Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v41n1p107-111/2021

TECHNICAL PAPER

USE OF RESIDUES FROM THE CELLULOSE INDUSTRY AND SUGARCANE BAGASSE IN PARTICLEBOARDS

Sérgio A. M. da Silva[1*], Larissa Q. Minillo[1], Vinícius B. de M. Aquino[2], Francisco A. R. Lahr[3], André L. Christoforo[4]

[1*]Corresponding author. Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP)/ Ilha Solteira - SP, Brasil.
E-mail: sergio.mello@unesp.br | ORCID ID: http://orcid.org/0000-0001-6114-0283

KEYWORDS

Industrial residues, *Eucalyptus*, sugarcane bagasse, particleboards, castor oil-based resin.

ABSTRACT

The use of alternative materials such as lignocellulosic residues in the production of particleboards has increased considering that these residues are produced in large volumes and often do not have an appropriate destination. This research studied the use of residues from cellulose industries, sugarcane bagasse, and castor oil-based polyurethane resin in the production of wooden panels and evaluated the influence of using these residues on the physical and mechanical properties of the panels. The products were manufactured according to the Brazilian standard ABNT NBR 14810 and the requirements of the panels were evaluated based on national and international standards. All treatments partially met the regulatory requirements. The addition of bagasse led to an improvement in physical and mechanical properties, with treatment 2 (50% wood residue and 50% bagasse) presenting the best performance, which indicates the possibility of using panels with residues with non-structural purpose in environments to improve the thermoacoustic performance of rural buildings. The statistical analysis indicated that the percentage of bagasse was significant, improving the evaluated properties.

INTRODUCTION

The use of engineered wood-based products, such as particleboards, medium-density fiberboard (MDP), oriented strand boards (OSB), and plywood panels has increased in rural structures, being an alternative to the use of sawn wood in buildings for structural use and ambiance, improving thermal and acoustic comfort in buildings ((Bertolini et al. 2019a; Bertolini et al. 2019b; Garzón-Barrero et al. 2016; Labans et al. 2017; Scatolino et al. 2017; Souza et al. 2014; Zhou & Pizzi 2014).

Particleboards, panels composed of processed wood and resin, joined under pressure and heat, stand out among these products (Ihnát et al. 2017; Iwakiri et al. 2005; Negrão et al. 2014; Silva et al. 2015). One possibility of reducing wood consumption as panels is the use of lignocellulosic residues to produce cleaner and more ecological (Fiorelli et al. 2013; Keskin et al. 2015). These residues may consist of corn ears (Paiva et al. 2012), poppy particles (Keskin et al. 2015), sugarcane bagasse (Fiorelli et al. 2013; Hofsetz & Silva 2012; Sugahara et al. 2019), and residues from the pulp and paper industry (Elliott & Mahmood 2007; Mäkelä et al. 2012).

Brazil has a vast sugarcane production area, with annual cultivation of approximately 620 million tons (CONAB 2019), producing a large volume of bagasse, which is largely used for energy production by burning it (Hofsetz & Silva 2012). It is also a major producer of paper and cellulose, with an annual production of 10 and 18 million tons annually, respectively (Indústria Brasileira de Árvores – IBÁ 2017). This industrial production process emits a large volume of residues, such as bark and branches of *Eucalyptus*, which are mostly used for energy production

---

[1] Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP)/ Ilha Solteira - SP, Brasil.
[2] Universidade Federal do Sul e Sudeste do Pará (UNIFESSPA)/ Santana do Araguaia - PA, Brasil.
[3] Escola de Engenharia de São Carlos (EESC)/ Universidade de São Paulo (USP)/ São Carlos - SP, Brasil.
[4] Universidade Federal de São Carlos (UFSCar)/ São Carlos - SP, Brasil.

Area Editor: Danilo Florentino Pereira
Received in: 4-14-2020
Accepted in: 10-21-2020

by burning (66%) and destined to landfills (5%) (Indústria Brasileira de Árvores – IBÁ 2017).

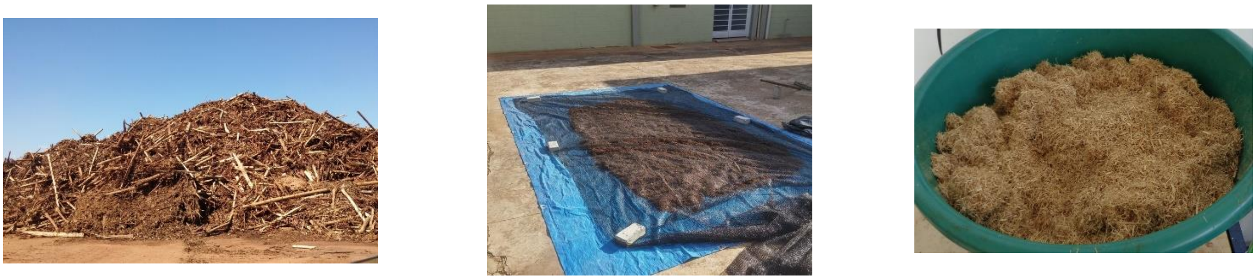
An important component in the production of panels is the resin, as it influences the physical and mechanical properties of the engineered wood-based product, varying the adhesive weight and the resin chemical composition. Commercial resins such as urea-formaldehyde and phenol-formaldehyde release formaldehyde gas throughout the production process, which is toxic to humans (Kusumah et al. 2017; Muttil et al. 2014; Pan et al. 2007; Zhou & Pizzi 2014). An alternative to the use of these adhesives is the castor oil-based bicomponent polyurethane resin, with oil of vegetable origin and without emission of toxic gases (Ferro et al. 2018; Fiorelli et al. 2019; Zau et al. 2014).

The use of particleboards for thermal and acoustic insulation is a possibility due to its porosity. The presence of air in the voids promotes thermal resistance and acoustic absorption, leading to thermal and acoustic comfort in rural and urban structures (Bertolini et al. 2019a).

This research aimed to evaluate the physical and mechanical properties of particleboards made with residues collected from paper and cellulose industries from *Eucalyptus urophylla*, *Eucalyptus* grandis, and *Eucalyptus camaldulensis*, sugarcane bagasse, and castor oil-based bicomponent polyurethane resin, as well as check the possibility of using these panels based on normative requirements.

MATERIAL AND METHODS

The panels were manufactured from debarking residues of logs of *Eucalyptus urophylla*, *Eucalyptus grandis*, and *Eucalyptus camaldulensis* (mixture of barks), collected in the pulp and paper industry Eldorado Brasil, Três Lagoas, Mato Grosso do Sul, Brazil (Figure 1a). The material was sun-dried until the apparent moisture reached between 10 and 12% (Figure 1b). After drying, the material was crushed to obtain particles with a size ranging from 2 to 6 mm. Sugarcane bagasse was collected at the Vale do Paraná S/A alcohol and sugar mill, being sun-dried until the apparent moisture reached between 10 and 12%. The material was also crushed to obtain a particle size between 4 and 10 mm (Sugahara et al. 2019).



(a) (b) (c)

FIGURE 1. Industrial residue of *Eucalyptus* (a); sun-drying of the industrial residue of *Eucalyptus* (b); sugarcane bagasse particles (c).

The resin consisted of a castor oil-based bicomponent polyurethane resin (PU), with polyol (1.1 g/cm^3), made from castor oil and polyfunctional isocyanate (1.24 g/cm^3) at a 1:1 ratio (polyol and isocyanate) (Ferro et al. 2014). The adhesive content used was 10% relative to the dry mass of particles (Sugahara et al. 2019).

The PU resin was mechanically homogenized with *Eucalyptus* particles and sugarcane bagasse. Subsequently, the mixture was taken to a mold to form the particle mattress for a pre-pressing at 0.015 MPa. Afterward, the panel was hot-pressed at 100 °C and 5 MPa pressure for 3 minutes. Decompression was performed for 30 seconds to eliminate gases that can cause voids in the panel and then a compression was applied for another 7 minutes (Sugahara et al. 2019). After that, the panel was squared and stored in an appropriate place.

Six panels with nominal dimensions 40 × 40 × 1 cm (1600 cm^3) and a nominal density of 0.8 g/cm^3 were produced for each treatment. Twelve specimens were extracted from each treatment in each property to evaluate physical (apparent density, thickness swelling, water absorption, and average moisture) and mechanical properties under static bending (modulus of strength and elasticity) and stress perpendicular to the faces. All properties were determined following the precepts of the Brazilian standard ABNT NBR 14810 (ABNT 2018).

Table 1 shows the treatments performed in the present study.

TABLE 1. Performed treatments.

Treatment	***Eucalyptus* residue (%)**	**Bagasse (%)**	**Total mass (g)**
0 (Ref)	100	0	1430
1	70	30	1430
2	50	50	1430
3	30	70	1430

An analysis of variance (ANOVA) at a 5% significance level was performed using the software Minitab® to investigate the influence of bagasse and industrial residue content on physical and mechanical properties.

The normality and homogeneity of the residual distribution were evaluated using the Anderson-Darling test to validate ANOVA ($\alpha = 5\%$) and the Tukey test ($\alpha = 5\%$). For the test formulation, a p-value equal to or higher than 0.05 implies that the sample distribution is normal and the variance between treatments is homogeneous, which validates the ANOVA model. According to the Tukey test, A denotes the treatment associated with the highest mean value, B the second highest mean value, and so on, and equal letters imply treatments with statistically equivalent means.

RESULTS AND DISCUSSION

Tables 2 and 3 show the physical (water absorption – WA, thickness swelling – TS, apparent density – AD, and moisture content – MC) and mechanical properties (modulus of strength – MOS, modulus of elasticity – MOE, and perpendicular stress – PS), mean values, coefficient of variation (CV), and the result of the Tukey test, considering the percentage of addition of sugarcane bagasse.

TABLE 2. Results of physical properties.

Tr	WA 24h (%) (Tukey) (CV)	TS 24h (%) (Tukey) (CV)	AD (kg/m³) (Tukey) (CV)	MC (%) (Tukey) (CV)
Ref	41.23 (A) (40.94 %)	19.03 (A) (9.51 %)	877.47 (A) (6.90 %)	11.27 (A) (16.85 %)
1	52.69 (A) (21.33 %)	22.16 (A) (6.04 %)	880.74 (A) (3.26 %)	8.11 (A) (1.72 %)
2	42.99 (A) (16.84 %)	17.79 (A) (34.28 %)	888.00 (A) (4.92 %)	9.43 (A) (18.87 %)
3	61.03 (A) (29.77 %)	26.42 (A) (64.04 %)	934.18 (A) (3.38%)	8.10 (A) (13.08 %)

TABLE 3. Results of mechanical properties.

Tr	MOS (MPa) (Tukey) (CV)	MOE (MPa) (Tukey) (CV)	PS (MPa) (Tukey) (CV)
Ref	18.28 (A) (6.51 %)	1282 (A) (39.63 %)	1.27 (A) (33.07 %)
1	16.76 (A) (15.39 %)	1023 (A) (27.15 %)	1.39 (A) (28.77 %)
2	15.50 (A) (8.00 %)	1395 (A) (11.66 %)	1.02 (A) (19.61 %)
3	10.38 (B) (11.36 %)	1403 (A) (11.06 %)	0.90 (A) (60.00 %)

The apparent density values ranged from 877 and 934 kg/m^3, similar to the values found by Sugahara et al. (2019) using *Eucalyptus* particles (60%) and sugarcane bagasse (40%) (880 kg/m^3 PU). The moisture values of all treatments met the Brazilian normative requirement (ABNT 2018), which recommends that moisture should be between 5 and 13%.

Only one study dealing with the use of industrial residues from tropical wood and sugarcane bagasse to produce particle boards and polyurethane resin can be found in the literature. Yano et al. (2020) evaluated the use of industrial residues from the woods of *Cariniana micrantha* (Tauari), *Goupia glabra* (Cupiúba), *Vochysia guianensis* (Cambará), *Tabebuia alba* (Ipê), and *Apuleia leiocarpa* (Garapa), sugarcane bagasse, and castor oil-based PU resin for the manufacture of panels. Five treatments were proposed with varying contents of sugarcane bagasse and industrial residues, and the adhesive content was 10% relative to the dry mass of particles. The treatment with the best performance had 50% bagasse and 50% industrial residue, with MOS equal to 11.09 MPa, MOE equal to 2034 MPa, and apparent density equal to 0.71 g/cm^3, which are values similar to those obtained in this research.

Table 4 shows the normative requirements for particleboards.

TABLE 4. Normative requirements.

Standard	Thickness (mm)	AD (kg/m³)	MOS (MPa)	MOE (MPa)	PS (MPa)	TS 24h (%)
NBR 14810 (2018) – P2	6-13	-	11	1800	0.35	22
NBR 14810 (2018) – P4	6-10	-	16	2300	0.40	19
ANSI A 208,1 (2009) – H-1	-	> 800	16.5	2400	0.90	8
CS 236:66 (1968)	-	> 800	16.8	2500	0.45	35

Table 4 shows that no treatment reached the normative requirements for the Brazilian (ABNT 2018) and American standards (ANSI 2009; ANSI 1968) regarding MOE. Considering the other mechanical requirements, Treatments Ref and 1 can be classified as a P4 panel, that is, a structural panel for use under dry conditions, H-1 panels (ANSI 2009), and also met the requirements of CS 236:66 (ANSI 1968). Treatments 2 and 3 can be classified as P2 panel, that is, non-structural panel for indoor use under dry conditions.

In general, the addition of sugarcane bagasse improved physical and mechanical properties. In this sense, Treatment 2 presented the highest dimensional stability, with the lowest values for WA and TS compared to the other treatments. Moreover, this treatment presented good performance for PS and MOE although the MOS value was lower than the other treatments. Further research is required to define the optimum bagasse content in the panels.

The results of this research indicate the possibility of using industrial residues from paper and cellulose companies and sugarcane bagasse in commercial panels with a non-structural function aiming at the thermoacoustic insulation of rural buildings.

CONCLUSIONS

The results of this research allow us to conclude that:

1. The treatments partially met the normative requirements, with Treatment 2 being the best fit between residues for panel production, with values similar to those found in the literature.

2. The incorporation of sugarcane bagasse promoted improvements in physical and mechanical properties, indicating the possibility of using industrial residues from paper and cellulose companies and sugarcane bagasse in commercial panels with a non-structural function aiming at the thermoacoustic insulation of rural buildings.

ACKNOWLEDGMENTS

The authors would like to thank the Coordination for the Improvement of Higher Education (CAPES) and the National Council for Scientific and Technological Development (CNPq) for all the support provided to conduct this research.

REFERENCES

ABNT - Associação Brasileira De Normas Técnicas (2018) NBR 14810-2: Chapas de madeira aglomerada. Rio de Janeiro, 82p.

ANSI – American National Standards Institute (2009) A 208.1: Particleboards Physical & Mechanical Properties Requirements.

ANSI – American National Standards Institute (1968) Mat formed wood particleboard - CS 236-66.

Bertolini MS, Morais CAG, Christoforo AL, Bertoli SR, Santos WN, Lahr FAR (2019a) Acoustic absorption and thermal insulation of wood panels: Influence of porosity. BioResources 14:3746–3757. DOI: https://doi.org/10.15376/biores.14.2.3746-3757

Bertolini MS, Morais CAG, Lahr FAR, Freire RTS, Panzera TH, Christoforo AL (2019b) Particleboards from CCB-Treated Pinus sp. Wastes and Castor Oil Resin: Morphology Analyses and Physical-Mechanical Properties. Journal of Materials and Civil Engineering (31):1–8. DOI: https://doi.org/10.1061/(ASCE)MT.1943-5533.0002929

CONAB – Companhia Nacional de Abastecimento (2019) Acompanhamento da Safra Brasileira. CONAB, v5, 113 p.

Elliott A, Mahmood T (2007) Pretreatment technologies for advancing anaerobic digestion of pulp and paper biotreatment residues. Water Research 41:4273–4286. DOI: https://doi.org/10.1016/j.watres.2007.06.017

Ferro FS, de Almeida DH, Souza AM, Souza AM, Icimoto FH, Christoforo AL, Lahr FAR (2014) Influence of Proportion Polyol/Pre-Polymer Castor-Oil Resin Components in Static Bending Properties of Particleboards Produced with Pinus sp. Advances in Materials Research:667–670. DOI: https://doi.org/10.4028/www.scientific.net/AMR.884-885.667

Ferro FS, Souza AM, Araujo II, Almeida MMVDN, Christoforo AL, Lahr FAR (2018) Effect of alternative wood species and first thinning wood on oriented strand board performance. Advances in Materials Science and Engineering, v. 2018. DOI: https://doi.org/10.1155/2018/4603710

Fiorelli J, Sartori DL, Cravo JCM, Savastano Junior H, Rossignolo JA, Nascimento MF, Lahr FAR (2013) Sugarcane bagasse and castor oil polyurethane adhesive-based particulate composite. Materials Research 16:439–446. DOI: https://doi.org/10.1590/S1516-14392013005000004

Fiorelli J, Bueno SB, Cabral MR (2019) Assessment of multilayer particleboards produced with green coconut and sugarcane bagasse fibers. Construction and Building Materials 205:1–9. DOI: https://doi.org/10.1016/j.conbuildmat.2019.02.024

Garzón-Barrero NM, Shirakawa MA, Brazolin S, Pereira, RGB, Lara IAR, Savastano Junior R (2016) Evaluation of mold growth on sugarcane bagasse particleboards in natural exposure and in accelerated test. International Biodeterioration and Biodegradation 115:266–276. DOI: https://doi.org/10.1016/j.ibiod.2016.09.006

Hofsetz K, Silva MA (2012) Brazilian sugarcane bagasse: Energy and non-energy consumption. Biomass and Bioenergy 46:564–573. https://doi.org/10.1016/j.biombioe.2012.06.038

Ihnát V, Lübke H, Russ A, Borůvka V (2017) Waste agglomerated wood materials as a secondary raw material for chipboards and fibreboards Part II. Preparation and characterization of wood chips in terms of their reuse. Wood Research 62:45–56.

IBÁ - Indústria Brasileira de Árvores (2017) Relatório 2017. Indústria Brasileira de Árvores 80. DOI: https://doi.org/10.1017/CBO9781107415324.004

Iwakiri S, Caprara AC, Saks DCO, Guisantes FP, Franzoni JA, Krambeck LBP, Rigatto PA (2005) Produção de painéis de madeira aglomerada de alta densificação com diferentes tipos de resinas. Scientia Forestalis (68):39–43.

Keskin H, Kucuktuvek M, Guru M (2015) The potential of poppy (Papaver somniferum Linnaeus) husk for manufacturing wood-based particleboards. Construction and Building Materials 95:224–231. DOI: https://doi.org/10.1016/j.conbuildmat.2015.07.160

Kusumah SS, Umemura K, Guswenrivo I, Yoshimura T, Kanayama K (2017) Utilization of sweet sorghum bagasse and citric acid for manufacturing of particleboard II: influences of pressing temperature and time on particleboard properties. Journal of Wood Science 63:161–172. DOI: https://doi.org/10.1007/s10086-016-1605-0

Labans E, Zudrags K, Kalnins K (2017) Structural performance of wood based sandwich panels in four point bending. Procedia Engineering 172:628–633. DOI: https://doi.org/10.1016/j.proeng.2017.02.073

Mäkelä M, Watkins G, Pöykiö R, Nurmesniemi H, Dahl O (2012) Utilization of steel, pulp and paper industry solid residues in forest soil amendment: Relevant physicochemical properties and heavy metal availability. Journal of Hazardous Materials 207-208:21–27. DOI: https://doi.org/10.1016/j.jhazmat.2011.02.015

Muttil N, Ravichandra G, Bigger SW, Thorpe GR, Shailaja D, Singh SK (2014) Comparative Study of Bond Strength of Formaldehyde and Soya based Adhesive in Wood Fibre Plywood. Procedia Materials Science 6:2–9. DOI: https://doi.org/10.1016/j.mspro.2014.07.002

Negrão WH, Silva SAM, Christoforo AL, Lahr FAR (2014) Painéis aglomerados fabricados com mistura de partículas de madeiras tropicais. Ambiente Construído 14:103–112. DOI: https://doi.org/10.1590/s1678-86212014000300008

Paiva A, Pereira S, Sá A, Cruz D, Varum H, Pinto J (2012) A contribution to the thermal insulation performance characterization of corn cob particleboards. Energy and Buildings 45:274–279. DOI: https://doi.org/10.1016/j.enbuild.2011.11.019

Pan Z, Zheng Y, Zhang R, Jenkins BM (2007) Physical properties of thin particleboard made from saline eucalyptus. Industrial Crops and Production 26:185–194. DOI: https://doi.org/10.1016/j.indcrop.2007.03.006

Scatolino MV, Costa A de O, Guimarães Júnior JB, Protásio TP, Mendes RF, Mendes LM (2017) Eucalyptus wood and coffee parchment for particleboard production: Physical and mechanical properties. Ciência e Agrotecnologia 41:139–146. DOI: https://doi.org/10.1590/1413-70542017412038616

Silva DW, Farrapo CL, Ribeiro DP, Mendes RF, Mendes LM, Scolforo JRS (2015) MDP com partículas de eucalipto e palha de milho. Scientia Forestalis 43:853–862. DOI: https://doi.org/10.18671/scifor.v43n108.10

Souza AM, Varanda LD, Macedo LB, Almeida DH, Bertolini MS, Christoforo AL, Lahr FAR (2014) Mechanical Properties of OSB Wood Composites with Resin Derived from a Renewable Natural Resource. International Journal of Composite Materials 4:157–161. DOI: https://doi.org/10.5923/j.cmaterials.20140403.01

Sugahara ES, Silva SAM, Buzo ALSC, Campos CI, Morales EAM, Ferreira BS, Azambuja MDA, Lahr FAR (2019) High-density Particleboard Made from Agro-industrial Waste and Different Adhesives. BioResources 14:5162–5170. DOI: https://doi.org/10.15376/biores.14.3.5162-5170

Yano BBR, Silva SAM, Almeida DAM, Aquino VBM, Christoforo AL, Rodrigues EFC, Carvalho Junior NA, Silva AP, Lahr FAR (2020) Use of Sugarcane Bagasse and Industrial Timber Residue in Particleboard Production. BioResources 15:4753-4762. DOI: https://doi.org/10.15376/biores.15.3.4753-4762

Zau MDL, Vasconcelos RP de, Giacon VM, Lahr FAR (2014) Avaliação das propriedades química, física e mecânica de painéis aglomerados produzidos com resíduo de madeira da Amazônia - Cumaru (Dipteryx Odorata) e resina poliuretana à base de óleo de mamona. Polímeros 24:726–732. DOI: https://doi.org/10.1590/0104-1428.1594

Zhou X, Pizzi A (2014) Pine tannin based adhesive mixes for plywood. International Wood Products Journal 5:27–32. DOI: https://doi.org/10.1179/2042645313Y.0000000043