THERMAL MODIFICATION OF SUGARCANE WASTE AND BAMBOO PARTICLES FOR THE MANUFACTURE OF PARTICLEBOARDS

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ABSTRACT – The thermal modification of particles of the paticleboards constituted of agroforest and industrial waste can improves the dimensional stability (thickness variation) and reduces the use of chemicals that can raise the costs of the process or be hazardous to humans and the environment. This study evaluated the effect of the thermal modification on the physical-mechanical properties and density profile of particleboards manufactured from sugarcane bagasse and bamboo (*Dendrocalamus* asper) (Schult f.) Backer ex Heyne). A mixture of 75% bamboo particles and 25% sugarcane bagasse was subjected to 220 °C temperature for 201 min. Urea-formaldehyde (UF)-based adhesive with three solids contents (10, 12 and 14%) based on the dry mass of the particles was used for the aggregation of the materials. Both temperature and increases in the adhesive content improved their dimensional stability, however, the thermal treatment reduced the mechanical properties. The particleboards composed of treated particles did not meet the minimum specifications established by the Brazilian norm utilized. The densitometric profiles were negatively influenced by the thermal modification and improved by the increase in adhesive content.

Keywords: Density profile; Physical-mechanical properties; Thermal treatment.

MODIFICAÇÃO TÉRMICA DE RESÍDUO DE CANA DE AÇÚCAR E PARTÍCULAS DE BAMBU PARA PRODUÇÃO DE AGLOMERADOS

*RESUMO – A modificação térmica de partículas de painéis constituídos de resíduos agroflorestais e industriais pode incorporar melhorias na estabilidade dimensional (variação na espessura) e reduzir a utilização de produtos químicos, que podem onerar o processo ou serem nocivos ao homem e ao meio ambiente. Assim, o objetivo da pesquisa foi avaliar o efeito da modificação térmica nas propriedades físico-mecânicas e no perfil de densidade de painéis constituídos com resíduo (bagaço) de cana e bambu (**Dendrocalamus** asper) (Schult f.) Backer ex Heyne). Para a produção dos painéis utilizou-se uma mistura de 75% de partículas de bambu e 25% de resíduo de cana. O material foi submetido à temperatura de 220 °C por 201 min. Para a agregação dos materiais utilizou-se adesivo a base de uréia formaldeído (UF) com três teores de sólidos (10, 12 e 14%) com base na massa seca das partículas. A temperatura e o aumento no teor de adesivo promoveram melhorias na estabilidade dimensional. Por outro lado, o tratamento térmico reduziu as propriedades mecânicas. Os painéis constituídos com partículas termorretificadas não atenderam às especificações mínimas exigidas pela norma brasileira utilizada. Os perfis densitométricos foram influenciados negativamente pela modificação térmica e melhorados pelo aumento no teor de adesivo.*

Palavras-Chave: Perfil de densidade; Propriedades físico-mecânicas; Tratamento térmico.

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1. INTRODUCTION

The search for ecologically correct and good-quality alternative materials is one of the objectives of the sustainable development for a more rational use of natural resources (Valarelli et al., 2013). Bamboo is among such resources; it includes 34 genera and 232 species, of which 174 are endemic in Brazil, and evidences its diversity, although little explored (Arruda et al., 2011). Some species are employed as building elements due to their strength, flexibility and versatility (Flander and Rovers, 2009), and raw material for the manufacture of particleboards (Almeida et al., 2017; Dinhane et al., 2015; Melo et al., 2015).

Agroforest and industrial waste are also used for the manufacture of particleboards, since they not only add value to the product, but also provide sustainability, reduce environmental pollution problems and help particleboard industries meet their demands (Negrão et al., 2014). Some studies have pointed to the use of sugarcane bagasse for the manufacture of particleboards (Fiorelli et al., 2013, 2016; Mendes et al., 2014). However, one of the technological obstacles for its use in reconstituted particleboards is its dimensional instability in comparison to particleboards manufactured from wood particles (Freire et al., 2011).

Such instability is due to the low sugarcane bagasse density, which results in a thick mattress and compression strain. On the other hand, mattresses from particles of wood or another denser material (bamboo) are less thick and can result in a low compression ratio. Therefore, the combination of materials of different densities might be an option for larger availability of raw material for the industry of reconstituted particleboards. Moreover, the thermal modification of raw material might improve some technological properties of particleboards manufactured from agroforest and industrial waste, as dimensional stability, and reduce the use of chemicals that might raise the costs of the process (paraffin)

The time and temperature adopted for the thermal modification process can improve the dimensional stability, strength to weather changes and biodeteriorating agents, wettability and bonding with hydrophobic adhesives, and reduce the equilibrium moisture content and swell the thickness of the particleboards (Brito, 2018). According to some studies, the thermal treatment of wood particles improved the physical properties of the particleboards (Paul et al., 2007; Mendes et al., 2013; Vital et al., 2014).

This article addresses an evaluation of the thermal modification effect on the physical-mechanical properties and density profile of particleboards manufactured from sugarcane bagasse and bamboo (*Dendrocalamus* asper) (Schult f.) Backer ex Heyne).

2. MATERIALS AND METHODS

2.1. Sugarcane waste (sugarcane bagasse) and bamboo particles

Sugarcane bagasse was obtained at a sugar mill located in Santa Bárbara D'Oeste, São Paulo state, Brazil. The collected waste showed an uniform color and no deterioration. They were transported to the Forest Sciences Department, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, São Paulo state, and air-dried (18%) and dried in a greenhouse (70 ± 2 °C) for 3 h, until reaching (10%). The material (sugarcane bagasse) was classified and 0.50 – 0.85 mm granulometry particles were used.

Over three-year-old bamboo (*Dendrocalamus* asper stems showed good mechanical strength properties and availability at the Agronomics Institute of Campinas, Tatuí, São Paulo state. They were transformed into splinters, according to the procedure described by Brito et al. (2018), which were planned for the removal of the internal layer (starch-rich) and the external one (bark) and transformed into chips by a band saw. Then, they were dried and processed similarly to sugarcane bagasse.

2.2. Thermal modification of the particles

The sugarcane bagasse and bamboo particles were dried in a greenhouse (3% humidity) and placed on hollow metallic trays (13 x 18 x 58 cm), which were deposited in rectangular metallic boxes in a greenhouse provided with a sensor that controlled the time and temperature of the thermal treatment. Nitrogen was injected into the boxes for the avoidance of ignition of the material.

The heat treatment parameters were defined based on the work of Mendes et al. (2013). The thermal modification of the particles started at ± 30 °C and the heating rate was 3.33ºC/ min^{-1} for 21 min, until reaching 100 ºC. Then it was reduced to 1 °C min^{-1} until reaching 220 °C (141 min) and kept for 201 min. for an effective treatment. The greenhouse was then switched off and the material remained there overnight (± 12 h). After the treatment, the particles remained in the boxes until reaching ambient temperature (± 30 °C).

Particle samples (control and treated) were placed in an acclimatized room (20 ± 2 ºC and 65 ± 5% relative humidity) until reaching equilibrium moisture content (± 12%).

2.3. Manufacture of sugarcane bagasse and bamboo particleboards

The manufacture of the particleboards followed the recommendations of (Surdi et al. (2018) and the material showed 0.65 $g.cm^{-3}$ nominal density, 15.70 mm nominal thickness and 10; 12; and 14% solids content of the urea-formaldehyde (UF)-based adhesive in relation to the mass of the particles. The percentages of solids (10, 12 and 14%) were defined based on those used by the industries for the production of agglomerated panels. The adhesive showed 64.16% solids content, 1.27 $g.cm^{-3}$ density and 7.88 pH and received an ammonia sulphate solution (catalyst) at 5% solids proportion. The mixture was homogenized and sprinkled on the particles in a slasher of warp (12 rpm) for 5 min and a paraffin emulsion (1.0% solids) was applied (5 min – 12 rpm).

The particles were weighed and placed into a wooden hollow mold of 40 x 40 cm on an aluminum plate (50 x 50 cm). The mattress was cold pre-consolidated (5 $kgf.cm^{-2}$ =pressure for 5 min), removed from the box and hot-pressed (180 ºC; 35 $kgf.cm^{-2}$; 10 min). A 1.57 cm thick delimiter was used, which were arranged on the sides of the pre-pressed mattress, ensuring that the applied pressure was equally distributed across the panel area. It was then arranged in a vertical position for cooling and acclimatized (22 ± 2 ºC and 65 ± 5% relative humidity - RH) prior to the removal of the samples for physical-mechanical and density profile tests, according to Regulatory Brazilian Norm – NBR 14810 of the Brazilian Association of Technical Norms – ABNT (2013).

2.4. Density profile

The density profile was determined according to Surdi et al. (2014) and the effect of variables checked on the pressing process in the compaction of the particleboards. This study contributes to the quality control of both experimental and industrial particleboards (Wang et al., 2004).

Four samples of 15.70 x 50 x 50 mm (thickness x width x length) were removed from each particleboard, which totaled 12 per treatment, and sandpapered (# 80 sandpaper) prior to the tests. Since the density profile analysis is non-destructive, the samples were used for internal bond (IB) strength tests.

The analysis was conducted in a QMS QDP-01X model X-ray densitometer of 10-50 KV, 1.5 mA current and initial and final collimation of 180 and 90 μm beams, respectively.

The sweeping of the samples changed the X-ray beams into density values obtained every 20 μm through QMS program; a DAT-format file was created and read by Excel software, which enabled the construction of a graph of maximum and minimum apparent density profile of the samples.

Three reading points, i.e., two for the external layer and one for the central layer (B), were established after the obtaining of the density profile. A 2 mm band from each end to the particleboard´s thickness direction was considered for the density measurement of points A. The average values between points A was considered for the central layer.

2.5. Experimental delineation and data analysis

The particles were subjected to 220 °C temperature and three UF-based adhesive levels were adopted (10; 12 and 14%). The particleboards were manufactured with 75% bamboo particles and 25% sugarcane bagasse were defined based on the best compaction ratio (relation between the specific masses of the panel and the raw material), among some compositions tested. Those manufactured with non-treated particles glued with 10% adhesive were taken as control.

The effects of both thermal modification on the equilibrium moisture content of the particles and adhesive contents and thermal treatment on the properties of the particleboards were tested by variance analyses and F tests ($p < 0.05$). Tukey test ($p < 0.05$) checked the discrimination of the averages, whereas Lilliefors and Cochran tests evaluated the normality of the data and homogeneity of the variances, respectively.

The results of the physical and mechanical tests were confronted with the values established by NBR 14810 (ABNT, 2013). The humidity content of the particleboards was analyzed by descriptive statistics that considered averages and standard deviations.

3. RESULTS

3.1. Equilibrium moisture content and alteration in the color of the particles

The temperature used reduced the hygroscopicity of the particles and the equilibrium moisture contents of the control particles were larger in relation to those thermally modified (Table 1).

3.2. Physical properties of the particleboards

The results of the physical properties of particleboards were calculated (Table 2). The treatments showed differences for all evaluated properties, except for apparent density (AD).

3.3. Mechanical properties of the manufactured particleboards

The results were obtained for the mechanical properties of the particleboards (Table 3). The treatments showed differences regarding modules of rupture (MOR) and modules of elasticity (MOE), surface screw withdrawal (SSW) and top screw withdrawal (TSW) and internal bond (IB).

3.4. Density profile of the particleboards

The treatments showed differences regarding the densities of the external and central layers (Table 4).

The density profiles of the particleboards were obtained by the X-ray attenuation for each treatment (Figure 1).

4. DISCUSSION

4.1. Equilibruim moisture content and alteration in the color of the particles

It was observed that the thermal treatment reduced the equilibrium moisture content of the particles and 35.86 and 12.38% were obtained for sugarcane bagasse and bamboo, respectively. Vital et al. (2014) obtained

Table 1 – Equilibrium moisture content of sugarcane residue and bamboo particles.
Tabela 1 – *Teor de umidade de equilíbrio das partículas de resíduo de cana e bambu.*

Particles	Treatment	Equilibrium moisture content (%)
Residue of sugarcane	Control	10.82 a
	Heat treatment	6.94 c
Bamboo	Control	10.18 a
	Heat treatment	8.92 b
Overall mean	9.21	
CV (%)	5.17	

Means followed by the same letter do not differ (Tukey; $p > 0.05$).

Table 2 – Apparent density (AD), Moisture Content (MC) WA2H (water absorption, 2 hours) and WA24H (water absorption, 24 hours), Thickness swelling in 2h (TS2h), in 24h (TS24h) and non-recoverable tax (NRT), of the particleboards according to the treatments and adhesive contents used.
Tabela 2 – *Densidade específica aparente (DEA), teor de umidade (TU), absorção de água em 2h (AA2h) e 24 horas (AA24h), Inchamento em espessura após 2h (AA2h) e 24 h (AA24h) de imersão em água e taxa de não-retorno em espessura (TNRE) dos painéis em função dos tratamentos e teores de adesivo empregados.*

Treatments	AD** ($g.cm^{-3}$)	MC (%)	WA2h (%)	WA24h (%)	TS2h (%)	TS24h (%)	NRT (%)
* T1	0.59	7.7 (1.91)	69.45 a	94.28 a	13.85 a	17.39 a	9.55 a
T2	0.58	7.73(1.91)	20.79 b	75.18 b	4.14 b	14.16 b	9.28 a
T3	0.60	7.50(1.86)	10.97 c	45.32 c	2.60 c	5.32 c	5.19 b
T4	0.60	7.57(1.88)	11.29 c	43.76 c	2.19 c	4.53 c	3.46 c
Overall mean	0.59	7.6(1.89)	28.12	63.79	5.69	10.35	6.87
CV (%)	1.89	1.56	11.45	2.02	7.56	5.94	6.01

T1 - Control (10%); T2 (Heat treatment 10%); T3 (Heat treatment 12%); T3 (Heat treatment 14%).

*Datas contained in Brito (2018), used as comparison in this article. Means followed by the same letter do not differ (Tukey; $p > 0.05$). CV: coefficient of variation.

Table 3 – Modulus of rupture (MOR), elasticity (MOE), surface screw withdrawal (SSW), top screw withdrawal (TSW) and internal bond (IB) of the particleboards according to the treatments and adhesive contents used.
Tabela 3 *– Módulo de ruptura (MOR), elasticidade (MOE), arrancamento de parafuso de superfície (APS), arranchamento de parafuso de topo (APT) e ligação interna (LI) dos painéis em função dos tratamentos e teores de adesivo empregados.*

Treatments/adhesive contents (%)		MOR (MPa)	MOE (MPa)	SSW (N)	TSW (N)	IB (MPa)
*Control	T1 - 10	7.54 a	994.75 a	711.39 a	561.18 a	0.36 a
	T2 - 10	2.47 c	416.72 b	336.79 c	343.33 b	0.17 b
Tratamento térmico	T3 - 12	4.27 b	752.26 a	487.90 b	514.05 a	0.27 ab
	T4 -14	5.95 b	924.28 a	612.59 a	609.01 a	0.33 a
Overall mean		5.06	772.00	537.17	506.89	0.23
CV (%)		10.23	16.25	8.60	10.88	15.48

*Datas contained in Brito (2018), used as comparison in this article. Means followed by the same letter do not differ (Tukey; $p > 0.05$). CV: coefficient of variation.

Table 4 – Mean values of the apparent density of the outer layer and central layer of the particleboards according to the treatments and adhesive contents used.
Tabela 4 *– Valores médios da densidade aparente das camadas externa e central dos painéis de acordo com os tratamentos e teores de adesivo empregados.*

Treatments/adhesive moisture (%)		Aparrent density of the layers ($kg.m^{-3}$)	
		Outer Layer	Central Layer
*Control	T1 - 10	679.43 a	643.05 a
Heat Treatment	T2 - 10	559.50 c	596.94 b
	T3 - 12	626.86 b	630.02 a
	T4 - 14	657.64 ab	619.90 ab
Overall mean		630.85	622.48
CV (%)		2.45	1.75

*Datas contained in Brito (2018), used as comparison in this article. Means followed by the same letter do not differ (Tukey; $p > 0.05$). CV: coefficient of variation.

Note: Figure 1A, contained in Brito (2018), used as comparison in this article.
Nota: *Figura 1A, contida em Brito (2018), utilizada como comparação neste artigo.*

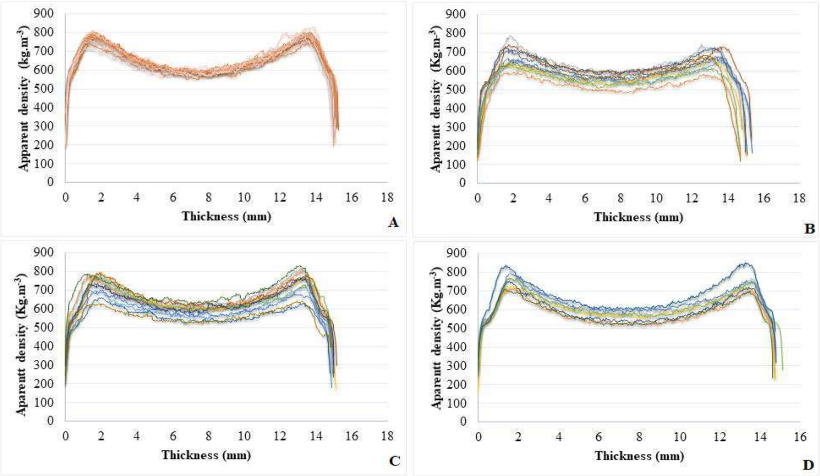

Figure 1 – Density profiles of particleboard: (A) Particleboards with 75% particles bamboo and 25% particles sugarcane residue (control – 10% adhesive moisture) (B) Particleboards with 75% particles bamboo and 25% particles sugarcane residue (heat treated – 10% adhesive moisture); (C) Particleboards with 75% particles bamboo and 25% particles sugarcane residue (heat treated – 12% adhesive moisture) (D) Particleboards with 75% particles bamboo and 25% particles sugarcane residue (heat treated – 14% adhesive moisture).
Figura 1 *– Perfis de densidade ao longo da espessura dos painéis aglomerados constituídos de partículas modificadas termicamente: (A) Painéis de partículas controle encoladas com 10% de adesivo; (B) Painéis de partículas modificadas termicamente encoladas com 10% de adesivo; (C) Painéis de partículas modificadas termicamente encoladas com 12% de adesivo; (D) Painéis de partículas modificadas termicamente encoladas com 14% de adesivo.*

49.58, 56.87 and 67.87% reductions, respectively, for 180, 200 and 220 °C temperatures in relation to the control particles.

A thermal treatment to the material reduces its hygroscopicity (Araújo et al., 2012). The specific superficial area of the sugarcane bagasse particles is larger than that of bamboo, therefore, such particles show larger numbers of sorption sites (hydroxyl groups) available for bonds with water molecules. The specific densities of sugarcane bagasse and bamboo are, respectively, 0.09 g.cm^{-3} and 0.53 g.cm^{-3} (Brito, 2018), which indicate a possible higher degradability of the sugarcane bagasse particles, hence, lower equilibrium moisture content.

The thermal treatment modifies the structure of the material and reduces the equilibrium moisture content through the degradation of the chemical components and formation of a lignin crossed bond, which affects the water adsorption (Surini et al., 2012). The decrease in the equilibrium moisture content enables the manufacture of particleboards of higher dimensional stability, however, the degradation of the OH- (hydrophilic) groupings may hamper the action of the adhesive during the consolidation of the particleboards (Vital et al., 2014).

The particles showed a darker coloration after the thermal treatment due to possible alterations in their structure and caused by the chemical modification of the chromophore groups responsible for the characterization of color (Ahajji et al., 2009).

4.2. Physical properties of the particleboards

No differences were detected among the treatments regarding apparent specific density, however, it was reduced in relation to the pre-established one (0.65 g.cm^{-3}), which usually occurs due to losses of materials during the manufacture stages (Iwakiri et al., 2012).

The increase in the adhesive content does not increase the specific mass of the particleboards (Santos et al., 2009; Colli et al., 2010; Bianche et al., 2012), which can be included in the average-density category, since they met the requirements regarding humidity content for commercialization, i.e., between 5 and 11%, according to NBR 14810 (ABNT, 2013).

Particleboards composed of control particles showed higher values for Water Absorption (WA, 2 hours and WA, 24 hours). Treatments T1 and T2 were comprised of particles glued with the same adhesive content, however, those of T2 were constituted by thermally modified particles. The thermal treatment reduced the water absorption, i.e., 70.06% (WA2h) and 20.26% (WA 24 h). Mendes et al. (2013) observed a similar effect, i.e 25% (WA 2 h) and 36% (WA 24 h) reductions in oriented strand boards (OSB) manufactured with thermally modified particles (200 and 240 °C), which proved the thermal treatment reduces the water absorption by the particles.

Particleboards composed of thermally modified particles and glued with 10% adhesive showed higher water absorption in comparison to those for which 12 and 14% adhesive was used. The increase in the adhesive contents reduced 46.70% (WA 2 h) and 41% (WA 24 h) in relation to those composed of 10% adhesive content.

The higher amount of adhesive applied to the particles promotes better water proofing of the surfaces and reduces the water absorption rate. On the other hand, treatments T3 and T4 provided similar absorption rates and indicated 12% adhesive would be sufficient for the improvement desired, hence, a more economical process, since the adhesive can correspond to up to 40% of the final cost of the particleboard (Carneiro et al., 2007).

The increase in the adhesive contents favored the water absorption reduction for particleboards composed of *Pinus* spp. particles and sugarcane bagasse (Mendes et al., 2012), *Eucalyptus saligna* waste (Pedrazzi et al., 2006) and candeia wood associated with pinus and eucalipto (Santos et al., 2009) The absorption decrease in function of the increase in the adhesive content is due to the distribution of the same of the particles that have better bond quality (Mendes et al., 2012).

The treatments showed differences regarding thickness swelling (TS). The thermal modification (T2) reduced 70.11% (TS 2 h) and 8.57% (TS 24 h) of the thickness in comparison to the control particleboards (T1).

Mendes et al. (2013) observed 58.9% (TS 2 h) and 50.0% (TS 24 h) reductions in particleboards composed of strand particles treated at 240 °C in relation to the control particleboards. Particles subjected to thermal modification showed lower swelling due to the decrease in the OH- groupings available for water adsorption in the constituents of the cell wall (Vital et al., 2014).

The increase in the adhesive contents (T3 and T4) reduced 42.15% (2 h) and 62.25% (24 h) of the TS in relation to T2 and promoted the lowest swelling. Pedrazzi et al. (2006), Colli et al. (2010) and Mendes et al. (2012) observed the same result and attributed it to the difficult contact between water and particles caused by a better cover of the adhesive that, consequently, delayed and reduced the thickness swelling indexes of the particleboards.

The particleboards met the 18% maximum TS after 24 h water immersion, as established by NBR 14810 (ABNT, 2013) for type 2 particleboards (internal use under dry conditions).

No difference was observed for Non-Recoverable Tax NRT between T1 and T2, which leads to the conclusion the thermal treatments of the particles did not influence such a property. T3 and T4 provided the best values due to the higher adhesive contents used in the composition of the particleboards, and 44.07 and 62.72% reductions in comparison to T1. Presumably, the higher adhesive content resulted in a better adhesion of the particles and avoided the release of higher compression strains imposed on the pressing process. The increase in the availability of adhesive per superficial area of the particles improves their bond, hence, properties, as TS 24 h and NRT (Mendes et al., 2003).

4.3. Mechanical properties of the manufactured particleboards

The thermal modification of the particles (T2) reduced 67.24% (MOR), 58.00% (MOE), 52.66% (SSW), 38.82% (TSW) 52.78% (IB) in relation to T1, probably due to the degradation of some chemical constituents of the particles (mass loss) and consequent low mechanical strength of the particleboards.

Mendes et al. (2013) observed 48.8 and 37.2% (perpendicular MOR), 30.9 and 26.4 (parallel MOE), and 61.7 and 50.0% (IB) reductions, respectively, for OSB manufactured from thermally modified particles (200 – 240 °C), in relation to the control particleboards, due to the moving of the extractives towards the surface, which caused its partial inactivation (Sernek et al., 2004).

The increase in the adhesive content increased the values of all properties evaluated – in some cases, the values were similar to those of the control particleboards. Therefore, the increase in the adhesive content compensated for the reduction in the strength caused by the thermal modification and improved the adhesion process probably due to the better distribution of the resins in the particles.

Such results confirmed those obtained by Pedrazzi et al. (2006), Colli et al. (2010) and Ayrilmis et al. (2012), who observed improvements in the strength properties of the particleboards due to the increase in the adhesive content. The increased availability of the resin promotes higher adhesion, hence, better gluing quality (Mendes et al., 2003).

The particleboards manufactured did not reach the minimum values of 11 MPa (MOR) and 1.600 MPa (MOE) established by NBR 14810 (ABNT, 2013), and SSW (1.020 N) and TSW (800 N), required by NBR 14810 (ABNT, 2006). Only those composed of control particles (T1) met the requirements of NBR 14810 (ABNT, 2013), for type 2 particleboards (internal use under dry conditions) regarding IB (0.35 MPa).

4.4. Density profile of the particleboards

T2 decreased 17.65% and 7.17% the apparent density of such layers in relation to T1, respectively, which shows negative influences of the thermal modification on the density profile of the particleboards.

The increase in the adhesive content increased the specific density of the external layer. Since the results of 12 and 14% content were similar, the use of 12% is recommended, due to economic issues (the adhesives may correspond to up to 50% of the process cost).

From the profiles of the analyzed particleboards it is observed that T1 showed more pronounced peaks of apparent specific density on the external layer in comparison to T2, whereas the peaks of particleboards composed of 12% (T3) and 14% (T4), were more pronounced in relation to T2.

T4 particleboards showed a denser region on the central layer, of characteristics similar to those of T1, which indicates a higher uniformity of the readings in relation to T2 and T3. Therefore, the increase in the adhesive content promoted a better consolidation in the external and internal layers that improved the performance of the particleboards regarding the mechanical properties evaluated.

5. CONCLUSIONS

Both thermal modification and increase in the adhesive content improved the WA and TS properties, but reduced the mechanical strength of the particleboards.

Although the adhesive content improved NRT and all mechanical properties evaluated, the particleboards did not meet the requirements of the Brazilian Norm. Similarly, the densitometric profiles were negatively influenced by the thermal treatment, which resulted in a reduction in the apparent density. However, they were improved by increase in adhesive content which provided more homogeneous profiles, thus confirming the improvements in the evaluated mechanical properties.

6. REFERENCES

Ahajji A, Diouf PN, Aloui F, Elbakali I, Perrin D, Merlin A, et al. Influence of heat treatment on antioxidant properties and colour stability of beech and spruce wood and their extractives. Wood Science and Technology. 2009;43:69-83.

Almeida AC, Araújo VA, Morales EAM, Gava M, Munis RA, Garcia JN, et al. Wood bamboo particleboard: mechanical properties. BioResources. 2017;12(4):7784-92.

Araújo SO, Vital BR, Mendoza ZMSH, Vieira TA, Carneiro ACO. Propriedades de madeiras termorretificadas de Eucalyptus grandis e sp. Scientia Forestalis. 2012;40(95):327-36.

Arruda LM, Del Menezzi CHS, Teixeira DE, Araújo PC. Lignocellulosic composites from Brazilian giant bamboo (*Guadua magna*) Part 1: Properties of resin bonded particleboards. Maderas Ciencia y Tecnología. 2011;13(01):297-306.

Associação Brasileira de Normas Técnicas – ABNT. 2013. NBR 14810: chapas de madeira aglomerada – métodos de ensaio. Rio de Janeiro: ABNT; 2013. (in Portuguese).

Ayrilmis N, Kwon JH, Han TH. Effect of resintype and content on properties of composite particleboard made of a mixture of woodand rice husk. International Journal of Adhesion and Adhesives. 2012;38:79-83.

Bianche JJ, Carneiro ACO, Vital BR, Pereira FA, Santos RA, Soratto DN. Propriedades de painéis aglomerados fabricados com partículas de eucalipto (*eucalyptus urophylla*), paricá (*schizolobium amazonicum*) e vassoura (*sida* spp.). Cerne. 2012;18(4):623-30.

Brito FMS. Produção e avaliação da qualidade de painéis aglomerados constituídos por partículas de bagaço de cana-de-açúcar e bambu [tese]. Piracicaba: Escola Superior de Agricultura “Luiz de Queiroz”; 2018.

Brito FMS, Paes JB, Oliveira JTS, Arantes MDC, Vidaurre GB, Brocco VF. Physico-mechanical characterization of heat-treated glued laminated bamboo. Construction and Building Materials. 2018;190:719-27.

Carneiro ACO, Vital RB, Pereira FA. Adesivos e sua importância na indústria madeireira. In: Oliveira JT, Fiedler NC, Nogueira M, editors. Adesivos e sua importância na indústria madeireira: Tecnologia aplicadas ao setor madeireiro II. Vitória: Gráfica Aquarius; 2007. p.99-128.

Colli A, Vital BR, Carneiro ACO, Silva JC, Carvalho AMML, Della Lucia RM. Propriedades de chapas fabricadas com partículas de madeira de paricá (*Schyzolobium amazonicum* huber ex. ducke) e fibras de coco (*Cocos nucifera* l.). Revista Árvore. 2010;34(2):333-8.

Dinhane FCR, Araújo II, Valarelli ID, Bueno MAP, Ferreira BS, Campos CI. Particleboard manufactured with bamboo and coconut fibers in different ratios of adhesive. Advanced Materials Research. 2015;1088:672-5.

Fiorelli J, Sartori DL, Cravo JCM, Savastano Júnior H, Rossignolo JA, Nascimento MF, et al. Sugarcane bagasse and castor oil polyurethane adhesive-based particulate composite. Materials Research. 2013;16(2):439-446.

Flander K, Rovers R. One laminated bamboo-frame house per hectare per year. Construction and Building Materials. 2009;23(01):210-8.

Freire CS, Silva DW, Scatolino MV, César AAS, Bufalino L, Mendes LM. Propriedades físicas de painéis aglomerados comerciais confeccionados com bagaço de cana e madeira. Floresta e Ambiente. 2011;18(2):178-85.

Iwakiri S, Silva LS, Trianoski R, Bonduelle GM, Rocha VY. Avaliação do potencial de utilização da madeira de *Schizolobium amazonicum* "Paricá" e *Cecropia hololeuca* "Embaúba" para produção de painéis cimento-madeira. Cerne. 2012;18(2):303-8.

Mendes LM, Iwakiri S, Matos JLM, Keinert Jr S, Saldanha LK. Efeitos da densidade, composição dos painéis e teor de resina nas propriedades de painéis OSB. Floresta e Ambiente. 2003(1):1-17.

Mendes LM, Guimaraes Junior JB, Santos RC, César AAS. Efeito da associação de bagaço de cana, do tipo e do teor de adesivo na produção de painéis aglomerados. Ciência Florestal. 2012;22(01):161-70.

Mendes RF, Bortoletto Júnior G, Almeida NF, Surdi PG, Barbeiro IN. Effect of thermal treatment on properties of OSB panels. Wood Science and Technology. 2013;47:243-56.

Mendes RF, Mendes LM, Oliveira SL, Freire TP. Use of sugarcane bagasse for particleboard production. Key Engineering Materials. 2014;634:163-71.

Melo RR, Stangerlin DM, Sousa AP, Cademartori PHG, Schneid E. Propriedades físico-mecânicas de painéis aglomerados madeira-bambu. Ciência Rural. 2015;45:35-42. DOI: 10.1590/0103-8478cr20120970.

Negrão WH, Silva SAM, Christoforo AL, Lahr FAR. Painéis aglomerados fabricados com mistura de partículas de madeiras tropicais. Ambiente Construído. 2014;14(3):103-12. DOI:10.1590/S1678-86212014000300008.

Paul W, Ohlmeyer M, Leithoff H. Thermal modification of OSB-strands by a one-step heatpre-treatment – Influence of temperature on weight loss, hygroscopicity and immprovedfungal resistance. Holz als Roh- und Werkstoff. 2007;65:57-63. DOI: 10.1007/s00107-006-0146-4.

Pedrazzi C, Haselein CR, Santini EJ, Schneider PR. Qualidade de chapas de partículas de madeira aglomerada fabricadas com resíduos de uma indústria de celulose. Ciência Florestal. 2006;16(2):201-12.

Santos RC, Mendes LM, Mori FA, Mendes RF. Chapas de partículas aglomeradas produzidas a partir de resíduos gerados após a extração do óleo da madeira de candeia (*Eremanthus erythropappus*). Scientia Forestalis. 2009;37(84):437-46.

Sernek M, Kamke AF, Glasser WG. Comparative analysis of inactivated wood surface. Holzforschung. 2004;58:22-31.

Surini T, Charrier F, Malvestio J, Charrier B, Moubarik A, Castéra P, et al. Physical properties and términte durability of maritime pine (*Pinus pinaster* Ait.) heat-treated under vacuum pressure. Wood Science and Technology. 2012;46(1):487-501. DOI: 10.1007/s00226-011-0421-3.

Surdi PG, Bortoletto Júnior G, Castro VR, Mendes RF, Almeida NF, Tomazello Filho M. Relação entre perfil de densidade e ligação interna de painéis OSB de *Pinus* spp. Floresta e Ambiente. 2014;21(3):349-357. DOI: 10.1590/2179-8087.063413.

Surdi PG, Bortoletto Júnior G, Castro VR. Evaluating the effects of removing fines from particleboards manufactured from Amazonian wood residue. Floresta e Ambiente. 2018;25:1-10. DOI: 10.1590/2179-8087.049017.

Valarelli ID, Azambuja MA, Bastistelli RAG, Campos CI. Avaliação do desempenho de painéis de partículas aglomeradas de bambu da espécie Dendrocalamus giganteus. In: Lahr FAR, Christoforo AL, organizadores. Painéis de partículas de madeira e de materiais lignocelulósicos. São Carlos: USP/EESC; 2013. v. 1. p.179-217

Vital BR, Andrade PIL, Carneiro ACO, Cabral CPT, Carvalho ANM. Estabilidade dimensional e resistência à tração perpendicular de painéis fabricados com partículas termorretificadas oriundas de embalagens de pinus sp. Revista Árvore. 2014;38(5):951-9. DOI: 10.1590/S0100-67622014000500020.

Wang S, Winistorfer PM, Young TM. Fundamental of vertical density profile formation in wood composites: part 3- MDF density formation during hot pressing. Wood and Fiber Science. 2004(36):17-25.