UFSM

Ciência Florestal

ISSN 1980-5098
Open access

Ci. Fl., Santa Maria, v. 32, n. 1, p. 187-205, Jan./Mar. 2022 • https://doi.org/10.5902/1980509846908
Submitted: 03rd/06/2020 • Approved: 30th/06/2021 • Published: 25th/03/2022

Artigos

Optimization of castor oil polyurethane resin content of OSB panel made of *Dendrocalamus asper* bamboo

Otimização do uso de resina poliuretana de óleo de mamona em painéis OSB de bambu *Dendrocalamus asper*

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ABSTRACT

This work presents a study of the optimization of castor oil polyurethane (PU) resin content for the production of Oriented Strand Boards (OSB) using bamboo (*Dendrocalamus asper*). For this study, medium-density (650 kg/m^3) OSB panels were produced with different resin contents (8%, 10%, 12%, and 15%). The bamboo particles were characterized through physical, chemical and anatomical analyses, identifying the potential of this product as a raw material for OSB panels. Subsequently, the physical and mechanical properties of OSB panels were evaluated. The results indicated that bamboo and castor oil PU are suitable for the production of OSB panels, and all the conditions met the minimum requirements of the European standard EN 300 (2002), for OSB type 1. In particular, the best overall properties were obtained by the panels with a resin content of 12%, achieving the minimum requirements for applications as a structural panel (type 4), opening new opportunities for formaldehyde-free engineered bamboo materials for the built environment.

Keywords: Oriented particles; Bamboo strands; PU-Castor oil; Formaldehyde-free

RESUMO

Este trabalho apresenta um estudo da otimização do teor de resina poliuretana (PU) a base de óleo de mamona para a produção de painéis de partículas orientadas (OSB) utilizando bambu (*Dendrocalamus asper*). Para este estudo, painéis OSB de densidade média (650 kg/m^3) foram produzidos com diferentes teores de resina (8%, 10%, 12% e 15%). As partículas de bambu foram caracterizadas através das análises física, química e anatômica, identificando o potencial deste produto como matéria-prima para a produção de painéis OSB. Posteriormente, foram avaliadas as propriedades físicas e mecânicas dos painéis OSB. Os resultados indicaram que o bambu e a resina PU a base de óleo de mamona se mostrou adequado para a produção de painéis OSB e todas as condições atendem aos requisitos mínimos da norma europeia EN 300 (2002), para OSB tipo 1. Em particular, as melhores propriedades em geral foram obtidas pelos painéis com um teor de resina de 12%, atingindo todos os requisitos mínimos para aplicações como um painel estrutural (tipo 4), abrindo novas oportunidades para materiais de bambu projetados sem formaldeído para o ambiente construído.

Palavaras-chave: Partículas orientadas; Lascas de Bambu; PU-óleo de mamona; Livre de formaldeído

1 INTRODUCTION

Bamboo is an excellent example of an abundant material available in nature with outstanding properties and versatility. It is a plant with a high growth rate that is industrially used for several applications in the energy, chemical, and civil construction sectors (SASTRY, 1999 apud PEREIRA, 2012). There is a growing global market for bamboo, mainly due to the high demands of sustainable products in Europe and in the United States. The International Network for Bamboo and Rattan (INBAR) evaluated the global economy of bamboo in US$ 60 billion with a high potential for additional income for rural communities. In this context, several researchers have been studying and developing bamboo-based products as building materials (non-structural and structural), in their natural form (full-culm) or as engineered materials such as Laminated Bamboo Lumber, Particleboards, OSB, and cement-reinforced composites (GHAVAMI; TOLEDO FILHO; BARBOSA, 1999; PAPADOPOULOS *et al*., 2004; GHAVAMI, 2005; MATTONE, 2005; ESPELHO; BERALDO, 2008; ARRUDA *et al*., 2011; HARRIES; SHARMA; RICHARD, 2012; ALMEIDA *et al*., 2013; SHARMA; HARRIES; GHAVAMI, 2013; CORREIA *et al*., 2015; SHARMA *et al*., 2015a, 2015b; YU *et al*., 2015; GAUSS; KADIVAR; SAVASTANO, 2019).

One such application is oriented strand board (OSB). These panels consist of thin, oriented chips that are shaped by resin, heat and pressure (BORTOLETTO JÚNIOR; GARCIA, 2004). The use of OSB panels has grown significantly and occupied the previously exclusive space of plywood, as the plywood panels require logs of higher quality for their manufacture and, therefore, they are of relatively higher cost (BORTOLETTO JÚNIOR; GARCIA, 2004). Surdi (2012), highlights some applications of OSB panels, such as the use in walls, furniture, packaging, floor supports, and even the use of constructive elements.

Febrianto et al. (2012), demonstrated the effects of strand length and pre-treatment techniques on the physical, mechanical and durability properties of OSB panels made from Betung bamboo (*Dendrocalamus asper* (Schultes.f) Backer ex Heyne). The panels were produced with different strand lengths (50, 60, and 70 mm), with a nominal density of 700 kg/m3 and a 5% content of commercial methylene diphenyl diisocyanate (MDI) adhesive. The results obtained by the authors indicated that the values of modulus of elasticity (MOE) and modulus of rupture (MOR) in the perpendicular direction were significantly affected by strand length. OSB prepared from strands with 70 mm strand length had better values compared to 60- and 50-mm strand lengths.

Sun *et al*. (2018), evaluated the effects of culm age, height, and node on the properties of OSB made from bamboo and the effect of adhesive loading on the board durability. The strands of bamboo were classified into different types, for example, bamboo age, height, and node or internode. The panels were produced with a nominal density of 800 kg/m^3 and a resin content of 6% of commercial MDI and phenol-formaldehyde (PF). The bamboo age was not significant for both mechanical properties (MOR and MOE), and physical properties (thickness swelling), but had an influence on the internal bond (IB) strength.

The Brazilian and the international literature have no studies related to the OSB panels with the use of *Dendrocalamus asper* bamboo agglomerated with castor oil polyurethane resin. However, promising results have been reported using this resin for the production of particleboards (FIORELLI *et al*., 2012; CESAR *et al*., 2015; ZAIA *et al*., 2015). Therefore, this study aimed to analyze a new potential for bamboo in the production of medium-density (650 kg/m^3) OSB particleboards and evaluate different castor oil PU resin contents on the physical and mechanical performance of the final material.

2 MATERIAL AND METHODS

2.1 Bamboo material

Mature culms (more than three years old) of *D. asper* bamboo were harvested at an experimental field in the USP campus, Pirassununga, Brazil, and stored in a protected environment. Samples extracted from the middle section of different culms (more uniform region) were used to prepare the strand particles for the OSB panels. Only internodes were used.

2.2 Real density and pH

The real density of the bamboo was determined using a helium pycnometer following the methodology established by Moura and Figueiredo (2002). The bamboo particles were dried at 60°C for 48 h before the measurement. For the pH measurement, a modification was made in the methodology proposed by Vital (1973) and described by Barbirato *et al*. (2018)Springer Nature B.V. This work presents a study for using Balsa wood (Ochroma pyramidale.

2.3 Apparent density

The apparent density of the bamboo was measured by the water immersion method at 27°C (water density = 0.9965 g/cm3), as described in ASTM Standard D2395 – 17.

2.4 Chemical composition

The determination of the chemical constituents (lipids, nitrogen, fats, and soluble compounds) and contents of the cell wall (protein, hemicellulose, cellulose, and lignin) of the bamboo particles was carried out following the methodology proposed by Van Soest (1994) described by Barbirato *et al*. (2018)were produced OSB panels with different densities (300 kg/m3 and 400 kg/m3.

2.5 Anatomy of the bamboo

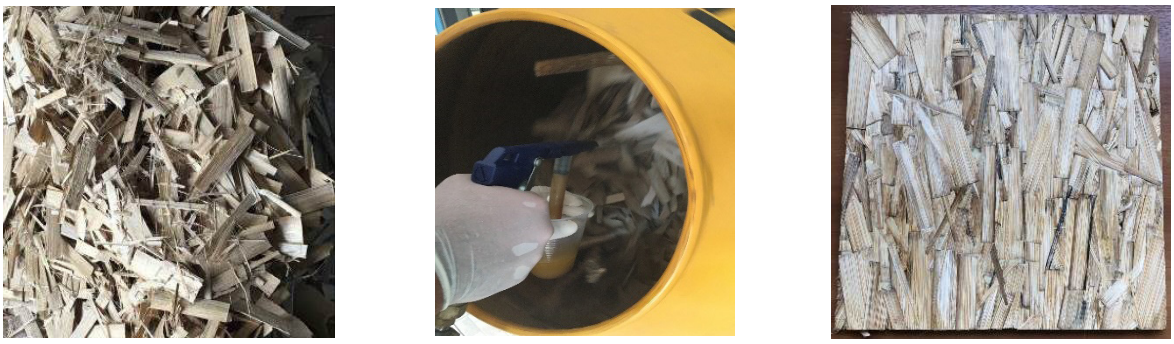
The anatomy of the bamboo (fiber bundle, parenchyma, vessels, and phloem) was evaluated in a Scanning Electron Microscope (SEM), Hitachi microscope model TM300. The samples were analyzed using a backscattered electron detector at an acceleration voltage of 15 kV.

2.6 Production of the OSB panels with bamboo and PU resin

The OSB panels were produced with bamboo particles as follows: small samples of bamboo (9 cm for width and 3 cm for length) were processed in a Marconi electric motor chip mill, generating strands with 9 cm in length, 2.5 cm in width and 0.1 cm thick (Figure 1a). These particles were then dried at 65°C for 48 hours to obtain a material with a moisture content of 8% and then sieved to remove the fines.

The castor oil polyurethane resin was prepared with a prepolymer/isocyanate ratio of 1:1, sprayed onto the particles and mixed in a rotary drum blender. Different resin contents were used based on the dry weight of the particles. The material was then placed on a forming pad (60 x 60 x 1 cm) with a ratio of 30:40:30 for each orientation layer (face:core:face). The obtained mattress was manually pre-pressed, inserted into a thermo-hydraulic press (Figure 1b) and pressed for 10 minutes at 100°C with a pressure of 50 kg/m^2. Two panels for each treatment (Figure 1c) of medium-density (650 kg/m^3), based on the dry weight of the particles and different resin contents (8%, 10%, 12% and 15%) were produced, according to Table 1.

Figure 1 – Production process of OSB panels. A) Strands of bamboo. B) Spraying the resin. C) OSB bamboo panel



(a) (b) (c)

Source: Authors (2021)

Table 1 – Parameters of treatments

Treatments	Panels by Treatment	Density (kg/m^3)	Dimension (cm)	Thickness (mm)	Resin content (%)
T1	2	650	60 x 60	10	8
T2	2				10
T3	2				12
T4	2				15

Source: Authors (2021)

2.7 Characterization of the OSB bamboo panels

The physical and mechanical characterization of the medium-density OSB panels were carried out following the procedures established by the European Committee for Standardization (2002). It was determined the bulk density, thickness swelling (TS), longitudinal and transverse modulus of rupture (MOR), longitudinal and transverse modulus of elasticity (MOE), and internal bond strength (IB) of the panels.

The descriptive statistics evaluated the values obtained for the physical-mechanical properties to organize the results. Arithmetic means were used as a measure of central tendency and coefficients of variation as a measure of dispersion. Subsequently, the data were inserted into an inferential analysis to check a significant difference between the treatments studied. A completely randomized design was used, and the data compared by the Tukey test when the ANOVA was significant, both of which were tested at $p < 0.05$.

The results obtained were compared with the requirements indicated by the European standard EN 300 (2002) - Oriented Strand Board (OSB) – *Definitions, classification and specifications*.

3 RESULTS AND DISCUSSION

This section presents the results of the physical-chemical characterization of the bamboo particles, the physical and mechanical characterization of the panels, and the microstructural analysis of the particles.

3.1 Physical, chemical and anatomical properties of the bamboo

Table 2 presents the average values obtained for the physical and chemical properties of the bamboo used in this work.

Table 2 – Mean values of physical and chemical properties of bamboo particles

Sample	Apparent density (kg/m^3)	Real density (kg/m^3)	Holocellulose (%)	Lignin (%)	Source
Bamboo (*Dendrocalamus asper*)	690	1303	68.50	20.2	This study
	-	-	53.00	25.00	Dransfield and Wijaya (1995)
	-	-	65.8	30.4	Laemsak and Kungsuwan (2000)
	-	-	74.00	28.5	Kamthai (2003)

Source: Authors (2021)

The apparent density of bamboo is high compared to different species of

Eucalyptus and *Pinus spp*. woods used in the production of commercial OSB panels, e.g., 510 kg/m^3 to *Eucalyptus urophylla* and 620 kg/m^3 to *Eucalyptus grandis* according to Brito and Barrichelo (1977), and 527 kg/m^3 to *Pinus taeda* according to Trianoski *et al*. (2014). This characteristic will imply less volume of particles to make the panels and consequently require less resin content to ensure an adequate agglomeration of the particles.

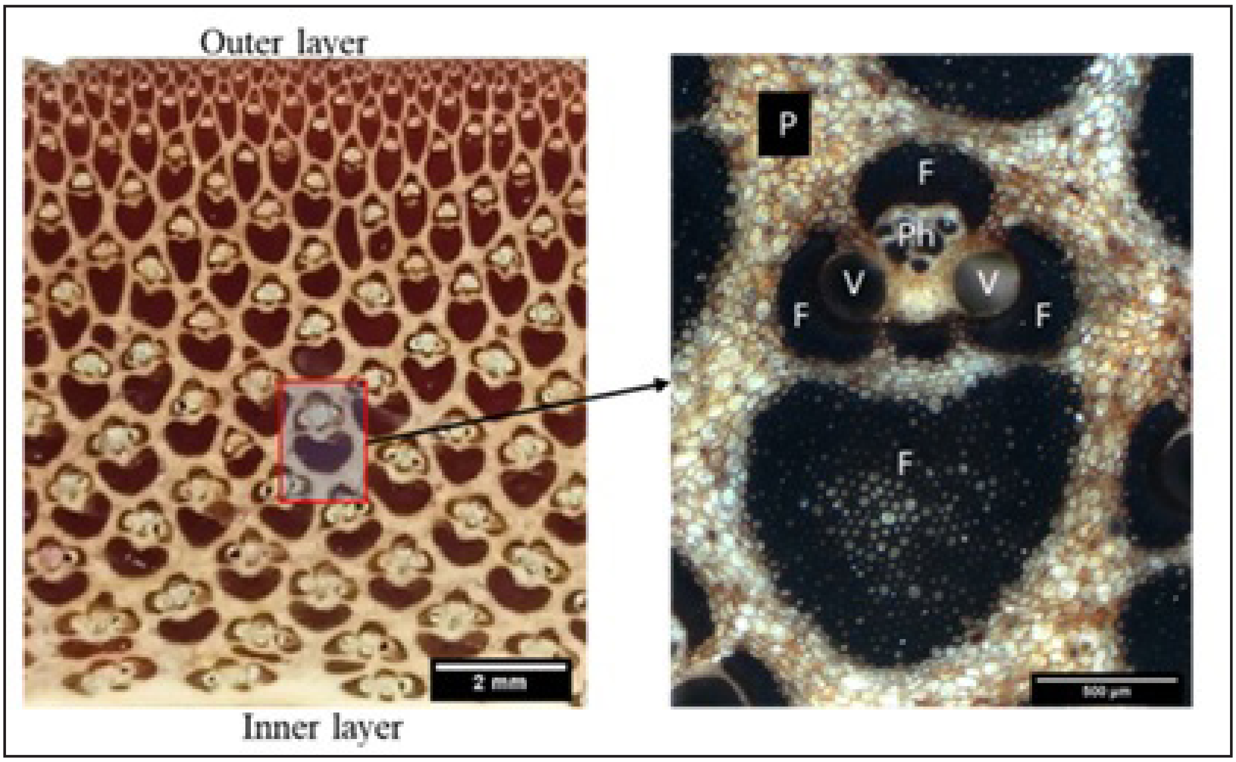
The real density of bamboo proved to be very close compared to other lignocellulosic fibers and wood species, e.g., 1240 kg/m^3 to *Pinus spp*., 1400 kg/m^3 to Sugarcane bagasse, 1370 kg/m^3 to Peanut shell and 1300kg/m^3 to Coconut shell fiber according to Fiorelli *et al* (2014).

In terms of chemical composition, the bamboo particles used in this work presented higher levels of holocellulose and lower levels of lignin contents compared to other studies. Kamthai (2003), investigated the chemical composition at different locations along the culm length of three years old *D. asper* bamboo. The results indicated that the chemical compositions show relatively small differences among different locations. In general, the composition of the bamboo used in this study is within the range reported for different species of bamboo, holocellulose between 54-82% and lignin between 20-34% (LI *et al*., 2015; LIESE; TANG, 2015; DEPUYDT *et al*., 2019)cellulose and lignin are important for moso bamboo processing in biomass energy industry. The feasibility of using near infrared (NIR. Compared to the other wood species (FENGEL; WEGENER, 1984), the chemical compositions of *D. asper* are similar to those of hardwoods and softwoods.

3.2 Anatomical characteristics of bamboo

Figure 2 shows the transverse cross-section of a sample of bulk bamboo used in this work. The main anatomical constituents, e.g., fiber bundle, parenchyma, vessels, and phloem, are presented. The fiber bundles/vessels combined are also called vascular bundles.

Figure 2 – Optical microscopy of the transverse cross-section of bulk bamboo used in this work showing the main anatomical constituents: F (Fiber bundle), P (Parenchyma), V (Vessels), and Ph (Phloem) (GAUSS, 2020)

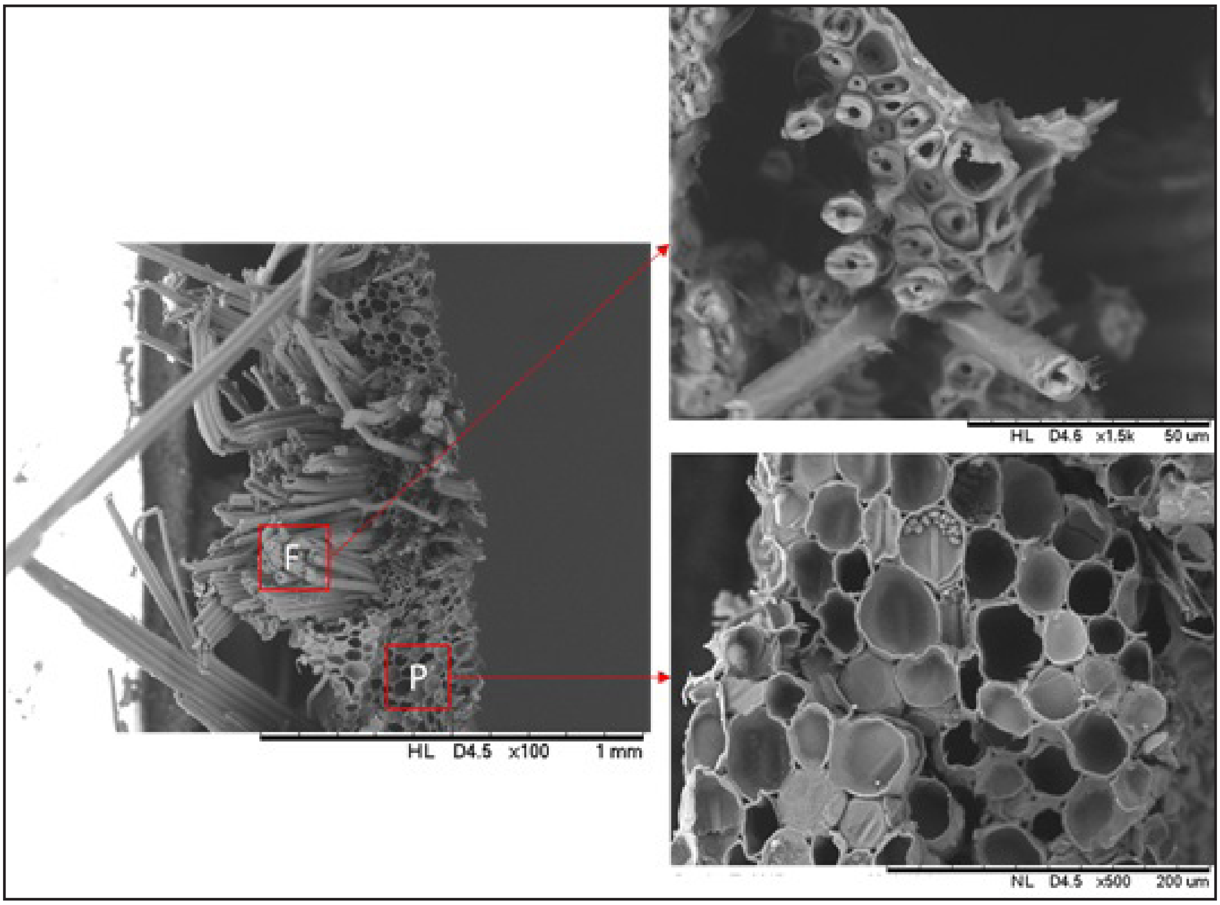


Source: Authors (2021)

According to Grosser and Liese (1971), the vascular bundle shape, size, arrangement, and number in the transverse section of the internode part can be used to classify the bamboo anatomical structure; for example, *D. asper* bamboo is classified under anatomical group D for having type IV vascular bundles (GROSSER; LIESE, 1971). Additionally, although there is no correlation of the vascular bundles' fraction with age, the fraction of fiber bundles changes along the culm height, with higher fractions towards the top region (GROSSER; LIESE, 1971; LIESE; WEINER, 1996).

Figure 3 presents the transverse section of a fractured bamboo strand analyzed through SEM. The fiber bundle is the main component responsible for the bamboo strength, especially in tensile loading. Its presence is clearly identified in the fractured strand, and it works as a reinforcement phase in a weaker matrix (parenchyma). The parenchyma cells have a more uniform and isotropic shape (see the bottom image of Figure 3), which reflects in a “sponge” like behavior. It also acts as an energy reservoir (mainly starch) for the bamboo plant. This unique configuration as a natural composite gives the bamboo an advantage in terms of failure mode over other common wood strands (LIESE; TANG, 2015).

Figure 3 – Transverse section of the bamboo strand highlighting its main constituents: fiber bundles (F) and parenchyma cells (P)



Source: Authors (2021)

3.3 Physical and mechanical properties of OSB panels

Table 3 presents the mean values, and the respective coefficients of variation (COV) of the physical (bulk density, water absorption, and thickness swelling) properties and Table 4 gives the mean values and the respective COV of the mechanical (MOR, MOE and IB) properties of the OSB panels (T1 to T4 treatments). For all the tests (physical and mechanical), 10 specimens per condition were evaluated. Besides, values of those properties recommended by the European normative document EN 300 (2002) for OSB panels type 1 to 4 are presented.

Table 3 – Average values obtained from the physical properties and values recommended by the European Standard EN 300 (2002) for OSB panels type 1 to 4

Treatment	**Bulk density**	**Water Absorption (%)**	**Thickness Swelling (%)**
	kg/m³	**24 h**	**24 h**
T1	653.77[a]	49.07[a]	20.43[a]
(CV)	(6.00)	(10.66)	(12.49)
T2	638.28[a]	28.81[b]	13.00[b]
(CV)	(4.46)	(6.45)	(16.73)
T3	650.60[a]	28.94[b]	9.70[c]
(CV)	(4.65)	(6.55)	(14.22)
T4	643.46[a]	23.51[c]	8.45[c]
(CV)	(4.69)	(8.75)	(17.9)
EN 300 (2002) Type 1	----	----	25
EN 300 (2002) Type 2	----	----	20
EN 300 (2002) Type 3	----	----	15
EN 300 (2002) Type 4	----	----	12

Source: Authors (2021)

In where: Means followed by different lowercase letters in the column differ significantly at 5% by the Tukey Test.

For the water absorption (24 hours), the T1 treatment showed a significant difference ($p<0.05$) in relation to T2 treatment. However, although T2 is not significantly different from T3, both showed a significant difference ($p<0.05$) in comparison with treatment T4. For the thickness swelling (24 hours), T1, T2, and T3 are statistically different ($p<0.05$), while T3 presented similar value to T4, which showed the lowest TS among the analyzed conditions. When compared to the EN 300 (2002) Standard, the T1 treatment could be classified as OSB type 1 (general-purpose, non-load-bearing panels, and panels for interior fitments for use in dry conditions), presenting values close to OSB type 2 panels. The T2 treatment was classified as OSB type 3 (load-bearing panels for use in humid conditions), while the T3 and T4 treatments achieved OSB type 4 panels (heavy-duty load-bearing panels for use in humid conditions). It is also important to emphasize that, as expected, as the resin content increases, the average values of physical properties (water absorption and thickness swelling) decreases, proving a direct relationship between the resin and the physical properties.

Tabela 4 – Average values obtained from the mechanical properties and values recommended by the European Standard EN 300 (2002) for OSB panels type 1 to 4

Treatment	MOR (MPa)		MOE (MPa)		IB (MPa)
	Long.	Trans.	Long.	Trans.	
T1	27.73[a]	25.47[a]	5804[a]	2121[a]	0.73[a]
(CV)	(19.54)	(13.19)	(19,16)	(11.22)	(8.10)
T2	40.09[b]	30,37[a]	6955[a]	2643[b]	0.96[b]
(CV)	(13.54)	(17.43)	(18.91)	(14.35)	(11.89)
T3	49.75[c]	30.85[a]	8393[b]	2302[ab]	1.38[c]
(CV)	(9.76)	(17.80)	(13.36)	(19.23)	(11.50)
T4	42.63[bc]	25.33[a]	6579[a]	1845[a]	1.32[c]
(CV)	(17.16)	(24.51)	(14.96)	(19.43)	(8.14)
EN 300 (2002) Type 1	20	10	2500	1.200	0.30
EN 300 (2002) Type 2	22	11	3500	1.400	0.34
EN 300 (2002) Type 3	22	11	3500	1.400	0.34
EN 300 (2002) Type 4	30	16	4800	1.900	0.50

Source: Authors (2021)

In where: Means followed by different lowercase letters in the column differ significantly at 5% by the Tukey Test.

Along with the results obtained for the mechanical properties, it was observed that for the longitudinal MOR, treatment T1 showed a significant difference ($p<0.05$) in comparison with the other treatments, presenting the lowest value. Although with considerably different resin contents, T2 and T4 did not present a significant difference. T3 showed the highest longitudinal MOR, statistically equivalent to T4 but different from T2. For the transverse MOR, interestingly, no significant difference was noted among the different treatments.

In terms of longitudinal MOE, although treatments T1, T2 and T4 showed no significant difference, their values are statistically lower than T3. For the transverse MOE, similar values were obtained for all the conditions, with the highest values (and statistically different) observed for the T2 and T3 conditions.

For internal bond strength, the lowest value was observed on the T1 treatment, significantly different from the other conditions. T3 and T4 presented the highest values of IB, with no statistical difference between them. Comparing the treatments, in terms of mechanical properties with EN 300 (2002) - Oriented Strand Board (OSB) - Definitions, classification and specifications, all conditions achieved OSB type 3 panels. Treatments T2 and T3 were the only ones to achieve OSB type 4 panels.

Papadopoulos *et al*. (2004)probably reflecting the same values of bulk density between bamboo and wood chips. The results obtained in this study showed that bamboo chips can be successfully used, as an alternative lignocellulosic raw material, to manufacture P3 boards for interior fitments using a relatively low resin dosage (10% UF, validated the technical feasibility of producing one layer of experimental particleboard from bamboo chips bonded with UF resin. Bamboo chips were characterized by having higher length to thickness and length to width ratios and lower bulk density than industrial wood chip particles. The panels were produced with a density of 750 kg/m^3 and differents resin contents (10, 12 and 14%). The results obtained in this study showed that bamboo strands can be successfully used, as an alternative lignocellulosic raw material, to manufacture boards type 3 for interior applications using a relatively low resin dosage (10% UF). Similarly to the results presented in our work, satisfying physical and mechanical properties can be achieved (complying with EN300 (2002) requirements) using bamboo strands even when lower contents of resin are used. The castor oil-based polyurethane resin can be successfully applied for bamboo OSB boards, presenting a promising option for formaldehyde-free engineered bamboo materials.

Febrianto *et al*. (2015)namely Andong (Gigantochloa verticillata, evaluated the effect of bamboo species and resin content on the physical and mechanical properties of OSB prepared from steam-treated bamboo strands of three species of Indonesian bamboo, namely Andong (*Gigantochloa verticillata*), Betung (*Dendrocalamus asper*), and Ampel (*Bambusa Vulgaris*). The OSB panels were prepared by bonding the strands with 3 to 5% of methylene diphenyldiisocyanate (MDI) resin and 1% paraffin. The mean values of water absorption and thickness swelling varied from 19.3% to 36.9% and from 8.6% to 14.1%, respectively. The mean values of longitudinal and transverse MOR in the dry-state ranged between 21 and 65 MPa and between 11 and 43 MPa, respectively, whereas in the wet-state, the mean values of MOR ranged from 9 to 51 MPa and 11 to 32 MPa, respectively. The longitudinal and transverse MOE, in the dry-state, ranged from 4828 to 10215 MPa and 1267 to 3496 MPa, respectively whereas in the wet-state, MOE values were 1701 to 6222 MPa and 1012 to 2612 MPa, respectively. In conclusion, higher resin content in resulted in better physical and mechanical properties.

4 CONCLUSIONS

1. Bamboo (*Dendrocalamus asper*) demonstrates high potential for the production of Oriented Strand Boards (OSB) panels based on physical, chemical and microstructural characterizations.

2. The evaluated treatments (T1 to T4) met the minimum requirements of the European standard EN 300 (2002) - Oriented Strand Board (OSB) – *Definitions, classification and specifications,* for OSB type 1. In particular, panels with 10%, 12% and 15% resin contents comply with the minimum recommendations for applications as structural panels.

3. The different resin contents show a direct relationship with the physical and mechanical properties of the OSB panels. It can be concluded that for this study, the optimum resin content for the production of medium-density (650 kg/m^3) OSB panels with *D. asper* bamboo was 12%, which presented the best physical and mechanical performance.

4. The results presented in this study show the potential of using castor oil-based polyurethane resin in combination with bamboo strands for the production of formaldehyde-free engineered bamboo materials for structural applications.

ACKNOWLEDGMENTS

The authors would like to thank FAPESP (proc. 2017/18076-4) for their research support. CG thanks FAPESP for his research grant (proc. 2016-26022-9). This study was partially financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) - Finance Code 001.

REFERENCES

ALMEIDA, A. E. F. S. *et al*. Improved durability of vegetable fiber reinforced cement composite subject to accelerated carbonation at early age. **Cement and Concrete Composites**, Barking, v. 42, p. 49-58, 2013.

ARRUDA, L. M. *et al*. Lignocellulosic composites from Brazilian giant bamboo (Guadua magna) part 1: Properties of resin bonded particleboards. **Maderas**: Ciencia y Tecnologia, Concepcion, v. 13, n. 1, p. 49-58, 2011.

BARBIRATO, G. H. A. *et al*. OSB Panels with Balsa Wood Waste and Castor Oil Polyurethane Resin. **Waste and Biomass Valorization**, [*s. l.*], v. 11, n. 2, p. 743-751, fev. 2018.

BORTOLETTO JÚNIOR, G.; GARCIA, J. N. Propriedades de resistência e rigidez à flexão estática de painéis osb e compensados. **Árvore**, Viçosa, MG, v. 28, n. 4, p. 563-570, 2004.

BRITO, J. O.; BARRICHELO, L. E. G. Correlações entre características físicas e químicas da madeira e a produção de carvão vegetal: I . Densidade e teor de lignina da madeira de eucalipto. **IPEF**, Piracicaba, v. 14, n. 14, p. 9-20, 1977.

CESAR, J. *et al.* Manufacture of particleboard based on cement bag and castor oil polyurethane resin. **Construction and Building Materials**, Guildford, v. 87, p. 8-15, 2015. DOI: http://dx.doi.org/10.1016/j.conbuildmat.2015.03.114

CORREIA, V. C. *et al*. Bamboo cellulosic pulp produced by the ethanol/water process for reinforcement applications. **Ciencia Florestal**, Santa Maria, v. 25, n. 1, p. 127-135, 2015.

DEPUYDT, D. E. C. *et al*. Bamboo fibres sourced from three global locations: a microstructural, mechanical and chemical composition study. **Journal of Reinforced Plastics and Composites**, Westport, v. 38, n. 9, p. 397-412, 2019.

DRANSFIELD, S.; WIJAYA, E. A. **Plant resources of South-East Asia. No 7, Bamboos**. [*S. l.: s. n.*], 1995.

ESPELHO, J. C. C.; BERALDO, A. L. Avaliação físico-mecânica de colmos de bambu tratados. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 12, n. 6, p. 645-652, 2008.

EUROPEAN COMMITTEE FOR STANDARDIZATION. **European Standard - EN 300**: oriented strand boards (OSB): definitions, classification and specifications. Portugal, 2002.

FEBRIANTO, F. *et al.* Effect of bamboo species and resin content on properties of oriented strand board prepared from steam-treated bamboo strands. **BioResources**, [*s. l.*], v. 10, n. 2, p. 2642-2655, 2015.

FEBRIANTO, F. *et al*. Properties of oriented strand board made from Betung bamboo (Dendrocalamus asper (Schultes.f) Backer ex Heyne). **Wood Science and Technology**, New York, v. 46, n. 1/3, p. 53-62, 2012.

FENGEL, D.; WEGENER, G. **Wood chemistry, ultra structure - reactions**. [*S. l.: s. n.*], 1984.

FIORELLI, J. *et al.* Particulate composite based on coconut fiber and castor oil polyurethane adhesive : an eco-efficient product. **Industrial Crops & Products**, [*s. l.*], v. 40, p. 69-75, 2012. DOI: http://dx.doi.org/10.1016/j.indcrop.2012.02.033

FIORELLI, J. *et al*. Physico-chemical and anatomical characterization of residual lignocellulosic fibers. **Cellulose**, [*s. l.*], v. 21, n. 5, p. 3269-3277, 2014.

GAUSS, C. **Preservative treatment and chemical modification of bamboo for structural purposes**. 2020. Thesis (PhD) - University of São Paulo, São Paulo, 2020. 333 f.

GAUSS, C.; KADIVAR, M.; SAVASTANO, H. Effect of disodium octaborate tetrahydrate on the mechanical properties of Dendrocalamus asper bamboo treated by vacuum/pressure method. **Journal of Wood Science**, [*s. l.*], v. 65, n. 1, 2019.

GHAVAMI, K. Bamboo as reinforcement in structural concrete elements. **Cement and Concrete Composites**, Barking, v. 27, n. 6, p. 637-649, 2005.

GHAVAMI, K.; TOLEDO FILHO, R. D.; BARBOSA, N. P. Behaviour of composite soil reinforced with natural fibres. **Cement and Concrete Composites**, Barking, v. 21, n. 1, p. 39-48, 1999.

GROSSER, D. .; LIESE, W. On the anatomy of Asian Bamboos, with special reference to their vascular bundles. **Wood Science and Technology**, New York, v. 5, n. 4, p. 290-312, 1971.

HARRIES, K. A.; SHARMA, B.; RICHARD, M. Structural Use of Full Culm Bamboo: the Path to Standardization. **International Journal of Architecture, Engineering and Construction**, [*s. l.*], v. 1, n. 2, p. 66-75, 2012.

KAMTHAI, S. **Alkaline Sulfite Pulping and Ecf-bleaching of Sweet Bamboo (Dendrocalamus Asper Backer)**. [*S. l.*]: Kasetsart University, 2003.

LAEMSAK, N.; KUNGSUWAN, K. Manufacture and properties of binderless board from Dendrocalamus asper Backer. *In*: THE BAMBOO 2000 INTERNATIONAL SIMPOSIUM, 2000. **Anais** [...]. [*S. l.: s. n.*], 2000.

LI, X. *et al*. Determination of Hemicellulose, Cellulose and Lignin in Moso Bamboo by Near Infrared Spectroscopy. **Nature Publishing Group**, [*s. l.*], v. 5, 2015. Available in: https://www.nature.com/articles/srep17210.pdf. Access in: 12 set. 2017.

LIESE, W.; TANG, T. K. H. Properties of the Bamboo Culm. *In*: LIESE, W.; KÖHL, M. (ed.). **Bamboo**: the plant and its uses. [*S. l.*]: Springer, 2015. p. 227-256.

LIESE, W.; WEINER, G. Ageing of bamboo culms. A review. **Wood Science and Technology**, New York, v. 30, n. 2, p. 77-89, 1996.

MATTONE, R. Sisal fibre reinforced soil with cement or cactus pulp in bahareque technique. **Cement and Concrete Composites**, Barking, v. 27, p. 611-616, 2005.

MOURA, M. J.; FIGUEIREDO, M. M. Aplicação das técnicas de picnometria de gás e de porosimetria de mercúrio à caracterização da madeira de *E. globulus* . **Silva Lusitana**, [*s. l.*], v. 10, n. 2, p. 207-216, 2002.

PAPADOPOULOS, A. N. *et al.* Bamboo chips (Bambusa vulgaris) as an alternative lignocellulosic raw material for particleboard manufacture. **Holz als Roh - und Werkstoff**, Berlin, v. 62, n. 1, p. 36-39, 2004.

PEREIRA, M. A. R. **Projeto bambu**: introdução de especies, manejo, caracterização e aplicações. [*S. l.: s. n.*], 2012.

SHARMA, B. *et al*. Engineered bamboo: state of the art. **Proceedings of the Institution of Civil Engineers - Construction Materials**, [*s. l.*], v. 168, n. 2, p. 57-67, 2015a. DOI: http://www.icevirtuallibrary.com/doi/10.1680/coma.14.00020

SHARMA, B. *et al.* Engineered bamboo for structural applications. **Construction and Building Materials**, Guildford, v. 81, p. 66-73, 2015b.

SHARMA, B.; HARRIES, K. A.; GHAVAMI, K. Methods of determining transverse mechanical properties of full-culm bamboo. **Construction and Building Materials**, Guildford, v. 38, p. 627-637, 2013.

SUN, Y. *et al*. The effect of culm age, height, node, and adhesive on the properties of bamboo oriented strand boards. **Wood and Fiber Science**, Madison, v. 50, n. 4, p. 430-438, 2018.

SURDI, P. G. **Produção de painéis de partículas orientadas (OSB) a partir da madeira de um híbrido de Pinus elliottii var . elliottii x Pinus caribaea var . hondurensis**. 2012. Dissertação (Mestrado em Recursos Florestais) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, 2012.

TRIANOSKI, R. *et al*. Avaliação das propriedades mecânicas da madeira de especies de Pinus tropicais. **Scientia Forestalis**, Piracicaba, v. 42, n. 101, p. 21-28, 2014.

VAN SOEST, P. J. **Nutritional ecology of the ruminant**. [*S. l.: s. n.*], 1994.

VITAL, B. R. **Effects of Species and Panel Densities on Properties of Hardwood Particleboard**. 1973. Dissertation (M. S.) - University of Wisconsin, Wisconsin, 1973.

YU, Y. *et al*. Fabrication, material properties, and application of bamboo scrimber. **Wood Science and Technology**, New York, v. 49, n. 1, p. 83-98, 2015.

ZAIA, U. J. *et al.* Production of particleboards with bamboo (Dendrocalamus giganteus) reinforcement. **BioResources**, [*s. l.*], v. 10, n. 1, p. 1424-1433, 2015.

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How to quote this article

Barbirato, G. H. A.; Gauss, C.; Lopes Junior, W. E.; Martins, R.; Fiorelli, J. Optimization of castor oil polyurethane resin content of OSB panel made of Dendrocalamus asper bamboo. Ciência Florestal, Santa Maria, v. 32, n. 1, p. 187-205, 2022. DOI 10.5902/1980509846908. Available from: https://doi.org/10.5902/1980509846908.