Pressing Temperature Effect on the Properties of Medium Density Particleboard Made with Sugarcane Bagasse and Plastic Bags

Nayra Diniz Nogueira[a], Carolina Rezende Pinto Narciso[a], Adriele de Lima Felix[a],

Rafael Farinassi Mendes[a]* ⓘ

[a]Universidade Federal de Lavras (UFLA), Av. Doutor Sylvio Menicucci, Lavras, MG, Brasil.

The objective of this work was to evaluate the effects of different pressing temperatures on the physical and mechanical properties of Medium Density Particleboard (MDP) manufactured with sugarcane bagasse and waste plastic bags. The temperatures of 160, 180, 200 and 220ºC were evaluated for the panels pressing. The panels were produced with a nominal density of 0.70 g/cm³, a face/core ratio of 40:60, 12% urea-formaldehyde adhesive for the faces and 8% for the core. The panels were evaluated for properties of density, compaction ratio, humidity, water absorption after two and twenty-four hours (WA2h and WA24h), thickness swelling after 2 and 24 hours of immersion in water (TS2h and TS24h), module of rupture (MOR) and module of elasticity (MOE) in static bending, internal bonding, janka hardness and screw pulling. There was no significant effect of pressing temperature on density, MOR, MOE, internal bonding and janka hardness of the panels. The pressing temperature significantly influenced the properties of WA, TS and screw pullout, promoting a decrease in the mean values of WA2h, WA24h, TS2h and TS, and an increase in screw pullout resistance. The temperature of 220°C resulted in MDP panels with sugarcane bagasse and residual plastic bags of better quality.

Keywords: *Agroindustrial residues, particleboard, plastic residues, sustainability, reuse, sugarcane bagasse.*

1. Introduction

The forestry sector plays a significant role in the Brazilian gross domestic product (GDP) creating jobs and generating income, with current trends and needs demonstrating an increase of planted forests share in the socioeconomic development of various regions of Brazil[1,2].

The forest production chain associated with the *Eucalyptus* and Pine tree plantations is characterized by the great diversity of products, including particleboard panels. However, there is a need for diversification of this industry by using new raw materials on the production process[3-5].

Medium density particleboard (MDP) panels can be produced with any type of lignocellulosic material, as long as they have adequate physico-mechanical properties[6-8]. Although, currently, the industry basically uses wood of pine and eucalyptus species[3,9]. Despite this, and due to the high demand from the sectors that consume these panels, the number of researches is increasing with the analysis of the potential of new types of lignocellulosic materials as a source of raw material for MDP panels[9,10].

According to Jesus et al.[11], the use of agricultural residues may contribute to the demand for raw material for the production of MDP panels, since it presents a wide range of residues and physical-chemical and mechanical properties that can be better utilized, such as maize cob and straw[12,13], rice husk[14], castor husk[15], sorghum bagasse[16], coffee plant bean parchment[17], coffee plant stem[18], and banana tree pseudostem[19].

Studies with sugarcane bagasse demonstrated its potential for use in the production of MDP panels[1,3,8-10,20-23]. The residue is obtained in large volumes, which helps in its application on an industrial scale[20]. According to the Brazilian Institute of Geography and Statistics - IBGE, the Brazil production estimate for the 2019/2020 harvest is 665.9 million tons, which means the generation of approximately 186.5 million tons, because for each ton of processed cane a total of 280 kg waste is generated[13]. However, study demonstrates that sugarcane bagasse panels still have greater water absorption and thick swelling than panels with eucalyptus wood, which may limit certain applications[8]. Thus, viable alternatives are needed to control such variables in order to increase the applications range for these panels.

However, besides the need to improve the physical properties of sugarcane bagasse panels, there is also a demand for the development of more sustainable panels[24,25], focusing on the use of a second residue; plastic bags. 15 billion units of this residue are produced per year in Brazil[7] posing serious concerns regarding its disposal[26].

Particleboard panels produced from agroindustrial and other residues are included in the premise that the product should offer quality, low environmental impact, and competitive price to its direct competitors. In addition to contributing to the panels technological advancement and their large-scale use[4,27]. Therefore, this work aimed at evaluating the technological feasibility of particleboard

panels produced with sugarcane bagasse using plastic bag residue at different pressing temperatures.

2. Materials and Methods

2.1. Raw material obtaining and characterization

The sugarcane bagasse was obtained from Bocaina Distillery, located in Lavras-MG, Brazil. Low density polyethylene (LDPE) plastic bag waste was supplied by Diplapel located in Divinópolis-MG, Brazil. The plastic waste used in this study had 1.89% volumetric shrinkage, 18 MPa tensile rupture and 389% elongation at break.

For chemical characterization, the sugarcane bagasse was processed in a hammer mill and the particles went through 40 and 60 mesh sieves for classification. The chemical tests were performed in triplicate. The lignocellulosic material was chemically characterized to quantify ash (NBR 13999[28]), extractives (NBR 14853[29]), lignin (NBR 7989[30]), holocellulose (Browning[31]), cellulose (Kennedy, Phillips e Willians, 1987[32]), and hemicellulose contents (Holocellulose – Cellulose).

For the determination of sugarcane bagasse basic density, which was carried out according to a method adapted from NBR 11941[33], the particles were saturated in water and their volume was later determined by the water displacement method (immersion method) using a measuring cylinder. The particles were brought to the oven at 105°C where they remained until reaching the constant mass. After that, the dry mass of the particles was established. The plastic residue density was provided by the manufacturer.

The samples morphological characterization was performed using ImageJ® (Powerful Image Analysis) software. 30 length and 30 thickness measurements were collected for each type of particle (sugarcane bagasse - face and core; and plastic residue).

2.2. MDP panels production

In order to obtain sugarcane bagasse particles, the material was ground in a hammer mill. Subsequently, the particles were classified in 12 and 20 mesh sieves to discard thicker particles and obtain a uniform particle size. The thicker particles were used in the core, while the thin ones were used on the faces of the panels. After sorting, the particles were oven dried at 70°C until reaching a humidity level close to 5%.

The plastic bag residue was obtained after processing in a plastic reclaimer, on the company's production line. The equipment consisted of a hammer mill and refrigeration, allowing to keep the material without softening.

Three panels (repetitions) were produced for each treatment, totalling four treatments where the 160, 180, 200, and 220°C pressing temperatures were evaluated. The lowest temperature of 160° C was chosen by the fact that companies use this temperature for the particleboard production in industrial scale, aiming at the adequate cure of the urea-formaldehyde adhesive. While the highest maximum value of 220°C was chosen because it is the value that presents the greatest peak of degradation of hemicellulose[34] which at higher temperatures could result in a decrease in the mechanical resistance of the panels[35]. This panel pressing temperature range between 160 and 220°C is also commonly seen in other scientific articles[37, 38, 3, 39].

The panels produced were of MDP type, with a 0.70 g/cm³ nominal density and 20/60/20 (face/core/face) particles percentage distribution. A 20% replacement of core sugarcane bagasse particles was made by plastic residue particles. The application of urea-formaldehyde adhesive to the cores and faces particles was performed separately for each panel. 12% of adhesive was used on the faces and 8% on the core. The application of the adhesive was carried out separately for each layer. The adhesive was applied in a rotating drum with spray application. The particles were impregnated with adhesive and then placed in a 30cm x 30cm x 1.5cm mattress-forming box where the layers were distributed one by one (face/core/face) pressed in a manual press at 0.4 MPa. After pre-pressing, 1.5 cm thick metal delimiters were placed and the mattress was hot pressed, following the temperatures set for each treatment, at 4.0 MPa pressure for eight minutes. Pressure and temperature being kept constant during pressing. The physical and mechanical properties of panels were evaluated after removal of the test samples. The production sequence of the panels is shown in Figure 1.

The panels were accommodated in an acclimatization room at 20 ± 2°C and 65 ± 3% relative humidity. The specimens' removal process for the panels was done using a circular saw. For physical and mechanical properties determination, the MDP panels were tested after reaching the constant mass. The NBR 14810-2 [40] standard was used to evaluate the properties Water absorption after 2h immersion (WA_2h), Water absorption after 24h immersion (WA_24h), Screw pull-out, *Janka* Hardness, Thickness swelling after 2h immersion (TS_2h), Thickness swelling after 24h immersion (TS_24h), Humidity, Apparent density and Internal Bonding (IB). The DIN-52362[36] standard was used to evaluate the properties Static bending – Modulus of elasticity (MOE) and Static bending – Modulus of rupture (MOR).

2.3. Microstructural characterization

The microstructural characterization evaluation of the panels was performed with scanning electron microscopy (SEM). The tests were carried out on a ZEISS equipment, DMS 940 model. The tests used representative fragments of the samples previously tested in the internal bonding test in order to observe the interfacing between the plastic bag and sugarcane bagasse particles.

2.4. Statistical analysis

The experiment was carried out according to a completely randomized design with four treatments. Each treatment was performed in triplicate totalling 12 panels. The results were submitted to analysis of variance (ANOVA) using the Sisvar software and Scott-Knott test, both at a 5% significance level.

3. Results and Discussion

3.1. Morphological, physical, and chemical properties of particles

Table 1 shows the average values for the morphological characterization of sugarcane bagasse and plastic bag
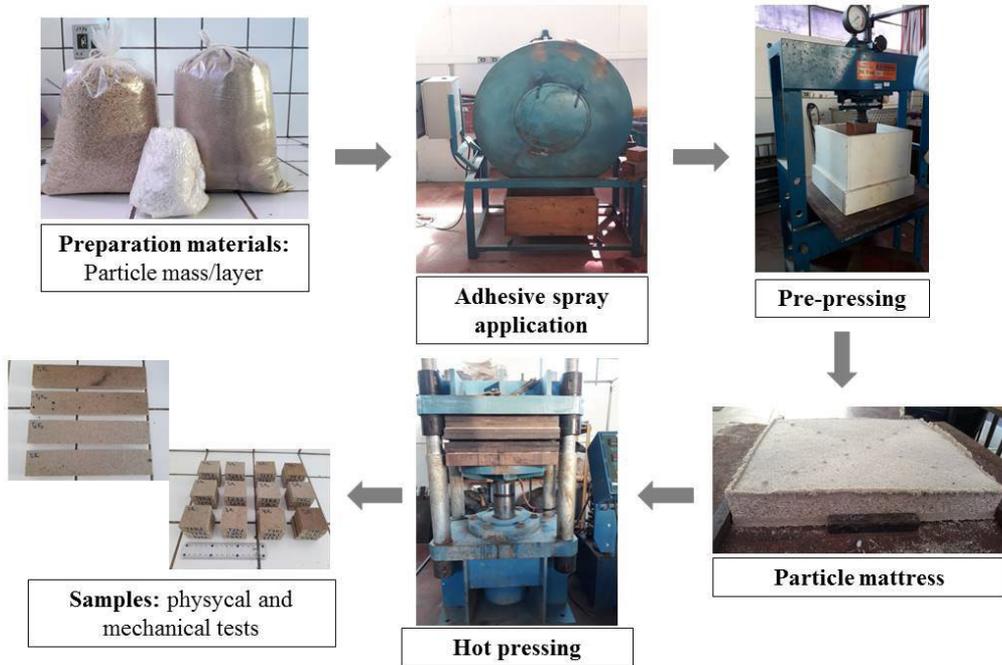
Figure 1. Production sequence of the particleboard.

particles. The average length of sugarcane bagasse particles classified to be used on the faces and cores of panels were respectively 1.8 mm and 3.59 mm and the average length of plastic bag particles was 5.34 mm. For thickness, the sugarcane bagasse particles of the face had 0.55mm average value, varying from 0.93mm (maximum value) and 0.26mm (minimum value). The sugarcane bagasse particles used in the core showed 0.74 mm average thickness value, varying from 1.31mm (maximum value) and 0.41mm (minimum value). The plastic bag particles showed 4.05mm average thickness value, varying from 6.4mm (maximum value) to 2.61mm (minimum value).

For slenderness, which is the length and thickness ratio of particles, 3.62mm and 5.32mm average values were found for the particles of the face and for the core, respectively. A 1.36mm average value was found for the plastic bags. According to Iwakiri[37], the slenderness ratio, exerts influence on the quality of finish and machinability, besides affecting the mechanical and dimensional properties. The average basic density with the respective standard deviation of the sugarcane bagasse particles was 0.175 ± 0.011 g/cm^3.

Barros et al.[38] characterized and compared particleboard panels produced with sugarcane bagasse with urea-formaldehyde and melamine-formaldehyde and found an 0.099 g/cm^3 average value for bagasse basic density. Protásio et al.[39], when evaluating Brazilian lignocellulosic residues for bioenergy production, found a 0.104 g/cm^3 average value for sugarcane bagasse basic density. Soares et al.[1], when evaluating the physical and mechanical properties of particleboards made with different amounts of sugarcane bagasse and *Eucalyptus grandis* wood found 0.12 g/cm^3 for sugarcane bagasse basic density. The difference in basic density values found for sugarcane bagasse particles was related to the raw material source.

Table 1. Sugarcane bagasse and plastic bag particles characterization.

Parameters	Sugarcane bagasse		Plastic bag
	Face	Core	
Lenght (mm)	1.80 ± 0.4	3.59 ± 0.89	5.34 ± 1.05
Thickness (mm)	0.55 ± 0.12	0.74 ± 0.18	4.05 ± 0.85
Slenderness ratio	3.62 ± 1.29	5.32 ± 1.76	1.36 ± 0.28

Table 2. Sugarcane bagasse chemical composition.

Chemical component	Mean
Holocellulose	62.15 ± 0.69
Cellulose	30.71 ± 0.10
Hemicelluloses	31.43 ± 0.10
Total extractives	20.87 ± 0.21
Insoluble Lignin	21.12 ± 0.28
Ashes	0.93 ± 0.19

* Average values in percentage found in dry base.

For plastic bag particles, an apparent density average value of 0.95 ± 0.012 g/cm^3 was found. This value is consistent with the one found by Coutinho et al.[40], who reported apparent density values ranging between 0.94-0.97 g/cm^3.

Sugarcane bagasse particle chemical composition is shown in Table 2. The extractives from the material are mainly responsible for its pH[37]. This pH could influence the adhesive curing since the presence of such substances favours its prehardening[20]. The hemicellulose levels were high, which might have contributed to the increased water absorption of the sugarcane bagasse panels, further demonstrating the need for new processes and addition of materials that could improve the MDP panels' final quality[38].

Satyanarayana et al.[41] evaluated sugarcane bagasse chemical composition from several countries. When evaluating

sugarcane bagasse from Brazil the contents ranged from 54.3 to 55.2% cellulose, 25.3 to 24.6% lignin, 16.8 to 29.7% hemicellulose, 0.9 to 1.1% ash, and 0.7 to 3.5% extractives.

Protásio et al.[39], in a study on Brazilian lignocellulosic residues for bioenergy production, obtained 26.7% lignin, 55.7% holocellulose, 16.6% extractives, and 1% ash values for sugarcane bagasse chemical composition. The difference between the contents found by the authors and this work was due to the method used in the chemical analysis as well as the material source.

4. Physical and Mechanical Properties of Panels with the Varying Pressing Temperatures

Table 3 presents the average values for apparent density, compaction ratio, and humidity of the panels as a function of temperature levels evaluated during pressing.

There was no statistical difference for apparent density, compaction ratio, and humidity as a function of the applied temperature. The apparent density values ranged from 0.591 to 0.609 g/cm³, characterized as medium density panels, in accordance to NBR 14810-2 classification[42], which establishes a 0.55 to 0.75 g/cm³ range.

The compaction ratio of the panels produced with sugarcane bagasse ranged from 3.42 to 3.58. These values were consistent with those obtained in the literature for particleboard panels produced with agroindustrial residues. Mendes et al.[20] evaluated the effect of sugarcane bagasse associated with *Eucalyptus* wood in different levels and adhesives types for particleboard production and found compaction ratio values ranging from 1.39 to 3.07.

The panels produced presented humidity values between 5.07 and 5.89%, complying to the average values set by NBR 14810-2 standards[42] for particleboard panels (from 5 to 11%) and they also comply with the EN 312 trading standard[43] which stipulates 5 to 13% as suitable values for panel humidity. Oliveira et al.[44] found an average of 9% humidity values for commercial sugarcane bagasse panels.

Figure 2 shows the average water absorption values for MDP panels after 2 h (WA2h) and after 24 h (WA24h) immersion, for each treatment.

Significant differences were observed among all treatments for water absorption property after 2 h immersion (WA2h). As the pressing temperature increased, a reduction in the average values for water absorption was noted. This reduction is associated with the degradation of the hydroxyl groups from the sugarcane bagasse as the pressing temperature increased[10,45], as well as a greater lignin softening, which promotes greater particles convergence and decreases empty spaces in the panel[34], and also the effect of the higher

temperature level, that allowed better softening of the plastic bag residue at 220°C, resulting in greater recovery of sugarcane bagasse particles and pore filling between the particles, promoting a reduction in the water absorption panels. Despite the plastic bags softening, which are made of Low Density Polyethylene (LDPE), happen with the application of 160°C[40,46], as its use was in the core of the panels, the polymeric residue demanded a higher pressing temperature in order to be able an adequate flow of heat between the sugarcane bagasse particles, which demonstrate a certain capacity for thermal insulation, thus allowing the softening of the plastic bag particles in an adequate manner at higher temperatures.

For water absorption after 24 h immersion (WA24h), the panels produced at 220°C pressing temperature were statistically different from the other treatments, presenting the lowest water absorption average value. The panels produced at 180°C and 200°C pressing temperatures were statistically similar differing from the panels pressed at 160°C, obtaining lower average values. As explained for WA2h, WA24h reduction was associated with the decrease of hydroxyl groups as a function of temperature increase, especially those related to hemicelluloses that present high contents in sugarcane bagasse (Table 2) and lower temperature of thermal degradation, ranging from 180 to 280°C, with a maximum peak of 220°C[34]. Another factor that affected the property was the softening of the plastic bags residue and
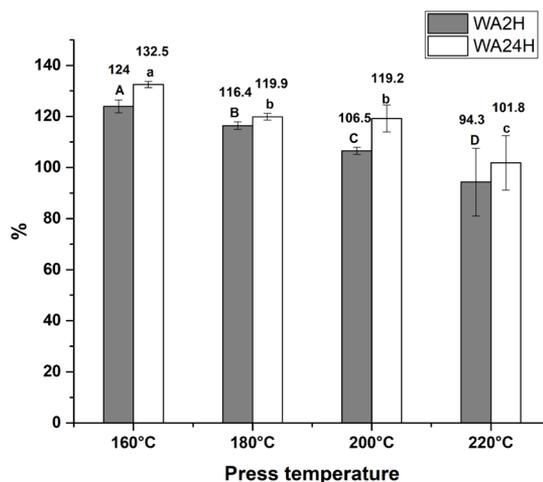
Figure 2. Water absorption for particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. *Averages followed by a similar letter (uppercase for WA2h and lower case for WA24h did not differ statistically by the Scott-Knott test at a 5% significance level.

Table 3. Apparent density, compaction ratio and humidity of panels produced as a function of pressing temperature.

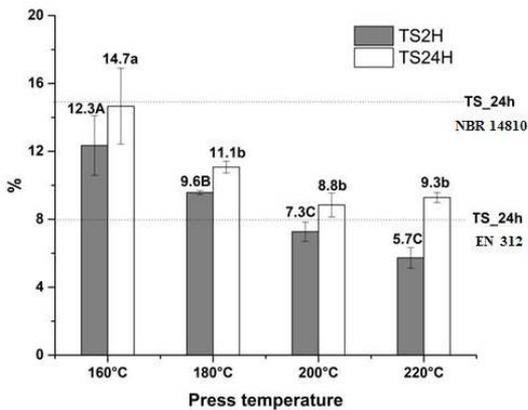| Treatment	Aparent density (g/cm³)	Compaction ratio	Humidity (%)
160°C	0.592 ± 0.01 A	3.485 ± 0.01 A	5.83 ± 0.3 A
180°C	0.591 ± 0.02 A	3.480 ± 0.02 A	5.89 ± 0.12 A
200°C	0.603 ± 0.01 A	3.549 ± 0.01 A	5.65 ± 0.08 A
220°C	0.609 ± 0.03 A	3.581 ± 0.02 A	5.07 ± 0.41 A

*Averages followed by a similar letter on each column did not differ statistically by the Scott-Knott test at a 5% significance level.

Pressing Temperature Effect on the Properties of Medium Density Particleboard Made with Sugarcane Bagasse and Plastic Bags

5

consequently the covering of the sugarcane bagasse particles and pores filling of the panels.

Battistelle et al.[22] when evaluating sugarcane bagasse panels with 12% castor oil bicomponent adhesive found values between 8 to 10% for WA2h and 29 to 37% for WA24h. Mesquita et al.[47] when evaluating sugarcane bagasse MDP panels with urea-formaldehyde adhesive and 160°C pressing temperature, with and without the addition of cellulose nanocrystals, obtained WA2h values in the range between 52 to 81% and for WA24h values between 86 to 112%.

The MDP average swelling values in thickness for panels after 2 h water immersion (IE2h) and after 24 h water immersion (IE24h), for each treatment, are shown in Figure 3.

The panels produced at 160 °C were statistically different from the other treatments, obtaining the highest TS2h and TS24h average values. Both 200 and 220°C pressing temperatures presented statistical equality and differed from the 180°C one, obtaining the lowest TS2h values. There was no differentiation between the 180, 200, and 220°C pressing temperatures when evaluating TS24h. The lower swelling thickness after 2 h water immersion for treatments at 200 and 220°C pressing temperatures in relation to the ones at 180 and 160°C was related to lower water absorption of sugarcane bagasse particles, which occurred due to the greater plastic residue coating and the water absorption obstruction by the particles cell wall. The use of a higher temperature for panels pressing allowed a greater softening of the plastic waste and, consequently, a better covering of the sugarcane bagasse particles (Figure 4B), reducing the water absorption of the lignocellulosic material and its swelling in the first hours of contact with the water. While for the panels produced with lower temperatures, greater spaces were observed between the two types of residues (Figure 4A), allowing greater ease for water absorption and thickness swelling.

However, greater water penetration in the particles cell wall occurred after increasing time exposure to water, allowing for statistical equality of treatments with 180, 200 and 220°C. It is also observed that there was no strong interaction between the plastic bags residue and the sugarcane bagasse particles, capable of reducing the thickness swelling, therefore, not functioning as an adhesive between the particles[48].

Barros et al.[38] evaluated the quality of particleboard panels made with sugarcane bagasse in conjunction with *Eucalyptus* and pine wood and using urea-formaldehyde and melamine-formaldehyde adhesives, with 160°C pressing temperature, and obtained values between 7.0 to 26.5% for TS2h and between 16.3 to 36.2% for TS24h. Ribeiro et al.[27] evaluated the effect of heat treatment on the properties sugarcane bagasse panels MDP with urea-formaldehyde adhesive and 160°C pressing temperature, and obtained mean values ranging from 34 to 45.5% for TS2h and 53 to 69.7% for TH24h. Mesquita et al.[47] when studying the effect of the use of cellulose nanocrystals on the properties of sugarcane bagasse MDP panels, with and 160°C pressing temperature, obtained values between 8 to 16% for TS2h and between 13 to 20% for TS24h.

The results for physical properties were satisfactory according to data found in the literature. According to NBR 14810 standard[42,] all treatments met the standard that was set the limit at 15% for swelling thickness after 24 h immersion. EN 312[43] sets at 8% the maximum value for swelling thickness after 24 h immersion. None of the treatments met this standard. Although no treatment meets the EN312 standard[43], as previously seen, treatments with

Figure 3. The swelling thickness of particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. *Averages followed by a similar letter (uppercase for TS2h and lower case for TS24h) did not differ statistically by the Scott-Knott test at a 5% significance level.

Figure 4. Images obtained by scanning electron microscopy for panels produced at 160°C (A) and 220°C (B).

180, 200 and 220°C showed marked reductions in TS24h compared to panels with 160° C, which are in the order of 24.5; 40.1 and 36.7%, respectively. This fact demonstrates the potential of associating plastic bags waste and temperature to improve physical properties, but it also demonstrates the need to associate adjustments to other variables, such as the association with paraffin, which helps repel water and has not been used in this study, as well as a small increase in the adhesive amount, an increase in the plastic waste amount, among other associations.

5. Mechanical Properties

The modulus of rupture (MOR) and modulus of elasticity (MOE) for static bending, and Internal Bonding (IB) values for each treatment are presented in Figures 5, 6, and 7, respectively.

The panels produced at different pressing temperatures did not differ statistically in terms of MOR and MOE for static bending and internal bonding. It is shown that the plastic bag residue particles did not promote adequate chemical and/or mechanical interaction among the sugarcane bagasse particles (Figure 4), thus not affecting the bonding properties amongst the particles (Figure 7).

The low average values for internal bonding might be related to the lower amount of adhesive available per particle, since to obtain a 0.70 g/cm³ nominal density MDP panel, larger amounts of sugarcane bagasse particles are required when compared to pine tree and *Eucalyptus* particleboard panels due to lower basic density of sugarcane bagasse[44].

Barros et al.[38] evaluated the quality of particleboard panels produced with sugarcane bagasse combined with *Eucalyptus* and Pine wood using urea-formaldehyde and melamine-formaldehyde adhesives, with and 160°C pressing temperature, found average values of 0.20 to 0.63 MPa for internal bonding (IB), from 710.8 to 1129 MPa for MOE, and 3.42 to 5.91 MPa for MOR.

Tabarsa et al.[49] evaluated panels of Three-layer mats, density of 0.70 g/cm³ and variable factors were as wood species (bagasse, poplar and mixed hardwood species), moisture content of mat (face layer: 12%, 14% and core layer: 9%, 11%) and press time (6 and 8 min) and with 170°C press temperature constant, the authors obtained for the sugarcane bagasse panels average values between 1400 to 2120 MPa for MOE, 14 to 20.5 MPa for MOR and 0.26 and 0.42MPa for IB.

Kariuki et al.[10] evaluated particleboard of sugarcane bagasse, corn straw and rice husk bonded with chemically modified Cassava peel starch, the authors obtained average values between 2364 to 3329 MPa for the MOE, 13.5 to 14.8 MPa for MOR and 1.6 to 2.37MPa for IB.

ANSI A208.1 standard establishes for standard type (M-S) panels[50], minimum values of 12.8 MPa MOR, 1943.8 MPa MOE, and 0.40 MPa IB. EN 312 standards[43] establishes 13 MPa for MOR, 1800 MPa for MOE, and 0.30 MPa for IB as the minimum values. NBR 14810-2 standard[42] sets 11 MPa for MOR, 1600 MPa for MOE, and 0.40 MPa for IB as the minimum values. Therefore, all treatments met trading standards when evaluating MOR at static bending. No treatment met the standards for internal bonding and ANSI A208.1[50] and EN 312[43] standards for MOE
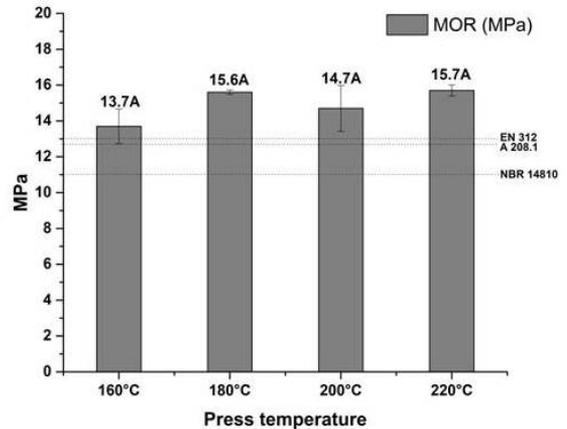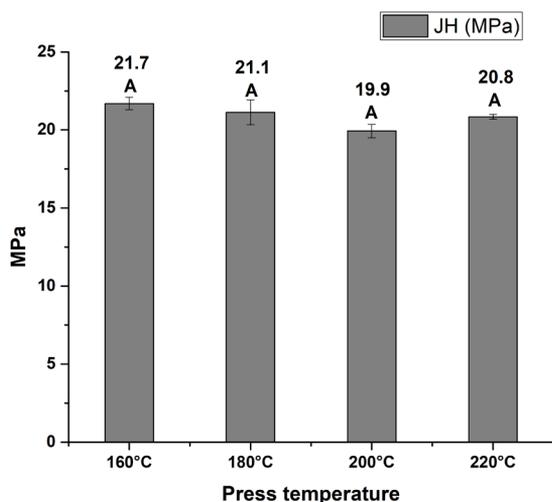

Figure 5. Modulus of rupture (MOR) for particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. * Averages followed by similar letter did not differ statistically by the Scott-Knott test at 5% significance level.
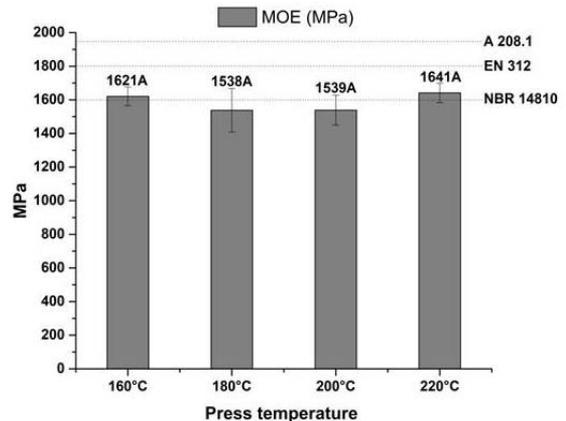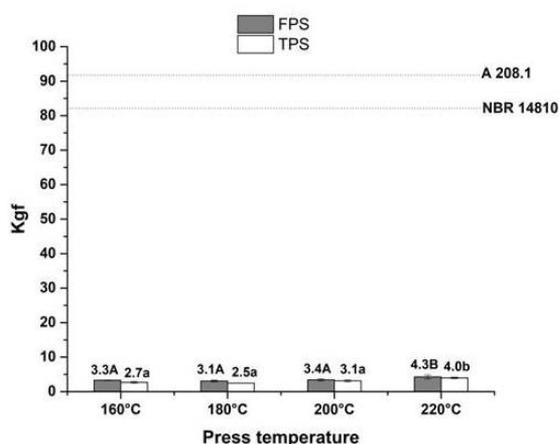

Figure 6. Modulus of elasticity (MOE) for particleboard panels produced with sugarcane bagasse particles at different pressing temperatures. * Averages followed by similar letter did not differ statistically by the Scott-Knott test at 5% significance level.
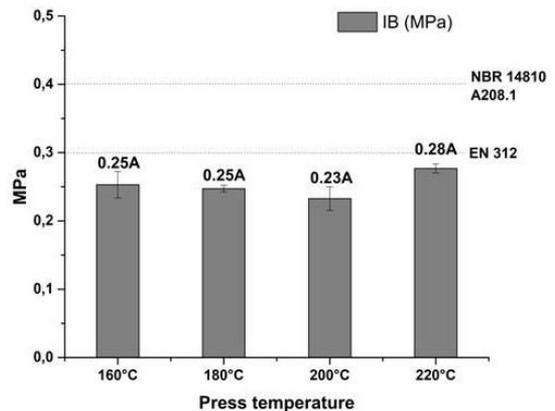
Figure 7. Internal bonding (IB) for particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. * Averages followed by similar letter did not differ statistically by the Scott-Knott test at 5% significance level.

Figure 8. *Janka* hardness (JH) for particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. * Averages followed by similar letter did not differ statistically by the Scott-Knott test at 5% significance level.

Figure 9. Face screw (FSP) and top (TSP) pull-out for particleboard panels produced with sugarcane bagasse and plastic bag particles at different pressing temperatures. * Averages followed by a similar letter (uppercase for APF lower case for APT) did not differ statistically by the Scott-Knott test at 5% significance level.

at static bending. The panels produced at 160 and 220°C meet NBR 14810-2 standards[42] for MOE at static bending.

The average values for *Janka* hardness (JH), face screw (FSP), and top screw (TSP) pull-out properties are shown in Figures 8 and 9, respectively. No pressing temperature effect on the *Janka* hardness property occurred for MDP panels made with sugarcane bagasse and plastic bag residue. For face and top screw pull-out, the panels produced at 220°C pressing temperature differed statistically from the other treatments, obtaining the highest resistance values. There was no significant difference between panels produced at 160°C, 180°C and 200°C for top and face screw pull-out from the panels.

The significant improvement for screw pull-out using 220°C pressing temperature for panels is correlated to a greater plastic residue softening and the greater void-filling by the polymer, as well as the greater particles compaction due to lignin softening, as discussed for the water absorption.

None of the treatments managed to meet the ANSI A208.1[50] and ABNT NBR 14810-2[40] standards that set minimum values at 92 Kgf and 81.6 Kgf, respectively. According to Oliveira et al.[44], this may have occurred due to smaller adhesive amounts available per particle, since a larger amount of sugarcane bagasse particles is required to obtain a $0.70 g/cm^3$ nominal density MDP panel when compared to Pine wood and *Eucalyptus* particles panels.

6. Conclusions

The pressing temperature significantly influenced only the properties of water absorption, thickness swelling and screw pullout (Top and Face). There was no effect of the pressing temperature on the other physical and mechanical properties of the sugarcane bagasse panels in association with plastic bag.

The use of the 220°C temperature resulted in the lowest WA2h and WA24h values and in the highest values of screw pullout at the top and face. The temperatures of 200 and 220°C obtained the lowest TS2h values, and the temperatures of 180, 200 and 220°C obtained the lowest TS24h values. These properties were influenced by the covering of the sugarcane bagasse particles and also by filling in the empty spaces due to the melting of the polymeric residue.

7. Acknowledgments

8. References

1. Soares SS, Guimarães JB Jr, Mendes LM, Mendes RF, Protásio TP, Lisboa FN. Valorização do bagaço de cana-de-açúcar na produção de painéis aglomerados de baixa densidade. Braz J Wood Sci. 2017;8(2):64.

2. Odppes GF, Bulle C, Ugaya CML. Wood forest resource consumption impact assessment based on a scarcity index accounting for wood functionality and substitutability (WoodSI). Int J Life Cycle Assess. 2021;26(5):1045-61.

3. Brito FMS, Bortoletto G Jr, Paes JB, Belini UL, Tomazello-Filho M. Technological characterization of particleboards made with sugarcane bagasse and bamboo culm particles. Constr Build Mater. 2020;262:120501.

4. Jumaidin R, Sapuan SM, Jawaid M, Ishak MR, Sahari J. Thermal, mechanical, and physical properties of seaweed/sugar palm fibre reinforced thermoplastic sugar palm starch/agar hybrid composites. Int J Biol Macromol. 2017;97:606-15.

5. Nakanishi EY, Cabral MR, Fiorelli J, Santos V, Christoforo AL, Savastano H Jr. Study of the production process of 3-layer sugarcane-bamboo-based particleboards. Constr Build Mater. 2018;183:618-25.

6. Rowell RM, Han JS, Rowell JS. Characterization and factors effecting fiber properties. In: FROLLINI, E. (Ed.). Natural

polymers and agrofibers bases composites. São Carlos: USP/IQSC. 2000; 115-134.

7. Pereira AA, d'Almeida JR. Mechanical and physical screw withdrawal properties behavior of agglomerated panels reinforced with coir and pejibaye fibers. Wood Mater Sci Eng. 2018;13(5):286-95.

8. Mendes RF, Mendes L, Guimarães J Jr, Santos R, Bufalino L. The adhesive effect on the properties of particleboards made from sugar cane bagasse generated in the distiller. Rev Cienc Agrar. 2009;32(2):209-18.

9. Hansted FAS, Hansted ALS, Padilha ERD, Caraschi JC, Goveia D, Campos CI. The use of nanocellulose in the production of medium density particleboard panels and the modification of its physical properties. BioResources. 2019;14(3):5071-9.

10. Kariuki SW, Wachira J, Kawira M, Leonard GM. Characterization of prototype formulated particleboards from agroindustrial lignocellulose biomass bonded with chemically modified cassava peel starch. Adv Mater Sci Eng. 2019;2019:1-15.

11. Jesus LCC, Luz S, Leão R, Zattera A, Amico S. Thermal properties of recycled polystyrene composite reinforced with cellulose from sugarcane bagasse. Rev Matéria. 2019;24(3):1-11.

12. Mgbemene C, Rosenkranz A, Pichelin F, Lehmann M, Job C, Kimeng H, et al. Feasibility study on the production of particleboard from maize cobs, rice husks, and groundnut shells using acacia mimosa tannin extract as the bonding adhesive. J Archit Eng. 2014;20(1):04013006.

13. Silva DW, Farrapo CL, Ribeiro DP, Mendes RF, Mendes LM, Scolforo JRS. MDP com partículas de eucalipto e palha de milho. Sci For. 2015;43(108):853-62.

14. César AADS, Bufalino L, Mendes LM, Mesquita RGDA, Protásio TDP, Mendes RF, et al. Transforming rice husk into a high-added value product: potential for particleboard production. Cienc Florest. 2017;27(1):303-13.

15. Silva DW, Scatolino M, Prado N, Mendes R, Mendes L. Addition of different proportions of castor husk and pine wood in particleboards. Waste Biomass Valoriz. 2016;16:1-7.

16. Guimarães JB Jr, Xavier MM, Santos TS, Protásio TDP, Mendes RF, Mendes LM. Inclusão de resíduo da cultura de sorgo em painéis aglomerados de eucalipto. Pesqui Florest Bras. 2016;36(88):435-42.

17. Scatolino MV, Costa AO, Guimarães JB Jr, Protásio TP, Mendes RF, Mendes LM. Eucalyptus wood and coffee parchment for particleboard production: physical and mechanical properties. Cienc Agrotec. 2017;41(2):139-46.

18. Cesar AAS, Bufalino L, Macedo LB, Mesquita RGA, Protásio TP, Mendes LM. Use of coffee plant stem in the production of conventional particleboards. Key Eng Mater. 2014;600:703-8.

19. Guimarães BMR, Mendes LM, Tonoli GHD, Bufalino L, Mendes RF, Guimarães JB Jr. Chemical treatment of banana tree pseudostem particles aiming the production of particleboards. Cienc Agrotec. 2014;38(1):43-9.

20. Mendes RF, Mendes L, Abranches R, Santos R, Guimarães J Jr. Painéis aglomerados produzidos com bagaço de cana em associação com madeira de eucalipto. Sci For. 2010;38(86)

21. Okino EYA, Andahur JPV, Santana MAE, Souza MR. Resistência físico-mecânica de chapas aglomeradas de bagaço de cana-de-açúcar modificado quimicamente. Sci For. 1997;(52):35-42.

22. Battistelle RA, Fujino DM, Bezerra BS, Valarelli IDD. Physical and mechanical characterization of sugarcane bagasse particleboards for civil construction. J Sustainable Dev Energy Water Environ Syst. 2016;4(4):408-17.

23. Oliveira SL, Freire TP, Mendes LM, Mendes RF. The effect of post-heat treatment in mdf panels. Mater Res. 2017;20(1):183-90.

24. Curling SF, Laflin N, Davies GM, Ormondroyd GA, Elias RM. Feasibility of using straw in a strong, thin, pulp moulded packaging material. Ind Crops Prod. 2017;97:395-400.

25. Barreca F, Martinez Gabarron A, Flores Yepes JA, Pastor Pérez JJ. Innovative use of giant reed and cork residues for panels of buildings in Mediterranean area. Resour Conserv Recycling. 2019;140:259-66.

26. Brasil. Ministério do Meio Ambiente. Brasília: Ministério do Meio Ambiente; 2016 [cited 2016 Dez 19]. Avaiable from: http://www.mma.gov.br/ responsabilidade-socioambiental/producao-e-consumo sustentavel /saco-e-um-saco/saiba-mais.

27. Ribeiro DP, Vilela AP, Silva DW, Napoli A, Mendes RF. Effect of heat treatment on the properties of sugarcane bagasse medium density particleboard (MDP) panels. Waste Biomass Valoriz. 2020;11(11):6429-41.

28. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 13999: papel, cartão, pastas celulósicas e madeira - determinação do resíduo (cinza) após a incineração a 525°C. Rio de Janeiro: ABNT; 2003. 4 p.

29. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 14853: madeira: determinação do material solúvel em etanol-tolueno e em diclorometano e em acetona. Rio de Janeiro: ABNT; 2010. 3 p.

30. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 7989: pasta celulósica e madeira: determinação de lignina insolúvel em ácido. Rio de Janeiro: ABNT; 2010. 6 p.

31. Browning BL. The chemistry of wood. New York: John Wiley; 1963. 689 p.

32. Kennedy F, Phillips GO, Williams EPA. Wood and cellulosics: Industrial utilization, bioctechnology, structure and properties. Chichester: Ellis Hordwood; 1987. 1130 p.

33. Associação Brasileira de Normas Técnicas. NBR 11941: madeira: determinação da densidade básica. Rio de Janeiro: ABNT; 2003. 6 p.

34. Figueroa MJM, Moraes PD. Comportamento da madeira a temperaturas elevadas. Ambient Constr. 2009;9(4):157-74.

35. Mendes RF, Bortoletto GB Jr, Almeida NF, Surdi PG, Barbeiro IN. Effect of thermal treatment on properties of OSB panels. Wood Sci Technol. 2013;47(2):243-56.

36. Deutsches Institut fur Normung. DIN 52362: testing of wood chipboards, bending test, determination of bending strength. Berlin; 1982. 40 p.

37. Iwakiri S. Painéis de madeira reconstituída. Curitiba: FUPEF; 2005. 247 p.

38. Barros RM Fo, Mendes LM, Novack KM, Aprelini LO, Botaro VR. Hybrid chipboard panels based on sugarcane bagasse, urea formaldehyde and melamine formaldehyde resin. Ind Crops Prod. 2011;33(2):369-73.

39. Protásio TP, Bufalino L, Tonoli GHD, Guimarães M Jr, Trugilho PF, Mendes LM. Brazilian lignocellulosic wastes for bioenergy production: characterization and comparison with fossil fuels. BioResources. 2013;8(1):1166-85..

40. Coutinho F, Mello IL, Santa Maria LC. Polietileno: principais tipos, propriedades e aplicações. Polímeros. 2003;13(1):1-13.

41. Satyanarayana KG, Guimarães JL, Wypych F. Studies on lignocellulosic fibers of Brazil. Part I: source, production, morphology, properties and applications. Compos, Part A Appl Sci Manuf. 2007;38(7):1694-709.

42. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 14810: chapas de madeira aglomerada. Rio de Janeiro: ABNT; 2013. 51 p.

43. European Committee for Standardization. EN 312: particleboard: specifications. Brussel; 1993.

44. Oliveira SL, Mendes RF, Mendes LM, Freire TP. Particleboard panels made from sugarcane bagasse: characterization for use in the furniture industry. Mater Res. 2016;19(4):914-22.

45. Xiong W. Bagasse composites: A review of material preparation, attributes, and affecting factors. J Thermoplast Compos Mater. 2018;31(8):1112-46.

46. Barbosa LA, Dreger AA, Schneider EL, Morisso FDP, Santana RMC. Polietileno de baixa densidade-PEBD: mercado, produção,

Pressing Temperature Effect on the Properties of Medium Density Particleboard Made with Sugarcane Bagasse and Plastic Bags

9

principais propriedades e aplicações. Revista Espacios. 2017;38(17):1-13.

47. Mesquita RGA, Mendes LM, Sanadi AR, Sena AR No, Claro PIC, Corrêa AC, et al. Urea formaldehyde and cellulose nanocrystals adhesive: studies applied to sugarcane bagasse particleboards. J Polym Environ. 2018;26(7):3040-50.

48. Buzo ALSC, Sugahara ES, Silva SADMD, Morales EAM, Azambuja MDA. Painéis de pínus e bagaço de cana empregando-se dois adesivos para uso na construção civil. Ambient Constr. 2019;19(4):183-93.

49. Tabarsa T, Ashori A, Gholamzadeh M. Evaluation of surface roughness and mechanical properties of particleboard panels made from bagasse. Compos, Part B Eng. 2011;42(5):1330-5.

50. ANSI: American National Standard. ANSI A208.1: medium density fiberboard for interior use. National particleboard assoc. Gaithersburg: ANSI; 1999.