First International Conference on Bio-based Building Materials

June 22nd - 24th 2015
Clermont-Ferrand, France

PARTICLEBOARD WITH COIR FIBER AND SUGAR CANE BAGASSE: THERMAL-PHYSICAL-MECHANICAL PROPERTIES

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Abstract:

This study assessed boards of homogeneous particles of green coconut husk fiber and multilayer (3 layers: outer layers with sugarcane bagasse and inner layer with green coconut husk fiber) bonded with polyurethane resin based on castor oil and densities of 500 kg m -3 and 700 kg m -3. The 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 test and internal adherence (IA) were evaluated following the ABNT NBR 14810: 2013 standard recommendations; and thermal conductivity was determined by adapting the methodology established by ISO 8301: 1999. Density profiles indicated that the multilayer boards showed higher sides density; TS results showed no significant difference between treatments and WA indicated that the multilayer boards presented lower absorption; the MOR and MOE values of multilayer boards were higher than the homogeneous boards of corresponding densities; the thermal conductivity of homogeneous and multilayer boards were similar, indicating that the inclusion of sugarcane bagasse did not affect this behavior of the particle boards. Therefore multilayer boards incorporating sugarcane bagasse on the outer layers provided significant increases in physical and mechanical properties of the material for promising indoor application for housing and civil construction.

Keywords:

Particleboard; Thermal Insulation; Physical-Mechanical Properties; Coir Fiber; Sugar Cane Bagasse.

1 INTRODUCTION

The increase in demand for wood products (plywood and particleboard) and the cost elevation of the wood, led to the development of studies focusing on the use of agricultural and forest residues [Teixeira, 1997].

Coconut husk fiber, sugarcane bagasse, peanut hulls and wood shavings are examples of agro-industrial waste generated in Brazil with a potential application in the production of particulateboards [Fiorelli et al., 2014].

Particleboards can be basically manufactured with any type of lignocellulosic material which conveys satisfactory physical and mechanical properties [Rowell, 2000]. Coconut is abundant in the coastal areas of tropical countries. Coconut husk is available in large quantities as residue from fruit production. Coir fibers contain a high content in lignin, which can be considered an advantage since it acts as a resin, contributing to particle agglomeration at high temperature [Van Dam, 2004].

The sugarcane bagasse is currently considered one of the most promissory lignocellulosic materials apart of wood [Ashori, 2009]. However, either large quantities of waste remain unused or are burned to generate energy during its production system [Widyorini, 2005].

Fiorelli et al. (2011) studied the physical and mechanical properties of homogeneous particleboards produced with sugarcane bagasse and polyurethane resin based on castor oil, with a density of 930 kg m^{-3}. The production parameters used were 4 MPa of pressure and 100°C. The values obtained for modulus of elasticity and modulus of rupture passed the requirements of the ANSI A208.1: 1993 Standard.

Fiorelli et al. (2012) studied the coconut husk fibers for the production of homogeneous particleboards with nominal densities of 800 and 1000 kg m^{-3} and polyurethane resin based on castor oil and urea-formaldehyde. The results of this study showed a reduction of thickness swelling and increasing of the modulus of rupture of the boards produced with polyurethane resin from castor oil. Boards with density values of 1000 kg m^{-3} were recommended to be used in the agricultural infrastructure and in civil construction.

In the industrial process multilayer boards are normally produced using larger particles in the inner layer and fine particles on the surface. The main purpose of this configuration is to facilitate the application of coatings due to the better finishing, and maximize the physical and mechanical properties [Iwakiri, 2005].

According to Kelly (1997) the size and geometry of the particles used in the production of panels represent an important parameter in the production process, since they have close relation with the amount of resin employed.

The smaller particles require higher amount of resin because of their higher specific surface area [Maloney, 1993] as it would be normally expected.

In the determination of new uses for particleboards, innovative techniques for materials characterization have been employed, e.g. density profile, which consists in a non-destructive method for identifying defects in the manufacture of the panels, allowing the correction of inadequacies or variations deriving from the parameters of the production process [Belini, 2007], as well as thermal conductivity, enabling its use as an insulator.

[Belini, 2009] evaluated the wood fiber boards density profile (MDF) for both manufactured in the laboratory and commercial boards, with nominal density of 700 kg m^{-3}. The results indicated that the MDF plates manufactured in the laboratory showed no significant difference from those from the industrial process, relating the results to the similarity between both pressing cycles.

[Panyakaew, 2011] evaluated the thermal conductivity of homogeneous sugarcane bagasse and coir fiber particles with nominal densities of 350 kg m^{-3}. The production parameters were 14 MPa and temperatures of 180, 200 and 220°C for coir fiber boards and 160, 180 and 200°C for sugarcane bagasse. Pressing times were 7, 10 and 13 min. Resin was not used in this study. The results obtained for the boards were similar to those for conventional cellulosic fiber materials.

With the same scope, this study evaluated the physical, mechanical and thermal properties of homogeneous coconut husk particles boards (1-4 mm) and multilayer boards, with sugarcane bagasse (0.3-1 mm) in the outer layers and coconut husk fiber in the inner layer (1-4 mm), bonded with polyurethane bi-component resin based on castor oil.

2 MATERIAL AND METHODS

In this research coconut husk and sugarcane fibers were used. They were supplied by Brazilian companies working on the processing of these materials.

The adhesive used for the particle boards production was bi-component polyurethane based on castor oil (polyol: isocyanate), comprising Lecopol E0921 and 0911 in a ratio of 1: 1.

The coir and sugarcane bagasse fibers were dried in a recirculating 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 coir fiber particles retained in a 1-2 mm mesh sieve were used for the production of homogeneous boards and in the inner layers of the multilayer boards. The sugarcane bagasse particles used in the outer layers of the multilayer plates were those retained in the 0.3 to 0.6 mm sieve mesh. The types of boards produced were homogeneous and multilayer (mass ratios of 10:80:10 respectively in the outer:inner:outer layers). The amount of resin used for homogeneous boards and the inner layers was 12% by mass and 15% for the outer layers. The densities of the produced sheet were 500 and 700 kg.m^{-3} and dimensions were 40 x 40 x 1.5 cm. Table 1 presents the experimental design adopted in the study.

Table 1 Experimental design.

Treatment	Configuration	Density kg.m^{-3}	Binder content (%)
T1	Homogenous (coconut fiber)	500	12
T2	Multilayer (coconut fiber + sugar cane bagasse)	500	IL12 OL15
T3	Homogenous (coconut fiber)	700	12
T4	Multilayer (coconut fiber + sugar cane bagasse)	700	IL12 OL15

IL: Inner layer; EL: Outer layer.

Resin was mixed with the particles by spraying with air; subsequently, the resin particles were placed in the forming mold with 40 x 40 cm dimensions and placed in thermo-hydraulic press (pressure of 5 MPa and temperature of 100°C) for 10 min.

2.1 Density profile by x-ray

X-ray densitometry technique was used for the determination of the density profile of the boards. The 50 x 50 mm samples were prepared for each treatment and the density values obtained every 20 microns through the thickness of the sample. A 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. It is possible to determine the average density, maximum density of the faces and minimum density.

2.2 Physicochemical Properties

For particleboards T1, T2, T3 and T4 both physical (density, water absorption and thickness swelling) and mechanical properties (modulus of rupture - MOR and modulus of elasticity - MOE) under bending loading were evaluated according to the NBR 14810: 2013 Standard due to the similarity between wood particleboards and the ones evaluated in this study.

2.3 Thermal conductivity

The thermal conductivity test was performed with a Thermal Conductivity Tester (Discovery DTC-300) equipped with heat flow meters and operates in steady-state upward heat flow. 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 50 mm diameter were used for each treatment.

2.4 Statistical Analysis

The results of the physical, mechanical and thermal properties for the different treatments were compared by Turkey test, with a significance level of 5% to check the divergences between densities and layers configurations.

3 RESULTS AND DISCUSSION

3.1 Density profile

The results obtained by evaluation of X-ray densitometry are typical profiles for both homogeneous and multilayer boards (Figure 1). Profiles for the different treatments showed no significant deformations caused by any defect in the process (heating or uneven pressure on the surfaces, low pressure, low humidity on the mattress, low or high pressing speed) [Belini, 2009]. Treatments 1 and 3 had a homogenous density profile, i.e., density does not vary through the thickness of the board, in contrast to treatments 2 and 4, which have a multi-layer density profile for boards, revealing density peaks in the first 2 mm from both sides due to the increased resin content in the bagasse layers.

Density average values for all treatments were close to those proposed. Table 2 shows the average values of densities. Statistical analysis indicates that there is no significant difference ($p > 0.05$) between homogeneous particleboards and multilayer particleboards (T1 - T2 and T3 - T4).

Table 2 Average density values

Treatment	Density $kg.m^{-3}$
T1	518.43 a
T2	529.71 a
T3	667.71 b
T4	692.29 b

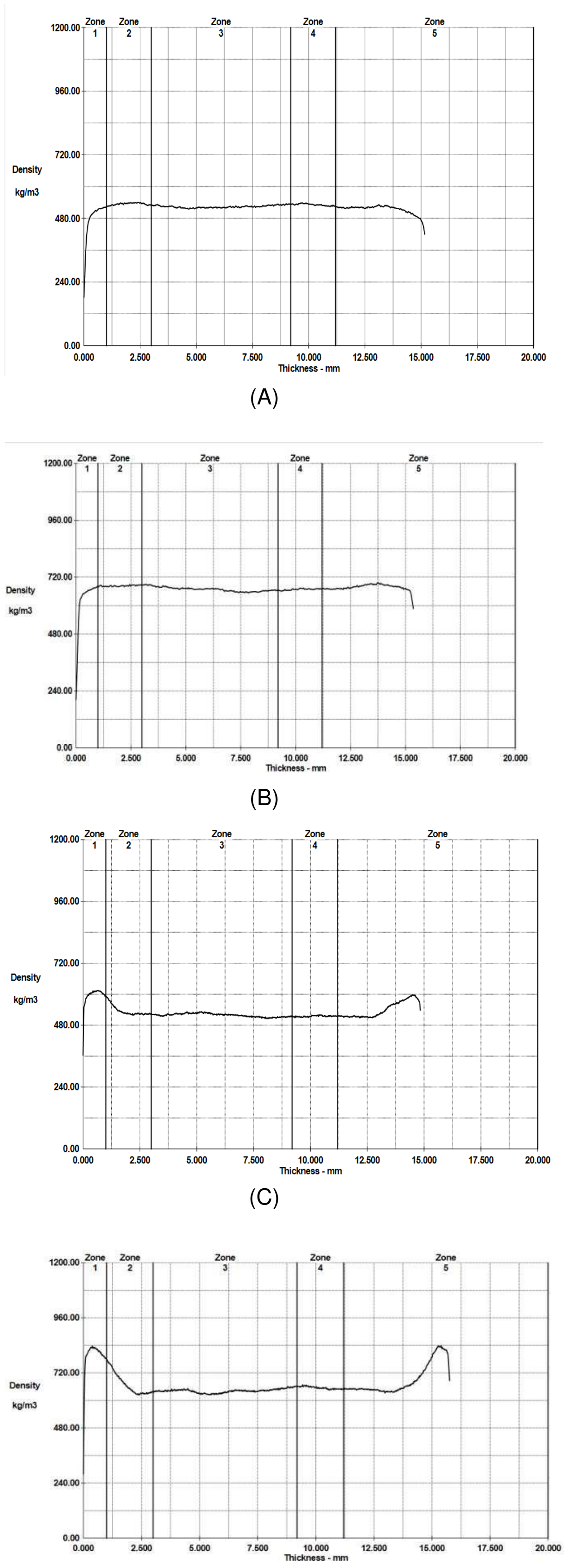
* Different letters in the same column indicate significant difference ($p < 0.05$)

T1 and T2 are classified as low-density and T3 and T4 as medium density, according to ANSI 208-1; 1999 classification.

As the T1 and T2 showed statistically different density values ($p < 0.05$) from T3 and T4, physical and mechanical properties were analyzed separately for these two groups and data were crossed-referenced as follows: T1xT2 and T3xT4.

3.2 Water absorption and thickness swelling

Table 3 shows mean values of water absorption (WA), coefficient of variation and results from inferential statistical analysis.



(A)

(B)

(C)

(D)

Fig. 1: Density profiles through the board thickness (A) T1 – Homogenous board, density 500 $kg.m^{-3}$, (B) T3 – Homogenous board, density 700 $kg.m^{-3}$, (C) T2 – Multilayer board, density 500 $kg.m^{-3}$, (D) T4 – Multilayer board, density 700 $kg.m^{-3}$.

From Table 3 it may be identified that higher density panels (T3 and T4) had WA values at 2 h and 24 h which do not differ statistically from each other ($p > 0.05$). This behavior is related to the greater amount of particles and lower porosity. For T1 and T2 boards, WA values (2 h and 24 h) were statistically significant ($p < 0.05$), indicating that the use of sugarcane bagasse in the outer layers contributed to the particleboard densification and WA decreasing.

Table 3 WA average values at 2 and 24 h

Treatment	% WA 2 h	% WA 24 h
T1	26.21 (29) a	74.27 (17) a
T2	17.96 (17) b	40.22 (13) b
T3	17.38 (30) c	50.67 (18) c
T4	14.6 (35) c	54.56 (36) c

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

Table 4 shows average values of thickness swelling (TS) after 2 and 24 h of immersion.

Table 4 TS average values at 2 and 24 h

Treatment	% TS 2 h	% TS 24 h
T1	11.88 (15) a	27.65 (16) a
T2	5.91 (27) b	13.82 (26) b
T3	6.77 (14) c	19.33 (12) c
T4	8.44 (23) c	23.08 (18) c

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

For TS after 2 and 24 h the same behavior described in relation to WA was observed for all treatments.

The coefficient of variation indicates an average distribution of data. This can be explained by some of the factors that influence physical properties, e.g., stress release generated during the pressing, resin distribution and board density [Melo, 2010].

CS 236-66: 1968 Standard indicates values of 30%-35% of TS for low and medium density boards, respectively. From the values obtained, we note that all evaluated boards (T1, T2, T3 and T4) meet the recommendations of this Standard.

In a similar study, [Fiorelli, 2011] manufactured homogeneous particleboards with sugarcane bagasse bonded with polyurethane resin from castor oil, with thickness of 15 mm and density of 930 kg m^{-3}. TS average values of 25% at 24 h were obtained. This value also met the recommendations of the normative document CS 236-66: 1968.

It is remarkable that the particleboards analyzed in this study show similarity with the wood particleboards and developed Standards to meet the requirements of this material.

3.3 Modulus of elasticity (MOE) and modulus of rupture (MOR)

Table 5 shows the average values of modulus of rupture (MOR) and modulus of elasticity (MOE) and the respective coefficients of variation.

Table 5 Average values of MOR e MOE

Treatment	MOR (MPa)	MOE (MPa)
T1	2.39 (15) a	323 (14) a
T2	5.89 (12) b	650 (8) b
T3	11.28(12) c	1133(13) c
T4	16.2(19) d	1879(12) d

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

The MOR and MOE values presented statistically significant difference ($p < 0.05$) for all treatments. Note that the multilayer boards of low and medium density (T2 and T4) showed better mechanical performance compared with homogeneous particles boards (T1 and T3) and also met the recommendations of ANSI A208: 1999.

3.4 Thermal conductivity

Table 6 shows the mean values of thermal conductivity for each treatment and their corresponding coefficient of variation.

Table 6 Thermal conductivity average values

Treatment	Thermal conductivity (W/m-k)
T1	0.1433 (5) a
T2	0.1426 (0,15)a
T3	0.1546 (5) b
T4	0.1766 (2) c

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

The values of the thermal conductivity showed no statistically significant difference ($p > 0.05$) between T1 and T2, indicating that the use of sugarcane bagasse in the outer layers of low density boards did not interfere in this property.

Medium density boards (T3 and T4) showed significant difference ($p < 0.05$) for thermal conductivity values, indicating that the inclusion of sugarcane bagasse contributed to the increased thermal conductivity. This result can be explained by a higher resin content and smaller particles in the multilayer boards.

It can be seen a similarity between the values obtained with polypropylene - 0.12 W / mK, polystyrene - 0.13 W / mK and phenol formaldehyde - 0.15 W / mK [Callister Jr, 2008].

Payakaew (2011) studied the thermal properties of particle boards made with coir fiber and sugarcane bagasse without the use of adhesive. The densities used were 250 and 350 kg m^{-3}, the results obtained for the coir fiber board were between 0.046 to 0.068 W / mK and the bagasse boards from 0.049 to 0.055 W / mK. Common thermal conductivity values for cellulose fibers are between 0.040 and 0.045 W / mK.

4 CONCLUSIONS

From the obtained results it can be concluded that:

- The density profile for both homogeneous and multilayer boards showed a typical trend, indicating that the process of production and resin content was appropriate.

- The multilayer boards (T2) showed lower values of TS and WA in comparison with homogeneous particleboards (T1), indicating that the addition of sugarcane bagasse and multilayer configuration contributed to the improvement of these physical properties, without varying the board density;

- Multilayer particleboards (T2 and T4) met the minimum recommendations established by ANSI A208.1-1999 Standard regarding mechanical properties and were superior to homogeneous particleboards properties (T1 and T3);

- Thermal conductivity of the boards under study, despite presenting significant differences between treatments, showed similar performance to commercial polymeric materials used as thermal insulation.

5 ACKNOWLEGMENTS

FAPESP, CAPES, CNPq and USP.

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