https://doi.org/10.22320/s0718221x/2024.32

ARTÍCULO

Evaluation of OSB panels using residual wood with low contents of castor oil polyurethane resin

Guilherme Henrique Ament Barbirato [1] https://orcid.org/0000-0003-1215-4931♠
Wanley Eduardo Lopes Junior[-1] https://orcid.org/0000-0002-6647-5469
Romulo Henrique Batista Martins[1] https://orcid.org/0000-0002-2556-7762
Cristiane Inácio de Campos[2] https://orcid.org/0000-0001-9669-6820
Juliano Fiorelli[1] https://orcid.org/0000-0001-7012-068X

[1]Universidade de São Paulo (USP). Faculty of Animal Science and Food Engineering (FZEA). Pirassununga, Brazil.
[2]Universidade Estadual Paulista (UNESP). Itapeva Campus. Itapeva, Brazil.

♠Corresponding author: guilhermebarbirato@terra.com.br

Abstract:
The use of residues from human activities has been currently gaining ground in the national and international markets, aiming toward the production of more sustainable materials that are less aggressive to the environment. Reusing and adding value to new products has also become an important factor in reducing production costs and the best alternative for this is process optimization. The choice for residual balsa wood was due to its rapid growth and low density, as well as for its ease of engineering and determining the ideal amount of resin for different types of panels. This study aims to investigate the influence of the content variation of castor oil-based polyurethane resin on the physical and mechanical properties of OSB board particles made from residual balsa wood in reforestation areas. The panels were produced with 8, 10, and 12 % commercial castor oil-based polyurethane resin and 9 mm long particles; their physical and mechanical characterizations followed international normative recommendations. The results indicated that the panels with resin contents higher than 10 % reached the minimum regulatory requirements for type 2 OSB panels, suitable for structural application. On the other hand, the panels produced with 8 % resin reached the minimum requirements for type 1 OSB panels, suitable for non-structural use by the furniture industry, such as linings and partitions. Therefore, our study concludes that the variation of resin contents for OSB panels of residual balsa wood allowed us to achieve optimal levels for the use of castor oil-based polyurethane resin, reaching minimum values recommended by regulations for OSB panels type 1 and 2 and a great possibility of application of this product for engineered materials.

Keywords: Balsa wood, mechanical properties, Oriented Strand Board, organic resin, physical properties.

Received: 24.10. 2022
Accepted: 28.01.2024

Introduction

Aiming at reducing the pressure on the environment and contributing to the promotion of sustainability in industrial processes, particle boards (among them, OSB panels - Oriented Strand Board) with residual forest biomass agglomerated with organic resin are being consolidated in the market as alternatives to various applications, such as linings and partitions for the furniture industry (Surdi 2015), as well as being used in construction, in applications such as floorings and sealing.

The residual balsa wood from reforestation regions has a rapid growth rate, ready for use within 4 to 5 years, whereas the commercial trees (Pine and Eucalyptus), which are used by the plywood industry, demand approximately 8 to 12 years. Moreover, Balsa wood has a low apparent density, around 200 kg/m^3, compared to Pine and Eucalyptus, which reach 600 to 800 kg/m^3 values. This low density is essential for its easy handling, allowing it to be engineered into panels of specific density.

Some recent studies have investigated OSB panels produced with balsa wood residue from reforestation, agglomerated with organic resin (Barbirato *et al.* 2019, Barbirato *et al.* 2018, Campos Filho *et al.* 2021, Hellmeister *et al.* 2021, Lopes Junior *et al.* 2021, Soriano *et al.* 2021). All these studies, however, used resin contents higher than 11 %.

Lopes Junior *et al.* (2023) developed OSB panels of Balsa wood waste with castor oil polyurethane resin incorporating 1 % to 3 % of the resin mass of aluminum oxide (Al_2O_3) microparticles to enhance the physical and mechanical performance of the OSB panels. The authors produced panels with a medium density (650 kg/m^3) and 13 % of resin content. The results indicated that the OSB panels with 2 % Al_2O_3 presented an increase in physical and mechanical properties (accelerated aging and internal adhesion).

Martins *et al.* (2023) also studied OSB panels with Balsa wood waste however, the authors studied another geometry (sandwich with undulated core), which is another type of material but the faces of this sandwich panel used OSB flat panels. The authors produced OSB panels with low density (550 kg/m^3) and 13 % castor oil polyurethane resin content. The physical and mechanical results for OSB flat panels indicated lower values when compared to other studies. Both recent studies produced OSB flat panels with 13 % resin content which is higher in comparison to the wood panel industry.

The wood panel industry often uses urea-formaldehyde and phenol-formaldehyde resins, and the reported resin contents are less than 10 %. The main objective is achieving a lower resin content while meeting the normative recommendations. Notably, the wood panel industries in countries with wood supply use only the trunk of trees. To produce OSB panels, however, it is possible to use residues, such as chips, logs with imperfections (nodes and bark), and low-quality wood. This practice allows for a sustainable destination for this material, adds value to this new product, contributes to the reduction of the environmental impact caused by the disposal or burning of this raw material, and incorporates the product into the circular economy of the timber sector.

The novelty of this study is in the reduction of castor oil-based polyurethane resin contents in the production of OSB panels of residual balsa wood to approximate the contents used commercially, presenting the physical and mechanical performance as well as the anatomical characteristics of this new product. This reduction in resin content seeks a more sustainable alternative, since the wood comes from reforestation, and presents a more economical alternative since the amount of resin used is lower when compared with percentages greater than 12 %.

Therefore, this study aims to investigate the influence of the variation of castor oil-based polyurethane resin content on the physical and mechanical properties of OSB particle panels made of residual balsa wood from reforestation areas, with a density of 650 kg/m^3 (density used commercially for OSB panels), agglomerates with low contents (8, 10, and 12 %) of castor oil polyurethane resin (phenol-free). The mechanical characterization of these flat OSB panels, for possible applications in both the furniture and construction business, follows the minimum recommendations of the EN 300 (2006).

Materials and methods

Production of OSB panels of residual balsa wood (RBW)

OSB panels were produced from balsa wood waste from reforestation regions (SisGen A4206B8), i.e.: 1- Balsa wood residue (woodchips) was processed in a wood chipper (Marconi brand, model MA685), and chips with a length of 90 cm, a width of 25 cm, and thickness of 1 mm were produced (Figure 1a); 2- after the production of the chips, they were sent to a greenhouse with a temperature of 65 °C, for 48 hours, to obtain a material with 8 % humidity; 3- After drying, the chips were sieved to remove the finer grains 4- An estimation was performed of the number of particles for the targeted density of 650 kg/m^3 panel and for the variation of the contents (8, 10, and 12 %) of castor oil-based polyurethane resin (castor-PU) to be used by the panel. Subsequently, the particles were inserted into a concrete mixer and the resin was applied by spraying to obtain a homogeneous distribution of the resin along the particles; 5- the material was inserted into a mattress mold (600 mm × 600 mm × 10 mm), considering the face-core-face mass ratio of 30:40:30 (Figure 1b), and then transferred to the thermohydraulic press (pressure 5 MPa, the temperature of 100 °C, and pressing time of 10 minutes) (Figure 1c). At the end of the pressing process, the panels were stored at room temperature for 72 h, a period marked by the continuation of the resin curing process. After this period, the panels were tapered in their final dimensions (580 mm × 580 mm) from which specimens were extracted for physical, mechanical, and anatomical characterization tests. Thus, OSB panels of residual balsa wood (Figure 1d) were manufactured according to the experimental plan presented in Table 1, totaling 8 panels (two for each treatment). The OSB panels of balsa residual wood of this study were referenced with the following abbreviations: RBW-8, RBW-10, and RBW-12.

Figure 1: Production process: (a) Balsa wood chips; (b) particle forming and guiding mold; (c) Mattress pressing; (d) Balsa wood OSB panel.

Table 1: Treatments studied and resin contents.

Treatments	Density (kg/m^3)	Thickness (mm)	Resin contents (%)
RBW-8			8
RBW-10	650	10	10
RBW-12			12

Physical and mechanical characterization of residual balsa wood OSB panels

The physical (water absorption, thickness swelling, and apparent density) and mechanical (static bending, internal adhesion, and screw pullout for face and top) characterization of residual balsa wood OSB panels (RBW panels) followed the recommendations of normative documents EN 310 (1993), EN 317 (1993), EN 319 (1993), EN 320 (2011), and EN 323 (1993). Table 2 shows the description of each test, the standards used, dimensions, and the total quantity of samples per test. The physical tests performed were done to prove the efficiency of the resin concerning impermeability when in contact with water, and the mechanical tests were made to evaluate the characteristics of the wood and its potential for applications in the furniture industry or construction.

Table 2: Experimental plan of physical and mechanical tests.

<table>
<tr><th>Properties</th><th>Normative</th><th>Length (mm)</th><th>Width (mm)</th><th colspan="2">Nº samples</th></tr>
<tr><td>Apparent density</td><td>EN 323</td><td>50</td><td>50</td><td colspan="2">10</td></tr>
<tr><td>Water absorption</td><td rowspan="2">EN 317</td><td rowspan="2">50</td><td rowspan="2">50</td><td colspan="2">10</td></tr>
<tr><td>Thickness swelling</td><td colspan="2">10</td></tr>
<tr><td>Bending test</td><td>EN 310</td><td>250</td><td>50</td><td>Transv.
15</td><td>Long.
15</td></tr>
<tr><td>Internal adhesion</td><td>EN 319</td><td>50</td><td>50</td><td colspan="2">8</td></tr>
<tr><td>Screw withdrawal</td><td>EN 320</td><td>50</td><td>50</td><td>Face
10</td><td>Top
10</td></tr>
</table>

The results obtained were compared with the minimum requirements of the European standard EN 300 (2002) that defines four types of uses for OSB panels, regarding their use in the furniture and construction industry.

For the statistical analysis of the data, an inferential analysis was performed to diagnose the existence of a significant difference between the treatments studied (RBW-8, RBW-10, and RBW-12). The completely random design (CRD) was used, and the data were compared by Tukey's test when the ANOVA was significant, both were tested with $p<0,05$.

Anatomical characterization of residual balsa wood OSB panels

The images of the OSB panels of residual balsa wood were obtained through a Scanning Electron Microscope (SEM), Hitachi TM300 model. For the acquisition of the images, the electron backscattering technique was used, amplified by 50×, 100×, and 200×, which allowed for the identification of the dispersion of the resin inside the panels according to the variation of the contents used. This analysis is also important to understand the efficiency of panel compaction, an extremely important characteristic since it directly reflects on the physical and mechanical properties of the panels.

Results and discussion

The results obtained from the physical, mechanical, and anatomical characterizations from RBW-8, RBW-10, and RBW-12 panels agglomerates with different levels of castor oil polyurethane resin (Castor-PU) are presented in the next items.

Physical and mechanical characterization of residual balsa wood OSB panels

Table 3 shows the physical properties of RBW panels, such as apparent density, water absorption (2 hours and 24 hours), and thickness swelling (2 hours and 24 hours), compared to the specifications of the European standard EN 300 (2002), which are presented by the mean and respective coefficient of variation (CV). This regulation presents four types of OSB panels up to 10 mm thick (Types 1 to 4), which are indicated according to the application of the panel as structural or non-structural, in dry or humid environments, and external or internal use of the construction.

Table 3: Mean values for the physical properties of OSB panels of residual balsa wood.

Treatments	Apparent density (kg/m^3)	Water absorption (%)		Thickness swelling (%)	
		2 H	24 H	2 H	24 H
RBW - 8 % (CV)	635,11a (5,25)	31,60a (14,60)	67,67a (8,78)	12,02a (11,40)	26,49a (11,52)
RBW - 10 % (CV)	621,56a (3,71)	29,58a (10,56)	68,71a (6,57)	12,65a (9,74)	23,83ab (15,00)
RBW - 12 % (CV)	633,80a (4,28)	19,28b (13,51)	49,43b (9,59)	10,94a (8,29)	18,09b (13,27)
EN 300 - OSB 1	-	-	-	-	25
EN 300 - OSB 2	-	-	-	-	20
Lopes Junior *et al.* (2021) (13 %)	650	-	-	-	23,26
Lopes Junior *et al.* (2023) (Reference)	650	-	-	-	30,77
Martins *et al.* (2023)	550	49,74	114,02	11,34	21,12

RBW – Residual Balsa Wood Panel; OSB – Oriented Strand Board. Mean values followed by different letters in the column differ significantly to 5 % ($p<0,05$) by the Tukey's Test.

With the results obtained for the physical properties, it was observed that for water absorption (WA) (2 hours and 24 hours) the treatments RBW-8 and RBW-10 showed no statistically significant difference between them but showed a statistically significant difference ($p<0,05$) about the RBW-12 treatment. For the values obtained from thickness swelling (TS) (2 hours), all treatments showed no statistical difference among themselves. For The TS (24 hours) the treatments RBW-8 and RBW-10 did not present significant difference ($p<0,05$) among themselves, but the RBW-8 treatment showed a significant difference for the RBW-12 treatment, which showed no statistical difference for the RBW-10 treatment. When compared with EN 300 (2002), the RBW-8 treatment did not reach values for TYPE 1 OSB panels, the RBW-10 treatment reached for OSB type 1 panels, and the RBW-12 treatment reached minimum requirements recommended by the regulatory for type 2 OSB panels (Figure 2).

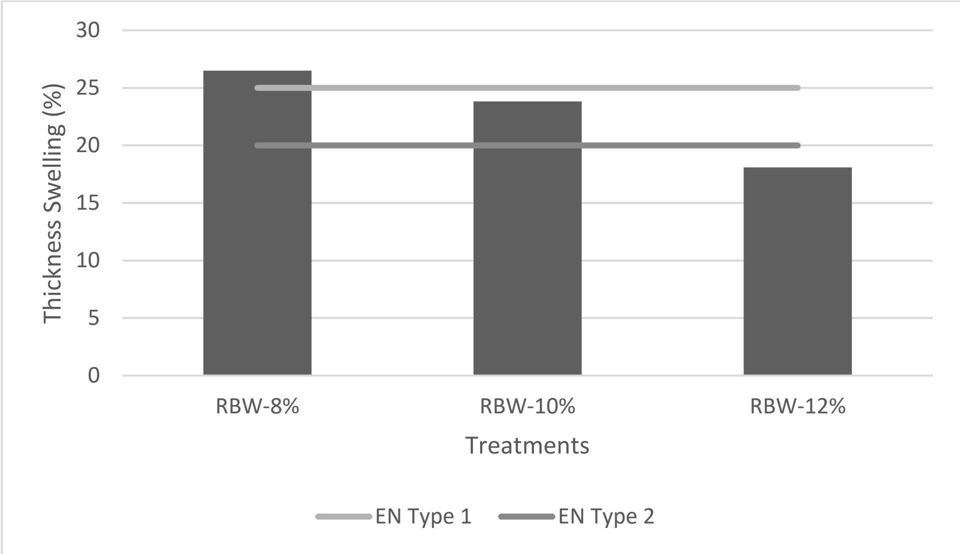

Figure 2: Comparison of treatment results with the standard EN 300 (2002). Thickness Swelling 24 hours.

It is important to highlight that as the resin content increases there is a tendency for less water absorption, this also happens for thickness swelling, proving a direct relationship between the resin content and the physical properties of the panels. The RBW-10 treatment showed results for TS (24 h) close to Lopes Junior *et al.* (2021), which obtained TS (24 h) value equal to 23,26 % for OSB panels of residual balsa wood of 650 kg/m³ and castor-PU resin content of 13 %. Barbirato *et al.* (2019) obtained results for WA (24h) of 134 % and 106 % considering OSB panels of residual balsa wood of 650 kg/m³ and castor-PU resin contents of 11 % and 15 %, respectively.

Overall, there was no statistical difference between the mean values obtained for apparent density and they are within the range of 621,56 to 643,57 kg/m³, this proves that the production process of the residual balsa wood OSB panels was successfully performed and reached the intended target density of 650 kg/m³.

Mechanical characterization of residual balsa wood OSB panels (RBW)

Table 4 shows the mechanical properties of RBW panels obtained by static bending tests (MOR and MOE), internal adhesion (IA), and screw pullout (face and top) compared to the specifications of the European standard EN 300 (2002), which are presented by the mean and respective coefficient of variation (CV).

Table 4: Mean values for the physical properties of OSB panels of residual balsa wood.

Treatments	MOR (MPa)		MOE (MPa)		IA (MPa)	Screw withdrawal (N)	
	Longitudinal	Transverse	Longitudinal	Transverse		Face	Top
RBW - 8 % (CV)	27,11a (10,45)	17,54a (9,79)	4194a (10,80)	1462a (9,57)	0,43a (4,88)	1032,35a (8,40)	826,71a (6,30)
RBW - 10 % (CV)	27,86a (12,94)	16,74a (15,82)	3882a (9,18)	1427a (13,39)	0,61b (8,13)	1177,98b (6,90)	919,16ab (5,31)
FRBW - 12 % (CV)	24,84a (9,01)	17,34a (14,68)	3750a (15,52)	1404a (10,33)	0,54b (13,22)	1234,59b (8,67)	1156,32b (13,06)
EN 300 - OSB 1	20	10	2500	1200	0,30	-	-
EN 300 - OSB 2	22	11	3500	1400	0.34	-	-
Lopes Junior *et al.* (2021) (13 %)	34,00	12,79	5668	1281	0,33	-	-
Lopes Junior *et al.* (2023) (Reference)	27,26	12,99	4514	1280	0.29	-	-
Martins *et al.* (2023)	-	-	-	-	0.35	-	-

RBW – Residual Balsa Wood Panel; OSB – Oriented Strand Board. Mean values followed by different letters in the column differ significantly to 5 % (p<0,05) by the Tukey's Test.

With the results obtained for the mechanical properties, it was observed that for the longitudinal and transverse rupture modulus (MOR) and the longitudinal modulus of elasticity (MOE), the treatments RBW-8, RBW-10, and RBW-12 did not present significant differences ($p<0,05$) between them. For the transverse modulus of elasticity, however, the RBW-8 treatment showed no significant difference ($p<0,05$) compared to the RBW-10 treatment but presented a statistical difference from the RBW-12 treatment, which, in turn, did not present a statistically significant difference compared to the RBW-10 treatment. For internal adhesion (IA), the RBW-10 and RBW-12 treatments showed no statistically significant difference between them, while the RBW-8 treatment showed a significant difference compared to the other treatments studied. Comparing the results of the treatments with the EN 300 (2002), they all achieved sufficient results to be classified as type 2 OSB panels (Figure 3).

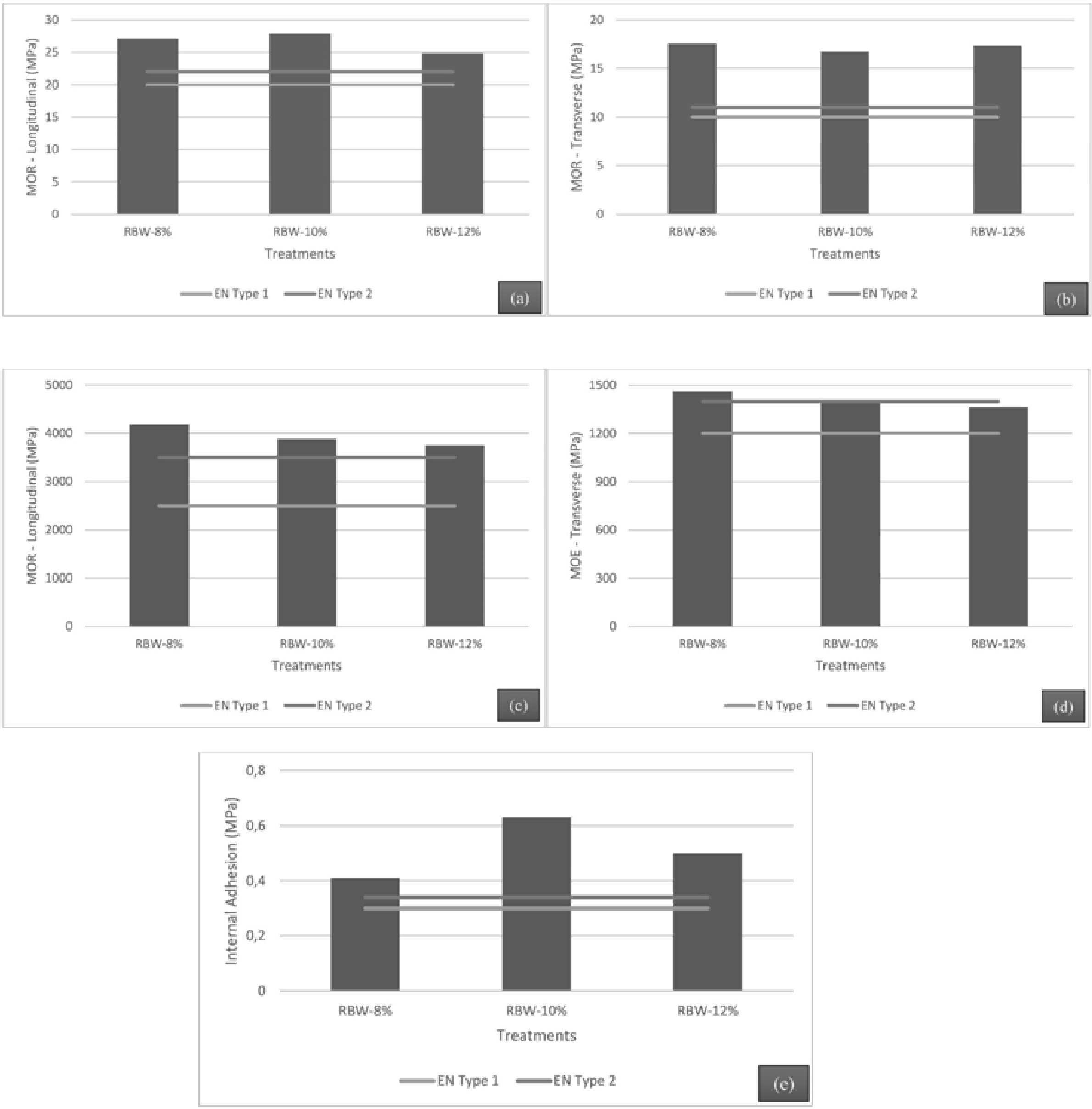

Figure 3: Comparison of treatment results with the standard (EN 300 (2002)). (a) and (b) Modulus of rupture longitudinal and transverse. (c) and (d) Modulus of elasticity longitudinal and transverse. (e) Internal Adhesion.

Lopes Junior *et al.* (2021) and Campos Filho *et al.* (2021) worked with OSB panels of residual balsa wood with a density of 650 kg/m³ and castor oil resin content of 13 %. Considering the treatments RBW-8 and RBW-10, our study obtained values for transverse MOR, longitudinal MOE, and IA are higher than those obtained by the aforementioned authors, using lower resin contents.

For the withdrawal test, the analysis of the mean values obtained allowed us to observe that the increase in density and resin content, from RBW-8 to RBW-12, resulted in a better performance. Thus, it is important to emphasize that the optimization of the resin content with the density used is extremely valuable for the physical and mechanical properties of the OSB panel of residual balsa wood.

Anatomical characterization of OSB panels of residual balsa wood

Figure 4 shows the scanning electron microscope (SEM) images of the cross-section of the RBW panels amplified by 100×. There is adequate compaction of the particles; however, Figure 4a, with a resin content of 8 %, shows a greater number of voids compared to the other treatments, a characteristic that directly influences the physical and mechanical properties of the panels. Figure 4b, with a resin content of 10 %, presents a smaller number of voids compared to Figure 4a, and these voids are reduced with the increase of the resin content (Figure 4c).

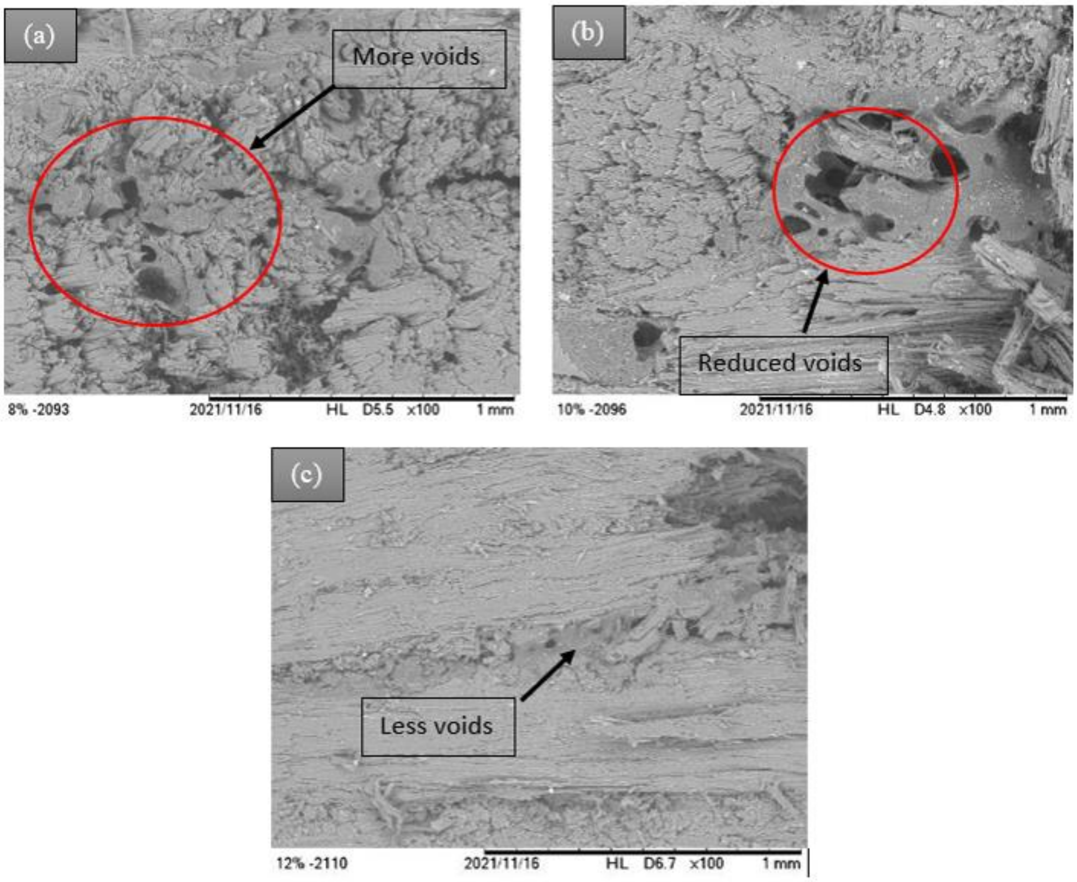

Figure 4: Cross section - SEM (Zoom 100x): (a) 8 %; (b) 10 %; (c) 12 %.

Conclusions

The study of the resin content for residual balsa wood OSB panels from reforestation regions showed that panels with 8 % castor PU resin presented results very close to the minimum requirements presented by the standard and in comparison, with other literature found, it presented a very good performance similar being superior in some tests, as was the case of Internal Adhesion (IA). For panels with more than 10 % castor PU resin, standard recommendations were met. This content is justified by the characteristics of the wood (porous), to achieve the minimum requirements of the European standard for OSB type 2 structural panels. Studies have also shown that it is possible to produce panels with resin levels below 10 % for non-structural applications such as furniture, linings, and partitions, reaching the minimum requirements for type 1 OSB panels.

Authorship contributions

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

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank FAPESP (proc. 2017/18076-4 – Recipient Juliano Fiorelli) and CNPq (Proc. 407451/2018-8 and 304106/2017-8 - Recipient Juliano Fiorelli) for their research support. This study was partially financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 – Recipient Guilherme Henrique Ament Barbirato.

References:

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

Barbirato, G.H.A.; Lopes Junior, W.E.L.; 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

Campos Filho, L.E.; Freire, M.T.A.; Schmidt, R.M.; Lopes Júnior, W.E.; Barbirato, G.H.A.; Martins, R.H.B.; Fiorelli, J. 2021. Embalagem secundária do tipo display de OSB de resíduo de madeira-balsa (*Ochroma pyramidale*). *Revista Ciência*, *Tecnologia & Ambiente* 11:1-11. https://doi.org/10.4322/2359-6643.11186

EN. 1993. Wood-based panels - determination of modulus of elasticity in bending and of bending strength. EN 310. Bruxelas, 12.

EN. 1993. Particleboards and fiberboards - Determination of thickness swelling after water immersion. EN 317. Bruxelas, 12.

EN. 1993. Wood-based panels - Determination of density. EN 323. Bruxelas, 12.

EN. 1993. Particleboards and fiberboards - Determination of tensile strength perpendicular to the plane of the board. EN 319. Bruxelas, 12.

EN. 2006. Oriented Strand Board (OSB) - Definitions, classification, and specifications. EN 300. Portugal, 24.

EN. 2011. Particleboards and fibreboards - determination of resistance to axial withdrawal of screws. EN 320. Bruxelas, 14.

Hellmeister, V.; Barbirato, G.H.A.; Junior, W.E.L.; dos Santos, V.; Fiorelli, J. 2021. Evaluation of Balsa wood (*Ochroma pyramidale*) waste and OSB panels with castor oil polyurethane resin. *International Wood Products Journal* 12(4): 267-276. https://doi.org/10.1080/20426445.2021.1977519

Lopes Junior, 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): 1-11. https://doi.org/10.18671/scifor.v49n129.22

Lopes Junior, W.E.; Cabral, M.R.; Christoforo, A.L.; de Campos, C.I.; Fiorelli, J. 2023. Investigating the Effects of Al2O3 Microparticles on WoodWaste OSBs: A Study on Physical, Mechanical, and Durability Performance. *Polymers* 15(12): e2652. https://doi.org/10.3390/polym15122652

Martins, R.H.B.; Barbirato, G.H.A.; Campos Filho, L.E.; Fiorelli, J. 2023. OSB sandwich panel with undulated core of balsa wood waste. *Maderas. Ciencia y Tecnología* 25: 1-10. http://dx.doi.org/10.4067/s0718-221x2023000100425

Soriano, J.; Fiorelli, J.; Lopes Junior, W.E.; Barbirato, G.H.A.; Deldotti, L. R. 2021. Numerical modeling for adjustment of the equivalent moduli of elasticity of OSB layers estimated from experimental flexural rigidity. *Journal of Materials Research and Technology* 14: 1630-1643. https://doi.org/10.1016/j.jmrt.2021.07.048

Surdi, P.G. 2015. Aproveitamento de resíduos do processamento mecânico de madeiras amazônicas para a produção de painéis aglomerados de alta densificação. 200 f. Tese (Doutorado) - Universidade de São Paulo Escola Superior de Agricultura 'Luiz de Queiroz' Piracicaba. https://www.teses.usp.br/teses/disponiveis/11/11150/tde-06042016-183539/pt-br.php