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Durability Evaluation of Agro-Industrial Waste -Based Particle Boards Using Accelerated Aging Cycling Tests

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Abstract. The degradation of agro-industrial waste-based particle boards reinforced with sugar cane bagasse was evaluated by comparing their physical and mechanical properties. The particle boards were prepared with sugar cane bagasse particles (85% by weight of composite) and mixed with bi-component polyurethane resin based on castor oil (15% by weight). After mixing for 2 to 3 min, the resulting mixtures were pre-pressured. Standard molding conditions were: temperature, 100°C; pressure during heating, 5 MPa; and heating time, 10 min. The dimensions of the particle boards produced in the laboratory were 0.40 m x 0.40 m x 0.01 m. The boards were cut into testing specimens with dimensions 0.25 m × 0.05 m × 0.01 m. The accelerated aging test was carried out based on the ASTM D 1037 standard in order to determine the main factors that cause degradation and to identify their influence. The test consists of cycles of six treatment steps, i.e., immersion in water at 49°C for 1 h, steaming at 93°C for 3 h, freezing at -12°C for 20 h, drying at 99°C for 3 h, steaming at 93°C for 3 h, and drying at 99°C for 18 h. This cycle was applied six times for all specimens. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), water absorption (WA%) and thickness swelling (TS%) were measured before and after the cycles of accelerated aging. The performance of the particle boards before accelerated aging presented acceptable mechanical performance, MOR: 21.86 ± 2.16 MPa, MOE: 2.77 ± 0.26 GPa, and IB: 1.18 ±0.40. The performance of the particle boards decreased after accelerated aging showed, MOR: 6.25 ± 0.70 MPa, MOE: 0.52 ± 0.10 GPa, and IB: 0.15 ± 0.07. The results were influenced by the temperature, relative humidity and warm water. After the accelerated aging process, the materials showed mechanical behavior similar to Low-Density grade Particleboard (LD1).

Introduction

The use of alternative resources to substitute wood in the particle board industry has increased in recent years mainly due to the depletion of forest resources. Potential substitutes for wood include harvesting residues, barks, annual plants, plant residues, residues of pulp plants and recycled paper [1]. The characteristics of composite materials produced from agro-industrial waste with various additives are determined by internal reactions taking place upon aging. The aging process may considerably reduce the physical-mechanical performance of such materials. One of the current methods for evaluating bond durability of particle boards and other wood-based panels subjected to severe exposure is the six-cycle accelerated-aging test presented in the ASTM D 1037 Standard [2].The National Bureau of Standards (NBS) developed this test in the 1930s to determine fiberboard sheathing durability [3].The ASTM D 1037 standard includes freezing stages that are not realistic in tropical regions such as Brazil. This opens the opportunity to discuss adjusting the methodology of the accelerated aging test for different climates.

The particle boards industry in Brazil prefers to use waste from wood pine reforestation and some species of eucalyptus. However, lignocellulosic materials from agro-industrial residues are a viable alternative material in the production of particle boards The increasing Brazilian agricultural production (and subsequently the production of agro-industrial residues) contributes to these new developments in wood panel manufacturing.

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For this reason, the durability of a particleboard reinforced with sugar cane bagasse must be tested. The sugar cane waste is a lignocellulosic material composed of a hydrophilic natural polymeric material with many –OH groups, which is able to combine with water molecules. However, no significant change occurs in the microstructure of the composite, as the reinforcing filler is encapsulated in the hydrophobic matrix polymer [4]..Studies of the particle board production reinforced with sugar cane bagasse, such as those developed by Battistelle et al. (2009) [13]evaluated the possibility of producing particle board from the bamboo (*Dendrocalamus giganteus*) stem fibers leaves, and sugar cane bagasse (*Saccharum officinarum*) and urea resin as polymer matrix. The results showed that the sugar cane bagasse has a good potential for particle board production and the physical and mechanical properties meet the recommendations set by the normative documents.

The usual role of an aging test is to simulate in a short period of time one or more extreme environmental conditions that can be expected from a real product in use. [14] The ASTM six-cycle method is a common test method and it is detailed in the ASTM D1037 Standard for Wood-Base Fiber and Particle Panel Materials [2]. The test consists of six cycles, each with six individual exposure steps. The most often reported problem with the ASTM D 1037 test is that it is too much long to be used as an in-plant quality control check. Compared to other standard methods, the ASTM D 1037 six-cycle procedure provided the most severe treatment [6]. Each of the six cycles contains six individual exposure steps. The test normally takes 2-1/2 weeks to complete since the cycle can be interrupted only at the freezing step. After accelerated aging, additional time is needed to recondition the specimens before stiffness and strength can be measured. The objective of the present study was to evaluate the physical and mechanical performance of the composites reinforced with sugar cane waste and bi-component polyurethane resin based on castor oil submitted to accelerated aging test following the ASTM D 1037 Standards.

Materials and methods

Particle boards. The particle boards were manufactured in the laboratory scale. Agro-industrial waste -based particle boards reinforced sugar cane bagasse and bi-component polyurethane resin based on castor oil were homogenized in the planetary dough. The particle board was prepared with sugar cane bagasse particles (85% by weight of composite) and mixed with bi-component polyurethane resin based on castor oil (15% by weight). After mixing 2 to 3 min, the resulting mixtures were pre-pressured. Standard molding conditions were: temperature, 100°C; pressure during heating 5 MPa; heating time, 10 min. The dimension of the particle board was 0.40 m x 0.40 m x 0.01 m. Boards were cut into testing specimens with dimensions 0.25 m × 0.05 m × 0.01 m. The samples were kept at 20°C and 65% relative humidity for one week before the physical mechanical tests.

Accelerated aging test. The nominal dimensions of the specimens were 1 cm x 5 cm-x 25 cm. All specimens were marked in order to identify the type of material and number of the sample. Five specimens were randomly selected and tested for each series. The accelerated aging test was based on ASTM D 1037 standard. The test consists of the following six steps as shown Table 1:

Table 1 Phases for ASTM D 1037 accelerated-aging test

Step	Exposure phase	Temperature (°C)	Time (h)
1	Water soak	49	1
2	Steam	93	3
3	Freezing	-12	20
4	Dry air	99	3
5	Steam	93	3
6	Dry air	99	18

After the accelerated aging test the specimens were conditioned at 65% of relative humidity and 20°C room temperature during 48 h before determining physical and mechanical characteristics.

Determination of physical and mechanical properties. The Residual thickness (RT), Thickness swelling (TS), water absorption (WA), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) were evaluated before and after accelerated aging test.

Residual thickness (RT): The thickness of the specimens was measured in five different points along each side of the specimen using a digital caliper, according to ASTM D 1037 standards. This measure was performed before and after accelerated aging test. The percentage of the residual thickness was calculated using Eq. 1.

$$\mathrm{RT}\ (\%)= \left[\frac{\mathrm{T_f} - \mathrm{T_i}}{\mathrm{T_i}}\right] \cdot 100 \tag{1}$$

where T_f is the final thickness and T_i is the initial thickness, respectively, before and after accelerated aging test.

Thickness swelling (TS). The thickness swelling tests were conducted according to ABNT NBR 14810 -3 Brazilian standards. The thickness swelling consists of the difference of specimen thickness before and after soaking in the water by 2 h and 24 h. It was assessed using a digital caliper with a precision of 0.01 mm. The percentage of the thickness swelling was calculated using Eq. 2.

$$\mathrm{TS}\ (\%)= \left[\frac{\mathrm{T_f} - \mathrm{T_i}}{\mathrm{T_i}}\right] \cdot 100 \tag{2}$$

where T_f is the final thickness after soaking in the period of 2h and 24h and T_i is the initial thickness.

Water absorption (WA): The water absorption tests were conducted according to ABNT NBR 14810 -3 Brazilian standards. The samples before and after accelerated aging were soaked in water by 2 h and 24 h. The water absorption was calculated using Eq. 3.

$$\mathrm{WA}\ (\%) = \left[\frac{W_f - w_i}{w_i}\right] 100 \tag{3}$$

where W_f is the final weight after soaking in the period of 2 h and 24 h and W_i is the initial weight

Mechanical testing: The internal bond and flexural tests were conducted using a universal testing machine at room temperature, according to ABNT NBR 14810-3 [7] Brazilian standards (Figure 1). The loading rate for the bonding strength was controlled at 4 mm/min. Modulus of rupture (MOR) and modulus of elasticity (MOE) were determined by a three-point bending test with the universal testing machine operating with a load cell capacity of 5 kN and cross speed of 6 mm/min. The major span between supports was 200 mm.

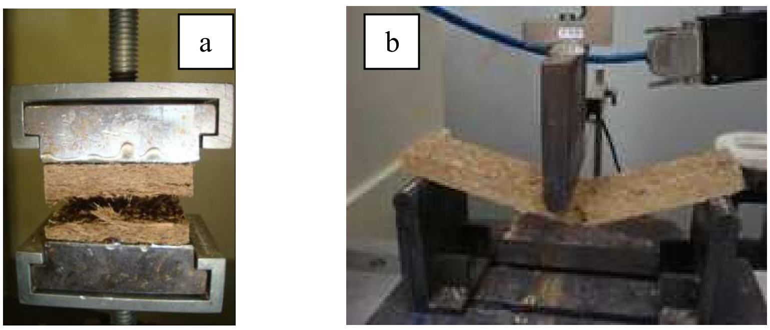

Fig.1. Mechanical testing (a) internal bond and (b) flexural test.

Results and discussion

Modification of physical behavior of composites during aging test. The schematic chart with steps of the accelerated aging test and changes of the physical characteristics of particle board can be seen in Fig. 2. In the first step specimens were immersed in water (soaking). In this step it was noted water absorption and consequently a change in the color of the material. In the second step the material was submitted to steam in order to identify expansion and thickness swelling. In the freezing step it was observed gain of weight and humidity in the specimens. In the steps D and F the specimens were submitted to dry air. Damages were observed at the lateral faces of the specimens and delamination into layers which increased with the number of cycles.

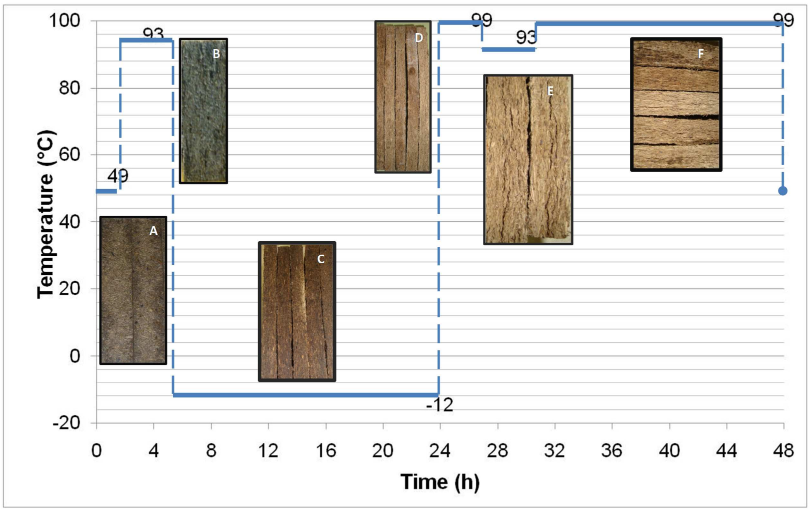

Fig.2. Visualization of changing physical characteristics for each step of accelerated aging based on ASTM D 1037 standards. (A) Water soak; (B) steam; (C) freezing; (D) dry air; (E) steam; (F) dry air

Residual thickness, thickness swelling and water absorption. Fig. 3 shows the percentage of the variation in the thickness before and after six cycles of accelerated aging. Average thickness was of 36% considering all values of five specimens. This percentage is typical of panels made from large flat flakes (such as, wafer, strands) [8].

Fig. 4 shows delaminated composites after stresses of six cycles of soaking, freezing, steaming and dry air. Such delamination in the composite caused an increasing in the water absorption as can be seen in the Fig. 5 in the period of 2 h and 24 h. The aged composite presented the highest percentage of water absorption as compared with those that were not submitted to accelerated aging.

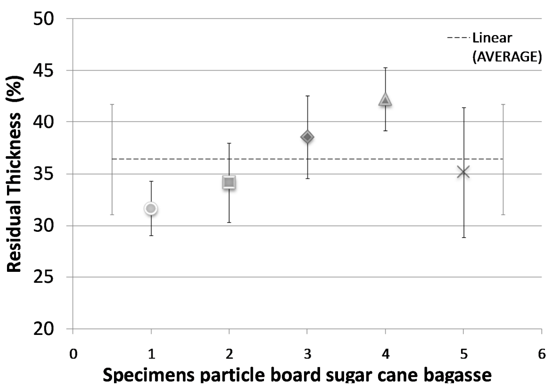

Fig.3. Residual Thickness of five specimens before and after six cycles of the accelerated aging.

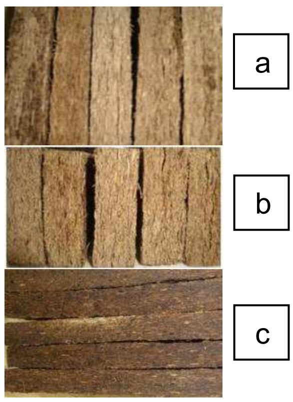

Fig.4. Composites delamination after aging test. Exposure phases: (a) Steam, (b) dry air and (c) freezing.

During moisture swelling, first the water starts to fill the spaces between the bundles of fibers. After that, occurs the moisture swells in the cell wall of the lignocellulosic material until its saturation and that free water does not further swells the inside of the fiber bundles [9]. The water absorption increased in the samples after accelerated aging test because decreasing the adhesion of the particles.

Fig 6 shows an increase in the thickness swelling of the reference specimens (not submitted to the accelerated aging). Nevertheless, specimens submitted to accelerated aging present a stability in the values of thickness swelling. This dimensional stability may be caused by hardening effect after the accelerated aging.

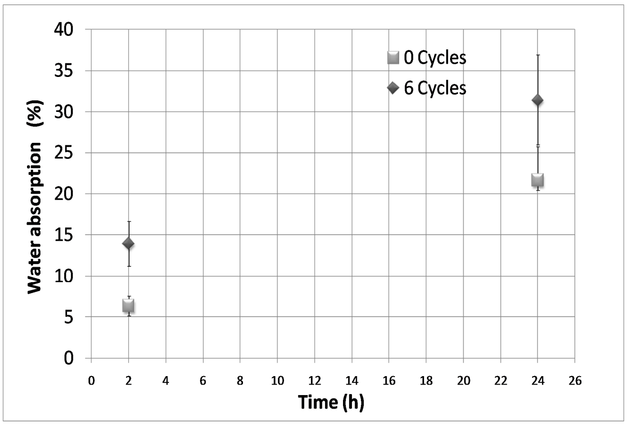

Fig.5. Water absorption of the particle board: reference (0 cycles) and aged (6 cycles).

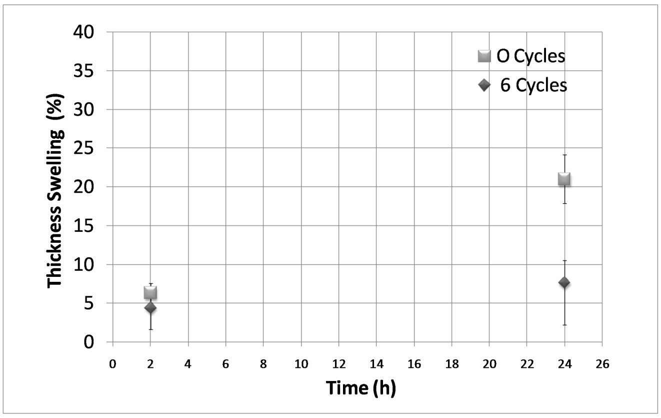

Fig.6. Thickness swelling of the particle board before-after accelerated aging test.

Flexural test and internal bonding. It was shown in Table 2 that MOR, MOE and IB decreased after accelerated aging. The MOR values were the highest from the specimens reference (0 cycles), statistical comparison showed significant difference with the undamaged particle board. The strength not remained in the specimens from accelerated aging test. This study was used the American National Standard ANSI/A208.1-1999 [10] to evaluate the values of modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) for particle boards.

The specimens showed a mechanical behavior similar to high-density grade particleboard (H-1) reference based on ANSI; A208.1-1999. After the accelerated aging process, the materials showed mechanical behavior similar to low-density grade particleboard (LD1).

The MOE values were 0.52 GPa for the specimens after accelerated aging test. The values of MOR after accelerated aging test were 6.24 MPa and the values of internal bond (IB) were 0.15 MPa. The particle boards with sugarcane bagasse failed to achieve the requirements for H1 and H2 High -density values recommended for general use panels by the ANSI/A208.1 -1999 after accelerated aging methodology based on ASTM D 1037.

Table 2 Average values and standard deviations of mechanicals properties reference specimens and after the accelerated aging of Particle Board Sugar Cane Bagasse

Description	IB (MPa)	MOR (MPa)	MOE (GPa)	LOP (MPa)
0 Cycles	1.18 ±0.40	21.86 ± 2.16	2.77 ± 0.26	10.26 ± 0.82
6 Cycles	0.15 ± 0.07	6.25 ± 0.70	0.52 ± 0.10	3.40 ± 0.72
ANSI/A208.1 - 1999 Standard for LD 1	0.1	3	0.55	ND
IB: internal bond MOR: modulus of rupture MOE: modulus of elasticity LOP: limit of proportionality ND: Not defined				

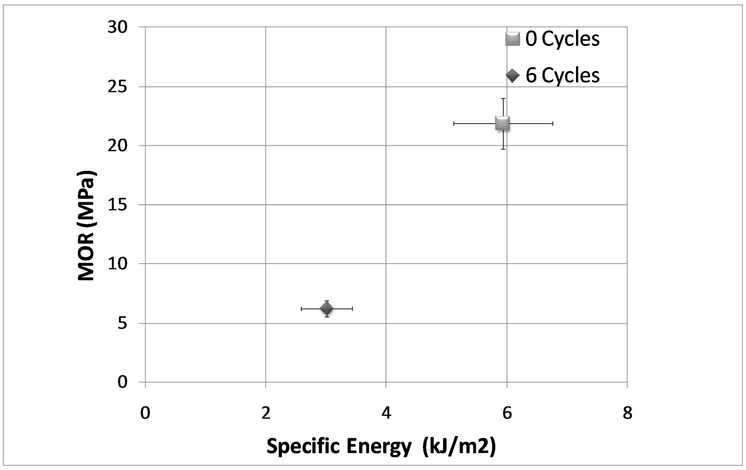

Fig.7. Correlation between modulus of rupture (MOR) and specific energy (SE)

The correlation between modulus of rupture (MOR) and specific energy (SE) of the PBSC is showed at Fig.7. After the accelerated aging test decreased the load capacity and its ability of absorb energy as submitted to impact, due to delamination of the material. Fig 8 (c) The image (b) show the initial appearance of the samples particle board with sugar cane bagasse, observing the loss of color and brightness on the surface (d) after the accelerated aging test.

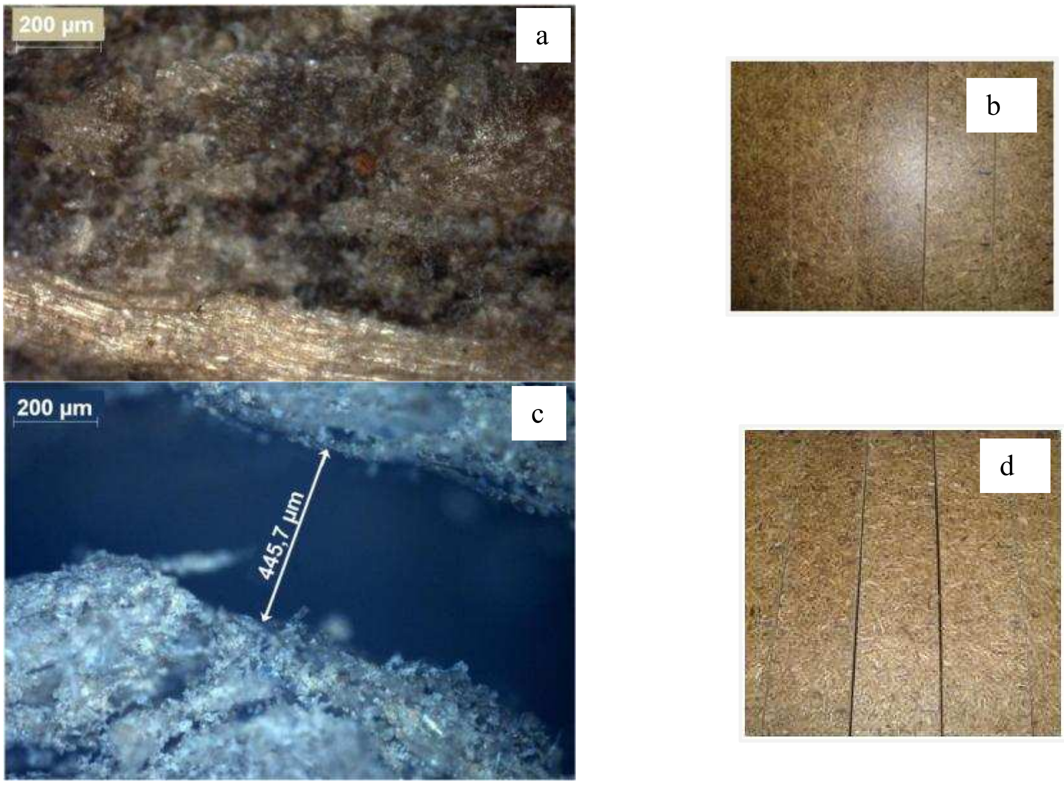

Fig.8. Optical microscopy images of the particle board reinforced with sugar cane bagasse: (a) and (b) before and (c) and (d) after accelerated ageing.

Concluding remarks

- The samples showed a decrease in all tested mechanical properties after the accelerated aging test based on ASTM D 1037 standards. The average values of IB, MOR and MOE of the specimens submitted to accelerated aging are lower than those not submitted to accelerated aging.

- The particle boards in this study showed mechanical behavior similar to High-Density grade Particleboard (H-1) reference not aged based on ANSI;A208.1-1999. After the accelerated aging process, the materials showed mechanical behavior similar to Low-Density grade Particleboard (LD1).
- The particle boards with sugarcane bagasse failed to achieve the requirements for H1 and H2 High -density values recommended for general use panels by the ANSI/A208.1 -1999 after the accelerated aging methodology based on ASTM D 1037 The IB values after the accelerated aging test were 83% less the US Standard ANSI/A208 for high density particle board. Modulus of elasticity for the results shown a 78.3% less the standard for high-density particle board by US Standard ANSI/A208.1 -1999. The values obtained for modulus of rupture (MOR) shown a percentage below the standard in a range between 8.1% and 11.7%..
- The ASTM D 1037 standards includes freezing stages that are not realistic in tropical regions such as in Brazil. The results presented in this study encourage discussion on adjusting the methodology of the accelerated aging test for different climates.

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