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MULTILAYER PARTICLEBOARD WITH SUGAR CANE BAGASSE AND BAMBOO: THERMAL-PHYSICAL-MECHANICAL PROPERTIES

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Summary: *This study assesses different thermal-physical-mechanical properties of multilayer particleboards consist of (3 layers: outer layers with sugarcane bagasse and inner layer with sugarcane bagasse or sugar cane bagasse and bamboo particles - Bambusa vulgaris. The layers are bonded with polyurethane resin based on castor oil with adensity of 550 kg m^{-3}. The particle boards density profiles were tested by x-ray. The water absorption (WA), thickness swelling (TS), modulus of elasticity (MOE), modulus of rupture (MOR) in bending and internal bond (IB) were evaluated following the ABNT NBR 14810: 2013 standard recommendations. The thermal conductivity was determined by adapting the methodology established by ISO 8301: 1999. Density profiles indicated that the multilayer boards presents higher side density. The IB values of multilayer boards with bamboo particles were higher than those of sugar cane multilayer boards for the corresponding densities. The thermal conductivity of multilayer boards were similar, indicating that the inclusion of bamboo particles did not affect the behavior of the particle boards. The durability evaluation indicated that the use of bamboo particles does not affect the properties of the boards.*

1 INTRODUCTION

Currently, there is an intense effort in the search for more energetically efficient non-polluting materials. The selection of materials is determined mainly by cost and ease of production or processing. Industrial materials, such as Portland cement and steel are used in virtually all civil works anywhere in the world, even in countries like Brazil, where non-conventional materials are locally produced.

In developing countries, education systems are still largely dependent on academic models that have been developed in industrialized nations in the twentieth century. In these countries, there are still no systematic and sufficient initiatives for education that aims to reach a better understanding of the properties, characteristics and the potential application of locally available materials. In addition to the lack of this knowledge, there is little interest and encouragement by the government and most of the industries. This leads almost invariably to the use of industrial materials which have been disclosed intensely by engineers, architects and technologists, addressed both to the technical community as to the general population.

For the deployment of non-conventional materials and technologies, a national and international effort is needed in the formation of human resources in this area. Materials abundantly available in developing countries are vegetable fibers (lignocelluloses) which consist of lignin, cellulose and hemicellulose. The plant tissue is called sclerenchyma and consists of two types of cells: sclereids, short cells, and sclerenchyma, elongated, flexible and resistant cells. These characteristics justify the use of vegetable fibers in activities where strength and flexibility are necessary. Some examples of known uses are reinforcement of both polymer and cement matrices, textile, manufacturing particulate panels, among others [1].

The Functionally Graded Materials (FGM) represent a new generation of composites formed by two or more constituent phases, whose main characteristic is its continuously variable composition. The microstructure and the physical-mechanical properties of FGM vary gradually along the thickness, whilst in conventional composites these properties remain constant.

National and international research indicates the feasibility of using the sugar cane bagasse in different polymer matrices for the manufacture of particle board [2] - [7] However, most studies focused on the study of particleboards with a single layer (homogeneous), unlike the panels produced by the industry, which are usually made of 3 layers (outer layers - OL and inner layer - IL) with different morphologies and amount of additives.

Fiorelli et al. [8] studied anatomical and physico-chemical properties of residual natural fibers (sugarcane bagasse) to evaluate their potential use for particleboard production. Results indicated similarities and differences between physic-chemical and anatomical characteristics of the residual lignocellulosic fibers when compared with those of the *Pinus sp*. wood commercially employed in the particleboard production. Sugarcane bagasse fibers show surface pores with diameters ranging from 1.2 to 2.1 µm, smaller than the 5 µm identified for *Pinus sp*. wood. This characteristic contributes to resin dispersion among particles, positively reflected on the physical–mechanical properties of the particle boards.

Belini et al. [9] evaluated the use of bamboo particles (*Bambusa vulgaris Schrad.*) as reinforcement for low density (550 kg m^{-3}) sugar cane bagasse multilayer panels bonded with castor oil polyurethane resin. The results indicated that the use of bamboo as reinforcement particles provided a light panel with a satisfactory technological performance, with product cost reduction and lower fiber content.

In this context, this paper presents a study of thermal-physical-mechanical properties of multilayer particle boards produced with sugar cane bagasse and bamboo particles. An analysis of the durability of this material also presented.

2 MATERIALS AND METHODS

2.1 Production of particleboards

In this research sugarcane bagasse and bamboo particles (*Bambusa vulgaris*) were used. The adhesive used was bi-component castor oil polyurethane adhesive (polyol: isocyanate), comprising Lecopol E0921 and 0911 in a ratio of 1:1.

The sugarcane bagasse fibers and bamboo particles were dried in a recirculation air oven at 60°C until the moisture content of 8 to 10% was achieved. Subsequently, the fibers were chopped in a knife mill and sieved to obtain the required particle size distribution. The fiber particles retained in the 1-2 mm mesh sieve were used for the production of homogeneous boards andfor the inner layer of the multilayer boards. The sugarcane bagasse and bamboo particles used in the outer layers were those retained in the 0.3 to 0.6 mm sieve mesh. The types of boards produced were multilayer (mass ratios of 10:80:10 respectively in the outer: inner: outer layers). The amount of resin used for the inner layer was 12% by mass and 15% for the outer layers. The density of the produced sheet was 550 kg.m^{-3} and dimensions were 40 x 40 x 1.5 cm. Table 1 presents the experimental design adopted in the study.

Treatment	Configuration	Density kg.m^{-3}	Binder content (%)
T1	Multilayer (sugar cane bagasse)	550	IL12 and OL15
T2	Multilayer (sugar cane bagasse + bamboo particle)	550	

IL: Inner layer; OL: Outer layer.

Table 1: Experimental design.

The resin was applied to the particles using an air spray. Subsequently, the resin particles were packed into a mold of 40 x 40 cm and placed into a thermo-hydraulic press (pressure of 5 MPa and temperature of 100°C) for 10 min. Figure 1 presents the particleboards production process.

(A) (B) (C)

Figure 1: Particleboards production process. A) Forming mold particleboard. B) Thermal press. C) Multilayer Particleboard

2.1 Thermal properties

The thermal conductivity test was performed with a Thermal Conductivity Tester (Discovery DTC-300) equipped with heat flow meters, operating in steady-state upward heat flow and adapting the methodology established by ISO 8301:1991 [10]. The specimen was placed between two plates (hot and cold plates), which ensures the heat flow. The temperature difference was 30°C. Ten specimens with 5 cm diameter were tested for each treatment (T1 and T2).

2.2 Physical properties

The physical properties of experimental panels were determined by water absorption (WA) and thickness swelling (TS) after 2 hours of immersion. To quantify these properties, specimens with nominal size 2.5 x 2.5 x 1,5 cm were used, submerged in a container with distilled water at 20^{o}C. For the execution of physical tests, recommendations of the ABNT NBR 12 14810-1: 2006 [11] were adopted by the similarity with the product produced. To record the average values of these variables with their respective standard deviations, 10 specimens were used for each property, being 4 of them randomly extracted from each panel.

X-ray densitometry was used for the determination of the density profile of the particleboards. Specimens with 5.0 x 5.0 cm were prepared for each treatment and the density values obtained every 20 microns through the thickness of the specimens. An X-ray densitometer, GreCon, DA-X model was used. The parameters used were 33 kV of voltage, 0-1 mA of amperage, 11° angle of radiation, initial and final disposition of the beams 100 and 50 microns. Thus it is possible to determine the average, maximum and minimum densities of the faces.

2.3 Mechanical properties

Modulus of rupture (MOR) and modulus of elasticity (MOE) in bending test and Internal Bond (IB) were determined following recommendations of the ABNT NBR 12 14810-1:2006 [11] that were adopted by the similarity with the product produced. To record the average values of these variables with their respective standard deviations, 12 specimens were used for each property, being 4 of them randomly extracted from each panel.

2.4 Durability analysis

The durability analysis was carried out adjusting the procedures indicated by the standard APA D1: 1994 [12], for Brazilian humidity and temperature, aimed at internal application.

For accelerated aging test specimens of 35 x 5 cm were prepared. The edges of the samples were coated with an acrylic paste and covered with a sealant material. The surface of the edge protection was used with the specific purpose of minimizing the action of damaging agents (water, humidity and temperature) in this area, which represents 30% of the surface of the specimen [13].

The test consisted of evaluating the material by accelerated aging in a UV chamber at 12 h cycle,(8 h of UVB irradiance of 0.49 at 60°C f 4 h of condensation at50°C) in order to simulate the degradation mechanisms of materials used indoors. The specimens were evaluated after 8 cycles and 16 cycles.

3 RESULTS AND DISCUSSION

This topic presents results of thermal-physical-mechanical properties of multilayer particleboards (3 layers: outer layers with sugarcane bagasse and inner layer with sugar cane bagasse or sugar cane bagasse with added bamboo particles) bonded with castor oil polyurethane resin with a density of 550 kg.m^{-3} and a study of the performance of these particleboards after accelerated aging test.

3.1 Thermal properties

The values of the thermal conductivity showed no statistically significant difference (p> 0.05) between T1 and T2, indicating that the use of bamboo particles did not change this property (table 2).

Treatment	Thermal Conductivity (W.m^{-1}.K^{-1})
T1	0,144±0,008 a
T2	0,140±0,008 a

* Different letters in the same column indicate significant difference (p < 0.05)

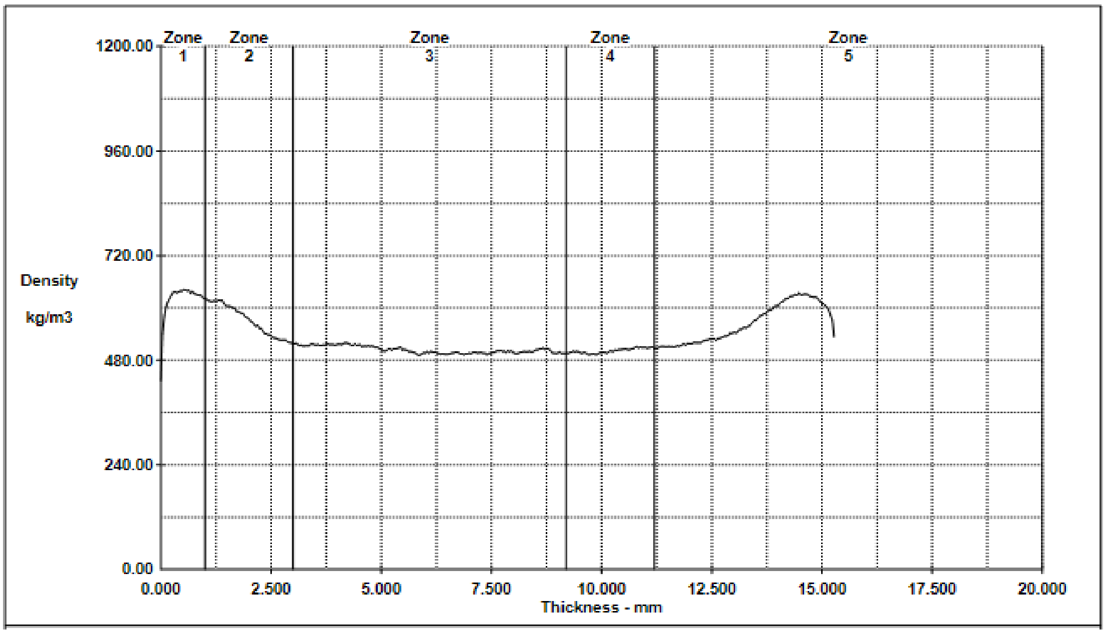
Table 2: Thermal conductivity average values

A similarity between the values obtained with polypropylene (0.12 W.m-1.K-1) polystyrene (0.13 W.m-1.K-1) and phenol formaldehyde (0.15 W.m-1.K-1) was observed [14].

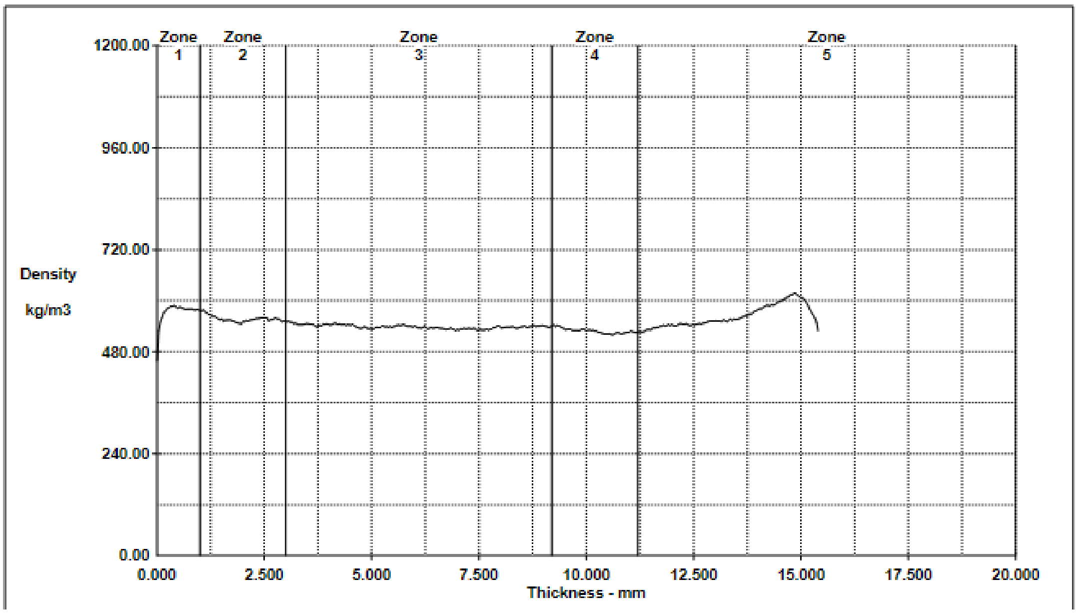
The thermal properties of particle boards made with coir fiber and sugarcane bagasse without the use of adhesive were studied. The densities used were 250 and 350 kg.m3. The results obtained for the coir fiber board varied from 0.046 to 0.068 W.m-1.K-1 and for the bagasse boards from 0.049 to 0.055 W.m-1.K-1. Common thermal conductivity values for cellulose fibers are between 0.040 and 0.045 W.m-1.K-1 [15].

3.2 Physical properties

The results obtained by evaluation of X-ray densitometry are typical profiles for multilayer boards (Figure 2).



(A)



(B)

Figure 2: X-ray densitometry. A-Sugar cane bagasse (550 $kg.m^{-3}$). B- Sugar cane bagasse + bamboo particle (550 $kg.m^{-3}$)

T1 and T2 are classified as low-density according to ANSI A 208-1 [16]. Profiles for the different treatments showed no significant deformations caused by any defect in the process such as heating or uneven pressure on the surfaces, low pressure, low humidity on the mattress, low or high pressing speed [17].

The multilayer particleboards (T1 and T2) had a higher surface density, identified by higher density values on the faces. This feature ensures a surface with less roughness, which can receive a coating or be painted.

Table 3 shows mean values of water absorption (WA) and thickness swelling (TS), standard deviation and results from inferential statistical analysis.

Treatment	% WA 2 h	% TS 2 h
T1	27,9 ± 2,3a	4,8 ± 0,7a
T2	27,5 ± 4,0a	3,5 ± 0,6a

* Different letters in the same column indicate significant difference ($p < 0.05$)

Table 3: WA and TS average values (2h)

Table 3 shows similar values of WA and TS (2 h) from treatment T1 and T2 which do not differ statistically from each other ($p > 0.05$). The values are lower than NBR 14810:2006 indications [11] that establish (8%) for TS. This behavior may be related to the greater amount of particles and lower porosity.

3.3 Mechanical properties

Table 4 shows the average values of MOR, MOE and IB, standard deviation and results from inferential statistical analysis.

Treatment	MOR (MPa)	MOE (MPa)	IB (MPa)
T1	12,1 ± 0,8a	1104,4 ± 58,6a	0,38 ± 0,09a
T2	10,5 ± 0,8a	1045,0 ± 100,4a	0,57 ± 0,14b

* Different letters in the same column indicate significant difference (p< 0.05)

Table 4: Average values of MOR e MOE

The MOR and MOE values did not present a statistically significant difference ($p > 0.05$) for all treatments. The IB for treatments T1 and T2 presents a statistically significant difference. The insertion of bamboo particles (*Bambusa vulgaris*) in the internal layer caused an increase in these mechanical properties. These results can be explained by the geometry of bamboo particles that filled the empty spaces. The values are higher that indicated by ANSI A208.1:1993 [18] and CS 236-66:1968 [19] that were established for low density particleboards (640 kg.m^{-3}) with values for MOR of 5,0 MPa, for MOE of 1025 MPa and for IB of 0,21.

3.4 Durability analysis

Figures 3 and 4 present mean values and standard deviation of physical (WA, TS) and mechanical (MOR, MOE) properties of the particle boards (T1 and T2) after 8 and 16 cycles of accelerated aging test.

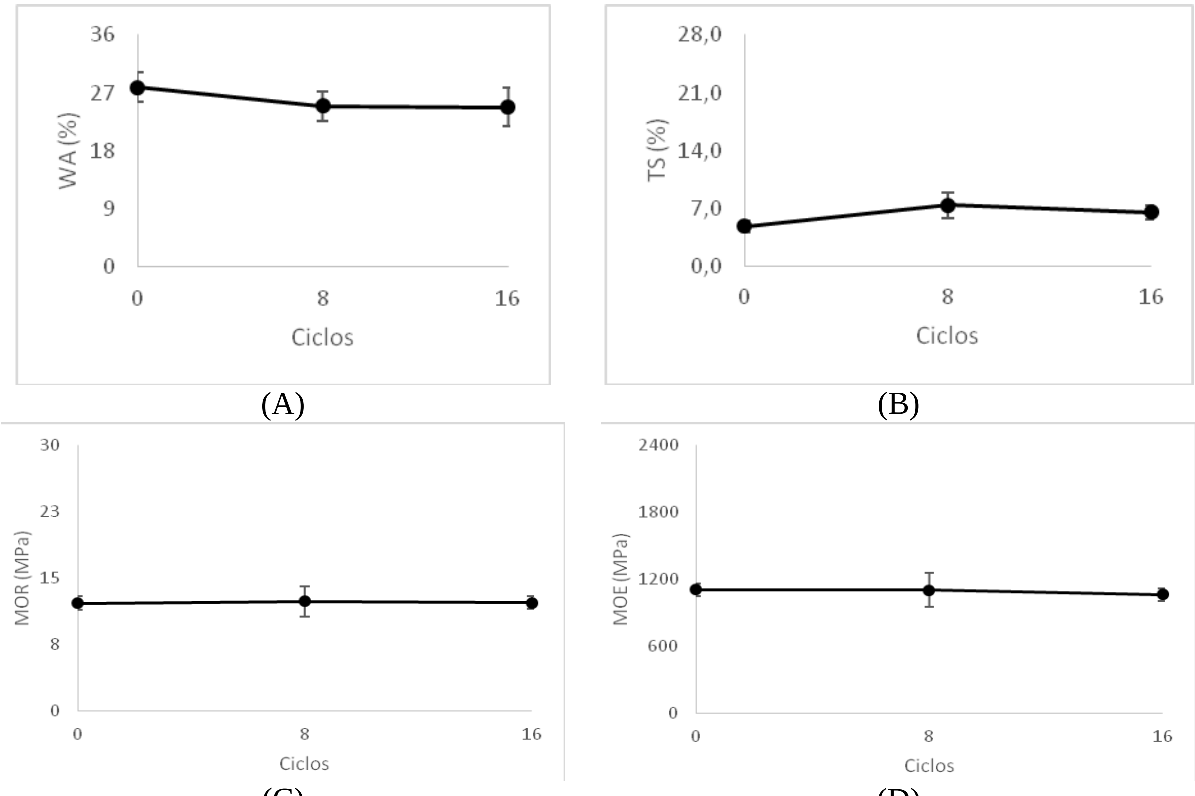


Figure 3: Sugar cane bagasse particle board (T1). A) WA. B) TS. C) MOR. D) MOE.

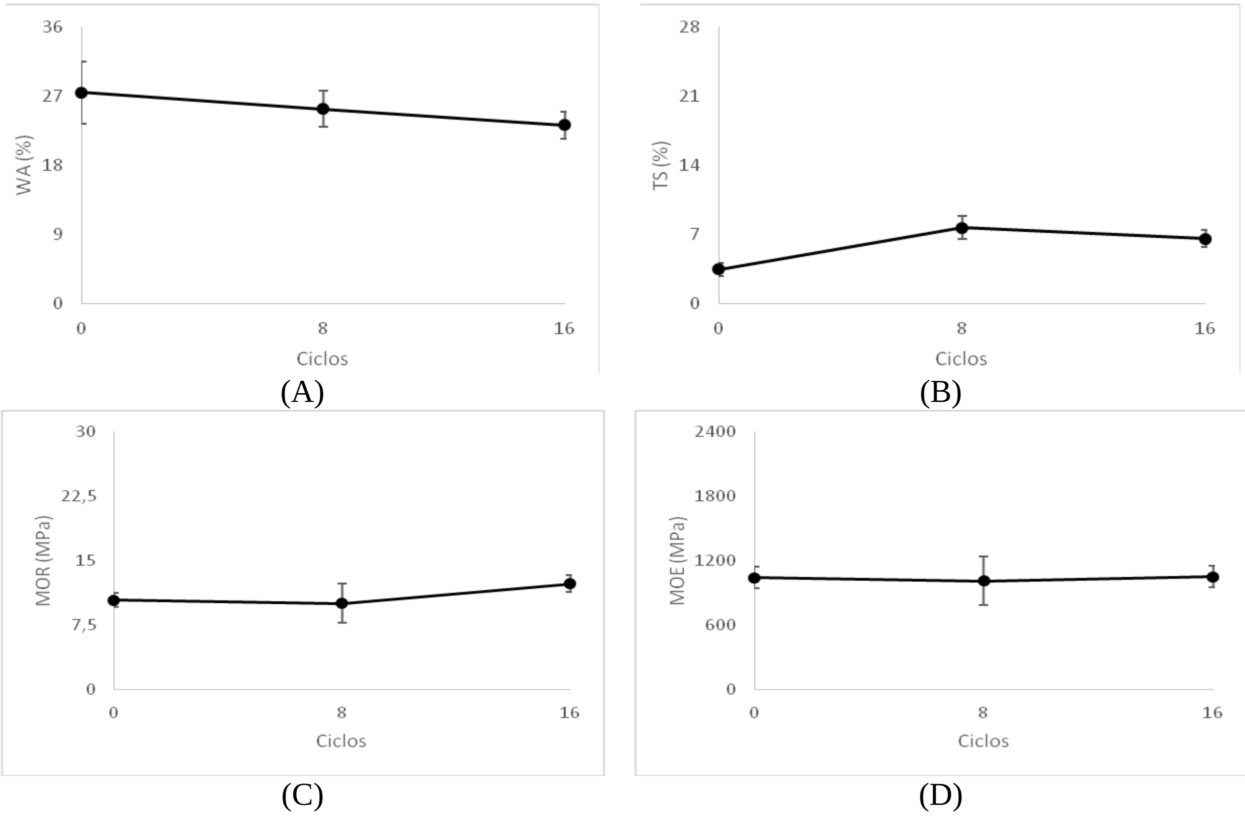


Figure 4: Sugar cane bagasse and bamboo particle board (T2). A) WA. B) TS. C) MOR. D) MOE.

The results presented in figures 2 and 3 indicate that 16 cycles of accelerated aging test do not modify physical and mechanical properties of the particleboards T1 and T2. These results are important for the evaluation of the performance of those composites when exposed to UVB radiation and humidity. New cycles of accelerated aging tests will be necessary to be applied to this particle boards to evaluate the performance when exposed to severe conditions???

4 CONCLUSION

The production of multilayer particleboards with agro industrial wastes and functionally graded properties leads to the development of studies aiming at inserting reinforcement materials. Theses newly developed composites allowing the fabrication of panels with lower density, similar or superior physical-mechanical properties to conventional wood particleboards. The accelerated aging test indicated that for the exposure conditions established in this study, significant variations in physical and mechanical properties were not identified. The use of bamboo associated with sugarcane bagasse has been shown to be feasible for the fabrication of particleboard.

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