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ADDITION OF SUGARCANE BAGASSE FOR THE PRODUCTION OF PARTICLEBOARDS BONDED WITH UREA-FORMALDEHYDE AND POLYURETHANE RESINS

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ABSTRACT

The present study deals with a production of pine particleboards using the sugarcane bagasse content and using castor-oil based bicomponent polyurethane resin and urea-formaldehyde resin. The influence of incorporation of sugarcane bagasse on the physical and mechanical properties of the composites was evaluated. The particleboards were produced according Brazilian standard ABNT NBR 14810, but performance requirements have been analyzed using Brazilian and international standards, as well. Treatment 2, using PU resin, were considered the best treatment using pine residue and sugarcane bagasse, presenting physical properties values 60% lower and mechanical properties 65% higher on average when compared with panel without sugarcane bagasse, indicating the good performance of sugarcane incorporation and the possibility of its use on commercial purpose for thermal and acoustic insulation. The addition of sugarcane bagasse improved physical and mechanical properties of particleboards when compared to panels manufactured from pine wood particles only. Statistical analysis indicated that moisture content and bagasse content were significant, enhancing properties when compared with reference treatments.

KEYWORDS: *Pinus* sp., sugarcane bagasse, particleboards, urea-formaldehyde, polyurethane resin, castor oil.

INTRODUCTION

The adoption of wood engineered products, such medium density particleboard (MDP), oriented strand boards (OSB), cross laminated timber (CLT), plywood instead timber and lumber on furniture, manufactures, structures and others (Choi et al. 2018, Derkowski et al. 2015, Garzón-Barrero et al. 2016, Oliveira et al. 2017) has advanced, being an greener option and without considerable variability on properties when compared with timber (Bertolini et al. 2014). Particleboards (PB) are defined as a product made of processed wood and resin under temperature and pressure (Ihnát et al. 2017, Nascimento et al. 2016). A possibility to reuse waste on particleboard is to replace part of wood for refuse, such lignocellulosic waste (Akgül et al. 2017, Burawska et al. 2015, Ribeiro et al. 2019) as corn cob (Paiva et al. 2012), flax and hemp (Sam-Brew and Smith 2017), poppy hunks (Keskin et al. 2015), bamboo (Valarelli et al. 2014) and sugarcane bagasse (Fiorelli et al. 2018, Garzón-Barrero et al. 2016, Nakanishi et al. 2018).

The use of sugarcane bagasse is an alternative to be used on particleboards considering that Brazil is the largest producer in the world, with crops producing about 620,41 million tons per year (CONAB 2019). After sugar and ethanol production, a large amount of bagasse is generated and part of this residue is used to produce energy burning the waste (Hofsetz and Silva 2012). Such process releases greenhouse gases on atmosphere. Resin is an important factor on particleboard production, which may affect physical and mechanical properties depending on its chemical composition and grammage used. Commercial resins used on manufacture plants are polyvinyl acetate (PVA), phenol-formaldehyde (PF), resorcinol-formaldehyde (RF), urea-formaldehyde (UF) and polyurethane (PU) based on vegetal oils (Gonçalves et al. 2018, Macedo et al. 2019, Oliveira et al. 2017). For commercial particleboard confection it is used *Pinus* sp. and *Eucalyptus* spp., wood species which are produced in large scale as “reforestation woods” (Araujo et al. 2018, Indústria Brasileira de Árvores - IBÁ 2017, Palma and Ballarin 2011). It is possible highlight the pine wood use for structural purpose and furniture manufacture (García et al. 2016, Segundinho et al. 2017). On literature there are researches treating the use of sugarcane bagasse on particleboards and pine particles using phenol formaldehyde and PU resin (Milagres et al. 2019, Oliveira et al. 2016, Dos Santos et al. 2014). However, there is no researches comparing the resin performances and enable the possibility of use of sugarcane bagasse on commercial particleboards for structural purposes and coatings for buildings, enhancing thermal and acoustic comfort for users, reducing heat loss and improving acoustic isolation (Bertolini et al. 2019).

In order to evaluate the possibility of incorporation of sugarcane bagasse on particleboards, in the present study particleboards produced from bagasse and *Pinus* sp. using two different resins (urea-formaldehyde and polyurethane) and different moisture contents was presented. Possible application of these materials was considered based on standard requirements.

MATERIAL AND METHODS

Particleboards were produced from processed pine wood obtained from sawmills from region of São José do Rio Preto (São Paulo, Brazil). Sugarcane bagasse was collected from sugar and alcohol plants in region of Ilha Solteira (São Paulo, Brazil). As resins were used castor-oil based polyurethane resin (PU), with polyol (1,2 $g \cdot cm^{-3}$) made from castor oil and polyfunctional isocyanate (1.24 $g \cdot cm^{-3}$) on proportion 1:1 (polyol and isocyanate) (Ferro et al. 2014) and urea-formadehyde (UF) (1.25 $g \cdot cm^{-3}$). UF resin was characterized as an aqueous solution with a solids content of 58 - 62%, used with paraffin emulsion in the ratio of 1% to the mass of the particles, ammonium sulfate at the dosage of 2.5% catalyst solids relative to the solids content of the resin, and water to promote dissolution of the materials and achieve the desired moisture content for the particle mattress. The adhesive proportion utilized to manufacture panels was 10% of wood particles mass for all treatments. The pine particles and bagasse were crushed to reach 2 - 6 mm granulometry (Sugahara et al. 2019). The use of UF resin on particleboards demands a lower moisture content (MC) on the particle mixture, about 3% (Iwakiri et al. 2015) for a better adhesion between particles and resin. In order to simulate the use of bagasse without drying process, some treatments resulted in a moisture content higher than disposed on the literature.

Sugarcane bagasse used on treatment 5 underwent a drying process on greenhouse for 72 h under temperature 60°C ± 2°C. Wood particles used on treatments Ref (1), 3, 4 and 5 were dried in an oven at 90°C for 8 h. It was adopted a nominal density of 0.8 $g \cdot cm^{-3}$, with dimensions of 350 x 350 x 10 mm. Tab. 1 presents the treatments to evaluate the influence of resin and bagasse on the physical and mechanical properties of the particleboards.

Tab. 1: Treatments for particleboards.

Treatment	Pine (%)	Bagasse (%)	Adhesive	MC (%)	Mass (g)	Number of samples
Ref (1)	100	0	UF	3	980	5
Ref (2)	100	0	PU	10	980	5
1	40	60	PU	10	980	5
2	60	40	PU	10	980	5
3	40	60	UF	7	980	5
4	60	40	UF	7	980	5
5	60	40	UF	3	980	5

On PU and UF treatments, the resin was mechanically homogenized with wood particles and sugarcane bagasse and then, the mixture was taken to a mold the particle mattress to a pre-pressing of 0.015 MPa pressure. Then, the panels underwent a hot pressing of 3 MPa at 100°C (PU treatments) and 4 MPa at 130ºC (UF treatments) for 3 min initially, then pressure relief for 30 sec aiming gases elimination to avoid bubble formation on panels and then 7 min at last on pressure (Dos Santos et al. 2014, Silva et al. 2018).

From each treatment, five panels were produced and five specimens were extracted to evaluate mechanical properties (strength modulus and modulus of elasticity) on static bending test and five specimens for internal bond (tension perpendicular to the faces). Also, physical properties were determined such apparent density, thickness swelling (24 h) and water absorption (24 h) using 5 specimens. All properties were determined following the Brazilian standard ABNT NBR 14810 (ABNT 2018).

To investigate the influence of the factors and the interaction between them on physical and mechanical properties, the Analysis of variance (ANOVA), at level of 5% of significance, was performed aided by the software Minitab® (Minitab, State College, PA, USA). For ANOVA validation (α = 5%) and Tukey's test (α = 5%), the normality and homogeneity of the residual distribution were evaluated using the Anderson-Darling test and F-test, respectively. For tests formulation, P-value equal or higher than 0.05 implies the distribution by response is normal and the variances between treatments are homogeneous, which validates ANOVA model. From 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

Tabs. 2 and 3 presents the results the mean values of physical properties: water absorption (WA), thickness swelling (TS), apparent density (AD) and moisture content (MC) and mechanical properties: modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), coefficient of variation (CV) and the result of Tukey test considering the percentage of sugarcane incorporation. Checking the results of apparent density, the values fluctuated between 0.75 $g \cdot cm^{-3}$ and 1.06 $g \cdot cm^{-3}$, higher than obtained by Sugahara et al. (2019) using Eucalyptus residue and sugarcane bagasse 0.97 $g \cdot cm^{-3}$ (UF) and 0.88 $g \cdot cm^{-3}$ (PU), on proportion 60% of wood particles and 40% of bagasse. Fiorelli et al. (2013) reached values between 0.88 $g \cdot cm^{-3}$ and 0.95 $g \cdot cm^{-3}$ using only sugarcane bagasse, using castor-oil based PU resin. Observing physical and mechanical properties of Treatments 3 and 4, the use of particles with higher moisture content may led to a reduction on these properties. Comparing the results with reference values, water absorption and thickness in swelling values of Treatments 3 and 4 were 400% higher, on average. Considering moisture content, the values were 200% higher, on average, when comparing with Ref (1) value.

Tab. 2: Results of physical properties.

Treatment	Water absorption after 24h (%) (CV - %)	Thickness swelling after 24h (%) (CV - %)	Density ($g \cdot cm^{-3}$) (CV - %)	Moisture content (%) (CV - %)
Ref (1)	13.56 (A) (38.57%)	6.04 (A) (42.55%)	0.75 (A) (4.00%)	3.48 (A) (13.71%)
Ref (2)	31.00 (A) (20.30%)	11.00 (A) (9.61%)	0.81 (A) (10.90%)	9.02 (A) (0.46%)
1	25.24 (A) (32.15%)	18.06 (A) (12.61%)	0.86 (A) (13.78%)	10.00 (A) (15.78%)
2	10.25 (A) (37.89%)	6.80 (B) (7.60%)	0.94 (A) (4.38%)	8.40 (A) (0.83%)

3	73.45 (B) (36.97%)	94.53 (A) (31.62%)	0.78 (B) (11.93%)	11.00 (A) (35.75%)
4	82.37 (B) (39.97%)	82.00 (A) (42.61%)	0.78 (B) (10.57%)	11.00 (A) (38.91%)
5	19.80 (A) (42.67%)	6.80 (B) (19.90%)	1.06 (A) (2.92%)	3.81 (A) (18.85%)

* Values of coefficient of variation are in brackets.

Tab. 3: Results of mechanical properties.

Treatment	MOR (MPa) (CV - %)	MOE (MPa) (CV - %)	IB (MPa) (CV - %)
Ref (1)	9.75 (A) (17.63%)	1350 (A) (46.67%)	0.27 (B) (25.92%)
Ref (2)	20.60 (A) (15.52%)	2131 (A) (15.00%)	3.30 (A) (26.52%)
1	15.00 (A) (4.38%)	1800 (A) (32.54%)	0.42 (B) (23.38%)
2	35.00 (A) (10.00%)	3555 (A) (13.00%)	2.23 (A) (11.40%)
3	3.44 (B) (2.35%)	486 (B) (29.41%)	0.08 (A) (20.89%)
4	4.29 (B) (1.13%)	495 (B) (28.36%)	0.06 (A) (19.38%)
5	15.00 (A) (19.00%)	2416 (A) (20.00%)	1.14 (A) (6.20%)

* Values of coefficient of variation are in brackets.

It is important point out that UF resin use above recommended moisture content (3 - 6%) (Iwakiri et al. 2015) may contributed to delamination on panels, as illustrated on Fig. 1. Considering MOR and MOE results, Treatments 3 and 4 presented reduced values when comparing with Ref (1), with a reduction of 50% for MOR and 70% for MOE when comparing with Ref (1) values. Treatment 5 presented similar results on physical properties when compared with Ref (1) values. For mechanical properties, the values increased 50% on average when compared with Ref (1) values. It indicates the good performance of sugarcane incorporation on panels, respecting the limitation of the resin used.

Fig. 1: Delamination panels produced according to Treatments 3 and 4.

Analyzing the results of PU treatments, water absorption reduced in 18.5% and 67% when comparing Treatments 1 and 2 values with Ref (2) values. For thickness in swelling, the values were 64% higher for Treatment 1 and 38% lower for Treatment 2 when compared with Ref (2) value. For MOR, Treatment 1 and 2 values were 58% and 258% respectively, when compared with Ref (2) values. Considering MOE values, Treatment 1 were 15% lower than Ref (2) value and Treatment 2 were 67% higher than Ref (2) value. It indicates the good performance of sugarcane incorporation and the PU resin.

Checking the values of Tab. 4, Treatments 1, 2 and 5 fully met standard requisites of ABNT NBR 14810 (2018), ANSI A 208.1 (2009) and CS 236: 66 (1968). Treatment 1 can be classified as P2 (ABNT, 2018), nonstructural panels for indoor use on dry conditions. Treatment 5 can be partially fitted on P4 class (ABNT 2018), structural panel for use in dry conditions and on H-1 class (ANSI 2009), high density industrial panels, except for MOR value. Treatment 2 can be classified on P6 class (ABNT 2018), structural panel for use under severe loading condition in dry ambient and on H-3 class (ANSI 2009).

Tab. 4: Standard requisites.

Standard	Thickness (mm)	Apparent density (g·cm^{-3})	MOR (MPa)	MOE (MPa)	IB (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
NBR 14810 (2018) – P6	6-10	-	20	3150	0,60	16
ANSI A 208,1 (2009) – H-1	-	> 0,8	16,5	2400	0,90	8
ANSI A 208,1 (2009) – H-3	-	> 0,8	23,5	2750	1,00	-
CS 236:66 (1968)	-	> 0,8	16,8	2500	0,45	35

Considering all results, it must be pointed out that the incorporation of sugarcane bagasse improved physical and mechanical properties when compared with results of reference treatments of the present research. The use of undried bagasse with UF resin indicates its impossibility on use on particleboards, worsen physical and mechanical properties considerably due resin characteristics, which demands lower moisture content and impacted panel performance, with delamination effect. Considering the use of dried bagasse, properties increased and it indicates the possibility of use of sugarcane waste on commercial panels.

Observing PU resin treatments, a better adherence on use of undried bagasse were demonstrated, resulting in panels with requisites of structural and nonstructural purposes, implying the possibility of use of sugarcane bagasse on commercial panel. The use of undried bagasse may lead to energy saving along productive process, with the reduction of oven use.

CONCLUSIONS

The results of the present research enable to conclude that: (1) Part of treatments evaluated in this research met standardized requisites using *Pinus* sp. particles and processed sugarcane bagasse with different resins (UF and PU), with Treatments 2 being the best arrangement between wood particles and bagasse, presenting results on average 60% lower for physical properties and 65% higher for mechanical properties when compared with reference value. Treatment 5 displayed similar results for physical properties of reference panel and an increase of 50% on average of mechanical properties when comparing with reference value. (2) The use of sugarcane bagasse improved physical and mechanical properties, with treatments classified for structural and nonstructural use, indicating the possibility of use of sugarcane bagasse on commercial panels. (3) Treatment 2 panels were classified as P6 type by Brazilian standard, structural panel for use under severe loading condition in dry ambient, and on H-3 class by American standard, demonstrating the possibility of use for structural purpose. (4) Treatment 5 panels were classified partially as P4 type by Brazilian standard, structural panel for use in dry conditions, and H-1 type by American standard, demonstrating the possibility of use on coating to improve thermal and acoustic performance on buildings and furniture.

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