

Mechanical properties of accelerated aging particleboards

Propriedades mecânicas de painéis aglomerados submetidos ao envelhecimento acelerado

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The aim of this work was to evaluate the mechanical properties of particleboards before and after accelerated artificial aging. Particleboards were produced using wastes of *Eucalyptus grandis* wood and oat hulls (*Avena sativa*), glued with polyurethane adhesive based on castor oil. The mechanical properties modulus of elasticity (MOE) and modulus of rupture (MOR) were evaluated through ANSI A208.1: 1999 and BS EN 312: 2003. In the experimental design, the following experimental conditions were adopted: mass ratios of particles of *Eucalyptus grandis* wastes and oat hulls (100/0, 85/15, 70/30 and 0/100, respectively), and mass proportions of adhesive (10, 12 and 14%), generating 12 treatments. Six panels were produced per treatment, totaling 72 particleboards. An analysis of variance (ANOVA) was performed to evaluate if the factors and levels adopted in the experimental design influenced the mechanical properties evaluated. The accelerated artificial aging tests followed APA D-1 Cycle, from the APA PRP 108: 1994 standard. The results showed, in several treatments, the properties followed the standards' requirements, being superior to them in some treatments. After aging, only one treatment (for MOE) and three treatments (for MOR) met the requirements of at least one of the standards. It was concluded that the accelerated artificial aging (APA D-1 cycle) is the least aggressive cycle of the APA PRP 108 standard. Even so, it destroyed some of the panels and reduced density and MOE and MOR properties.

Keywords: Particleboards; Mechanical performance; Artificial aging; *Eucalyptus grandis*; Oat hulls.

Resumo

O objetivo deste trabalho foi avaliar as propriedades mecânicas de painéis de partículas antes e após o envelhecimento artificial acelerado. Na produção dos painéis de partículas foram utilizados resíduos da madeira de *Eucalyptus grandis* e de cascas de aveia (*Avena sativa*), coladas com adesivo poliuretano à base de óleo de mamona. Foram avaliadas as propriedades mecânicas módulo de elasticidade e módulo de ruptura, a partir das normas ANSI A208.1:1999 e BS EN 312:2003. No delineamento experimental foram adotadas as seguintes condições experimentais: relação mássica das partículas de resíduos de *Eucalyptus grandis* e cascas de aveia, respectivamente (100/0, 85/15, 70/30 e 0/100), e proporções mássicas de adesivo de 10, 12 e 14%, gerando 12 tratamentos. Foram produzidos seis painéis por tratamento, totalizando 72 painéis de partículas. Realizou-se uma análise de variância (ANOVA) para avaliar se os fatores e níveis adotados no delineamento experimental influenciaram nas propriedades mecânicas avaliadas. Os ensaios de envelhecimento artificial acelerado seguiram o Ciclo APA D-1, da norma APA PRP 108:1994. Os resultados mostraram que, em vários tratamentos, as propriedades atenderam aos requisitos das normas consultadas, sendo em alguns tratamentos, superiores aos requisitos das normas. Após o envelhecimento, apenas um tratamento (para o MOE) e três tratamentos (para o MOR) atenderam aos requisitos de pelo menos uma das normas. Concluiu-se que o envelhecimento artificial acelerado (ciclo APA D-1) é o ciclo menos agressivo da norma APA PRP 108. Mesmo assim, destruiu alguns painéis e reduziu a densidade e as propriedades MOE e MOR.

Palavras chave: Painéis de partículas; Desempenho mecânico; Envelhecimento artificial; *Eucalyptus grandis*; Cascas de aveia

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INTRODUCTION

Issues related to the study, development and characterization of new materials are constantly being discussed due to market needs such as search for more efficient materials, reduction of energy costs, greater versatility, less waste generation and impact on the planet (SILVA et al., 2015).

The improvement of the properties of solid wood and the possibility of using alternative raw materials in its manufacture show the advantage of wood products. The use of wood products has increased a lot in recent years, not only in Brazil but all over the world. Particleboards deserve an outstanding place in the wood scenario because they are the main raw materials used in a range of industries such as flooring, furniture, packaging, naval and civil (VARANDA et al., 2013).

Particleboards are characterized by the conversion of wood into particles which are dried and mixed with a thermosetting synthetic adhesive and randomly distributed among themselves (random matrix) under temperature and pressure (MOSLEMI, 1974). When it comes to the production of panels derived from wood is worth mentioning the resin used. The polyurethane resin based on castor oil, according to Jesus and Calil Júnior (2016), has some great advantages: it is a natural and renewable polymer derived from a native Brazilian plant and there is no need to add paraffin or ammonium sulfate in the adhesive formula. In addition, it does not emit formaldehyde.

The expansion of wood panel industries significantly increases the demand for raw materials, forcing the search for other ones. An alternative way found by several national and international researchers is the use of residual lignocellulosic materials from planted forests and agroindustry (ALVES et al., 2014; CASTRO et al., 2014; DINHANE et al., 2015; IWAKIRI et al., 2017; MACEDO et al., 2015; TRIANOSKI et al., 2015; WEBER; IWAKIRI, 2015).

The quality of wood-based panels is confirmed through their physical-mechanical properties. These properties are determined by tests such as static bending (modulus of elasticity and rupture), resistance to perpendicular traction, resistance to pulling of connectors, density, water absorption, swelling in thickness, among others (MOSLEMI, 1974).

The accelerated artificial aging test on wood-based panels has as objective to evaluate the exposure of these panels to the weather (critical conditions of heat and humidity) and its influence on their physical-mechanical performance. There are several methods of accelerated artificial aging in wood-based panels (KOJIMA; SUZUKI, 2011).

Aging tests on wood and its derivatives are important in predicting how these materials will behave in service over time. Studies of aging of wood and its derivatives have been done both in the form of accelerated artificial aging and outdoor aging. There are studies that even relate these two types of aging and formulate mathematical models that correlate them (GARCIA; NOGUEIRA; ABREU, 2004; GARZÓN et al., 2011; KOJIMA; NORITA; SUZUKI, 2009).

The aim of this work was to produce particleboards with wastes from *Eucalyptus grandis* and oat hulls (*Avena sativa*), adhered with a polyurethane resin based on castor oil, and characterize them for their mechanical properties: modulus of elasticity (MOE) and modulus of rupture (MOR). These panels were subjected to accelerated artificial aging tests and then mechanically characterized again in order to evaluate their performance before and after the process in accordance with ANSI A208.1-1999 (ANSI, 1999) and BS EN 312: 2003 (BS, 2003).

MATERIALS AND METHODS

Production of particleboards

To produce the particleboards, particles from *Eucalyptus grandis* wood and oat hulls (*Avena sativa*) were used. These materials were generated in a Willey-type knife mill, model MA 680, and passed through a set of sieves with 2.8 mm aperture. The wood of *Eucalyptus grandis* was obtained from a company in the region of São Carlos - SP, while the oat hulls were obtained from an industry located in the city of Porto Alegre - RS. The apparent density of the *Eucalyptus grandis* particles was 640 kg/m³, while the apparent density of the oat hulls particles was 290 kg/m³.

The particles of *Eucalyptus grandis* and oat hulls had average moisture contents of 7.9 and 10.3%, respectively. According to Nascimento et al. (2013), in the manufacture of panels, the ideal particle moisture should be within a range of 8 to 10% for castor-based polyurethane resin.

In the preparation of the panels, a polyurethane resin was used at a 1:1 ratio between prepolymer and polyol, obtained from the local market, because there are several chemical industries that produce such resin.

In each panel, 640 grams of particles agglutinated with the castor-based polyurethane adhesive were used, in different adhesive proportions: 10, 12 and 14% of the dry mass of the particles. The parameters used in the pressing were: pressure of 4 MPa, time of 10 minutes and temperature of 100°C.

The prepared particle panels were divided into groups, according to the different particle ratios of each material (*Eucalyptus grandis* and oat hulls) and adhesive. Thus, there were twelve experimental conditions (EC), as shown in Table 1.

Table 1 – Composition among factors

Tabela 1 – Composição entre fatores

EC*	Constituents Proportions
1	100% <i>Eucalyptus grandis</i> - 10% adhesive
2	100% <i>Eucalyptus grandis</i> - 12% adhesive
3	100% <i>Eucalyptus grandis</i> - 14% adhesive
4	(85% <i>Eucalyptus grandis</i> - 15% oat hulls) - 10% adhesive
5	(85% <i>Eucalyptus grandis</i> - 15% oat hulls) - 12% adhesive
6	(85% <i>Eucalyptus grandis</i> - 15% oat hulls) - 14% adhesive
7	(70% <i>Eucalyptus grandis</i> - 30% oat hulls) - 10% adhesive
8	(70% <i>Eucalyptus grandis</i> - 30% oat hulls) - 12% adhesive
9	(70% <i>Eucalyptus grandis</i> - 30% oat hulls) - 14% adhesive
10	100% oat hulls - 10% adhesive
11	100% oat hulls - 12% adhesive
12	100% oat hulls - 14% adhesive

*EC: Experimental Conditions

The proportions described in Table 1 were adopted from the results obtained in preliminary studies. The amount of adhesive used was around 12%.

For each of the twelve experimental conditions (EC), six identical panels were produced with the polyurethane adhesive based on castor oil, totaling 72 panels of particles with nominal thickness of 10 mm, since this is one of the most usual dimensions, and nominal dimensions of 280 x 280 mm.

After the conditioning period, the panels were subjected to squaring and subsequent sectioning to remove the specimens. Initially about 10 mm were removed from each end of the panel, using a circular saw. The panels had nominal dimensions of 260 x 260 x 10 mm. From the squaring, the panels were sectioned in the dimensions of the specimens for static flexion (250 x 50 x 10 mm). For both processes, it was used a circular saw, Invicta - model SCI-160. Figure 1 shows some of the steps in the making of the panels.

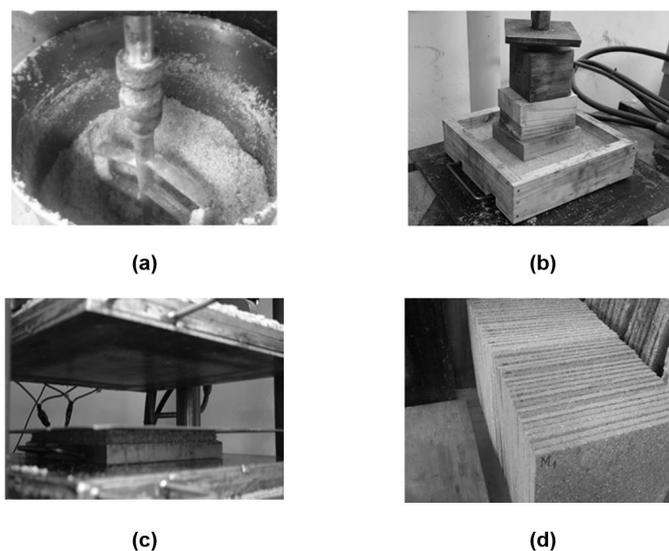


Figure 1 – Particle mixer with adhesive (a), pre-pressing (b), panel being pressed (c) and squared panels (d)

Figura 1 – Misturador das partículas com o adesivo (a), pré-prensagem (b), painel sendo prensado (c) e painéis esquadrejados (d)

Mechanical properties and accelerated artificial aging tests

It was necessary to know the moisture content of the panels when their physical-mechanical properties were determined, because the moisture content influences the properties of wood-based panels (JANKOWSKY, 2010). From the 72 panels produced, eight panels were randomly selected and the moisture content of each one was determined before and after accelerated artificial aging. The density of the panels was also determined.

The mechanical properties evaluated were: modulus of elasticity (MOE) and modulus of rupture (MOR), both obtained by the three-point static bending test. The mechanical characterization was performed in an AMSLER universal testing machine with a capacity of 250 kN. It used a speed of 6 mm/min (indicated for panels with thickness between 6 and 12 mm), according to ABNT NBR 14.810-3: 2002 (ABNT, 2002) standard. Static flexion tests (MOE and MOR determination) were performed before and after accelerated artificial aging.

The accelerated artificial aging tests evaluate the exposure of the panels to the weather (critical conditions of heat and humidity) and its influence on their physical-mechanical performance.

Accelerated artificial aging tests were performed according to the APA PRP 108: 1994 standard, specifically the APA D-1 Cycle. The choice of this accelerated artificial aging method was based on a study (KOJIMA; SUZUKI, 2011) which ranks this method as the least aggressive among five others. Even this less aggressive cycle significantly destroyed the panels and did not represent the aging reality of the outdoor panels, as observed by Kojima and Suzuki (2011).

The equipment used was: water-bath of Marconi, model MA 470 (Figure 2a), sterilization and drying oven of New Ethics, model 400-5 ND (Figure 2b) and climatic chamber of Thermotron, model SM-3.5 S (Figure 2c).

The process conditions used in the tests were: bain-marie at 66 °C for eight hours, oven at 82 °C for 14.5 hours and conditioning treatment at 20 ± 3 °C and humidity of $65 \pm 2\%$ for one and a half hours. All these process conditions were applied according to the APA D-1 Cycle, established by the APA normative document PRP 108: 1994 (APA, 1994).

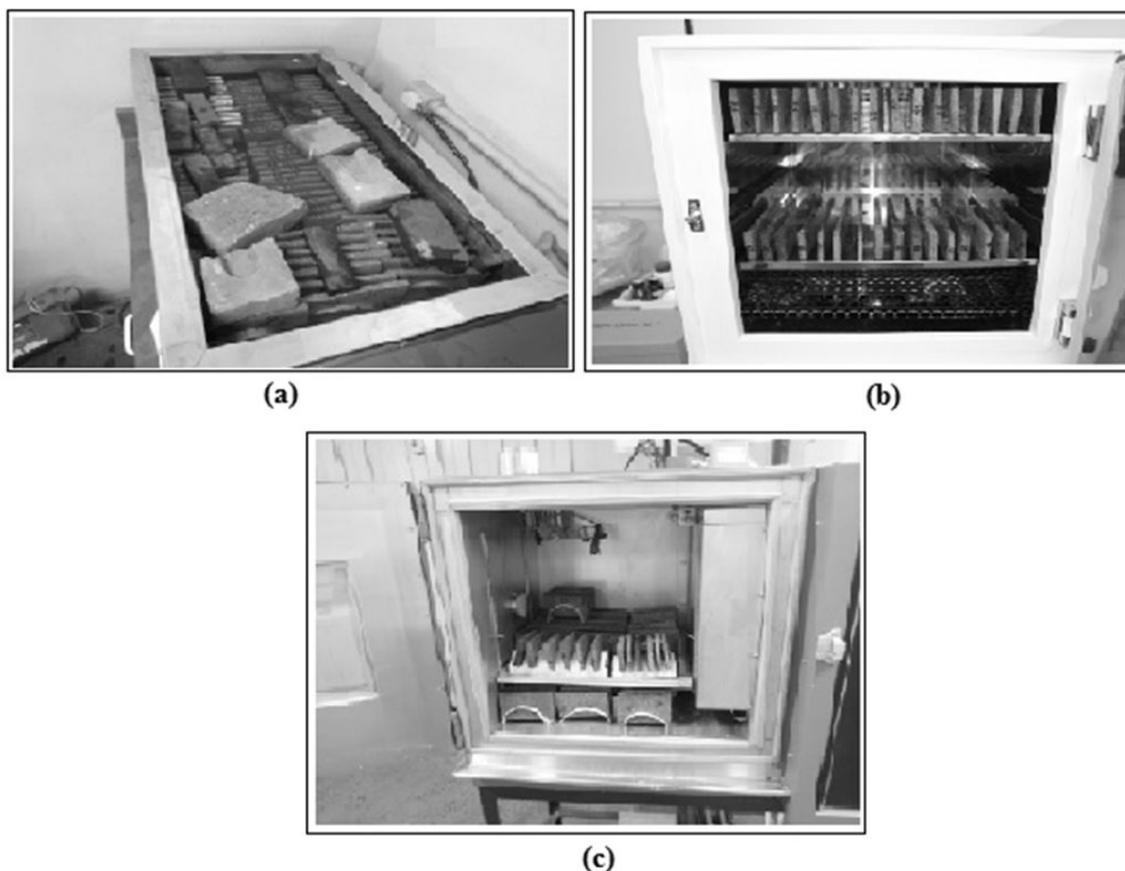


Figure 2 – Equipment used: bath with circulation (a), oven (b) and climatic chamber (c)
Figura 2 – Equipamentos utilizados: banho com circulação (a), estufa (b) e câmara climática (c)

All MOE and MOR data were submitted to statistical analysis to evaluate if the factors and levels adopted in the experimental design (Table 2) had influence on the mechanical performance of the panels at a significance level of 5%. The statistical analysis adopted was a variance analysis (ANOVA). The assumptions investigated to validate the ANOVA results for each property evaluated were normality in the distribution of responses (Anderson-Darling normality test) and homogeneity of variances between treatments (Bartlett's test).

RESULTS AND DISCUSSION

The average moisture content of the eight panels randomly evaluated before aging was 9.1%, with a coefficient of variation of 6.8%. After the accelerated artificial aging tests, the average moisture content decreased to 7.5%, with coefficient of variation of 6.4%.

The density of the 72 panels varied from 913 to 1016 kg/m³ for panels without the aging process and from 758 to 927 kg/m³ for panels after accelerated artificial aging. The reduction of the panels' density is associated with the aging cycle, which removed part of the constituent materials of the panels (particles). This reduced the mass of the panels and consequently reduced their density.

Table 2 presents the values obtained for the modulus of elasticity (MOE) for the panels before and after aging.

Table 2 – Average values of modulus of elasticity (MOE) of the panels

Tabela 2 – Valores médios do módulo de elasticidade (MOE) dos painéis

EC*	Before aging		After aging	
	MOE* (MPa)	CV* (%)	MOE (MPa)	CV (%)
100%E – 10%Ad	2349	14.0	1208	21.1
100%E – 12%Ad	2581	12.7	1438	14.3
100%E – 14%Ad	2982	10.0	2379	17.3
(85%E - 15%OH) – 10%Ad	2366	17.6	1099	8.3
(85%E - 15%OH) – 12%Ad	2364	9.3	1169	18.2
(85%E - 15%OH) – 14%Ad	2916	11.4	1980	11.0
(70%E - 30%OH) – 10%Ad	2342	9.5	755	19.0
(70%E - 30%OH) – 12%Ad	2389	8.8	914	14.9
(70%E - 30%OH) – 14%Ad	2560	17.3	1343	14.9
100%OH – 10%Ad	1942	13.3	521	20.6
100%OH – 12%Ad	2078	9.5	710	16.9
100%OH – 14%Ad	2171	4.0	1185	12.8

*EC: Experimental Conditions; E: *Eucalyptus grandis*; OH: oat hulls; Ad: Adhesive; MOE: modulus of elasticity; CV: coefficient of variation (%).

The reduction of MOE, after the accelerated artificial aging process, is due to the severity of the adopted method (APA Cycle D-1), even though the cycle is less aggressive than the standard used.

All MOE values for panels before aging met the requirement of BS EN 312: 2003 (BS, 2003) (minimum value of 2050 MPa), except the experimental condition 10. ANSI A208.1:1999 establishes the minimum value of 2400 MPa for the MOE. The requirements of this standard were met in four experimental conditions (2, 3, 6 and 9 - Table 2).

Some of these differences in the results can be due to the many variables involved in the production of the panels (material density, pressing variables, adhesive used), which directly influence their final quality and physical-mechanical properties (JANKOWSKY, 2010; MOSLEMI 1974).

For the MOE, after the aging of the panels, only experimental condition 3 (Table 1) met the requirement of BS EN 312: 2003.

Table 3 shows the results for the ANOVA of MOE, with p-values lower than or equal to 0.05 (5%) being considered significant at a significance level of 5%.

The experimental factors *Eucalyptus grandis*, adhesive and oat hulls were significant on the MOE property, before and after the aging of the panels. The interactions (*Eucalyptus grandis* - adhesive and oat hull - adhesive) were significant on the MOE property only after the aging of the panels, as shown in Table 3.

Table 4 presents the values obtained for the modulus of rupture (MOR) for the panels without aging and after aging.

Table 3 – P-values of the factors and interactions investigated in relation to the modulus of elasticity (MOE).

Tabela 3 – P-valores dos fatores e interações investigados em relação ao módulo de elasticidade (MOE).

Experimental factors	MOE* (MPa)	MOE* (MPa) after aging
<i>Eucalyptus grandis</i>	0.000	0.000
Adhesive	0.004	0.004
Oat hulls	0.000	0.000
<i>Eucalyptus grandis</i> – Adhesive	0.531	0.008
Oat hulls – Adhesive	0.231	0.008

* MOE: modulus of elasticity

Table 4 – Average values of the modulus of rupture (MOR) of the panels

Tabela 4 – Valores médios do módulo de ruptura (MOR) dos painéis

EC*	No aging		After aging	
	MOR* (MPa)	CV* (%)	MOR* (MPa)	CV* (%)
100%E – 10%Ad	18.2	19.5	9.9	24.9
100%E – 12%Ad	18.7	14.2	11.1	18.2
100%E – 14%Ad	24.1	14.0	22.3	11.4
(85%E - 15%OH) – 10%Ad	17.7	18.6	9.2	17.2
(85%E - 15%OH) – 12%Ad	18.2	8.0	9.8	10.9
(85%E - 15%OH) – 14%Ad	24.1	16.5	19.1	17.9
(70%E - 30%OH) – 10%Ad	19.9	14.6	6.2	24.3
(70%E - 30%OH) – 12%Ad	20.5	21.5	7.8	24.4
(70%E - 30%OH) – 14%Ad	21.5	20.2	13.2	18.7
100%OH – 10%Ad	24.5	17.1	5.8	25.5
100%OH – 12%Ad	24.9	16.1	9.5	32.3
100%OH – 14%Ad	27.0	11.0	15.9	28.9

*EC: Experimental Conditions; E: *Eucalyptus grandis*; OH: oat hulls; Ad: Adhesive; MOR: modulus of rupture; CV: coefficient of variation (%).

The reduction of MOR after accelerated artificial aging is also related to the severity of APA Cycle D-1, even though the cycle is less aggressive than the standard used.

All MOR values for panels without aging met the requirements of the standards ANSI A208.1: 1999 and BS EN 312: 2003, which establish the minimum values of 16.5 and 15 MPa, respectively.

For the MOR values of the panels after aging, only experimental conditions 3 and 6 (Table 4) met the requirements of the ANSI A208.1: 1999 standard.

The BS EN 312: 2003 standard establishes a minimum requirement of 15 MPa, which was met in the experimental conditions 3, 6 and also 12 (Table 4).

Table 5 presents the results for the ANOVA of MOR, with p-values lower than or equal to 0.05 (5%) being considered significant at a significance level of 5%.

Table 5 – P-values of factors and interactions investigated in relation to the modulus of rupture (MOR)

Tabela 5 – P-valores dos fatores e interações investigados em relação ao módulo de ruptura (MOR)

Experimental factors	MOR* (MPa)	MOR* (MPa) after aging
<i>Eucalyptus grandis</i>	0.000	0.000
Adhesive	0.003	0.000
Oat hulls	0.000	0.000
<i>Eucalyptus grandis</i> - Adhesive	0.555	0.061
Oat hulls - Adhesive	0.512	0.061

*MOR: Modulus of rupture.

The experimental factors *Eucalyptus grandis*, adhesive and oat hulls were significant on the MOR property, before and after the aging of the panels. The interactions (*Eucalyptus grandis* - adhesive and oat hulls - adhesive) were not significant on the MOR property, as shown in Table 5.

The reduction in the mechanical properties of the panels is associated with the aging cycle, which removed some of their constituent materials (particles). This affected the adhesion between the particles and the adhesive, reducing the properties MOE and MOR.

CONCLUSIONS

The panels produced are of high density (above 800 kg/m³). The residues of *Eucalyptus grandis* and oat hulls showed compatibility with the adhesive, giving adequate mechanical performance to the panels.

The panels present full conditions of application in the furniture and packaging industries and rural buildings, in indoor and non-structural uses.

Accelerated artificial aging (APA D-1 cycle) is the least aggressive cycle of the APA PRP 108 standard. Even so, it destroyed some of the panels and reduced density and MOE and MOR properties.

According to other studies, even the APA D-1 cycle (less aggressive of the APA standard) is not equivalent to the damage caused in outdoor aged panels. Accelerated artificial aging is more aggressive to panels.

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REFERENCES

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR14810-3**: Chapas de madeira aglomerada – Parte 3: Métodos de ensaio. Rio de Janeiro, 2002. 32 p.

ALVES, L. S.; SILVA, S. A. M.; AZAMBUJA, M. A.; VARANDA, L. D.; CHRISTOFORO, A. L.; ROCCO, F. A. L. Particleboard produced with sawmill waste of different wood species. **Advanced Materials Research**, v. 884/885, p. 689-693, 2014.

ANSI - AMERICAN NATIONAL STANDARD. **A208.1** - Particleboard. Gaithersburg, 1999.

APA – THE ENGINEERED WOOD ASSOCIATION. **APA PRP 108**: Performance Standards and Policies for Structural-Use Panels. Washington, 1994.

BS - BRITISH STANDARD. **BS EN 312**: Particleboards – specifications. London, 2003.

CASTRO, V. G.; BRAZ, R. L.; BELLON, K.; SANCHES, F.; IWAKIRI, S.; NISGOSKI, S. Avaliação colorimétrica de aglomerados produzidos com partículas de madeira de *Sequoia sempervirens* e *Pinus taeda* submetidos ao intemperismo natural. **Revista Floresta e Ambiente**, v. 21, p. 475-483, 2014.

DINHANE, F. C. R.; ARAÚJO, I. I.; VALARELLI, I. D.; BUENO, M. A. P.; FERREIRA, B. S.; CAMPOS, C. I. Particleboard Manufactured with Bamboo and Coconut Fibers in Different Ratios of Adhesive. **Advanced Materials Research**, v. 1088, p. 672-675, 2015.

GARCIA, L. C.; NOGUEIRA, A. C.; ABREU, D. C. A. Accelerated aging influence on *Anadenanthera colubrina* (Vellozo) Brenan – Mimosaceae seed vigour. **Ciência Florestal**, v. 14, n. 1, p. 85-90, 2004.

GARZÓN, N.; SARTORI, D.; ZUANETTI, I.; BARBIRATO, G.; RAMOS, R.; FIORELLI, J.; SANTOS, S. F.; SAVASTANO JR., H. Durability evaluation of agro-industrial waste -based particle boards using accelerated aging cycling tests. In: INTERNATIONAL CONFERENCE ON NOM-CONVENTIONAL MATERIALS AND TECHNOLOGIES. 13., 2001, Pequin. **Proceedings...** Pequin: NOCMAT, 2011.

IWAKIRI, S.; TRIANOSKI, R.; CHIES, D.; TAVARES, E. L.; FRANÇA, M. C.; LAU, P. C.; IWAKIRI, V. T. Use of residues of forestry exploration of *Pinus taeda* for particleboard manufacture. **Revista Árvore**, v. 41, p. 1-8, 2017.

JANKOWSKY, I. P. Equipamentos e processos para a secagem de madeiras. **Revista da Madeira**, v. 21, p. 58-64, 2010.

JESUS, J. M. H.; CALIL JÚNIOR, C. Estudo do Adesivo Poliuretano a Base de Mamona em Madeira Laminada Colada (MLC). **Revista Referência Industrial**, v. 3, n. 8, p. 74-83, 2016.

KOJIMA, Y.; SUZUKI, S. Evaluating the durability of wood-based panels using internal bond strength results from accelerated aging treatments. **Journal Wood Science**, v. 57, p. 7–13, 2011.

KOJIMA, Y.; NORITA, H.; SUZUKI, S. Evaluating the durability of wood-based panels using thickness swelling results from accelerated aging treatments. **Forest Products Journal**, v. 59, n. 5, p. 35–41, 2009.

MACEDO, L. B.; FERRO, F. S.; VARANDA, L. D.; CAVALHEIRO, R. S.; CHRISTOFORO, A. L.; LAHR, F. A. R. Propriedades físicas de painéis aglomerados de madeira produzidos com adição de película de polipropileno biorientado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 19, p. 674-679, 2015.

MOSLEMI, A. A. **Particleboard**. London: Southern Illinois University Press, 1974. 244 p.

NASCIMENTO, M. F.; CHRISTÓFORO, A. L.; BERTOLINI, M. S.; CHAHUD, E.; ROCCO LAHR, F. A. Painéis de partículas homogêneas fabricados com espécies de manejo da região da Caatinga do Brasil. **Construindo**, v. 5, p. 1-10, 2013.

SILVA, D. A. L.; LAHR, F. A. R.; VARANDA, L. D.; CHRISTOFORO, A. L.; OMETTO, A. R. Environmental performance assessment of the melamine-urea-formaldehyde (MUF) resin manufacture: a case study in Brazil. **Journal of Cleaner Production**, v. 96, p. 299-307, 2015.

TRIANOSKI, R.; IWAKIRI, S.; NASCIMENTO, C. C.; BILA, N. F. Painéis aglomerados produzidos com quatro espécies de madeiras tropicais da Amazônia. **Scientia Forestalis**, v. 43, n. 106, p. 85-95, 2015.

VARANDA, L. D.; NASCIMENTO, M. F.; CHRISTOFORO, A. L.; SILVA, D. A. L.; ROCCO LAHR, F. A. Oat Hulls as addition to high density panels production. **Materials Research**, v. 16, p. 1355-1361, 2013.

WEBER, C.; IWAKIRI, S. Utilização de resíduos de compensados, MDF e MDP para produção de painéis aglomerados. **Ciência Florestal**, v. 25, p. 405-413, 2015.

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