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Accelerated Artificial Aging of Particleboards from Residues of CCB Treated *Pinus* sp. and Castor Oil Resin

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Tests simulating exposure to severe weather conditions have been relevant in seeking new applications for particleboard. This study aimed to produce particleboards with residues of CCB (chromium-copper-boron oxides) impregnated *Pinus* sp. and castor oil-based polyurethane resin, and to evaluate their performance before and after artificial accelerated aging. Panels were produced with different particle mass, resin content and pressing time, resulting eight treatments. Particles moisture and size distribution were determined, beyond panel physical and mechanical properties, according to NBR14810-3: 2006. After characterization, treatments B and G (small adhesive consumption and better mechanical performance, respectively) were chosen to artificial aging tests. Statistical results analysis showed best performances were achieved for waterproof aged samples, of both B and G treatments. As example, in treatment B, MOR and MOE values were 23 MPa and 2,297 MPa, samples before exposure; 26 MPa and 3,185 MPa, 32 MPa and 3,982 MPa for samples after exposure (non-sealed and sealed), respectively.

Keywords: *particleboard, impregnated wood residues, mechanical properties, accelerated artificial aging*

1. Introduction

Technological progress in the timber sector, coupled with availability of planted forests, have enabled several alternatives to forest resource use, among them the panel production. Particleboards stand out among these products with the highest production volume worldwide and the possibility of employing wood residues in its production.

These panels are widely used in furniture industry, with little representation in building and packaging, always looking for indoor applications. In this sense, tests simulating weathering conditions have been relevant in seeking new applications for these products.

New inputs can bring benefits to outdoor application. Beyond impregnated wood waste, allowing resistance to biological agents, two-component castor oil based polyurethane resin is characterized as an adhesive with environmental appeal related to origin of one component and no formaldehyde emission. This is an important difference comparing with usual adhesives employed in industry, besides its properties of resistance to moisture and significant increase in mechanical properties.

Under this scenario, this study aimed to produce particleboards using CCB (chromium-copper-boron oxides) impregnated *Pinus* sp. residues and castor oil based polyurethane resin based oil and their characterization before and after artificial accelerated aging test, simulating cycle of one year exposure year to natural weathering.

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2. Literature Review

According to Campos[1], wood-based products provide an interesting alternative to expand the range of materials for use in civil construction and furniture industry. Brazil is an important worldwide producer/supplier of general purpose boards and possesses updated technology to produce these products.

Among wood based products, particleboard (recently called Medium Density Particleboard, MDP) use, as pointed by Trianoski[2], has presented one of the highest expansion rates, reaching more than 90 million cubic meters in 2009 (globally), according to Food and Agriculture Organization, FAO[3], and more than 3 million cubic meters in 2010, in Brazil, as mentioned by Brazilian Association of Wood Panels, ABIPA[4].

Particleboards are conceptualized by Iwakiri[5], Maloney[6] and Moslemi[7] such as panels made from wood particles, incorporating synthetic resins or other adhesives, consolidated by a process in which temperature and pressure are applied.

Particleboards are usually intended for indoor uses. According to ABIPA[4], applications of MDP have been focused in furniture industry. About 4% are employed in building construction, such as floors, walls, ceilings[8]. Packaging industry is also considered a promising scenario, once researches aimed superior properties for these panels by applying new inputs, industrial plants expansion and increased production capacity.

In this way, there are few studies about particleboards strength variation when exposed to weathering, i.e., evaluating possible outdoor uses.

Nascimento[9], studying particleboards manufactured with native species from northeastern Brazil, Jurema Preta (*Mimosa tenuiflora*), Algaroba (*Prosopis juliflora*) and Angico (*Anadenanthera macrocarpa*), and urea-formaldehyde resin, exposed these panels to natural weathering with and without coating. Samples were fixed in clean soil and remained under rain, sun, microorganisms and so. After 45 days, some samples broke up with the simple extraction, due to severe exposure conditions. Nascimento[9] also conducted testing of artificial weathering aging in chamber for a three months period, equivalent to 2.5 years of natural exposure, in samples from the same panels, but sealed with three coats at 24 hours intervals of other products. Visual classification was assumed to performance analysis. In general, best results were obtained to coating with castor oil polyurethane resin.

Kojima and Suzuki[10] analyzed particleboard durability of several wood based products, as MDF (Medium Density Fiberboard), OSB (Oriented Strand Board) and plywood used in Japanese building. Authors evaluated performance of these products in bending after five types of accelerated aging cycles, recommended or modified from codes: JIS-B and APA D-1, considering immersion, boiling and drying cycles; V313 of the European Standard and ASTM D1037, consisting of dipping, drying and freezing. It's interesting to mention that ASTM code also adopt vaporization aging cycles and VPSD (not based on standard codes) involves immersion in vacuous, followed by immersion and drying under pressure. To establish a correlation with natural aging, authors compared the panels bending properties aged in laboratory with a five years air exposed to air panel (in Shizuoka, Japan). This study provided correlations about one to one between methods JIS-B, APA D-1 and ASTM D1037, both after 6 cycles, and natural aging in bending properties. Bending performance of deteriorated panels was similar to natural aging sample in six repetitions of ASTM cycles. Taking in account the good correlation obtained by the authors, it is opportune to mention that environmental exposure conditions were consistent with tests conditions, yet at another location with different weather conditions, it would be possible different correlations.

Nascimento[9] register that particleboards require similar care that concerning to protection even they have some specific characteristics in production process, such as adhesive type, pressure and temperature applied during the pressing, imposing considerable influence on its weathering resistance. Furthermore, wood species employed in production can also be an influent parameter in this behavior.

Lepage et al.[11] mention that chemical, mechanical and energy factors lead to occurrence of the phenomenon called "weathering" when wood is soil contact free in outdoor exposition. Factors that promote wood changes by the described phenomenon are: *moisture* (with cell wall contraction and swelling); *light* (with photochemical degradation occurring rapidly in exposed surface, inducted by UV radiation); *heat* (with acceleration of chemical reactions rate); SO_2 (promotion of lignin softening); *abrasion* (caused by solid particles carried by wind).

Beyond changes in appearance, decomposition of chemical elements and changes in microscopic structure like cells separation, half-bordered pits extension, cell wall cracks as intracellular chaps shall reduce its mechanical performance.

Some wood finishes protect it from weather action: paints, varnishes, WR (Water Repellent) or WRP (Water Repellent Preservative) and stains. Paints and varnishes are film trainers and WR, WRP and stains penetrate wood[11].

Wood panels industry is a large-scale user of urea-formaldehyde (UF) adhesive. However, this input has drawbacks due to strength loss under moisture action, even for a relatively short time[12]. Besides, it has limitations related to energy consumption (cures in temperatures above 160 °C) and to formaldehyde emission.

Seeking outdoor uses, phenol formaldehyde resin (PF) has been conventionally used. Although increasing panel performance, PF presents the same UF drawbacks. According Iwakiri[5], PF resin has 2.5 times the cost of urea-formaldehyde.

Castor oil based polyurethane resin has been an alternative in wood products manufacture, as shown by Jesus[13], Campos[14], Dias[12] and Bertolini[15], by expressive performance added to the products, like moisture resistance and mechanical properties. This adhesive was originated in the 1940s[16]. Institute of Chemistry of São Carlos, University of São Paulo, produced the first two-component adhesive from castor-oil, composed of polyol, extracted from castor beans, and prepolymer (isocyanate), resulting in polyurethane, which cure, reached at room temperature, can be accelerated at 60-90 °C[12].

Despite cost slightly higher than usual adhesives in this market, the trend for products with environmental appeal have already placed PU resin based on castor oil in standard products, designed for floors manufacturing with a singular concept. This confirms that cost can be reduced over time if demand for products from renewable sources increases.

Another application of castor oil resin, taking into account the cited characteristics, is wood panel polymeric coating. Researches developed using this input to increase particleboard impermeability when exposed to artificial accelerated aging showed excellent results according to Nascimento[9] and Bertolini[15].

Almeida[17] highlights versatility of polyurethane resin, characterized by high chemical resistance when used as a polymeric coating, applied as films to cementitious matrices in building construction. In this usage, the polymeric material protects concrete, preserving its integrity. However, Almeida and Ferreira[18] point out that properties alteration will be detected in these polymeric materials under solar radiation action combined with oxygen.

Literature review permits to understand contribution of the present work in analysis of outdoor particleboard employments, by evaluating its performance after weathering exposure.

3. Experimental Procedures

3.1. *Material*

In particleboard production, CCB impregnated *Pinus* sp. residues (supplied by Matra Treated Timber LTDA, São Carlos, SP) were employed (Figure 1a). CCB is a mix of chromium, copper and boron oxides that contributes to retard biological attack in wood. Impregnation was performed under pressure, with retention of 7.5 $kg.m^{-3}$ of active ingredients, obeying NBR 7190:1997[19] recommendation (minimum of 4.0 $kg.m^{-3}$).

Particles were obtained by processing waste into the knife mill, Willye Marconi model MA 680. All material passing through a sieve of 2.8 mm was used in panel manufacture[9]. The so-called "thin" allows better adhesion of the resin particles, if used in small amount (less than 10% of particle mass), according to Bertolini[15].

Particles classification by size distribution was performed in equipment SOLOTEST, using sieves with openings 7, 10, 16, 30, 40 and 50 mesh. The test was conducted in triplicate, with a 200 g sample of material and 10 minutes vibration time. Particles moisture content was determined employing a thermo scale OHAUS, model MB 200.

In panel production, a two-component castor oil based polyurethane resin was used (Figure 1b) in 1:1 components (prepolymer and polyol) ratio, considering the high mechanical performance obtained in comparison with other ratios, according Bertolini[15]. Resin was provided by Plural Chemical Industry LTDA.

3.2. *Methods*

3.2.1. Panels production

The following production parameters were adopted based on Bertolini[15]: two quantities of particles (1300 and 1400 g), two adhesive levels (12 and 15%) and two pressing times (10 and 12 minutes). Variation in particles amount aimed to search for an effective panel compaction ratio, once CCB impregnated *Pinus* sp. residues were used (with higher density than the same species without treatment). Changes in pressing time aimed gains with lower production periods. Furthermore, adhesive proportions were based on related works, also employing a castor oil based PU resin, like Fiorelli et al.[20], Rodrigues[21] and Campos[14]. Combining these factors, eight treatments are obtained. Six panels of each treatment were produced, as shown in Table 1, according once more to Bertolini[15].

After homogenized in an appropriate recipient, particles and adhesive mixture was previously compressed in a small press (0.01 MPa pressure) and then subjected to hot (100 °C) pressing (4 MPa) in semiautomatic equipment Marconi Model MA 098/50. Panels nominal dimension were 40 cm × 40 cm, 10 mm thickness. After 72 hours of seasoning, panels were square in 35 cm × 35 cm (Figure 2).

3.2.2. Panels characterization

Particleboard characterization was performed according to NBR 14810-3: 2006[22]. The following parameters were determinate: density (to obtain compaction ratio); moisture content (MC); modulus of rupture (MOR) and modulus of elasticity (MOE) in bending, before and after artificial accelerated aging test.

Aiming to analyze the influence on samples bending performance (by means of MOR and MOE), after a period of exposure to critical conditions of heat and moisture, artificial accelerated aging test was carried out obeying ASTM G155: 1999[23] in an Atlas Weather-Ometer Equipment, model XW 65-WR1, operating with a 6500 W xenon lamp, was employed. The set consists of a rotating carousel for sample holder, automatic temperature and relative humidity control inside the chamber aging, as shown in Figure 3. The cycle of samples maintenance in equipment was 55 days (1200 hours, considering possible stops). According to manufacturer information, this time is equivalent to one year age[24]. Specimens for accelerated weathering test were placed "in natura" and also sealed with two coats of castor oil based polyurethane resin, with components of resin in ratio 1:1 and interval between coats 24 hours.

(a) (b)

Figure 1. CCB treated *Pinus* sp. residues (a) two-component castor oil based polyurethane resin (b).

Table 1. Treatments proposed for manufacture of particleboards.

Treatment	Composition				Pressing time (minutes)
	Wood particles (g)	Resin content[a] (%)	Resin components		
			Pre-polymer (g)	Polyol (g)	
A	1300	12	97.5	97.5	10
B	1300	12	97.5	97.5	12
C	1300	15	117	117	10
D	1300	15	117	117	12
E	1400	12	105	105	10
F	1400	12	105	105	12
G	1400	15	126	126	10
H	1400	15	126	126	12

[a]Based on quantity of wood.

Figure 2. Particleboards: before and after squaring, respectively.

(a) (b) (c)

Figure 3. Atlas Weather-Ometer Equipment, model XW 65-WR1 (a), rotating carousel for sample holder (b), xenon lamp (c).

For artificial accelerated aging test, treatment B was selected, because of panel's behavior in these conditions attended normative requirements with lower resin consumption content in its production, compared to the treatment G, which showed superior performance to other treatments, but higher adhesive consumption. Figure 4 shows positions of panels cutting in order to obtain test specimens.

Table 2 shows specimens employed to moisture, density and bending properties MOR and MOE determination, before and after artificial accelerated aging test, according to cutting scheme.

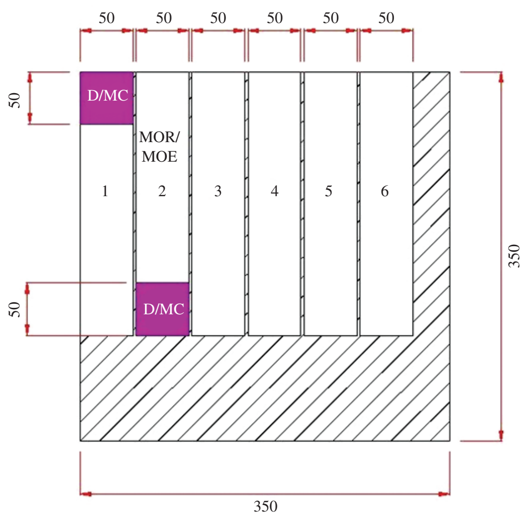

Figure 4. Particleboard cutting scheme in order to obtain test specimens, with dimensions in millimeters. D/MC = samples for density and moisture content; MOE/MOR = samples for modulus of rupture and modulus of elasticity in static bending.

Table 2. Scheme for specimens testing.

Test	Particleboard	Specimens
MC; Density; MOR; MOE	1 2 to 6	1 to 6 3 and 5
MOR – AAA; MOE – AAA	2 to 6	2
MOR – AAA_S; MOE – AAA_S	2 to 6	4

MC = moisture content; MOR – AAA and MOE – AAA = modulus of rupture and modulus of elasticity in bending after artificial accelerated aging test; MOR – AAA_S and MOE – AAA_S = modulus of rupture and modulus of elasticity in bending after artificial accelerated aging test in samples sealed with castor oil resin.

3.2.3. Results analysis

Tests results were compared with code requirements related to particleboards: NBR 14810-2: 2006; ANSI A208.1: 1999; CS 236-66: 1968 and EN 312: 2003 (Table 3).

Two steps were adopted for statistical analysis. Firstly, using variance analysis (ANOVA) to 95% probability for the Tukey test, average values related to physical and mechanical properties were compared to determine production parameters influence, aided by software Minitab 16. Second step took in account MOR and MOE values, before and after artificial accelerated aging, samples "*in nature*" (AAA) and coated (AAA_S). This comparison was conducted using a variance analysis (ANOVA) with repeated measurements, aided by software STATISTICA v.8.

MOE and MOR in static bending were chosen because are fundamental properties fairly applied in wood based products characterization. According to Silva et al.[29], MOR and MOE values express the combination of several factors as wood morphology, chemistry and anatomy.

4. Results and Discussion

4.1. *Particles characterization*

For CCB impregnated *Pinus* sp. particles, mean value of moisture content (MC) was 8.6%. Kollmann et al.[30] and Moslemi[7] report that recommended moisture for particles should be between 3-6%. However, values reported in literature refer to particleboards made with formaldehyde based adhesives. Isocyanate in castor oil base PU resin requires more MC particles, as outlined by Nascimento[9], to promote the reaction with hydroxyl groups compounding lignocellulosic material[31]. According to Silva[32], besides the main reaction among resin components, other reactions can occur, as isocyanate (highly reactive group) with water, releasing carbon dioxide (CO_2) and thereby facilitating polymer expansion.

Particle size classification (Table 4 and Figure 5) showed large fraction of particles (70%) with dimensions between 0.595 mm and 1.19 mm, and about 10% of "thin", i.e., particles smaller than 0.30 mm. Peixoto and Brito[33], comparing two compositions of different particle size distributions (4.37 to 0.61 mm; and 2.0 to 0.61 mm), found that particleboards with the smaller range of particle size distribution resulted in higher mechanical properties, as in internal bond and bending. According to authors it happens likely because to better uniformity of the material and occurrence of smaller internal spaces[33]. Figure 5 shows particles percentage retained in the sieves.

Table 3. Requirements established for particleboards.

Normative references	Particleboard thickness (mm)	D ($g.cm^{-3}$)	MOR (MPa)	MOE (MPa)
NBR 14810-2:2006[25]	8 to 13	-	18	-
ANSI A208.1: 1999[26]	-	>0.8	16.5	2400
CS236-66: 1968[27]	-	>0.8	16.8	2450
EN 312: 2003[28]*	> 6 to 13	-	16	2300

D = Density; MOR – modulus of rupture in bending; MOE – modulus of elasticity in bending. *Type P4 boards – Load-bearing boards for use in dry conditions.

4.2. *Particleboards properties*

Table 5 presents average values to particleboards density, compaction ratio and moisture content.

Treatments C and D (with smaller quantities of particles and greater resin content) are statistically different of E and F (which have a larger amount of particles and smaller resin content). In this regard, it appears that particles and adhesive are variables influencing on this property, and treatments with the greatest particles amount and a lower resin content lead to greater panel moisture content.

Particleboards density of both treatments (Table 5), statistically equivalent to each other, can be classified as high density panels (>0.8 g.cm^{-3}), according to ANSI A208.1:1999[26], CS236-66: 1968[27] and Moslemi[7]. This classification becomes important because panel properties are closely related to density[34]. Compaction ratio values were similar to Maloney[6] indication, even the author refers to particleboards based in low to medium density species, diverse condition compared with CCB *Pinus* sp. in this study, 0.70 g.cm^{-3} as Rocco Lahr et al.[35].

Bowyer et al.[36] emphasize that lower density species are indicated to particleboard production, to reduce panels density variation. However, it is observed that average density values from different regions of the panels (Figure 4), of both treatments, resulted in lower coefficients of variation.

Table 4. Particles classification by size distribution.

Sieves (mesh)	Sieves opening (mm)	Mass retained (g) (Mean Value)	Mass retained (%) (Mean value)
7	2.83	0.2	0.1
10	2	9.3	4.6
16	1.19	60.9	30.4
30	0.595	83.0	41.5
40	0.42	18.1	9.0
50	0.297	9.8	4.9
"Thin"(<50)	<0.297	19.4	9.7
Total		200.0	100.0

Figure 5. Particles retained in the sieves: a) >7 mesh; b) >10 mesh; c) >16 mesh; d) >30 mesh; e) >40 mesh; f) >50 mesh; g) <50 mesh.

Table 5. Mean values obtained for moisture content (MC), density and compaction ratio.

Treatment	MC (%)			Density (g.cm^{-3})			Compaction ratio
	Mean value		VC (%)	Mean value		VC (%)	
A	7.4	ab	3.14	0.88	a	5.25	1.3
B	7.53	ab	2.48	0.9	a	2.71	1.3
C	7.12	b	3.27	0.9	a	6.4	1.3
D	7.01	b	5.14	0.94	a	3.1	1.3
E	7.81	a	2.01	0.89	a	3.58	1.3
F	7.91	a	5.67	0.97	a	5.59	1.4
G	7.51	ab	4.04	0.95	a	8.45	1.4
H	7.54	ab	4.81	0.91	a	7.13	1.3

Means followed by same letter do not differ from one another in Tukey test at 95% probability. VC = variation coefficient of the means; MC = moisture content.

Table 6 shows bending properties (MOR and MOE) for analyzed treatments.

Treatments A and D presented statistical difference only between MOE values. So it's possible to correlate larger particle and resin content amounts with superior performance, for MOE. Considering mechanical properties, it appears that most of the treatments leaded to a superior performance, using codes requirements as reference (Table 3). Exceptions occurred to treatment A, related to ANSI 208.1: 1999[26] requirements about MOE.

MOR values were about 50% higher than standards requirements. Even treatment with lower values of MOR (24 MPa) is compatible to furnish particleboards to outdoor applications, based on American and Canadian standards indications (20.5 and 23.6 MPa, respectively). Iwakiri et al.[37] found that *Pinus* spp. panels with density exceeding 0.8 g.cm^{-3} resulted in higher bending properties (MOR and MOE: 18.8 MPa and 2250 MPa, respectively), emphasizing good performance achieved with treated wood particles.

Peixoto and Brito[33] produced particleboard with *Pinus taeda* and phenol-formaldehyde resin (8% dry weight basis) employing particles from 2.00 to 0.61 mm, resulting in MOR and MOE values, respectively, 196.20 kgf.cm^{-2} (19.24 MPa) and 30,110 kgf.cm^{-2} (2,953 MPa). Hashim et al.[38] produced particleboards, for exterior uses, with biomass obtained from fronds palm (industrial waste oil extraction) and 10% phenol-formaldehyde resin, pressed at 180° C and 5 MPa during 20 minutes. Panels resulted in values of MOR (16.5 MPa) higher than Japanese Industrial Standard (JIS A-5908:2003) requirements, used as a reference[38]. Thus, it appears that the particleboards produced with CCB treated *Pinus* sp. residues and castor oil based PU resin showed analog performance than other authors in same area, using phenol-formaldehyde adhesive.

It is observed that moisture content and mechanical properties in static bending (MOR and MOE) are influenced by resin content. In this work, samples with 12% of adhesive (similar to industrial-scale production with formaldehyde based resins) were employed and the results showed concordance to standard requirements. So, smaller adhesive amounts to reduce costs with this input would be possible.

Table 6. Mean values for modulus of rupture and modulus of elasticity in bending.

Treatment	MOR (MPa)			MOE (MPa)		
	Mean value		VC (%)	Mean value		VC (%)
A	25	a	10.37	2,304	b	6.7
B	24	a	12.3	2,537	b	8.39
C	26	a	18.36	2,474	ab	15.14
D	26	a	13.67	2,553	ab	11.05
E	28	a	9.21	2,670	ab	6.97
F	28	a	8.93	2,654	ab	7.13
G	29	a	18.66	2,911	a	13.22
H	28	a	15.71	2,764	ab	9.45

Means followed by same letter do not differ from one another in Tukey test at 95% probability. VC = variation coefficient of the means; MOR – modulus of rupture in bending; MOE – modulus of elasticity in bending.

4.3. *Weathering effect in mechanical properties*

Tables 7 and 8 show MOR and MOE values for non-aged samples conditions (NA) and after artificial accelerated aging, provided with and without aging sealing (AAA and AAA_S, respectively). Average values followed by coefficients of variation and ANOVA (with repeated measures on time) are presented to permit comparison between treatments (B and G) and in relation to time (or aging time).

For comparative purposes by using statistical analysis between properties before and after artificial accelerated aging, panel 1 of each treatment was dismissed for average values calculation, once these panels, as described in Table 2, have not been subjected to weathering.

About MOR (Table 7), standing the treatment and observing its behavior, for both B and G treatments, under conditions for NA and AAA, no statistical difference was detected. Statistically significant difference was obtained when AAA_S was compared with NA and AAA samples, for both treatments. It is an indication that weathering period

Table 7. Comparative of times and treatments by ANOVA for the MOR.

Treatments	Times/samples		
	Non-aged	Aged – "in nature"	Aged and sealed
B	23 ± 2.51Ba	26 ± 3.54Ba	32 ± 4.39Aa
G	29 ± 6.12Ba	30 ± 3.79Ba	32 ± 7.44Aa

Two means followed by same capital letter do not differ from another in the respective times, settling the treatments, in Tukey test at 95% probability. Two means followed by same small letter do not differ from another in the respective treatments, settling the times, in Tukey test at 95% probability.

Table 8. Comparative of times and treatments by ANOVA for the MOE.

Treatments	Times/samples		
	Non-aged	Aged – "in nature"	Aged and sealed
B	2,297 ± 267.70Cb	3,185 ± 591.27Ba	3,982 ± 519.10Aa
G	2,963 ± 406.09Ba	3,456 ± 252.35Aa	3,535 ± 552.62Aa

Two means followed by same capital letter do not differ from another in the respective times, settling the treatments, in Tukey test at 95% probability. Two means followed by same small letter do not differ from another in the respective treatments, settling the times, in Tukey test at 95% probability.

improved samples AAA_S performance. If treatment and settling time are considered, it can observed that within the same condition (NA, AAA or AAA_S), treatment B and G did not differ significantly.

According to Table 8, when fixing treatment and observing its behavior in terms of time, MOE differed statistically, for the treatment B, all conditions, NA, AAA or AAA_S. In G treatment, no equivalence statistic was observed only for NA samples compared to aged samples. Settling times and observing each treatment in a given condition, it is noticeable that treatments B and G show performance with statistical difference only in NA condition.

Using statistical analysis, it is noted superior performance for both MOR and MOE, after aging. This may be related to a possible increase in polyurethane resin crystallinity degree in the adopted aging period. It is possible to consider that cycles of greater exposure can result in more expressive degradation and in subsequent reduction of these properties.

Almeida and Ferreira[18] analyzed castor oil based polyurethane resin film coated plates (intended for outdoor application), exposed to artificial weathering in accordance with ASTM G53, to check their mechanical properties after exposure, according to the method ASTM D 638M: 1996. Authors found performance in tensile test to modulus of elasticity and tensile strength at break higher than the initial, approximately after 55 days of exposure, the voltage drop occurring at break after about 175 days in accordance with Figure 6. Furthermore, the Glass Transition Temperature (Tg) was found close to 54 °C, verifying that operating temperatures must not be close to Tg, can therefore result in changes, affecting polymer performance. Almeida and Ferreira[18] performed dynamic-mechanical tests; however Cassu and Felisberti[39] cited that not always results obtained by mechanical testing and dynamic-mechanical tests establish a direct relation, once it is primarily dependent on the nature of material analyzed.

In this sense, wood or preservative may also be responsible for the aged panel performance. Lepage et al.[11] point out that pre-treatments applied (in dilute aqueous solution) to wood surface can slow down its degradation by UV light. Best pre-treatments contain chromium in their composition, both under natural and artificial conditions, as showed in researches developed by "Forest Products Laboratory". So, the use of CCB treated *Pinus* sp. may have influenced the satisfactory particleboard performance, here presented. Important information could be obtained by analyzing chemical composition of this particleboard after aging or by studying longer periods of exposure to artificial accelerated aging.

Kojima and Suzuki[10] analyzed the performance in the bending of commercial particleboard made from waste wood and two types of adhesive, phenol formaldehyde and MDI (methylene diphenyl diisocyanate), after 1 to 5 years outdoor exposure. After aging in fifth time periods, retention properties of MOE and MOR were, respectively 59, 44, 33, 29 and 25% and 47, 30, 22, 19 and 14%, for panels with phenol-resin formaldehyde; and 96, 86, 67, 63 and 56% and 76, 70, 42, 49 and 40% for MDI panels with adhesive.

Results obtained by Kojima and Suzuki[10] demonstrate adhesive influence in properties after aging, once panels containing isocyanate-based resin had better properties retention. According Papadopoulos et al.[31], wood-based panels bonded with MDI exhibit extreme resistance to humidity, low levels of swelling and high mechanical strength.

Figure 7 shows bending specimens before and after aging, samples in conditions NA, AAA and AAAS.

Specimens after aging, with and without PU coating, presented dark color, probably due to lignin decomposition by photochemical degradation that occurs on the surface exposed to UV light, as highlighted by Lepage et al.[11].

Garzón et al.[40] analyzed durability of panels produced from agro-industrial waste (sugar cane bagasse) and 15% castor oil PU resin based on ASTM D1037:2006 recommendations: cyclically immersion in water at 49 °C for 1 hour; steam at 93 °C (3 hours), freezing at –12 °C (20 hours); drying at 99 °C (3 hours), steam at 93 °C (3 hours) and drying at 99 °C (18 hours). Each specimen was

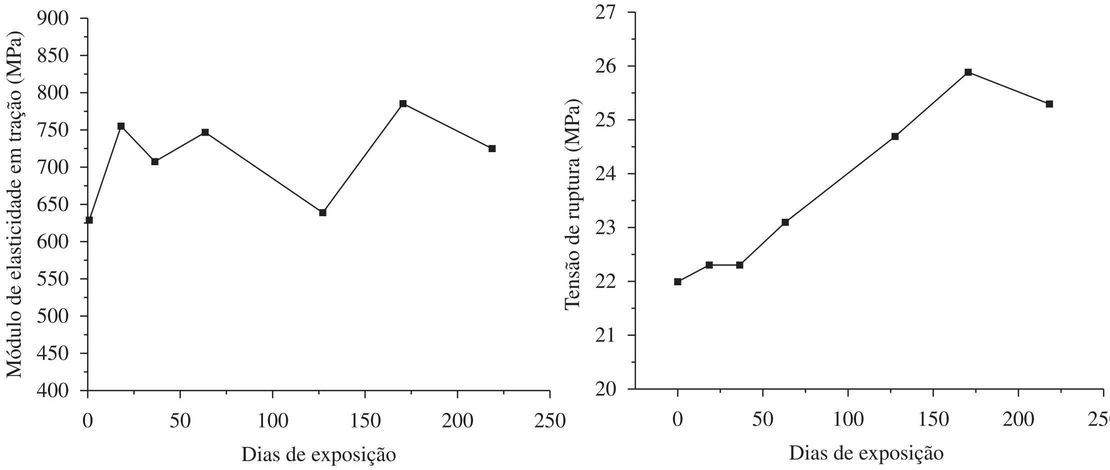

Figure 6. Modulus of elasticity (MPa) and tensile strength (MPa) in tensile test of castor oil samples in the corresponding days of exposure to weathering. Source: Almeida e Ferreira[18]. From left to right: modulus of elasticity in tension *versus* days of exposure and strength in tension *versus* days of exposure.

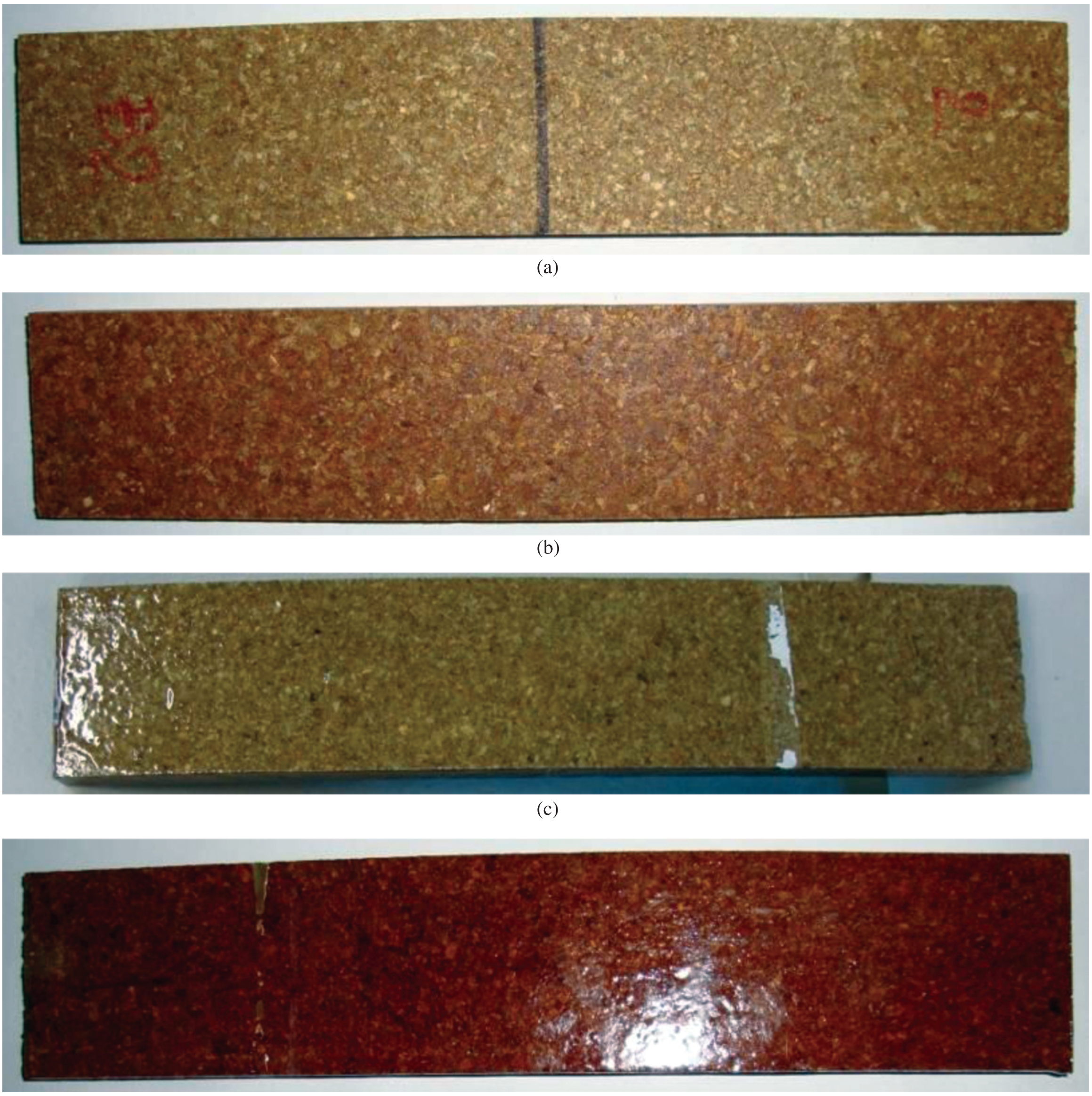

Figure 7. Bending samples before and after artificial accelerated aging: a) non-aged; b) aged; c) non-aged and sealed and d) aged and sealed.

tested six times in this cycle. Before aging, MOR and MOE reached 21.86 MPa and 2.77 GPa, performance of panels H1, according to ANSI A208.1 (1999). After aging, MOR and MOE were 6.25 MPa and 0.52 GPa, similar to panels LD1 performance, according to ANSI A208.1: 1999. Results were influenced by temperature, relative humidity and warm water. Authors reported that ASTM D 1037: 2006 test does not simulate the conditions of Brazilian tropical climate, and proposed new methodologies to take into account different climatic situations.

Nascimento[9] conducted artificial accelerated aging test on equipment similar to this work, for a three months period (equivalent to aging for 2.5 years of natural exposure), using Jurema Preta (*Mimosa tenuiflora*), Algaroba (*Prosopis juliflora*), Angico (*Anadenanthera macrocarpa*) and urea-formaldehyde resin particleboards, sealed with different products. For data analysis, panel visual classification was performed. In general, for all particleboards best protection was obtained with castor oil based PU. This factor may be related to the diisocyanate, a component of the polyurethane resin, with good resistance to humidity. However, Nascimento[9] observed a large cracks and ripples specimens to particleboards of all species.

5. Conclusions

Based on tests results, the following conclusions should be pointed out:

- Characteristics of particles employed in panel production present compatible moisture content (8.6%), providing good interaction with polyurethane adhesive. Particles with dimensions between 0.595 mm and 1.19 mm were consistent with literature recommendation for panel manufacture and provides better mechanical properties;

- Treatments with higher particles amounts and lower resin content resulted in higher values of moisture content. Particleboards from all treatments, resulting from variations in production parameters (particles, adhesive and time pressing) were ranked as high density. In addition, use of treated wood was satisfactory in particles compaction, as can be confirmed in 1.3 to 1.4 compaction ratio;
- Mechanical properties in bending exceeded normative requirements, highlighting MOR for all treatments. It was observed that treatments with higher inputs resulted in high MOE values. Treatments B and G (small adhesive consumption and better mechanical performance, respectively) were chosen for accelerate aging tests and subsequent mechanical characterization;
- Samples subjected to artificial aging with cycle equivalent to 1 year showed superior performance (in relation to MOR) when sealed; and to natural and sealed conditions (in relation to MOE). This may be related to an increase in resin crystallinity degree, resulting in better mechanical properties. However, after longer exposure cycles more degradation in resin might occur and subsequent reduction of these properties. In general, aged samples presented lightly dark surfaces, probably due to lignin decomposition by photochemical degradation.

Beyond, samples with 12% of adhesive (similar to industrial-scale production with formaldehyde based resins) were employed and the results reached standard requirements. So, smaller amounts of adhesive to reduce costs with this input would be possible.

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