Evaluation of CCB-Preserved Medium Density Particleboards under Natural Weathering

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Wood engineered products are alternatives to the use of timber for civil construction, manufacturing, and the furniture industry. One of these products is the medium density particleboard (MDP) panel, which is made of wood particles and resin under high temperature and pressure. This research produced a prototype to evaluate the use of MDP panels waterproofed by castor oil-based polyurethane resin and *Pinus* sp. residues treated with CCB preservative for use as a wall coating. The influence of weathering, position of wood panel, and waterproof treatment were evaluated. Panels were made under the requisites of Brazilian Standard ABNT NBR 14810 (2013) and evaluated with international standards. MDP panels met standard requisites, with properties similar to that reported in the literature, indicating the possibility of use as wall coating. Statistical analysis indicated the only significant factor was weathering, which influenced physical and mechanical properties.

Keywords: Pinus sp.; Medium density particleboard; Weathering; Castor-oil resin; Waterproofing

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INTRODUCTION

Brazil has the largest number of wood species across the globe, with 8,715 wood species in its territory. The country also has the largest vegetal cover, being about 58% of its mainland (494 million hectares) (Beech *et al.* 2017; Steege *et al.* 2019). The reforestation area of Brazil is composed of *Pinus* sp. and *Eucalyptus* wood species, with 7.84 million hectares in Brazil mainly used for paper and pulp production, furniture, and wood engineered products (Indústria Brasileira de Árvores - IBÁ 2017).

The use of wood engineered products has increased and is considered an alternative to the use of timber for civil construction. Among these products are the oriented strand board (OSB), plywood, medium density fiberboard (MDF), and medium density particleboard (MDP) (Dias and Lahr 2004; Akgül *et al.* 2017; Souza *et al.* 2018; Way *et al.* 2018; Bertolini *et al.* 2019b). Such wood products are produced with waste due to the timber manufacturing process. However, the demand for residue reuse promotes the use of these engineered products.

Medium density particleboard is defined as wood particles and resin consolidated under pressure and temperature (Garzón-Barrero *et al.* 2016; Silva *et al.* 2016; Bertolini *et al.* 2019a, b). The final particleboard displays regular properties, with less variations in properties when compared with timber (Paes *et al.* 2011; Ferro *et al.* 2014).

An important component of panels is the resin, which can influence physical and mechanical properties depending on its grammage and chemical composition. Several resins are available, such as urea-formaldehyde, phenol-formaldehyde, and castor oil-based polyurethane (PU) resins (Muzel *et al.* 2014; Zhou and Pizzi 2014; Mantanis *et al.* 2018; Nakanishi *et al.* 2018). During the manufacturing process, urea-formaldehyde and phenol-formaldehyde resins release formalin gas, which is toxic for humankind (Muttil *et al.* 2014; Zhou and Pizzi 2014; Mantanis *et al.* 2018). Considering this, polyurethane resin arises as an opportunity, whose components are natural and renewable (Negrão *et al.* 2014; Zau *et al.* 2014; Macedo *et al.* 2015; Nakanishi *et al.* 2018). Also, castor-oil PU resin can be used as varnish to protect wood panels from weathering.

To improve wood use in an environment prone to biological attacks, it is important to treat the wood product with CCA (chromated copper arsenate) or CCB (chromium copper boron) (Bayatkashkoli *et al.* 2016, 2017). CCA treatment, used for treatments on timber (Magalhães *et al.* 2012; Bertolini *et al.* 2014b; Ferro *et al.* 2016), is considered carcinogenic due to the presence of arsenate (Vidal *et al.* 2015). CCB is considered less toxic than CCA and enhances mechanical properties of the wood product (Bertolini *et al.* 2014a; Almeida *et al.* 2019).

Also, the use of resin as a preservative can be an alternative considering the extreme conditions that outdoor particleboards are subjected to, such as rain, insolation, and temperature changes (Korai *et al.* 2014; Korai and Saotome 2014). Thus, the use of resin as a preservative can be a factor that may improve MDP performance when used externally.

In order to simulate real conditions of weathering which MDP panels would experience, physical and mechanical properties before and after natural weathering were evaluated. The present research produced a prototype in laboratory scale with nonstructural MDP panels as wall coating made with *Pinus* sp. The residue was preserved with CCB and castor-oil based polyurethane resin covered with castor oil-based PU resin and Osmocolor® varnish under natural weathering. The objective was to test the use of such panels as wall coating on buildings, floors, and furniture.

EXPERIMENTAL

Materials

The MDP panels were made with *Pinus* sp. residues with 10% moisture content treated with CCB preservative, with retention of 7.5 kg/m³, specified by Prema Tecnologia e Comercio S/A, Rio Claro, São Paulo, Brazil. The resin used was the castor oil-based bicomponent polyurethane resin, with polyol made of castor oil, a density 1.2 g/cm³, and polyfunctional isocyanate, with a density of 1.24 g/cm³. The adhesive proportion utilized to manufacture panels was 12% of wood particle mass (Bertolini *et al.* 2013).

Castor-oil monocomponent PU resin was used to waterproof panels. The resin was made by Kehl Ind., São Carlos, São Paulo, Brazil and the Osmocolor® varnish was produced by Montana Quimica Co, São Paulo, Brazil.

Methods

Production of panels

Pinus sp. residues were cut to reach a 2.8 mm granulometry; 120 panels were produced, and for each panel, 1300 g of wood particles was used and 12% of resin (relative to particle mass) on a ratio 1:1 (Polyol and isocyanate) on nominal dimensions 32.5 cm x 50 cm x 1 cm (1625 cm^3) (Bertolini *et al.* 2013).

PU resin was mechanically homogenized with wood particles. Then the mixture was taken to a mold, where the particle mat was pre-pressed at 0.015 MPa pressure. Then, the panels underwent a hot pressing of 4 MPa at 100 °C for 12 min.

Weathering and waterproofing process

After the panel production, the panels were waterproofed with two treatments: castor-oil monocomponent PU resin and Osmocolor® varnish. The treatments were performed on both sides of the panels. Each wall of the prototype displayed one waterproof treatment (Fig. 1a). A layer of 1 L/m² of waterproofing was applied on wood panels on each treatment (PU and Osmocolor®). Physical and mechanical properties were evaluated before the weathering process.

The prototype was designed to leave the outdoor part under weathering and the indoor part protected from natural weathering (Fig. 1a). On the outside, the display is the same as shown in Fig. 1. The prototype stood on the Wood and Timber Structures Laboratory, University of São Paulo, São Carlos, São Paulo, Brazil (22°00'12" S, 47°53'57" W) for 150 days, from August 2013 to January 2014.

After weathering process, the panels were removed from the prototype and physical and mechanical properties were evaluated (Fig. 1b).

(a) (b)

Fig. 1. Distribution of walls according to waterproof treatment: PU panels and Osmocolor® panels (a); Prototype under rain (b)

Statistical analysis and physical-mechanical characterization

In the present research, the factors evaluated were the type of waterproof used [Imp] (PU; OC), position of panels [Po] (In; Out), and the exposure to natural weathering [Env] (Before [B]; After [A]), leading to eight different treatments, as listed in Table 1. The reference treatment takes into account only the MDP panel with CCB preserved *Pinus sp.* residue and bicomponent PU resin, with no waterproof treatment and weathering process.

Table 1. Treatments for Wall Panels on the Prototype

Treatment	Imp	Po	Env
Ref	-	-	-
1	PU	In	B
2	PU	In	A
3	PU	Out	B
4	PU	Out	A
5	OC	In	B
6	OC	In	A
7	OC	Out	B
8	OC	Out	A

Imp – Waterproof used; Po – Panel position; Env – Exposure to natural weathering

From each treatment, 12 specimens were chosen to evaluate mechanical properties (modulus of resistance and modulus of elasticity) in a static bending test. Five specimens were selected to evaluate the internal bond (tension perpendicular to the faces). Also, physical properties, such as thickness swelling (2 h and 24 h) and water absorption (2 h and 24 h) were determined using 5 specimens for each property. All properties were determined following the Brazilian Standard ABNT NBR 14810 (2013).

To investigate which factors influenced various properties and the interaction between them on physical and mechanical properties, the Analysis of Variance (ANOVA), at level of 5% of significance, was performed by means of the software Minitab® (Minitab, State College, PA, USA).

For ANOVA validation (α = 5%), normality and homogeneity of the distribution were evaluated using the Anderson-Darling test and F-test, respectively. For tests formulation, P-value above 0.05 implies the distribution by response is normal and the variances between treatments are homogeneous, which validates the ANOVA model.

RESULTS AND DISCUSSION

Physical and Mechanical Properties

Tables 2 and 3 present physical (water absorption and thickness swelling) and mechanical properties (MOR, MOE, and internal bond), their mean values, and coefficients of variation. The results of apparent density obtained for all treatments ranged from 0.83 g/cm³ and 0.93 g/cm³. These results are similar to those obtained by Bertolini *et al.* (2013) (0.90 g/cm³), using the same materials used in this study and with a minor panel area (1444 cm²) when compared with the panel area of this investigation (1465 cm²). A minor density of wall coating panels is desired, since it enables a reduction in wall load on the structure.

According to Tables 2 and 3, the factor waterproof [Imp] was not significant, with similar values of PU and Osmocolor® before and after natural weathering, respectively.

Table 4 displays the standard requisites used to characterize MDP panels. Analyzing the results in Table 3 and the standard requisites in Table 4, treatments 1, 3, 5, and 7 met the standardized conditions, indicating the possibility to use MDP panels as wall coating. Also, treatments under weathering with PU resin as a waterproof satisfied MOR requisites of ANSI A 208.1 (1999) and ANSI CS 236:66 (1968), but they did not match MOE requisites. Moreover, treatments under weathering with Osmocolor® waterproofing did not reach norm requisites for MOR and MOE properties. All treatments reached the requisites for the Internal Bond (IB) property.

Table 2. Results of Physical Properties

Tr	WA 2h (%) (CV)	WA 24h (%) (CV)	TS 2h (%) (CV)	TS 24h (%) (CV)
Ref	6.24 (14.16%)	19.64 (12.15%)	4.11 (14.45%)	10.52 (14.61%)
1, 3	5.80 (14.16%)	17.29 (12.15%)	3.79 (14.45%)	16.10 (14.61%)
2	6.60 (16.07%)	18.27 (15.15%)	4.83 (16.42%)	17.38 (16.37%)
4	6.83 (16.18%)	18.48 (15.32%)	5.13 (16.48%)	17.51 (16.49%)
5, 7	5.80 (14.16%)	17.29 (12.15%)	3.79 (14.45)	16.10 (14.61%)
6	6.62 (16.15%)	18.32 (15.23%)	4.89 (B) (16.53)	17.43 (16.42%)
8	6.91 (16.19%)	18.51 (15.41%)	5.10 (B) (16.58)	17.62 (16.53%)

WA – Water absorption; TS – Thickness swelling

Table 3. Results of Mechanical Properties

Tr	MOR (MPa) (CV)	MOE (MPa) (CV)	IB (MPa) (CV)
Ref	24.00 (12.30%)	2537 (8.39%)	1.59 (15.39%)
1, 3	19.90 (14.40%)	3299 (16.30%)	2.51 (18.38%)
2	16.20 (16.00%)	1878 (16.00%)	2.09 (19.55%)
4	17.40 (4.40%)	2113 (48.00%)	1.49 (29.89%)
5, 7	19.90 (14.16%)	3299 (16.30%)	2.51 (18.38%)
6	16.00 (14.50%)	1754 (9.50%)	2.37 (12.23%)
8	13.80 (9.40%)	1532 (9.40%)	1.15 (47.76%)

MOR – Modulus of Resistance; MOE – Modulus of Elasticity; IB – Internal Bond

Table 4. Standard Requisites

Standard	Thickness (mm)	Apparent Density (g/cm³)	MOR (MPa)	MOE (MPa)	IB (MPa)
NBR 14810 (2013)	8-13	-	18	-	0.35
ANSI A 208.1 (ANSI 1999)	-	> 0.8	16.5	2400	0.90
CS 236:66 (ANSI 1968)	-	> 0.8	16.8	2500	0.45

MOR – Modulus of Resistance; MOE – Modulus of Elasticity; IB – Internal Bond

Table 5 presents the ANOVA validation tests results (AD; F) and the results of ANOVA for physical and mechanical properties. The p-values are considered significant (p-value < 0.05). From Table 5, Imp x Po, Imp x Env, Po x Env and Imp x Po x Env are the interaction between factors considered.

Table 5. ANOVA Results of MDP Panels as Wall Coating

Resp	Validation		ANOVA						
	AD	F	Imp	Po	Env	Imp×Po	Imp×Env	Po×Env	Imp×Po ×Env
WA 2 h	0.179	0.237	0.368	0.239	<u>0.000</u>	0.682	0.423	0.398	0.289
WA 24 h	0.238	0.259	0.412	0.257	<u>0.000</u>	0.631	0.537	0.178	0.243
TS 2 h	0.241	0.189	0.453	0.378	<u>0.000</u>	0.587	0.362	0.227	0.311
TS 24 h	0.197	0.216	0.358	0.286	<u>0.000</u>	0.723	0.487	0.236	0.291
MOR	0.127	0.246	0.239	0.376	<u>0.000</u>	0.723	0.374	0.186	0.262
MOE	0.260	0.329	0.153	0.668	<u>0.000</u>	0.748	0.180	0.314	0.255
RTP	0.172	0.114	0.730	0.276	<u>0.000</u>	0.141	0.352	0.230	0.101

Imp – Waterproof used; Po – Panel position; Env – Exposure to natural weathering

From Table 5, the only factor considered significant by ANOVA was the natural weathering, which affected all properties evaluated. The factors waterproof [Imp] and wall position [In; Out] were not significant for the analyzed properties. Considering the relation between the two factors and among three factors, ANOVA results showed the non-significance, implying that type of waterproof and panel position provided equivalent results.

According ANOVA, wall position did not influence physical and mechanical properties significantly due to the environment, which was not all closed and, even being exposed to rain, part of the indoor panels was exposed to insolation by the afternoon, as shown in Fig. 1.

The main effects of ANOVA of natural weathering on WA (2 h and 24 h), TS (2 h and 24 h), MOR, MOE, and IB of manufactured MDP panels are displayed in Table 6.

Table 6. Results of ANOVA of Natural Weathering

Properties	Weathering	
	Before	After
WA 2 h (%)	5.80	6.75
WA 24 h (%)	17.29	18.20
TS 2 h (%)	3.79	4.75
TS 24 h (%)	16.10	17.50
MOR (MPa)	20.00	15.40
MOE (MPa)	3299	2345
IB (MPa)	2.50	1.86

The natural weathering process decreased MOR, MOE, and IB properties by 27%, 45%, and 27%, respectively. Physical properties increased by 16%, 5%, 25%, and 8% for WA 2 h, WA 24 h, TS 2 h, and TS 24 h, respectively. Based on these results, it is possible to affirm that weathering worsened panel properties, as expected.

To date, there have been no other studies that have evaluated MDP panels under natural weathering with waterproof treatment. The present results show that part of physical and mechanical properties of particleboards were compatible for usage as wall coating before weathering process, with their properties meeting standardized requisites. Considering the results of wood panel properties after natural weathering process, weathering was the main factor which decreased physical and mechanical properties, being significant by ANOVA, reducing panel performance, with their properties do not meeting norm parameters. Further improvements on waterproofing process encourage studies to enable the use of MDP panels outdoors, reducing weathering influence on physical and mechanical properties.

CONCLUSIONS

1. Physical and mechanical properties of MDP panels made of preserved *Pinus* sp. residues met the standard requisites before weathering. Some treatments reached the norm prescription after natural weathering, demonstrating the possibility for their use as wall coating on buildings; similar performance of MDP panels were reported on in the literature. The panels on the present research were subjected to extreme conditions of weathering.
2. The only significant factor in the statistical analysis was the weathering factor, which influenced physical and mechanical properties of MDP panels in this work. The interaction between factors was not significant according to ANOVA analysis.
3. Waterproof treatment did not influence physical and mechanical properties. Treatment was only affected by weathering conditions. Further research is encouraged for a better evaluation of natural weathering and its effect on waterproof protection.

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