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TECHNICAL PAPER

PARTICLEBOARDS PRODUCED WITH EPOXY INK WASTE AND BTH POLYMER AS ADHESIVES

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KEYWORDS

adhesives, particleboards, BTH polymer, mechanical properties, epoxy ink waste.

ABSTRACT

The aim of this research was to analysis the feasibility of production of wood particleboard with two alternative adhesives: epoxy ink waste and polyhydroxybutyrate polymer (BTH). Particleboard were produced with *Pinus* sp. wood specie wastes from sawmill process. For each alternative adhesive was proposed different combinations of parameters: time and temperature of press, pressure; alternative adhesive content and mass of wood particles. Two alternative adhesive contents were adopted, 10% and 20% replacing urea-formaldehyde adhesive. Mechanical properties (perpendicular tensile strength, pullout strengths of screw on face and top; modulus of elasticity and rupture) were determined according to ABNT NBR 14810:3 Brazilian Standard Code. The obtained results were compared to ABNT NBR 14810:3 and ANSI A.2018:1 Standard Codes requirements values. Particleboards produced with epoxy ink waste showed perpendicular tensile strength according to the minimum Standards requirements values. All proposed combinations to manufacture BTH polymer particleboards didn't show satisfactory mechanical properties in comparison to the Standard Codes values. Other combinations of wood species, time, pressure and temperature, epoxy ink waste and BTH polymer contents should be studied so that the requirements can be met.

INTRODUCTION

Wood is a versatile material that can be used in several situations (Lahr et al., 2016; Christoforo et al., 2017; Almeida et al., 2017). In order to have it as a raw material, several mechanical processes are necessary, from its extraction in the forest to the final product, and the generation of waste is inevitable (Fiorelli et al., 2014; Fiorelli et al., 2017).

It is estimated that in the processing of wood logs in sawmills, only 40% to 60% is transformed into final product, being generated around 50% of waste, from sawdust to other larger pieces without added value (Vieira et al., 2010; Ofoegbu et al., 2014; Silva et al., 2017; Monteiro et al., 2017).

For the production of particleboards, the conversion between raw material and final product is greater, because in addition the use of all log, it can be used wood wastes from other processes (Souza et al., 2014; Alves et al., 2014; Christoforo et al., 2015).

For consolidation of the particleboard in the production process, besides the wood is also necessary adhesives, right temperature and pressure (Feng et al., 2012; Silva et al., 2013a; Atar et al., 2014; Ruziak et al., 2017; Nascimento et al., 2017). Urea-formaldehyde is one of the main adhesives used to make panels, but in the hot pressing process, the emission of toxic gases that can be harmful to workers' health (Liu & Zhu, 2014; Belini et al., 2015; Liang et al., 2016a; Liang et al., 2016b).

For this reason, research with the use of alternative adhesives, such as castor-based polyurethane resin, among others, is being carried out with a view to reducing the use of urea-formaldehyde (Silva et al., 2013b; Mao et al., 2014; Ferro et al., 2014; Zeng et al., 2016; Zhang et al. 2017).

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Epoxy resins are used for the manufacture of automotive inks used in the process of finishing metal parts by the electrostatic painting technique. In this process, the powdered ink is charged electrostatically and thrown onto the surface of the object, the residue of which is the portion of ink did not adhere to the part.

Polyhydroxybutyrate polymer (BTH) is produced naturally by bacteria from renewable energy sources. The production process begins in the cultivation of bacteria of the species *Alcaligenes eutrophus* in bioreactors, in which these are fed with sugar cane, mainly sucrose. In their metabolism, microorganisms ingest the sugars and turn them into intracellular granules that are actually polyesters (Quental et al., 2010; Casarin et al., 2013).

The aim of this research is to verify the feasibility of the production of particleboards using wood wastes and two alternative substitute adhesives for urea-formaldehyde, which are the epoxy ink waste and polyhydroxybutyrate polymer (BTH), according to mechanical properties.

MATERIAL AND METHODS

In this research it was used *Pinus* sp. particles to the production of the boards, obtained by the processing of wood wastes in hammer mill Willye type (Marconi, Model MA 680). Particles were produced from wood wastes from a sawmill in the region of São Carlos, state of São Paulo, Brazil.

Urea-formaldehyde resin (pH = 7.8; solids content = 65%; density = 1.27 g/cm³) was used as adhesive. In order to replace the urea-formaldehyde, the epoxy ink waste and the polyhydroxybutyrate polymer (BTH), both in the solid state and in the form of very fine powders, were used in the proportions shown in Tables 1 and 2, respectively.

About the parameters presented in Table 1 (to particleboards with epoxy ink waste), the pressure used (4 MPa) was according to Nascimento et al. (2017), Macedo et al. (2015) and Bertolini et al., (2014). For pressing time, the minimum necessary to complete the melting of the epoxy ink waste at the adopted temperatures was used.

The curing agents of the epoxy ink react in the temperature range of 140°C to 200°C. For this reason, the temperature of the press was adopted at 180°C and 190°C, considering the thermal degradation of wood particles and the capacity of the press machine used.

About the epoxy ink waste content, a minimum percentage was established that could provide to the particleboards the minimum requirements values of mechanical properties according to ABNT NBR 14810:3 (2013) and ANSI A208:1 (2009) Standards Codes. Thus, the proportions of 10% and 20% were used arbitrarily, replacing the urea-formaldehyde resin, because authors didn't find in the literature any information about the use of this waste as adhesive on particleboards manufacturing.

TABLE 1. Particleboard manufacturing parameters combinations with epoxy ink waste.

Treatments	Particle Mass (g)	Epoxi ink content (%)	Temperature (°C)	Time (min)	Pressure (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

The parameters adopted for particleboards with BTH polymer as an adhesive manufacturing, except for the pressing temperature, were the same as those used in the production of particleboards with epoxy ink waste. Temperatures for pressing the BTH polymer particleboard were set below 175°C, which is the melt temperature of the polymer (Machado et al., 2010). Therefore, the adopted pressing temperatures were 140°C and 160°C (Table 2). Thus, the proportions of 10% and 20% were used arbitrarily, replacing the urea-formaldehyde resin, because authors didn't find in the literature any information about use of BTH polymer as adhesive on particleboards manufacturing.

TABLE 2. Particleboard manufacturing parameters combinations with BTH polymer.

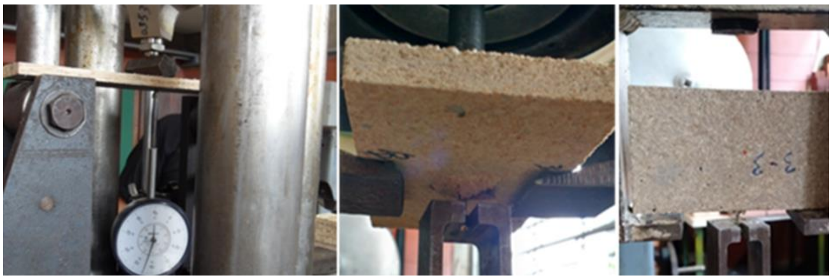
Treatments	Particle Mass (g)	BTH polymer content (%)	Temperature (°C)	Time (min)	Pressure (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

For each combination described in Tables 1 and 2, 3 particleboards (dimensions: 25 cm × 25 cm × 1 cm) were produced, totaling 108 particleboards for each type of used adhesive.

Particleboard mechanical properties determining carried out according to ABNT NBR 14810:3 (2013) Standard Code, and the mechanical tests are illustrated in the Figure 1. Table 3 presents the number of specimens (Nº) to mechanical property determining from each particleboard by treatment. The results obtained for the properties are compared with the requirements of ABNT NBR 14810:3 (2013) and ANSI A208:1 (2009).

TABLE 3. Particleboard manufacturing parameters combinations with BTH polymer.

Mechanical Properties	Symbol	Nº
Modulus of elasticity in static bending test	MOE	3
Modulus of rupture in static bending test	MOR	3
Perpendicular tensile of the particleboard face	PT	3
Pullout strength of screw (face)	RAP_f	1
Pullout strength of screw (top)	RAP_t	1



(a) (b) (c)

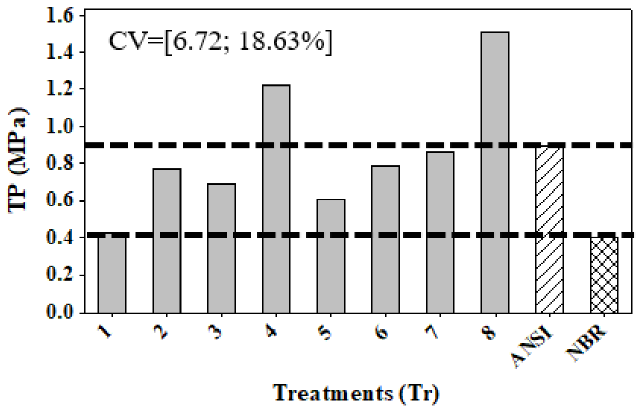
FIGURE 1. Mechanical tests: (a) static bending; (b) Pullout strength of screw on face; (c) Pullout strength of screw on top.

RESULTS AND DISCUSSION

Epoxy ink waste particleboards

Figures 2 to 6 presents average values and the range of the coefficient of variation (CV) for each epoxy ink waste particleboards manufacturing treatments amongst the minimum value required by ABNT NBR 14810:3 (2013) and ANSI A208:1 (2009) Standards Codes.

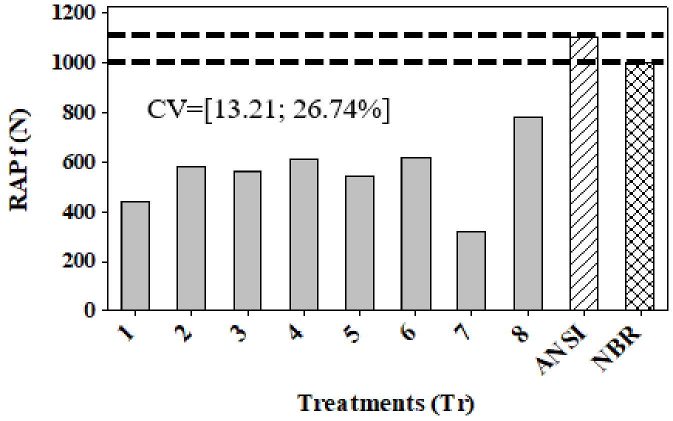
Average values of the perpendicular tensile of the particleboard on the face ranged from 0.45 MPa to 1.46 MPa (Figure 2). In comparison with the requirements values of ABNT NBR 14810:3 (2013), all results were higher. Particleboards with 20% epoxy ink waste content at 190°C were three and a half times above the minimum parameter of the ABNT NBR 14810:3 (2013). However, only particleboards at 190ºC exceeded the ANSI A208:1 Standard Code (F and H combinations).



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

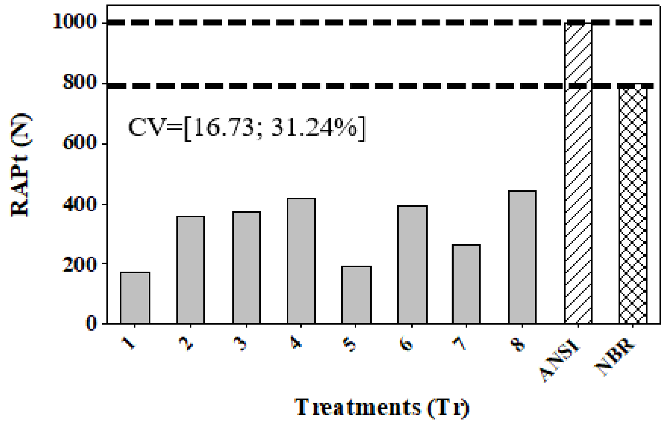
FIGURE 2. Results of perpendicular tensile on the face (epoxy ink waste particleboard).

RAP_f (Figure 3) and RAP_t (Figure 4) average values ranged from 340 N to 800 N and from 150 N to 450 N, respectively, below to the minimum values recommended by Standard Codes. Despite the poor performance, particleboards with 20% of epoxy ink waste, pressed for 10 minutes at 190°C (H combination), showed the best results.



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

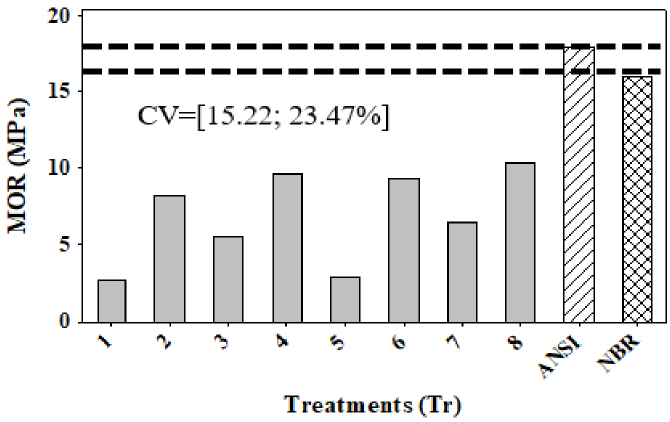
FIGURE 3. Results of pullout strength of screw (face) (epoxy ink waste particleboard).



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

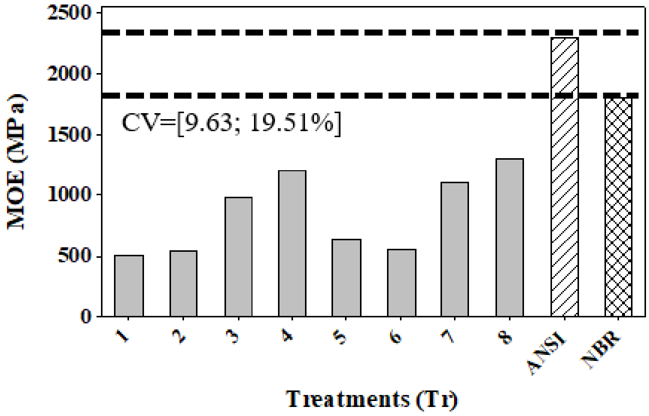
FIGURE 4. Results of pullout strength of screw (top) (epoxy ink waste particleboard).

MOR (Figure 5) and MOE (Figure 6) average values ranged from 3 MPa to 11 MPa and from 540 MPa to 1215 MPa, respectively. Particleboards from F and H combinations, presented better results when compared to the other combinations. However, all particleboard combinations did not reach the minimum MOE and MOR values required for the Standard Codes.



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

FIGURE 5. Results of modulus of rupture in static bending (epoxy ink waste particleboard).



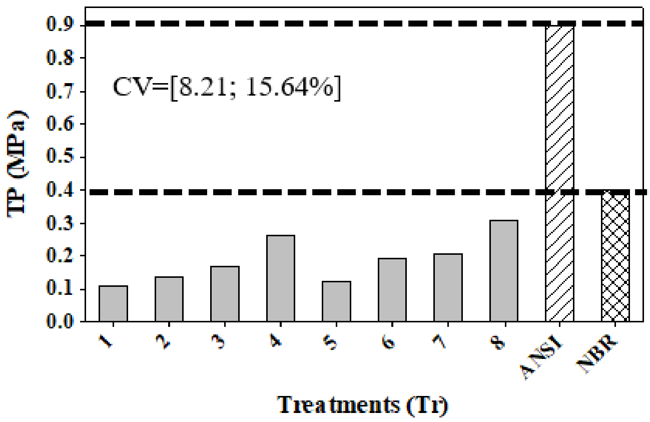
Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	180	5	4
2	582	10	180	10	4
3	582	10	190	5	4
4	582	10	190	10	4
5	533	20	180	5	4
6	533	20	180	10	4
7	533	20	190	5	4
8	533	20	190	10	4

FIGURE 6. Results of modulus of elasticity in static bending (epoxy ink waste particleboard).

BTH polymer particleboards

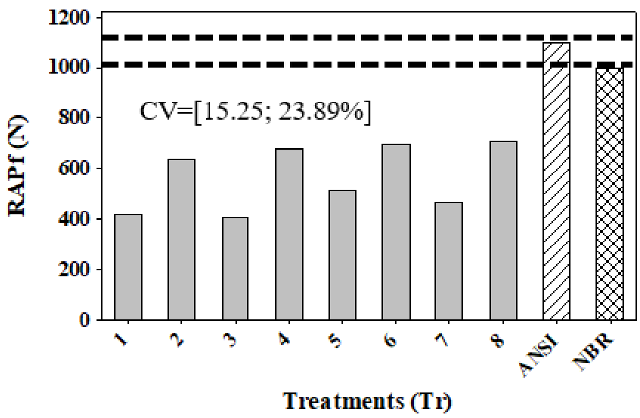
Figures 7 to 11 presents average values and the range of the coefficient of variation (CV) for each BTH polymer particleboards manufacturing combination and, for each mechanical property the minimum value required by ABNT NBR 14810:3 (2013) and ANSI A208:1 (2009) Standards Codes.

All proposed combinations to manufacture BTH polymer particleboards, didn't show satisfactory mechanical properties, in comparison to the Standard Codes, however, in spite of BTH polymer content and temperature, particleboards pressed per 10 minutes showed better results to mechanical properties.



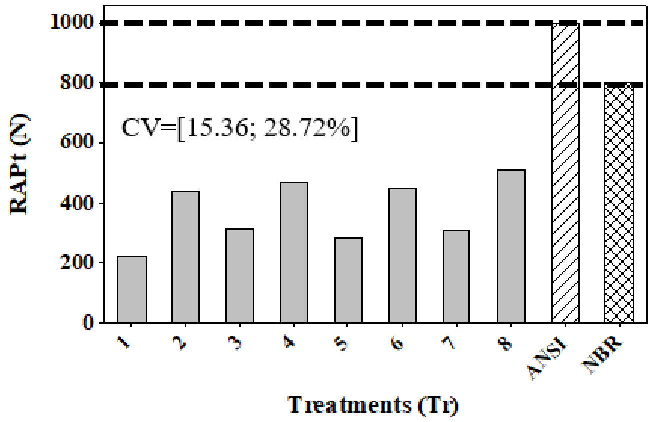
Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

FIGURE 7. Results of perpendicular tensile on the face (BTH polymer particleboard).



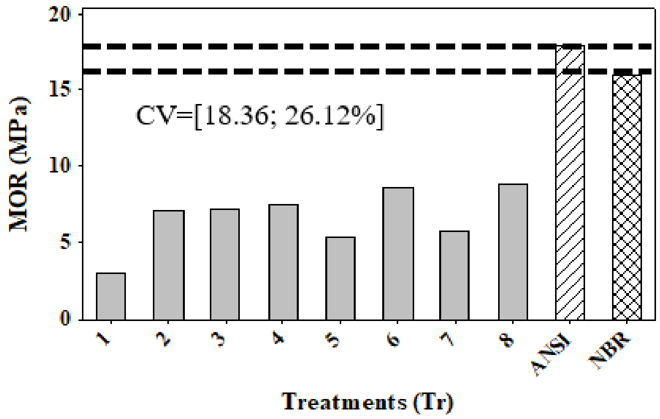
Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

FIGURE 8. Results of pullout strength of screw (face) (BTH polymer particleboard).



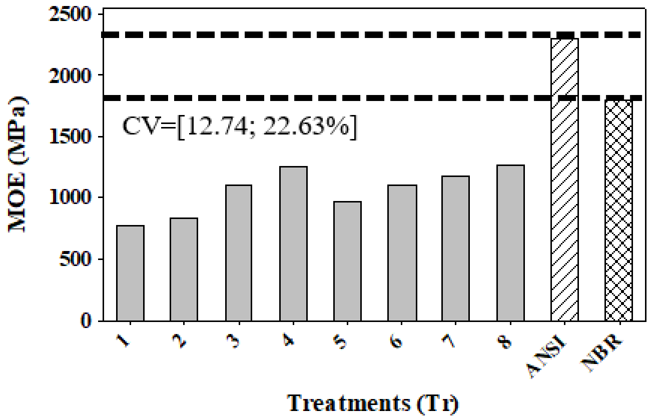
Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

FIGURE 9. Results of pullout strength of screw (top) (BTH polymer particleboard).



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

FIGURE 10. Results of modulus of rupture in static bending (BTH polymer particleboard).



Tr	P M (g)	Ep. (%)	Te (°C)	Ti (min)	Pr (MPa)
1	582	10	140	5	4
2	582	10	140	10	4
3	582	10	160	5	4
4	582	10	160	10	4
5	533	20	140	5	4
6	533	20	140	10	4
7	533	20	160	5	4
8	533	20	160	10	4

FIGURE 11. Results of modulus of elasticity in static bending (BTH polymer particleboard).

Discussions

MOR, RAP_f and RAP_t average values to ink waste particleboard were close to *Pinus* sp particleboard manufactured with urea formaldehyde by Torrell et al. (2013), but, for the BTH polymer particleboard, just MOR and RAPt average values were close.

Iwakiri et al. (2010) researched *Pinus taeda* particleboards with urea-formaldehyde and found to MOR, MOE and PT average values equal to 0.58 MPa, 12.03 MPa and 1866 MPa. MOR average values determined to epoxy ink waste and BTH polymer particleboards were close to the Iwakiri et al. (2010).

MOR average values determined to epoxy ink waste and BTH polymer particleboards were higher to the value determine by Fiorelli et al. (2014) for *Pinus* sp. particleboard manufactured with urea- formaldehyde (MOR = 8.69 MPa), but lower when compared to PT (0.54 MPa) and MOE (1,813 MPa) values.

Tas & Sevinçli (2015) studied particleboards manufactured with *Pinus brutia* and different urea-formaldehyde contents (6%, 10% and 12%). Epoxy ink waste particleboards PT average values determined in this research were higher to particleboards with *Pinus brutia* and all urea- formaldehyde contents. MOR average values found to epoxy ink waste and BTH polymer particleboards were close to particleboard with 6% of urea-formaldehyde content.

MOE values to particleboards studied in this research was lower in comparison with particleboards with *Pinus* sp. and urea- formaldehyde (Iwakiri et al., 2010; Torrell et al., 2013; Fiorelli et al., 2014; Tas & Sevinçli, 2015).

CONCLUSIONS

From the discussion of the results presented previously, it is concluded that:

- Researches about new raw materials to the production of wood panels instead of the traditional ones are important; therefore, they become an interesting way of using wastes in the manufacturing process;
- Particleboards combinations with epoxy ink waste reached the minimum requirements recommended by the Standard Code ABNT NBR 14810:3 (2013) for perpendicular tensile of the particleboard strength. Combinations produced at the pressing temperature of 190°C, reached the requirements of ANSI A208:1 (2009) for perpendicular tensile;
- All proposed combinations to manufacture BTH polymer particleboards didn’t show satisfactory mechanical properties in comparison to the Standard Codes;
- Average values to mechanical properties presented by epoxy ink waste and BTH polymer particleboard were close in comparison with other researches with *Pinus* sp. and urea- formaldehyde adhesive contents;
- Other combinations of wood specie, time, pressure and temperature, epoxy ink waste and BTH polymer contents can be studied for the manufacture of particleboards that meet regulatory requirements in relationship with their mechanical properties.

REFERENCES

ABNT - Associação Brasileira de Normas Técnicas (2013) Chapas de madeira aglomerada. Norma Brasileira NBR 14810:3, ABNT.

Almeida TH, Almeida DH, Araújo VA, Silva SAM, Christoforo AL, Lahr FAR (2017) Density as estimator of dimensional stability quantities of Brazilian tropical woods. BioResources 12(3):6579-6590.

Alves LS, Silva SAM, Azambuja MS, Varanda LD, Christoforo AL, Lahr FAR (2014) Particleboard produced with sawmill waste of different wood species. Advanced Materials Research 884-885:689-693. DOI: http://dx.doi.org/10.4028 /www.scientific.net/AMR.884-885.689

ANSI - American National Standard Institute (2009) American Standard Code A208:1, ANSI.

Atar I, Nemli G, Ayrilmis N, Baharoglu M, Sari B, Bardak S (2014) Effects of hardener type, urea usage and conditioning period on the quality properties of particleboard. Materials and Design 56:91-96. DOI: http://dx.doi.org/10.1016/j.matdes.2013.10.078

Belini UL, Fiorelli J, Savastano Jr H, Leite MK, Tomazello Filho M (2015) Formaldeído livre em painéis de Eucalipto e cana-de-açúcar. Ciência da Madeira 6(2):94-99. DOI: http://dx.doi.org/10.12953/2177-6830/rcm.v6n2p94-99

Bertolini MS, Nascimento MF, Christoforo AL, Lahr FAR (2014) Painéis de partículas provenientes de rejeitos de *Pinus* sp. tratado com preservante CCA e resina derivada de biomassa. Revista Árvore 38(2):339-346. DOI: http://dx.doi.org/10.1590/S0100-67622014000200014

Casarin SA, Agnelli JAM, Malmonge SM, Rosário F (2013) Blendas PHB/copoliésteres biodegrdáveis: biodegradação em solo. Polímeros 23(1):115-122. DOI: http://dx.doi.org/10.1590/S0104-14282013005000003

Christoforo AL, Aftimus BHC, Panzera TH, Machado GO, Lahr FAR (2017) Physical-mechanical characterization of the *Anandenanthera colubrine* wood specie. Engenharia Agrícola 37(2):376-384. DOI: http://dx.doi.org/10.1590/1809-4430-eng.agric.v37n2p376-384/2017

Christoforo AL, Silva SAM, Barbosa JC, Ribeiro Filho SLM, Panzera TH, Lahr FAR (2015) Particleboards manufactured with *Cordia goeldiana* wood wastes. Engenharia Agrícola 35(2):368-377. DOI: http://dx.doi.org/10.1590/1809-4430-Eng.Agríc.v35n2p368-377/2015

Feng Y, Mu J, Chen S, Huang Z, Yu Z (2012) The influence of urea formaldehyde resins in pyrolysis characteristics and products of wood-based panels. BioResources 7(4):4600-4613.

Ferro FS, Icimoto FH, Souza AM, Almeida DH, Christoforo AL, Lahr FAR (2014) Produção de painéis de partículas orientadas OSB com *Schizolobium amazonicum* e resina poliuretana à base de óleo de mamona. Scientia Forestalis 43(106):313-320.

Fiorelli J, Galo R G, Castro Jr S L, Belini U L, Lasso P R O, Savastano Jr H (2017) Multilayer particleboard produced with agroindustrial waste and Amazonia vegetable fibres. *Waste and* Biomass Valorization, 8, 1-11. doi: 10.1007/s12649-017-9889-x

Fiorelli J, Ramos RD, Sayama JT, Barrero NG, Palone EJA (2014) Particleboards with waste wood from reforestation. Acta Scientiarium. Technology 36(2):251-256. DOI: http://dx.doi.org/10.4025/actascitechnol.v36i2.18757

Iwakiri S, Manhiça AA, Parchen CFA, Cit EJ, Trianoski R (2010) Use of wood from *Pinus caribaea var. caribaea* and *Pinus caribaea var. bahamensis* for production of particleboards panels. Cerne 16(2):193-198.

Lahr FAR, Christoforo AL, Silva CEG, Andrade Jr JR, Pinheiro RV (2016) Avaliação de propriedades físicas e mecânicas de madeiras de Jatobá (*Hymenaea stilbocarpa Hayne*) com diferentes teores de umidade e extraída de regiões distintas. Revista Árvore 40(1):147-154. DOI: http://dx.doi.org/10.1590/0100-67622016000100016

Liang W, Lv M, Yang X (2016a) The combined effects of temperature and humidity on initial emittable formaldehyde concentration of a Medium-Density Fiberboard. Building and Environment 98:80-88. DOI: http://dx.doi.org/10.1016/j.buildenv.2015.12.024

Liang W, Lv M, Yang X (2016b) The effect of humidity on formaldehyde emission parameters of a Medium-Density Fiberboard: experimental observations and correlations. Building and Environment 101:110-115. DOI: http://dx.doi.org/10.1016/j.buildenv.2016.03.008

Liu T, Zhu X (2014) Measurement of formaldehyde and VOCs emissions from wood-based panels with nanomaterial-added melamine-impregnated paper. Construction and Building Materials 66:132-137. DOI: http://dx.doi.org/10.1016/j.conbuildmat.2014.05.088

Macedo LB, Ferro FS, Varanda LD, Cavalheiro RS, Christoforo AL, Lahr FAR (2015) Propriedades físicas de painés aglomerados de madeira produzidos com a adição de película de polipropileno biorientado. Revista Brasileira de Engenharia Agrícola e Ambiental 19(7):674-679. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n7p674-679

Mao A, Shmulsky R, Li Q, Wan H (2014) Recycling polyurethane materials: a comparison of polyol glycolysis with micronized polyurethane powder in particleboard applications. BioResources 9(3):4253-4265.

Machado MLC, Pereira NC, Miranda LF, Terence MC, Pradella JGC (2010) Estudo das propriedades mecânicas e térmicas de polímero Poli-3-Hidroxibutirato (PHB) e de compósitos PHB/pó de madeira. Polímeros 20(1):65-71. DOI: http://dx.doi.org/10.1590/S0104-14282010005000011

Monteiro TC, Lima JT, Silva JRM, Trugilho PF, Baraúna EEP (2017) Energy balance in sawing Eucalyptus grandis logs. BioResouces 12(3):5790-5800.

Nascimento MF, Christoforo AL, Fiorelli J, Varanda LD, Macedo LB, Lahr FAR (2017) Roughness study on homogeneous layer panels manufactured from treated wood waste. Acta Scientiarium. Technology 39(1):27-32. DOI: http://dx.doi.org/10.4025/actascitechnol.v39i1.29438

Ofoegbu C, Ogbonnaya S, Babalola FD (2014) Sawmill conversion efficiency and wood recovery of timber species in Cross River State Nigeria. Agriculture and Forestry 60(1):105-113.

Quental AC, Carvalho FP, Tada ES, Felisberti MI (2010) Blendas de PHB e seus colopolímeros: miscibilidade e compatibilidade. Química Nova 33(2):438-446.

Ruziak I, Igaz R, Krsiták L, Réh R, Mitterpach J, Ockajová A, Kucerka M (2017) Influence of urea-formaldehyde adhesive modification with Beech bark on chosen properties of plywood. BioResources 12(2):3250-3264.

Silva CP, Vieira RS, Silva IC, Pereira AS, Baraúna EEP (2017) Quantificação de resíduos produzidos nas industrias madeireiras de Gurupi, TO. Floresta e Ambiente 24:e00065613. DOI: http://dx.doi.org/10.1590/2179-8087.065613

Silva DAL, Lahr FAR, Garcia RP, Freire FMCS, Ometto AR (2013a) Life cycle assessment of Medium Density Particleboard (MDP) produced in Brazil. The International Journal of Life Cycle Assessment 18:1404-1411. DOI: http://dx.doi.org/10.1007/s11367-013-0583-3

Silva SAM, Christoforo AL, Panzera TH, Almeida DH, Segantini AAS, Lahr FAR (2013b) Painéis de partículas de madeira Leucena e resina poliuretana derivada de óleo de mamona. Ciência Rural 43(8):1399-1404. DOI: http://dx.doi.org/10.1590/S0103-84782013005000099

Souza AM, Varanda LD, Ferro FS, Christoforo AL, Icimoto FH, Almeida DH, Lahr FAR (2014) Screw pullout strength in particleboards manufactured with waste of *Eucalyptus grandis* wood specie and out hulls. International Journal of Composite Materials 4(3):162-167. DOI: http://dx.doi.org/10.5923/j.cmaterials.20140403.02

Tas HH, Sevinçli Y (2015) Properties of particleboards produced from Red Pine (*Pinus brutia*) chips and lavender stems. BioResources 10(4):7865-7876.

Torrell R, Hillig E, Corradi GM, Iwakiri S (2013) Influência da adição de serragem nas propriedades tecnológicas de painéis de madeira aglomerada de *Pinus taeda*. Ambiência 9(1):57-72. DOI: http://dx.doi.org/10.5777/ambiencia.2013.01.04

Vieira RS, Lima JT, Silva JRM, Hein PRG, Baillères H, Baraúna EEP (2010) Small wooden objects using Eucalypts sawmill wood waste. BioResouces 5(3):1463-1472.

Zeng X, Luo J, Hu J, Li J, Gao Q, Li L (2016) Aging resistance properties of poplar plywood bonded by soy protein-based adhesive. BioResources 11(2):4332-4341.

Zhang J, Liang J, Du G, Zhou X, Wang H, Lei H (2017) Development and characterization of a BayBerry tannin-based adhesive for particleboard. BioResources 12(3):6082-6093.