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OSB SANDWICH PANEL WITH UNDULATED CORE OF BALSA WOOD WASTE

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ABSTRACT

The production of wood-based materials is currently being expanded by the furniture industry and civil construction sector. In order to find new alternatives for the panel market, new configuration possibilities (geometry) of panels and the use of renewable raw materials must be explored. In this scope, the objective of this research was to evaluate OSB sandwich panels with an undulated core and flat faces (OSBUC panels) made of Balsa wood waste strands (*Ochroma pyramidale)* bonded with two-component castor oil polyurethane resin for use in civil construction. Two types of panels were produced with 13 % resin and varying the density of the core (OSBUC-T1 - faces 550 kg/m³ and core 400 kg/m³) and (OSBUC-T2 - faces 550 kg/m³ and core 500 kg/m³). The water absorption and thickness swelling of the face panels were determined based on the Brazilian standard NBR 14810 and the bending test properties of the OSBUC panels determined by the recommendations of the ASTM C393 standard. The results obtained were compared with the specifications of the PS-2-10 – "Performance Standard for Wood-Based Structural-Use Panels" that provides bending stiffness (EI) values and maximum bending moment (FbS) requirements for OSB panels according to different classes of use. The sandwich panels had maximum values of EI 6,48 x 106 N·mm²/mm and FbS 3065 N·mm/mm. The OSBUC-T1 treatment proved to be the most efficient, as it has mechanical properties that meet the normative recommendations for structural use and as flooring, with lower material consumption (lower density).

Keywords: Balsa wood waste, castor oil polyurethane resin, non-conventional materials, oriented particles, sandwich panels.

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INTRODUCTION

Currently, there is a demand for new building materials that consume less energy in their production, are less harmful to the environment and are made from renewable raw materials. In this sense, OSB (Oriented Strand Board), made from particles of residual forest biomass and bonded with two-component castor oil polyurethane resin (PU -castor oil), is a more sustainable alternative to conventional plywood or bonded panels (Barbirato *et al.* 2018, Barbirato *et al.* 2019). This unconventional composite material can has different configurations and geometries, such as the flat OSB panel (2D) or a sandwich with flat faces and a three-dimensional core (beehive or corrugated format) (Pozzer *et al.* 2020, Allen 1969).

The use of lignocellulosic wastes for the production of wood particleboards has been researched since the 1990s and has been commercialized more recently. However, further research is needed to evaluate the feasibility of using unexplored agroforestry byproducts for particleboard production (Martins 2021, Fiorelli *et al.* 2019, Madurwar *et al.* 2013).

One of these wastes that shows potential for use in particleboards is the waste of Balsa wood (specie *Ochroma pyramidale*). In 2008, the world market traded around 150 thousand m³ of wood and semi-finished products from Balsa wood, with a turnover of around US$ 71 million (Santin 2018, Midgley *et al.* 2010). The main buyers are the United States, China and India.

The particleboard industry, including OSB, still makes extensive use of synthetic resins such as urea formaldehyde and phenol formaldehyde, which release formaldehyde and are toxic to humans. To meet the demand for sustainable products, castor oil polyurethane resin is an option that has demonstrated potential for this type of application (Pozzer *et al.* 2020, Barbirato *et al.* 2018, Fiorelli *et al.* 2011).

The sandwich-type structure consists of two coating faces connected to a core. The faces are usually thin in relation to the total thickness of the composite, denser and more resistant than the core material (Carlsson and Kardomateas 2011). The differentiated geometry of the sandwich composite core contributes to weight reduction (while increasing the component's moment of inertia) and to thermal and acoustic insulation (Pozzer *et al.* 2020, Voth *et al.* 2015, Santos 1994). Generally, the cores have low density and depending on the format to provide a greater structural efficiency to the composite (Way *et al.* 2016). In addition, because it is an easy-to-handle material that saves time during the assembly phase in modular buildings, several combinations of materials have been studied and developed to be applied in the composition of sandwich panels to be used in civil construction (Davies 2001). With this configuration, properties such as high bending stiffness and low weight can be achieved at the same time (Carlsson and Kardomateas 2011, Gagliardo and Mascia 2011).

The bending stiffness of OSB 3D panels was evaluated by Voth *et al*. (2015), and the average results were 71 % higher than flat plywood panels and 88 % higher than flat OSB panels.

OSB panels with top and bottom layers of beech veneer with different types of fire-retardant treatments (FRT) forming a solid sandwich structure were evaluated for their physical, mechanical, and fire-retardant properties (Ayrilms *et al*. 2007, Candan *et al*. 2011). The results suggest that OSB panels coated with FRT could be used as engineered wood-based materials due to their better combustion characteristics and higher mechanical properties. The physical and mechanical properties of cardboard substrate panels overlaid with beech veneer was also evaluated by (Ayrilms *et al.* 2008) and the sandwich composite cardboards could be considered as an alternative raw material with accepted properties to be used in furniture applications such as counter tops, flooring, and kitchen cabinets. Corrugated core sandwich panels produced with oriented strands (OSB) were evaluated by Way *et al.* (2016) and the results validated that the three-dimensional design provides increased strength and stiffness without causing significant weight gains.

The mechanical performance of a panel of sugarcane bagasse particles bonded with PU-castor resin in sandwich format with trapezoidal corrugated core and flat faces was evaluated by Pozzer and Fiorelli (2018). Sandwich panels were produced with three different treatments, varying the densities of the faces and the core. At the junction of the outer faces with the core, a castor oil adhesive was used, which was evenly distributed on each contact surface of the corrugated core with the flat panels. All three treatments showed results of mechanical performance that allow to be classified as structural panels and, according to the normative document PS-2-10 of APA (2011), they are indicated for application as a floor.

Within this scope, the objective of this research was to evaluate OSB sandwich panels with an undulated core and flat faces (OSBUC) made of Balsa wood waste strands bonded with bicomponent castor oil polyurethane resin.

MATERIALS AND METHODS

Production of OSB sandwich panels with undulated core - OSBUC

For the manufacture of OSB oriented particleboards (faces and core), Balsa wood wastes (SisGen A4206B8) collected from a log processing company were used. The resin used as a binder for agglutination of wooden strands was the bicomponent castor oil polyurethane, type AGT1315 (*component A* - petroleum prepolymer and *component B* - polyol derived from castor). Component A has density 1240 kg/m³ and component B 1200 kg/m³ (Ferro *et al.* 2014). According to manufacturer it is a 100 % solids (solvent free) compound of high physicochemical stability, elasticity, impermeability and resistance to ultraviolet rays. The mixture of these two components was in 1:1 ratio. The physical and chemical properties of the Balsa wood waste (bulk density, pH and contents of cellulose, hemicellulose and lignin) are showed in Table 1.

Table 1: Physical and chemical properties of the Balsa wood waste.

Material	Bulk Density (kg/m^3)	pH	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Source
Balsa Wood Waste	200	4,96	70,14	16,13	7,72	Martins *et al.* (2022)

Figure 1 shows a drawing created in AutoCAD® software with the perspective and profile of the lower part of the mold (with its main directions) and a real image of the mold in profile. The technical justification for the use of this geometry (shape) of the core is that the arc-shaped structures (continuous arches) have a mechanical behavior of transferring stresses and strains mainly by compression (simple normal stress) (Nunes 2009). This fact may be beneficial for the gain of resistance in sandwich-type structures, which is the object of experimental observation in this study. Another important factor is that this type of configuration of the core avoids the occurrence of voids during the pressing (shaping) phase of the panel, as reported in the work of (Pozzer *et al*. 2020) when using a trapezoidal core.

Balsa wood strands were produced using a chipping mill (Marconi® brand type MA685) with dimensions approximately 9,0 cm in length, width ranging from 2,5 cm to 5,0 cm and thickness 1,0 mm. After the production of the strands and sieving to remove the fine dust, they remained in an oven for 48 hours, at a temperature of 65 °C, reaching a moisture content of 8 %.

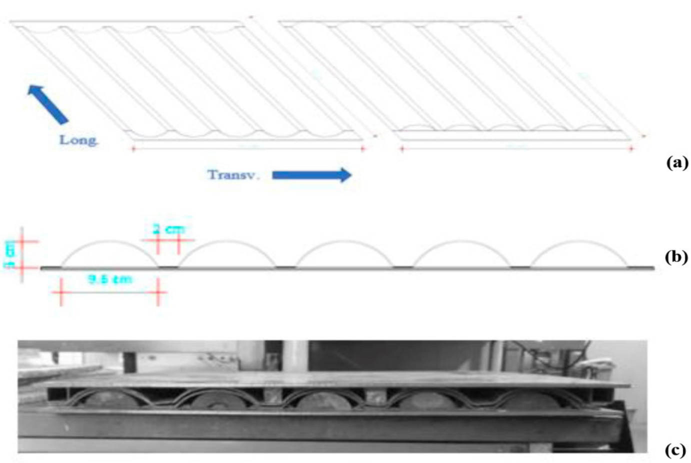

Figure 1: Schematic drawing of the mold. (a) Isometric perspective of the bottom and top with main directions (longitudinal and transversal). (b) Cross-section of the lower part. (c) Profile of the set.

For the production of the flat panels and the undulated core, the methodology described by (Barbirato *et al.* 2018) was used. The PU-castor resin in the content of 13 % of the dry mass of the particles was used following the optimized result obtained in the work of (Lopes Júnior *et al.* 2021) and mixed with the wooden strands by means of spraying in a rotary mixer. The particles were arranged in three layers perpendicular to each other (faces perpendicular to the core) and mass distribution in the ratio 30:40:30 (face: core: face). Then, the particle mattress was inserted in a thermo-hydraulic press (Hidral-Mac® model PHH-VB, Laboratory of Construction and Ambience, Faculty of Animal Science and Food Engineering, University of São Paulo - Brazil) and pressed at 3 MPa, for 10 min at 100 °C. A metal limiter was used to guarantee the final thickness of the panels approximately 1,0 cm. After 72 hours of curing in room temperature, the faces were fixed to the core by means of bonding using PU-castor resin.

Figure 2 illustrates the production process of the OSBUC panels. Table 2 shows the experimental plan in which different densities were used for the cores of the panels in order to obtain a lightweight product with mechanical properties that allow its application in civil construction.

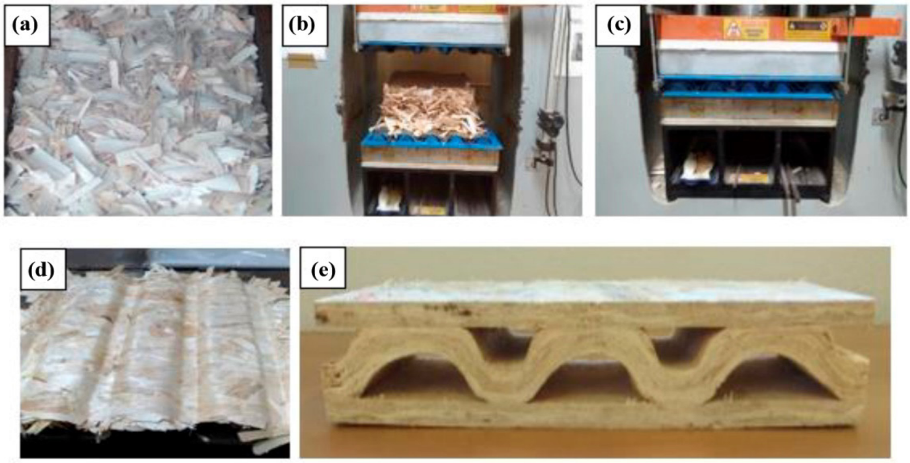

Figure 2: Undulated panel production. (a) Balsa wood waste processed. (b) Particle mattress before pressing. (c) Shaping (pressing) of the undulated OSB panel. (d) Shaped panel after compression. (e) Panel profile.

Table 2: Treatments evaluated in this study with different core densities.

Treatments	Faces (kg/m³)	Core (kg/m³)	Resin (%)	Number of Panels
OSBUC-T1	550	400	13	2
OSBUC-T2	550	500		

Characterization of Balsa wood OSB panels

The physical properties of water absorption (WA) and thickness swelling (TS) of the flat faces were determined following the guidelines of normative document NBR 14810-2 (2018). The internal bond strength (IB) of OSB flat faces was determined following EN 319 (1993) normative.

The mechanical properties (bending test) of the OSBUC panels were determined following the guidelines of the ASTM C393 (2016) and ASTM D3043 (2017) standards. An EMIC model DL 30000 universal machine with a displacement rate of 6 mm/min. and rupture (failure) occurring in the interval of 3 min to 6 min was used.

The OSBUC sandwich panels produced after hot pressing and cutting the edges were 36 cm x 37 cm. Samples were taken from the manufactured OSBUC panels with dimensions of 12 cm x 37 cm (width x length) in both panel directions (longitudinal and transverse) (Figure 3a, Figure 3b and Figure 3c). The width of the specimens was adjusted according to the geometry of the undulated core so that the cross-section of each longitudinal specimen included a cut (undulation) repeated in the direction of the transverse axis of the panel, covering an entire cell of the core (Figure 3a). The maximum dimensions for non-standard samples recommended by ASTM C393 (2016) were respected. Three specimens were used for each type of mechanical property evaluated.

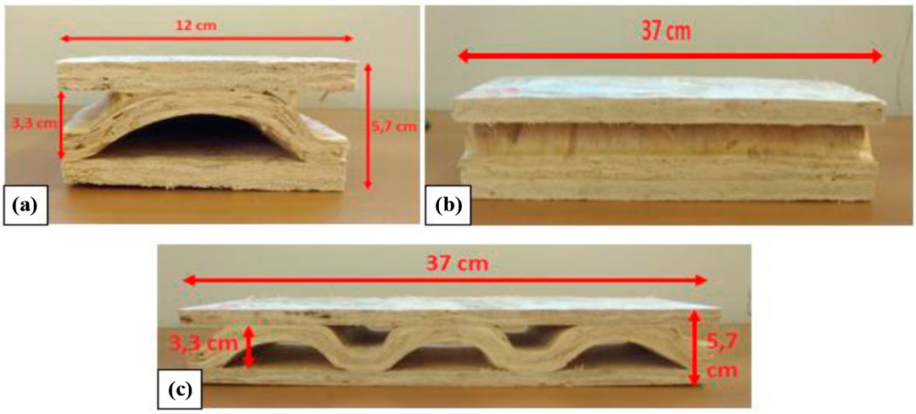

Figure 3: OSBUC Sandwich Panel specimens with respective dimensions. (a) Cross section of longitudinal specimen. (b) Longitudinal specimen (c) Transversal specimen.

The faces were about 12 mm thick, while the core thickness was 9 mm. The results obtained from the mechanical properties (bending stiffness - EI and maximum bending moment - FbS) were submitted to an inferential statistical analysis to diagnose if there was a significant difference between the T1 and T2 treatments. A completely randomized design (CRD) was used and the data compared by the Tukey test when ANOVA was significant, both tested with $p < 0,05$, using the Minitab® 19 software (2021).

RESULTS AND DISCUSSION

Physical properties and internal bond strength - flat panels

The main values and the respective coefficients of variation of the physical properties of WA and TS for flat panels are shown in Table 3. The results of WA and TS were compared with maximum values indicated by the standard EN 300:2006 (2006) and with values obtained for similar panels present in the literature.

Table 3: Experimental values of physical properties of flat panels (faces) and present in the literature.

Treatments	WA (%)		TS (%)		Source
	AVERAGE	COV (%)	AVERAGE	COV (%)	
OSB Flat Panel (550 kg/m³)	49,74 (2 h) 114,02(24 h)	25,37 16,50	11,34 (2 h) 21,12 (24 h)	16,35 24,48	Study
OSB Balsa Panel (650 kg/m³ - 13 % PU resin)	-------- --------		-------- 23,26 (24h)		Lopes Júnior *et al.* (2020)
OSB Balsa Panel with PU-castor resin	-------- 106 (24h)[2]		-------- 33,57(24h)[1]		Barbirato *et al.* (2018) and Barbirato *et al.* 2019)
EN 300:2006 - Panel type 1			-------- 25 (24h)		Standard EN 300:2006 (2006)

The results obtained indicate lower values of TS after immersion in water for 24 h in relation to the values obtained by Lopes Júnior *et al.* (2021) and Barbirato *et al.* (2018). Lopes Júnior *et al.* (2021) used flat OSB panels with the same type of raw material, same resin content, density 650 kg/m³ and obtained TS values of 23,26 %. Regarding the maximum value allowed by the standard (25 %), the panel has a characteristic that allows it to be classified as a type 1 panel, for use in furniture or dry indoor environments. WA values are similar to those presented by Barbirato *et al.* (2019) who evaluated Balsa wood OSB panels of 650 kg/m³ and 15 % resin content.

The OSB panel of Balsa wood waste tended to absorb more water when compared to studies of particleboards made up of other agroforestry residues (Fiorelli *et al.* (2019), Nakanishi *et al.* (2018), Varanda *et al.* (2018)), a trend that can be justified by the porosity of Balsa wood and also by the low density, which requires a greater volume of raw material for the shaping of the panels.

The IB value is shown in Table 4. This result was compared with the minimum value given in EN 300:2006 (2006) and with values obtained for similar panel presented in the literature.

Table 4: Internal bond strength of flat panel (faces) and respective coefficient of variation.

Treatments	IB (MPa)		Source
	AVERAGE	COV (%)	
OSB Flat Panel (550 kg/m³)	0,35	25,9	Study
OSB Balsa Panel (650 kg/m³ - 13 % PU resin)	0,33	12,9	Lopes Júnior *et al.* (2020)
Standard EN 300:2006 (2006) - Panel type 3 (board thickness range > 10 and < 18 mm)	0,32		Standard EN 300:2006 (2006)

The internal bond strength determined for the flat OSB panel (faces) was higher than that determined in the study by Lopes Júnior *et al.* (2021), 0,35 MPa and 0,33 MPa, respectively - allowing the production of a panel with the same raw materials, resin content, lower density and similar IB values. The determined value (0,35 MPa) allows the classification of the board in OSB class 3 - load-bearing boards for use in humid conditions - according to the standard EN 300-2006 (2006).

Bending test – OSB undulated core sandwich panels

The mechanical properties of EI and FbS for OSBUC panels are shown in Table 5. These values have been compared with the results of other works in the literature and also evaluated on the basis of the normative document PS-2-10 (APA 2011), which establishes the use classes for OSB panels in view of their application in civil construction.

OSBUC-T2 showed average values of EI and F_bS higher than those obtained for OSBUC-T1. However, the statistical analysis indicated a significant difference ($p < 0{,}05$) for (EI) and (FbS) only in the transverse direction of panels, which corresponds to the direction of the core undulations (Figure 3c). A possible explanation is the structure and geometry of the core shape, which allowed better shaping of the specimens in the transverse direction, showing the difference between treatments.

Table 5: Average experimental values of EI and F_bS and presented in the literature.

Sandwich Panels		Bending Stiffness-EI (N.mm²/mm) x 10^6		Maximum Moment-F_bS (N.mm/mm)		Source
		Long.	Transv.	Long.	Transv.	
OSBUC Panels	T1-400	5,28[a] (22,4)	3,96[a] (14,1)	2430[a] (14,4)	1140[a] (19,7)	Study
	T2-500	6,48[a] (20,6)	6,44[b] (13,2)	3065[a] (11,3)	2138[b] (17,2)	
Trapezoidal Sugarcane Bagasse Panel		2,1 (27,5)	0,73 (10,5)	1199 (29,9)	819 (19)	Pozzer *et al.* (2020),
Molded Core Panel (MCP)		19,1 (5,0)	12,1 (7,5)	3950 (12,3)	3353 (14,6)	Way *et al.* (2016)

Means followed by different lower-case letters in the same column differ significantly at 5 % by the Tukey test.

Pozzer *et al.* (2020) evaluated sandwich panels with a trapezoidal core consisting of sugarcane bagasse particles bonded with two-component castor oil polyurethane resin. Panels were produced with two different treatments and the best results for flexural stiffness and maximum longitudinal and transverse moment are shown in Table 5. The residual Balsa wood panels (OSBUC - T1 and T2) showed properties superior to those obtained by Pozzer *et al.* (2020).

The panels produced and evaluated by Way *et al.* (2016) showed superior mechanical performance at bending. They were produced from OSB corrugated core sandwich panels with 90 % aspen wood *(Populus* sp.*)* and 10 % mixed hardwood. The panels were produced with a phenol formaldehyde (PF) resin content of 4 % by weight, an average core density of 640 kg/m³ and an average face density of 630 kg/m³. The authors obtained the EI values of 19,1 x 10^6 N·mm²/mm and 12,1 x10^6 N·mm²/mm in the longitudinal and transverse directions of the particles and F_bS of 3950 N·mm/mm and 3353 N·mm/mm for longitudinal and transverse particle direction.

Table 6 shows the average values of bending stiffness (EI) and the maximum bending moment (F_bS) and the indicative values of the APA document PS-2-10 (2011), which establishes minimum requirements for the application of OSB panels as constructive elements.

OSBUC-T1 and OSBUC-T2 exhibited values that allow them to be classified as elements for sealing, structures, and floors with a maximum span of up to 32 inches (81,28 cm). These results serve as a basis for choosing OSBUC-T1 treatment as the most efficient, since it uses a smaller amount of raw material in its construction.

Table 6: Experimental EI and FbS and established.

Use	Class* APA PS 2-10 (2011)	EI (N-mm²/mm)		F_bS (N-mm/mm)	
		Long.	Trans.	Long.	Trans.
Sealing	Roof -32/subfloor-16	0,5x10^6	0,3x10^6	460	190
	Roof -40/subfloor-20	1,2x10^6	0,4x10^6	810	360
	Roof -32/subfloor-16	1,8x10^6	0,7x10^6	920	510
Structural	½	0,5x10^6	0,3x10^6	460	330
	19/32 & 5/8	1,2x10^6	0,5x10^6	810	500
	23/32 & ¾	1,8x10^6	0,7x10^6	920	650
Flooring	Single Floor - 24	1,6x10^6	0,5x10^6	910	320
	Single Floor - 32	4,2x10^6	1,3x10^6	1570	600
	Single Floor - 48	8,6x10^6	2,1x10^6	2080	820
This study	OSBUC-T1	5,28x10^6	3,96x 10^6	2430	1140
This study	OSBUC-T2	6,48x10^6	6,44x10^6	3065	2138

* The numbers and fractions shown in the Class column refer to the maximum span that the panel can support or the thickness of the panel, in the case of structural ones.

For the longitudinal specimens, there was a tendency of failure initially in the glue line between the core and the lower face of the sample, leading subsequently to a total rupture by shearing the core (Figure 4a and Figure 4b). This phenomenon is in accordance with that recommended by the ASTM C393 (2016) standard, which establishes the shear of the core or the core-face connection as the only acceptable failure modes for this test. The transverse specimens had fracture types that were more likely to be near the supports and at the point of load application. This fact can be explained due to the sample configuration which, in relation to the longitudinal samples, present glue lines more distributed and in an orthogonal direction to the action of the bending moment (Figure 4c and Figure 4d). All treatments studied showed similar behaviors regarding rupture.

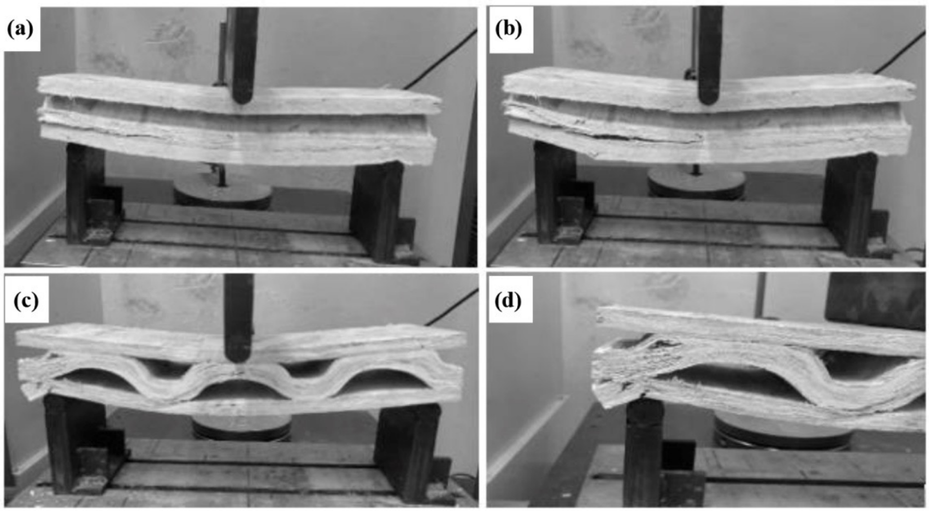

Figure 4: Specimens submitted to the bending test. (a) start of shear rupture in the glue line (longitudinal sample), (b) shear of the core-face interface and beginning of the core rupture, (c) transversal sample with rupture in the support and in the load application point and (d) detail of rupture in support.

CONCLUSIONS

The Balsa wood waste bonded with PU-castor has the potential to produce sandwich OSB panels (undulated core and flat faces).

The OSBUC panels of Balsa wood waste showed physical and mechanical properties that allow their use as sealing elements, structural and as a floor.

The panel with flat faces of (550 kg/m^3) and low-density core (400 kg/m^3) – OSBUC-T1 – is indicated as the most efficient treatment for presenting mechanical properties that meet the normative recommendations, with less consumption of raw materials and lower density. The 3D structure (corrugated core) of the undulated panels has the function of increasing the structural efficiency compared to the flat and solid panels.

From an industrial point of view, the production of OSB panels with corrugated core from forestry residual biomass represents an alternative for the marketing of a product with economic, technical and environmental advantages compared to flat OSB panels and industrial plywood.

AUTHORSHIP CONTRIBUTIONS

R. H. B. M.: Conceptualization, data curation, formal analysis, validation, investigation, visualization, methodology, writing - original draft, writing - review & editing; G. H. A. B.: Conceptualization, data curation, investigation, writing - review & editing; L. E. C. F.: Conceptualization, data curation, investigation; J. F.: Conceptualization, funding acquisition, methodology, project administration, resources, supervision, writing - review & editing.

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REFERENCES

Allen, H.G. 1969. Analysis and Design of Structural Sandwich Panels. Pergamon Press Ltd. Oxford - UK. https://www.sciencedirect.com/book/9780080128702/analysis-and-design-of-structural-sandwich-panels

ASTM. 2016. Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure. ASTM C393/C393M-16: ASTM. West Conshohocken, PA, USA.

ASTM. 2017. Standard Test Method for Structural Panels in Flexure. ASTM D3043-17. ASTM. West Conshohocken: PA, USA.

APA. 2011. Performance Standard for Wood-Based Structural-Use Panels. PS 2-10**.** APA: Tacoma, WA, USA.

ABNT. 2018. Painéis de partículas de média densidade - Parte 2: Requisitos e métodos de ensaio. NBR 14810-2. ABNT: Rio de Janeiro, RJ, Brasil.

Ayrilms, N.; Candan, Z.; White, R. 2007. Physical, mechanical, and fire properties of oriented strandboard with fire retardant treated veneers. *Holz Roh Werkst* 65: 449-458. https://link.springer.com/article/10.1007/s00107-007-0195-3

Ayrilms, N.; Candan, Z.; Hiziroglu, S. 2008. Physical and mechanical properties of cardboard panels made from used beverage carton with veneer overlay. *Materials & Design* 29: 1897-1903. https://doi.org/10.1007/s00107-007-0195-3

Barbirato, G.H.A.; Lopes Junior, W.E.; Hellmeister, V.; Pavesi, M.; Fiorelli, J. 2018. OSB Panels with Balsa Wood Waste and Castor Oil Polyurethane Resin. *Waste and Biomass Valorization* 11: 743-751. https://doi.org/10.1007/s12649-018-0474-8

Barbirato, G.; Fiorelli, J.; Mejia, J.; Sarasini, F.; Tirillò, J.; Ferrante, L. 2019. Quasi-static and dynamic response of oriented strand boards based on balsa wood waste. *Composite Structures* 219: 83-89. https://doi.org/10.1016/j.compstruct.2019.03.062

Carlsson, L.A.; Kardomateas, G.A. 2011. *Structural and Failure Mechanics of Sandwich Composites.* Springer: New York. https://link.springer.com/book/10.1007/978-1-4020-3225-7

CEN. 1993. Particleboards And Fibreboards: Determination Of Tensile Strength Perpendicular To The Plane Of The Board. EN 319. European Standard: Brussels, Belgium.

CEN. 2006. Oriented Strand Boards (OSB): Definitions, Classification and Specifications. EN 300:2006. European Standard: Brussels, Belgium.

Davies, J.M. 2001. *Lightweight Sandwich Construction*. Blackwell Science: Oxford, UK.

Fiorelli, J.; Bueno, S.B.; Cabral, M.R. 2019. Assessment of multilayer particleboards produced with green coconut and sugarcane bagasse fibers. *Construction and Building Materials* 205: 1-9. https://doi.org/10.1016/j.conbuildmat.2019.02.024

Fiorelli, J.; Lahr, F.A.R.; Nascimento, M.F.; Savastano Junior, H.; Rossignolo, J.A. 2011. Particleboards based on sugarcane bagasse and castor oil resin production and properties. *Acta Scientiarum Technology* 33(4): 401-406. https://doi.org/10.4025/actascitechnol.v33i4.9615

Gagliardo, D.P.; Mascia, N.T. 2011. Analysis of sandwich structures: design parameters. *Ambiente Construído* 10(4): 247-258. https://doi.org/10.1590/s1678-86212010000400017

Lopes Júnior, W.E.; Barbirato, G.H.A.; Pavesi, M.; Soriano, J.; Fiorelli, J. 2021. Avaliação do teor ótimo de resinas orgânicas para produção de painéis OSB de madeira balsa (*Ochroma pyramidale*) residual. *Scientia Forestalis* 49(129): e3442. https://doi.org/10.18671/scifor.v49n129.22

Madurwar, M.V.; Ralegaonkar, R.V.; Mandavgane, S.A. 2013. Application of agro-waste for sustainable construction materials: a review. *Construction and Building Materials* 38: 872-878. http://dx.doi.org/10.1016/j.conbuildmat.2012.09.011

Martins, R.H.B. 2021. Painel OSB sanduíche com núcleo ondulado de biomassa florestal residual. MSc thesis, Universidade de São Paulo, Faculdade de Zootecnia e Engenharia de Alimentos, Pirassununga. https://doi.org/10.11606/D.74.2021.tde-26102021-122453

Martins, R.H.; Barbirato, G.A.; Campos Filho, L.; Fiorelli, J. 2022. OSB panel with low density reforesting wood residue: physical and thermal characterization. In 18th International Conference on Non-conventional Materials and Technologies (NOCMAT 2022). https://doi.org/10.5281/zenodo.6570425

Midgley, S.; Blyth, M.; Howcroft, N.; Midgley, D.; Brown, A. 2010. Balsa: biology, production and economics in Papua New Guinea. ACIAR Technical Reports No. 73. Australian Centre for International Agricultural Research: Canberra, Australia. https://www.aciar.gov.au/sites/default/files/legacy/node/12685/balsa_biology_production_and_economics_in_papua__40057.pdf

Minitab. 2021. Minitab® 19 software. State Collegue: PA, USA.

Nakanishi, E.Y.; Cabral, M.R.; Fiorelli, J.; Dos Sanstos, V.; Christoforo, A.L.; Savastano Junior, H. 2018. Study of the production process of 3-layer sugarcane-bamboo-based particleboards. *Construction and Building Materials* 183: 618-625. https://doi.org/10.1016/j.conbuildmat.2018.06.202

Nunes, P.C.C. 2009. Teoria do arco de alvenaria: uma perspectiva histórica. MSc thesis, Universidade de Brasília, Faculdade de Tecnologia, Estruturas e Construção Civil. Brazil. https://repositorio.unb.br/handle/10482/4465

Pozzer, T.F.; Fiorelli, J. 2018. Painel Sanduíche com núcleo corrugado de partículas de bagaço de cana-de-açúcar. In: Rehabend 2018. Construction pathology, rehabilitation technology and heritage management. (7th REHABEND Congress). Caceres, Spain, May 15th-18th, 2018.

Pozzer, T.; Gauss, C.; Barbirato, G.H.A.; Fiorelli, J. 2020. Trapezoidal core sandwich panel produced with sugarcane bagasse. *Construction and Building Materials* 264: 1-6. https://doi.org/10.1016/j.conbuildmat.2020.120718

Santin, J.C. 2018. Avaliação silvicultural de pau-de-balsa. MSc thesis, Universidade Federal de Mato Grosso, Instituto de Ciências Agrárias e Ambientais, Programa de Pós-Graduação em Agronomia, Sinop, Brazil. https://cms.ufmt.br/files/galleries/98/DISSERTA%C3%87%C3%95ES/2018/Julio%20Cesar%20Santin.pdf

Santos, M.C.S. 1994. Estabilidade e fenômenos de localização em elementos de painel sanduíche. MSc thesis, Universidade de Coimbra, Departamento de Engenharia Civil, Coimbra, Portugal. http://hdl.handle.net/10961/1595

Varanda, L.D.; Yamaji, F.M.; Santos, R.L.O.; Silva, D.A.L.; Christofo, A.L.; Lahr, F.A.R. 2018. Physical performance of particleboards using Castor oil-based adhesive. *Revista Brasileira de Engenharia Agrícola e Ambiental* 22(10): 707-712. https://doi.org/10.1590/1807-1929/agriambi.v22n10p707-712

Voth, C.; White, N.; Yadama, V.; Cofer, W. 2015. Design and Evaluation of Thin-Walled Hollow-Core Wood-Strand Sandwich Panels. *Journal of Renewable Materials* 3(3): 234-243. https://doi.org/10.7569/JRM.2015.634109

Way, D.; Arijit, S.; Kamke, F.A.; Fujii, J.S. 2016. Evaluation of a Wood-Strand Molded Core Sandwich Panel. *Journal of Materials in Civil Engineering* 28(9): 1-9. https://ascelibrary.org/doi/10.1061/%28ASCE%29MT.1943-5533.0001589