h (%)	Abs- 24h (%)	IE-2h (%)	IE-24h (%)	MOE (MPa)	MOR (MPa)	RAPT (N)	RAPF (N)	TP (MPa)
ABNT NBR 14810 (2018)	P2	-	-	-	-	18	1800	11	-	-	0.40
	P3	-	-	-	-	17	2050	15	-	-	0.45
	P4	-	-	-	-	19	2300	16	-	-	0.40
	P5	-	-	-	-	13	2550	18	-	-	0.45
	P6	-	-	-	-	16	3150	20	-	-	0.60
	P7	-	-	-	-	10	3350	22	-	-	0.75
ANSI A208.1 (2009)		> 0.8	-	-	-	8	2400	16.5	1325	1800	0.90
CS 236-66 (1968)		> 0.8	-	-	-	55	2450	16.8	-	2041	1.40
EN 312 (2003)	P1	-	-	-	-	-	-	12.5	-	-	0.28
	P2	-	-	-	-	-	1800	13	-	-	0.45
	P3	-	-	-	-	14	2050	15	-	-	0.45
	P4	-	-	-	-	16	2300	16	-	-	0.40
	P5	-	-	-	-	11	2550	18	-	-	0.45
	P6	-	-	-	-	15	3150	20	-	-	0.60
	P7	-	-	-	-	9	3350	22	-	-	0.75

Where: Density (ρ); thickness swelling after 2 hours (IE-2h) and after 24 hours (IE-24h), water absorption after 2 hours (Abs-2h) and after 24 hours (Abs-24h), modulus of rupture (MOR), modulus of elasticity (MOE), normal tensile strength (TP), surface bolt pullout test (RAPf) and top bolt pullout test (RAPt)

Table 3 shows the classification of each experimental treatment according the NBR 14810 (ABNT 2018).

Table 3. Experimental treatments classification following ABNT NBR 14810.

Treatment	Classification
1 - 10% resin content, with CCB	P5
2 - 10% resin content, without CCB	P2
3 - 12% resin content, with CCB	P5
4 - 12% resin content, without CCB	P2
5 - 15% resin content, with CCB	P5
6 - 15% resin content, without CCB	P4

Observing the results disposed on Table 3, all treatments with CCB preservative were classified for structural purpose in humid environments. Wood panels without CCB preservative were not adequate for structural use, except treatment 6.

It is important point out the good performance of CCB treated panels against water attack. Treatment 1 thickness swelling value, which displayed the largest swelling value among CCB treatments, is 15% lower than the requisite for P5 classification. Normal tensile strength also presented a good performance, with the lowest value being 64.3 % higher the normative requisite (ABNT 2018).

Analyzing by the American National Standard, the panels did not meet ANSI A208.1 (2009) on thickness swelling and bolt pullout test properties. For standard CS 236-66 (ANSI 1968), bolt pullout test was not attended for any experimental treatment. For the EN 312 (EN 2003), the classification is nearly the same, which all treatments met the standard requirements.

For panels, Bertolini et al. (2013) produced with *Pinus* sp. treated with CCB and castor oil based bicomponent polyurethane resin, varying the amount of particles, pressing time and resin content. For comparison, the treatments with 10 minutes pressing time and densities close to those obtained in this work were chosen. The treatments chosen were: A (12 % resin) and C (15 % resin). compared with treatments 3 and 5 of this work, respectively. For the physical properties, the literature presented inferior performance in all the questions. with the exception of the thickness swelling after 2 hours, as well as for the mechanical properties MOE, MOR and TP.

Considering pressing parameters, Paes et al. (2011) evaluated the influence of pressing parameters (pressure and temperature) on the quality of *Pinus elliottii* particleboards bonded with 16 % of castor oil based bicomponent resin. Treatment 2 was chosen based on its density and similar production parameters to be compared with the Treatment 5 on the present research. Only the water absorption value after 2 hours presented better performance than the treatment 5, which had a much higher mechanical performance, being the difference of 1478 MPa for MOE, 16.6 MPa for MOR and 1.92 MPa for TP.

It demonstrates the good behavior of mixed vegetable oil-based polyurethane resin, having a performance close with the polyurethane resin based on castor oil. The improvement of the polyurethane resins of vegetable origin is remarkable when comparing the values obtained with previous studies. Over the years, the technology has been improved and its application for the production of particleboard are making them more interesting.

The values of normal tensile strength were much higher than those required in the normative documents, indicating an interesting performance using this resin. The normal tensile strength is directly linked to the quality of the panel, since it is one of the parameters evaluated during the production. A high value suggests a stable core piece of good quality and ensure that the panel will not fade in the middle easily.

In addition to guarantee better physical-mechanical properties to wood under biologic attacks, the primary function of the preservative is the conservation of the material, but other secondary functionalities observed were very positive, demonstrating the combination of CCB preservative and adhesive content to lead to better performance to particleboards.

5. CONCLUSIONS

Based on results obtained in this research, it can be concluded that treatment of the *Pinus* sp. with CCB was effective in the waterproofing of the wood. According statistical analysis, adhesive and CCB preservative factors and the interaction between them were significant, influencing physical and mechanical properties and enhancing dimensional stability of wood panels. The results show the technical feasibility of the production of particle panels with alternative mixed vegetal oil-based polyurethane resin. The attendance with the Brazilian and European standards demonstrate the possibility of using sustainable alternative resins on particleboards.

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Francisco Antonio Rocco Lahr: Conceptualization (Equal); Formal analysis (Equal); Investigation (Equal); Methodology (Equal); Project administration (Equal); Resources (Equal); Supervision (Equal); Validation (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).

André Luis Christoforo: Conceptualization (Equal); Data curation (Equal); Formal analysis (Equal); Investigation (Equal); Methodology (Equal); Project administration (Equal); Resources (Equal); Supervision (Equal); Validation (Equal); Writing – original draf (Equal); Writing – review & editing (Equal).

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