Viabilty of Eucalyptus Bark for the Composition of OSB Panels

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Lumber mills generate a huge volume of residues, with tree bark and saw shavings being main contributors. A small amount of this material is burned for energy generation, though most of it is left on the sawmill grounds or dumped in sanitary landfills, thus presenting a huge environmental issue. This study deals with the application of eucalyptus bark and saw shavings for the manufacturing of oriented strand board (OSB). Four types of panel compositions where studied: 25%, 50%, 75%, and 90% of bark content; 10% percent of shavings for all of them, and a variable content of pine strands. The adhesive was phenol formaldehyde at 6% related to the dry mass of the components. Because an important characteristic of OSB panels is their response to swelling, a 1% of paraffin emulsion was added to seal the particles. The results showed that only the 90%-bark panel could meet OSB standard prescriptions as a type 1 “dry environment application”.

Keywords: Lignocellulosics, Sustainable materials, Eucalyptus grandis bark; Pine shavings; Oriented strand boards – OSB; Design methodology

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INTRODUCTION

Lumber companies generate a very large volume of residues, which include tree bark and saw shavings. A small amount of these residues is burned for the generation of energy, whereas most of it is left on the sawmill grounds or dumped in sanitary landfills, which represents a major environmental issue. A way to mitigate the problem is to try to add value to the raw materials by introducing them into the manufacturing process of panels.

According to Foelkel (2006), the bark of eucalyptus trees is a viable and financially opportune fuel for the timber industries. Eucalyptus bark is presently used as mulch, fertilizer, phytochemicals (essential oils, tannins), and in charcoal production. Due to the huge volume produced by the wood industries (paper, solid wood, panels, *etc*.), most of it is not used. It is left on the industry grounds or sent to dump fills, where slurry can leach into the soil and water table, causing serious environmental impacts. However, from the production standpoint, eucalyptus bark is not a profitable product. Rocha *et al.* (2018) state that for several wood uses, such as pulp, paper and charcoal, the presence of the bark is undesirable, compromising production. Their research focused the influence of plant spacing on the bark properties of a eucalyptus clone. The authors report that the density of the bark increases in response to wider plant spacing.

The shaving residue can reach as much as 20% of the total raw material produced by sawmills (Coronel *et al.* 2008). Brito (1995) states that timber shavings is one of the types of residue that is used very little, especially in Southern Brazil where most of the timber industries are concentrated. Shavings can be used as fuel, although they have good characteristics to produce particle board. According to the author, it is possible to combine them with other raw materials.

Oriented strand board (OSB) is an advanced technical design forest product, made up of wood strands bonded with a synthetic resin and pressed under high temperatures. In the outer layers, the particles are disposed longitudinally with respect to the length of the panel, while in the intermediate layers, particles are arranged perpendicular to the length of the panel to increase their mechanical strength and stiffness (EPF 2016).

The production of the OSB panels in laboratories is described by Iwariki (2005) and Mendes (2001). In this process, it is first necessary to generate the particles and then mix the adhesive. Because a major issue with OSB panels is swelling, the authors suggest the addition of a paraffin emulsion to make particles waterproof and thus improve the performance. The addition of paraffin in the panel composition improves its response to swelling (Marra 1992; Cloutier 1998; Murakami 1999; Mendes *et al.* 2003; Morales 2014). Salari *et al.* (2013) worked on the improvement of some of applied properties of oriented strand board (OSB) made from underutilized low-quality paulownia; they point out that the addition of nano-SiO_2 significantly improved the resistance to water absorption and the thickness swelling of the panels. The layers should be pressed at a temperature ranging from 100 °C to 120 °C for 10 min.

Cloutier (1998) and Iwakiri *et al.* (2002) noted that the panels should be made up of three layers. The outer strand layers should be disposed in the same direction as the inner layer, following a random distribution, in a ratio of 40:60 between the face and core, based on the dry particle weight.

Density is an important feature to be considered. The bark of *Eucalyptus grandis* presents a low density, which leads to an increase in the number of particles to be pressed, thereby allowing an increased density of the panel as a whole. This finding agrees with previous works (Suchsland 1977; Sobral Filho 1981; Zhow 1990; Zhang *et al.* 1998). Rocha *et al.* (2018) studied, among other parameters, the influence of plant spacing on the density of eucalyptus bark; they found values of basic density ranging from 0.317 to 0.332 g/cm^3. Density affects the mechanical properties of the panel, as it generates higher compaction ratios (Kelly 1977; Maloney 1993; Hrázský and Král 2003). This feature increases the contact surface among particles, consequently improving the adhesion. Panels formed with low density materials generate panels with greater uniformity and a high capacity of distribution of forces among the flakes/particles, which improves their strength to static bending and internal bonding. Elevated compaction ratios may make it possible to achieve high mechanical performance; however, the long-term moisture absorption from the environment and, consequently, dimensional instability may increase (Moslemi 1974; Kelly 1977).

Denser panels result in lower values of initial water absorption in swelling tests (within 2 h) (Avramidis and Smith 1989; Zhow 1990). However, for a period of exposure longer than 24 h, the denser panels tend to absorb more water because of the larger number of particles, resulting in a greater contact area per volume. The reduced initial absorption can be explained by the fact that high density panels produce a physical barrier that prevents the access of water due to a greater amount of mass per volume (Mendes 2001).

Surdi *et al.* (2014), in their study relating density and internal bond, used two methods to determine density: conventional gravimetric and X-ray densitometry. They observed values of density ranging from 0.46 to 0.72 g/cm^3 by X-ray and 0.61 to 0.73 g/cm^3

by a gravimetric method. LP Brasil (2019) in their commercial catalogue indicate that OSB panels are manufactured with 0.64 g/cm^3 average density.

The prior research on OSB indicates that a combination of particles in OSB panels is possible. The major concern, along with mechanical properties, is swelling. Eucalyptus bark, being of low density, could improve compaction ratios, thus increasing the overall density, and consequently the mechanical properties. High density, in turn, could increase initial (2-h immersion) swelling, but it may have an adverse impact on the final swelling (24-h immersion). Sealing of the particles is a way to mitigate the problem that Mendes *et al.* (2014) and Salarai *et al.* (2018) observed in their research.

Mechanical performance of the panel is determined by two properties: Modulus of elasticity (MOE) and modulus of rupture (MOR). The MOE indicates how stiff and the MOR how resistant the material is. As for lignocellulosic materials, in general, both parameters vary as a function of density. In other words, the denser the stiffer and more resistant the material is. EN 3000 (2006) establishes that MOE and MOR to be assessed through bending tests both according to the panel's major and minor axis. The standard defines 3 different types of panels – OSB 1, OSB 2, and OSB 3 – depending on the values of MOE, MOR, and thickness. Table 1 shows an example of OSB type 1 minimum requirements required by the standard.

Table 1. Bending Properties, (in N/mm^2), to EN 300-(2006) – OSB Type 1 Class Requirements Dry Environment

Property	Thickness (mm, nominal)		
	6 a 10	10≤ t ≤18	18 a 25
Bending strength- major axis	20	18	16
Bending strength - minor menor	10	9	8
Bending MOE – major axis	2.500	2.500	2.500
Bending MOE - minor axis	1.200	1.200	1.200

Source: adapted from EN 300 (2006)

NDT (Non-Destructive Testing) methods can be accurate and quick alternatives to predict mechanical properties of lignocellosic materials. Barcarolo (2019) studied dowelled connections in nail-laminated beams graded yellow pine boards using both static and NDT ultrasound. The author observed that though the ultrasound test tends to overestimate the stiffness (MOE), the correlation with static tests was as good as 80% (R^2=0.8). Similar results were observed by Alencar and Moura (2019) in their research on CLT panels. Their data showed that NDT values were greater than static test ones, but the ultrasound was a good quick and low-cost method to predict timber stiffness. Barreto *et al.* (2019) in their work on cross laminated timber-bamboo, graded bamboo and yellow pine using both NDT-ultrasound and static tests. They reported a correlation between the predicted MOE values of the material, bamboo and pine, and the panel MOE as high as 95%. Bo *et al.* (2017) in their study on composite oriented strand board from reused prepreg had their panels mechanically characterized by ultrasound mehod very succssesfuly.

Wang *et al.* (2019) used the Transverse Vibration NDT method to assess in-plane shear modulus of OSB plates. They observed a very good relationship between the NDT method and the cantilever-plate torsional mode method. They also concluded that OSB should be treated as an orthotropic material rather than a unidirectional composite in theoretical analysis.

The viability of introduction of industry residues, eucalyptus bark, and sawmill shavings as raw materials to manufacture OSB-type panels, was the main objective of this research. Therefore, different proportions of these two materials were incorporated in their composition, and the quality of the final product was compared to the thresholds established by the standards and the published research.

EXPERIMENTAL

Materials

Raw material preparation

Three types of raw materials were used to create the panels: *Eucalyptus grandis* bark, provided by Technomade Indústria e Comércio de Madeiras Ltda; pine shavings, obtained in the Laboratory of Models at Londrina State University; and pine strands provided by LP Brasil OSB Building Products (Fig.1).

To achieve a standardization of the dimensions of the three materials to be used, the bark, strands, and shavings were taken to the vibrating sieve, and the particles retained in the 19 mm mesh tray were separated and stored in plastic bags.

The materials were placed in a ventilated oven at 135 °C until reaching a moisture content ranging from 3% to 4%. After drying, the bark was cut into strands with the dimensions of 15 mm in width and a length ranging from 40 mm to 60 mm. The particulate materials were separated in 38 mm, 19 mm, and 4.8 mm gage-mesh vibrating sieves. Only the amount retained in the 19 mm gage was separated for panel manufacture.

This procedure allowed for the homogenization of the particle with consideration of the optimal slenderness ratio (Barnes 2000).

Fig. 1. Particles composing the panels – bark, strands, and shavings

Methods

Four panel compositions (P1 to P4) were studied in this research. The aim was to produce panels with the same final 10 mm thickness required to commercial OSB type (8 to 10 mm, LP Brasil, 2019).

The determination of the particle mass for each type was established according to Table 2. Five panels of each type were manufactured, totaling 20 panels altogether.

Table 2. Particle Composition of Panels

Panel	Bark (g)	Strands (g)	Shavings (g)	Panel mass (g)
P1	260 (25%)	675 (65%)	105 (10%)	1040
P2	520 (50%)	415 (40%)	105 (10%)	1040
P3	1045 (75%)	205 (15%)	140 (10%)	1390
P4	1500 (90%)	0	165 (10%)	1650

Each group of panels received 6% resin and 1% of paraffin emulsion based on the dry weight of the particles. The introduction of paraffin in the panel composition was aimed to improve the response to swelling.

Phenol formaldehyde (PF) adhesive with a 53.2% solid content, pH of 12, and viscosity of 500 cp was supplied Si Group Crios Resinas S.A (Rio Claro-SP, Brazil). The composition (bark, shavings, and strands) was put into a 400-L concrete mixer with a steel drum and shaken for 5 min to standardize the mixture. The adhesive was applied by spraying, and the particles were mixed for 5 min to distribute the adhesive.

The particles were then taken to the particle separator (Fig. 2). The material was oriented in bins equipped with separation slides.

Fig. 2. Orientation of particle device – adapted from Nascimento *et al.* (2015)

Each panel had three layers within which the particles were laid down with face/core proportions of 40 to 60. The external faces were oriented in the same direction, whereas the core had a random distribution (Cloutier 1998; Iwakiri 2002). After setting up the panel, a pre-pressing was performed with the help of a hydraulic press (model ENERPAC IPE-3060, Diadema-SP, Brazil). The press-head was made of steel, and the dimensions were 40 cm^2 by 40 cm^2 by 2.54 cm (1”) thick. The panel received a constant pressure of 30 tons for 5 min. The panels were then taken to a door manufacture industry (Madeplak Comércio de Compensados e Madeiras) and submitted for final pressing through a mechanical hydraulic press (OMECO, Cuiritba-PR, Brazil), under an automatic temperature and pressure control system. The pressing was continuous with no pauses, and the temperature was set to 160 °C for 8 min at a pressure of 4 MPa (Iwakiri 2005; Nascimento *et al.* 2015; Bo 2017).

Laboratory-made panels can be of smaller proportions than those manufactured in the industry. Nascimento *et al.* (2015) performed their study using dimensions of 40 x 40 cm^2 with good results. The dimensions of the panels had fixed measures of 40 x 40 cm with the proportions showed in Table 1, as previously described.The panels remained stacked for 48 h to allow for completion of the curing process. Altogether, 5 panels of each composition were created. Then the panels were trimmed to a final dimension of 35 x 35 cm^2. The average thickness of the panels was 10 ± 2 mm. Each panel was cut into specimens as Fig. 3 depicts, complying with EN 326-1 (1994). Table 3 shows the number of specimens per test. In total, 120 specimens were tested.

Table 3. Number of Specimens per Test to be Performed According to the Specific Standard

Test	Standard	Number of Specimens
Static bending - B	EN 310 (1993a)	6
Apparent density - A	EN 323 (1993c)	6
Water absorption - A	EN 321 (2002)	6
Swelling in thickness (24h) - A	EN 317 (1993b)	6
Moisture Content (MC) - A	ABNT-NBR 14810-2 (2013)	6
Ultrasound NDT (MOEdyn) - C	ABNT-NBR 15630 (2009)	3

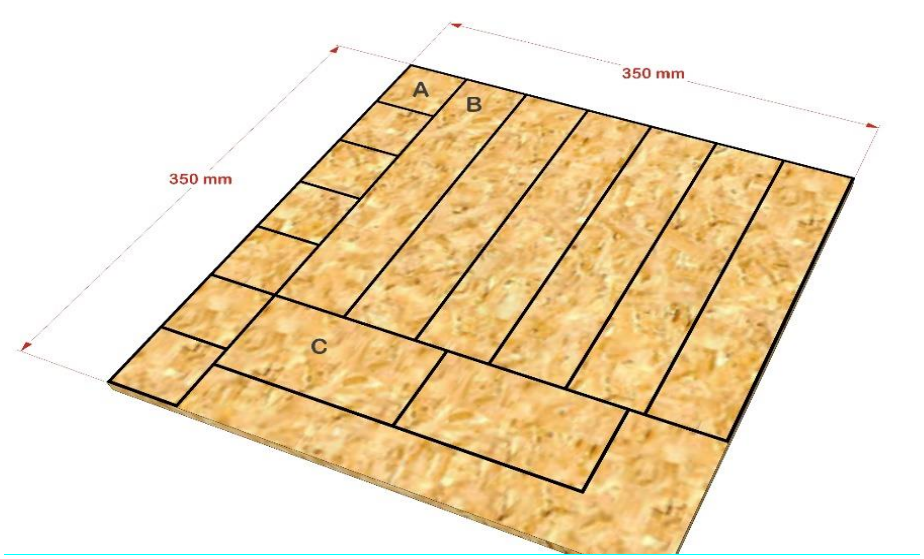

Fig. 3. Specimen cutting

The compaction ratio was calculated according to Eq. 1,

$$CR = \frac{\delta_{panel}}{\delta_{\sum mat}} \quad (1)$$

where *CR* depicts the compaction ratio, δ_{panel} is the panel density (g/cm3), and $\delta_{\sum mat}$ is the sum of the individual raw material densities (g/cm^3).

Nondestructive Ultrasonic Test

The nondestructive (NDT) ultrasonic test was performed on all panel's specimens, as described in Fig. 3 and Table 2. The equipment used was the Agricef–USLab model. The output was 700 V through metal-encapsulated transducers, which operated with a frequency of 45 kHz to directly measure the propagation velocity of the waves in microseconds. In the test, the transducers were placed on the center of the flat face of extremities of the specimen with an application of a thin layer of approximately 1 mm of gel without alcohol (Barcarolo 2019). The dynamic MOE (MOE_d) was determined through the following equation,

$$MOE_d = V^2 . \delta \tag{2}$$

where MOE_d is the dynamic modulus of elasticity (10^{-6} MPa), V is the longitudinal wave velocity (m/s), and δ is apparent density of the panel (g/cm^3)

RESULTS AND DISCUSSION

Table 4 shows the apparent density compaction ratio and the moisture content of the whole sample. The panels were designed to meet the values of density found in the literature, which average 0.65 as related by Cloutier (1998), Surdi *et al.* (2014), and LP Brasil (2019). Panels P3 and P4 presented the highest values of density compared to the rest of them. In these panels, the proportion of bark was higher than in the others to meet the final 10 mm of thickness, as stated above. As a consequence, the compaction ratio in these two types P3 and P4 increased (2.53 and 2.82, respectively), causing the densities and the final masses also to increase (Table 1). This finding agrees with the works by Suchsland (1977), Sobral Filho (1981), Zhow (1990), Zhang *et al.* (1998), and Morales (2014).

Particle density also affects the mechanical properties of the panel, since it is a function of the compaction ratio. Such a feature increases the contact surface among particles, consequently improving the adhesion. According to the authors, panels formed with low density materials generate panels with greater uniformity. Such panels have a high distribution capacity of forces among the particles, improving their strength to static bending and internal bonding (Kelly 1977; Hrázský and Král 2003; Maloney 1993; Surdi 2014).

The moisture content ranged from 7.63% to 8.83%. The panel types P3 and P4 presented a better response concerning this feature (7.84 and 7.63, respectively).

Table 4. Apparent Density, Compaction Ratio, and Moisture Content

		Apparent Density (g/cm^3)	Compaction Ratio	Moisture Content (%)
P1	Mean	0.514	1.13	8.83
	STD	0.08	0.18	0.63
	COV %	16.2	16.2	7.2
P2	Mean	0.567	0.86	8.80
	STD	0.068	0.07	0.76
	COV%	**11.9**	**5.4**	8.7
P3	Mean	0.914	2.53	7.84
	STD	0.11	0.30	0.23
	COV%	11.9	11.9	3.0
P4	Mean	0.909	2.82	7.63
	STD	0.016	0.56	1.03
	COV %	16.1	19.8	8.63

Table 5 displays the results of swelling and water absorption during the 2 and 24-hour immersions. Concerning swelling (Table 4), it was found that the panels P2, P3, and P4 (highest densities) presented mean values of swelling in a thickness lower than P1 after being submerged in water for both 2 and 24 h. As expected, the denser the panel, the lower the values of initial water absorption in the swelling tests (2 h).

Initial reduction of absorption can be explained by the fact that high density panels produce a physical barrier that prevents the access of water due to a greater mass (Mendes 2001). However, for longer periods of more than 24 h, the denser panels tend to absorb more water because of the larger number of particles resulting in a greater contact area per volume. This did not occur in the present study, possibly due to the addition of paraffin emulsion in the amount of 1% with relation to the dry weight of the particles. The paraffin emulsion reduced the water absorption by sealing the particles (Cloutier 1998; Marra 1992; Mendes *et al.* 2003, 2014).

Table 5. Swelling and Water Absorption

Panel		Swelling 2 h (%)	Swelling 24 h (%)	Water absorption 2 h (g)	Water absorption 24 h (g)
P1	Mean	19.2	29.5	81.9	90.7
	STD	4.1	8.6	8.8	6.1
	COV %	21.2	29.2	10.8	6.7
P2	Mean	11.4	17.1	40.8	51.2
	STD	1.7	2.4	4.5	3.7
	COV %	15.0	14.1	11.1	7.2
P3	Mean	11.2	20.0	34.0	49.5
	STD	3.3	2.3	9.4	9.5
	COV %	29.3	11.5	27.7	19.2
P4	Mean	8.3	20.5	39.2	56.5
	STD	1.8	1.1	9.4	8.8
	COV %	21.5	5.1	24.0	15.6

Concerning the 24-h swelling samples, the P2, P3, and P4 met the requirements of the EN 300 (2006) (17.1%, 20%, and 20.5%, respectively), as shown in Tables 4 and 6.

The mechanical properties of the panels are listed in Table 5. Panel 1 clearly presented the lower results concerning the MOE and MOR both transversally and longitudinally. The P2 and P3 had very similar values and the P4 is the best of all types according to EN 300 (2006), as shown in Table 1.

Regarding the bending tests (bending strength and stiffness), the modulus of elasticity (MOE) results observed in this work showed that only the P4-type panel fully met the OSB type 1 class requirements, established by the EN 300 (2006) (Table 6). Both P2 and P3 properties met the OSB type 1 requirements as well. However, both did not reach the minimum threshold established for EN 310 (1993a) transversal MOE (957 to P2 and 1097 to P3 compared to the standard's prescription of 1200 MPa).

The observation of the average values for the modulus of rupture (MOR) indicated that only the P4 type panels met the limits established by the EN 300 (2006), with respect to the OSB type 1 (Table 6). The other types did not reach the minimum values determined by the same standard. However, panels P2 and P3 could be employed to purposes different from the OSB. The P1 is not as suitable as the OSB panel.

Salari *et al.* (2013) found that the introduction of Nano-SiO_2 added at 3 levels of (1, 3, and 5 phc) improved significantly the mechanical properties of OSB made from underutilized low-quality paulownia. MOR and MOE increased when the Nano-SiO_2 was increased from 1 to 3 phc, but after that (5phc), both properties decreased.

Table 6. Mechanical Properties: Bending Static Tests and NDT Tests (in MPa)

		MOE_d - T	MOE_{st} - T	MOR -T	MOE_d - L	MOE_{st} - L	MOR -L	Density (g/cm^3)
P1	Mean	1023	369	2.5	797	949	4.1	0.514
	Max	1409	370	3.4	842	1086	4.4	0.595
	Min	1033	291	2.1	721	853	3.8	0.387
	STD	166	36	0.5	45	83	0.2	0.083
	COV%	16.2	9.8	18.7	5.7	8.7	5.6	16.2
	Mean	1157	957	6.1	2772	2249	14.5	0.567
	Max	1437	1233	7.3	3115	2347	15.2	0.553
P2	Min	984	818	7.3	2377	2069	13.1	0.495
	STD	174	168	7.3	254	106	0.8	0.029
	COV%	15.1	17.6	7.3	9.2	4.7	5.6	5.1
	Mean	1507	1097	7.8	3213	2435	17.4	0.914
	Max	1799	1192	9.7	3509	2554	18.4	1.071
P3	Min	1269	1022	6.5	3008	2288	15.9	0.809
	STD	217	69	1.3	203	110	1.1	0.108
	COV%	14.4	6.3	16.7	6.3	4.5	6.3	11.9
	Mean	1868	1228	9.7	3580	2780	18.4	0.909
	Max	1956	1261	10.3	4111	3126	19.1	1.060
P4	Min	1699	1204	9.2	2980	2325	16.2	0.710
	STD	94	21	0.4	391	294	1.1	0.016
	COV%	5.0	1.7	3.9	10.9	10.6	6.1	16.1

d: Dynamic NDT Test; st: Static Test

The addition of Nano SiO_2 could also be tested to improve mechanical properties of the panels in the present study. Concerning variation of results, for all parameters COV ranged from 5.1% to 16.1% which comply with the data by Bo (2017).

Figure 4 presents the correlation between the dynamic MOE (MOE_d) and static MOE (MOE_{st}). For all the types of panels, the trend is the same as the one depicted in Fig. 4, both for the longitudinal and transversal MOE. Although the dynamic ultra-sound underestimated the mechanical properties an average of 30%, the method could predict, quite accurately, the mechanical properties of the panel.

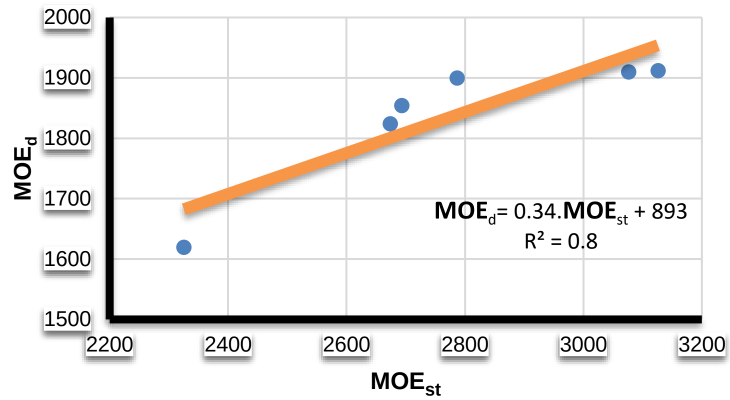

Fig. 4. Correlation between the MOE_d and MOE_{st}

CONCLUSIONS

1. With respect to the apparent density, compaction ratio, and moisture content, the panel types P3 and P4, specifically those with the highest amount of eucalyptus bark, presented satisfactory results concerning resistance to moisture absorption and to density.
2. As for swelling in thickness and water absorption in the periods of 2 h and 24 h, the panels P3 and P4, despite their high density, presented lower values than P1 type panels. P2 panels presented density close to P1 but swelling lower than P3 and P4. The application of the paraffin emulsion effectively influenced the reduction of the moisture absorption rates. Other materials such as Nano-SiO_2 could also be tested to improve this characteristic, as suggested by the literature.
3. The static bending results for panel type P4 have met the minimum limits required by the EN 300 (2006). Therefore, the P4-type panel fits as a general-purpose panel for use in dry environments.
4. P2 and P3 did not reach the minimum thresholds to be classified as OSB panels. However, those panels could be destined for purposes different from OSB. P1 type is not suitable as an OSB panel.
5. Ultra-sound testing is an accurate and quick method to predict mechanical properties of the panels, which was confirmed by the literature.
6. Eucalyptus bark, a rejected and environmentally harmful material, proved to be suitable

to produce OSB type panel, a highly value-added product.

7. The utilization of pine shavings, as well, even in low proportions, added value to a very poorly valued material, successfully.

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