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Research Article

Effect of Alternative Wood Species and First Thinning Wood on Oriented Strand Board Performance

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This study aimed to evaluate the feasibility of using and influence of alternative wood species such as Cambará, Paricá, Pinus, and wood from first thinning operations on oriented strand board (OSB) physical and mechanical properties. Besides that, an alternative resin, castor oil-based polyurethane, was used to bond the particles, due to the better environmental performance when compared to other resins commonly used worldwide in OSB production. Physical properties such as the moisture content, thickness swelling, and water absorption, both after 2 and 24 hours of water immersion, and mechanical properties such as the modulus of elasticity and resistance in static bending, in major and minor axes, and internal bonding were investigated. All tests were performed according to European code EN 300:2006. Results showed the influence of wood species on physical and mechanical properties. Panels made with higher density woods such as Cambará presented better physical performance, while those made with lower density woods such as Pinus presented better mechanical properties. Besides that, strand particle geometry was also influenced on all physical and mechanical properties investigated. Therefore, the feasibility of using alternative species and wood from first thinning and with castor oil-based polyurethane resin in OSB production was verified.

1. Introduction

Replacement of solid wood by composite panels for structural purposes, in several sectors of building construction, is often rising. Parameters concerning to ensure this context are, among others, definition of alternative raw materials (wood species and adhesives) as well as processing technologies that remain conferring physical and mechanical properties to the wood-based products, compatible with their specific applications [1–3].

Brazilian wood panel market, mostly constituted by producers of medium-density particleboards (MDPs), medium-density fiberboards (MDFs), and oriented strand boards (OSBs), is considerably growing in recent years [4]. Moreover, Brazil is among the countries with the most advanced manufacturing processes for wood panels from reforestation trees. According to data from the Brazilian Tree Industry (IBÁ), in 2015, the country was responsible for the production of 8 million m^3 of reconstituted wood panels, being the seventh largest worldwide producer [5].

Oriented strand board (OSB) is a well-known kind of panel made of strands or wafers, usually oriented, bonded with waterproof synthetic resin, and consolidated under heat and pressure [6–8]. Particles of the surface layer are aligned and arranged in parallel direction to the length or width of the panel, while particles of the core layer are randomly oriented or aligned generally in the perpendicular direction to the surface layer particles [9].

OSB market is also growing worldwide, and it is expected a growth rate of ≈28% until 2022 [10]. This increasing consumption in different sectors (mainly construction, furniture, and packing) is related to improvements in panels' properties such as strength, workability, and versatility [10].

These panels have a diversified range of uses, like packages, pallets, stands for display, frames for furniture, fences, and formworks, among others, wherever they are mainly intended for structural application [11, 12].

OSB panel is generally manufactured with low-density wood species. In Brazil, for example, industry uses mainly *Pinus* sp. wood species (mainly *Pinus elliottii* and loblolly pine *Pinus taeda*) in OSB production. Consequently, aspects like easy adhesion but high values of water absorption and thickness swelling are commonly observed in these products, as pointed out by Nascimento and Morales [13] and de Souza et al. [14].

Environmental concerns throughout the world have been showing that OSB is really a very newsworthy product because inclusions of more dense materials are true possibilities to expand OSB production and uses. Document of the Canadian Forest Industries [15] evidences that, since that date, excellent quality OSB has been produced with up to 50% of medium- and high-density wood species addictions. But it is always necessary to establish new alternative inputs, once application of wood-based products remains growing in several developing countries like Brazil and South Africa [16–18].

As raw materials of low density for alternative inputs, it can be considered *Pinus* sp. from first thinning and Paricá (*Schizolobium amazonicum*) wood species from planted forest in the Brazilian Amazonian region [19, 20]. These inputs can represent an important percentage of proper wood to OSB production.

When OSB with high physical performance is required, it is convenient to suggest that medium-density wood species be employed, once water absorption and thickness swelling reach interesting values, turning viable the application of essences with expressive availability in Brazilian Tropical Forest as Amescla (*Trattinickia* sp.), Cajueiro (*Anacardium* sp.), and Cambará (*Erisma uncinatum*) as explained by Freitas et al. [17].

Considering Brazilian diversity of wood species, this study aimed to evaluate the feasibility of using and the influence of alternative wood species on the physical and mechanical properties of OSB. Besides that, an alternative resin, castor oil-based polyurethane resin, was used to bond particles, due to the better environmental performance when compared to phenol formaldehyde and methylene diphenyl diisocyanate (MDI), both commonly used in OSB production.

2. Materials and Methods

For the development of this study, three different wood species were used: *Pinus* sp. with a bulk density of 500 kg/m^3, Cambará (*Erisma uncinatum*) with a bulk density of 720 kg/m^3, Paricá (*Schizolobium amazonicum*) with a bulk density of 400 kg/m^3, and *Pinus* sp. wood from first thinning, with a bulk density of 450 kg/m^3. Each wood species is from a different region of Brazil. *Pinus* sp. wood species and *Pinus* sp. wood from first thinning came from São Carlos City, State of São Paulo (Brazil southeast region). Cambará wood species came from Alta Floresta, State of Mato Grosso (Brazil midwest region), while Paricá came from Paragominas, State of Pará (Brazil north region).

Strands were generated from each wood species. For that, firstly, wood beams were cut into 90 mm wide and 35 mm thickness, which defined the strand's length and width, respectively. Strands were generated in a chipper disc, and they were obtained with a medium thickness of 0.7 mm as shown in Figure 1(a) [19–21].

OSBs were manufactured using an alternative resin, the castor oil-based polyurethane resin, of bicomponent type (Figure 1(b)). This resin is composed of polyol, a component derived from vegetable oil, and polyfunctional isocyanate (prepolymer), derived from crude oil. The ratio between polyol and isocyanate used was 1 : 1, and wax and other additives are not used in panel manufacturing.

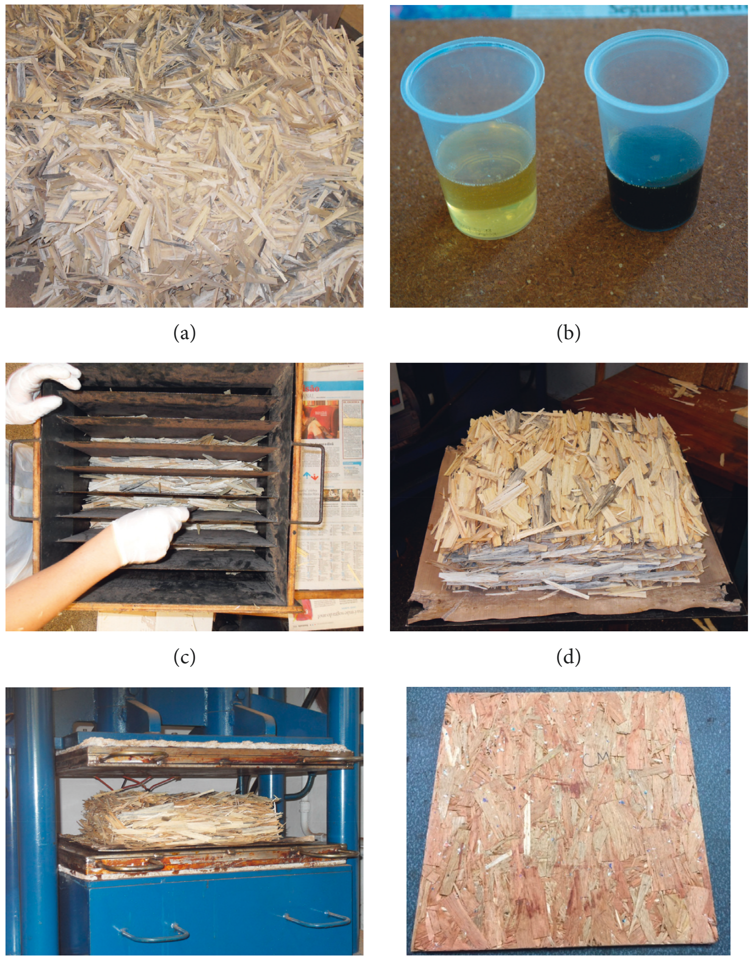
For all experimental conditions, 12% of resin content was used, in relation to dry mass of particles. The use of castor oil-based polyurethane resin, as well as the ratio between its components, is justified by the excellent results obtained in previous studies with wood-based panels. Besides that, castor oil-based polyurethane resin presents better environmental performance when compared with other resins such as MDI (methylene diphenyl diisocyanate) and phenol formaldehyde, both commonly used worldwide by the OSB industries [19–22]. Table 1 shows the experimental design of this study.

OSBs were manufactured with a nominal density of 650 kg/m^3 and in three layers (Figure 1(c)). Strands of each layer were manually distributed, with the strands of surface layers arranged in an oriented way (longitudinal direction of the panel), while particles of the core layer were randomly distributed. The face/core/face ratio of strands was 20 : 60 : 20, due to great results obtained in the literature such as Cloutier [23], Ferro et al. [24], and Nascimento et al. [25].

The formed mats were pressed for 10 minutes at a temperature of 100°C and specific pressure of 4 MPa (Figure 1(d)). For stabilization and complete cure of resin, panels were conditioned for 48 hours under environmental conditions. After this period, they were cut for subsequent removal of the specimens for physical and mechanical tests (Figure 1(e)) [26, 27].

Tests were performed according to European normative code EN 300 "*Oriented Strand Boards (OSB): Definitions, Classification and Specification*" [9] and complementary codes, due to the absence of Brazilian codes about OSB. Physical properties evaluated were the moisture content (MC), thickness swelling after 2 hours (TS2h) and 24 hours (TS24h), and water absorption after 2 hours (WA2h) and 24 hours (WA24h) of water immersion. Mechanical properties verified were the bending stiffness (MOEpar) and bending strength (MORpar) in the major axis and modulus of elasticity (MOEper) and resistance (MORper) in the minor axis and internal bonding (IB).

The Tukey test, at 5% of the significance level, was used to group the levels of the wood factor (Wood) (Cambará (Ca), Pinus (Pi), Paricá (Pa), and thinning (Wt)) used in the OSB manufacture. From Tukey's test, letter "a" denotes the level



(a) (b) (c) (d) (e) (f)

Figure 1: Steps of OSB production.

Table 1: Experimental design.

Experimental condition	Wood species	Bulk density (kg/m³)
Ca	Cambará (*Erisma uncinatum*)	720
Pa	Paricá (*Schizolobium amazonicum*)	400
Pi	*Pinus* sp.	500
Wt	*Pinus* sp. wood from first thinning	450

of the highest mean value factor, "b" the second highest mean value, and so on, and same letters imply levels with statistically equivalent means.

Anderson-Darling (AD) and Bartlett (Bt) variance homogeneity tests were used in the validation of Tukey's test. For the hypotheses formulated, P value (probability P) equal to or higher than the significance level implies normality and homogeneity of variances by property, which validates Tukey's test.

Table 2 shows the number of determinations for each property and for each wood species used in OSB production, which resulted in 620 experimental results.

Table 2: Number of determinations for each property and for each wood species used.

Properties	Cambará (Ca)	Pinus (Pi)	Paricá (Pa)	Thinning (Wt)
MC	5	12	14	30
TS2h	15	12	18	30
TS24h	15	12	18	30
WA2h	15	12	18	30
WA24h	15	12	18	30
MOEpar	15	12	18	28
MORpar	15	12	18	28
MOEper	5	4	5	5
MORper	5	4	5	5
IB	15	12	18	30

3. Results and Discussion

The density mean values for all experimental conditions are in accordance with the nominal density of 650 kg/m³ initially defined for panel production. The values obtained were 680,

Table 3: Physical property results in %.

Properties	Cambará (Ca)	Pinus (Pi)	Paricá (Pa)	Thinning (Wt)	CV (%)
MC	8.67 bc	9.30 ab	8.13 c	9.57 a	3.25; 12.88
TS2h	5.74 b	15.34 a	13.84 a	12.11 a	28.51; 37.85
TS24h	8.78 c	25.90 a	28.74 a	19.54 b	12.92; 26.45
WA2h	8.21 c	34.92 a	21.31 b	20.88 b	23.10; 34.01
WA24h	21.21 c	52.75 a	57.63 a	29.96 b	13.62; 23.35

700, 640, and 620 kg/m^3 for the OSB produced with Cambará, Pinus, Paricá, and wood from the thinning operations, respectively. Differences are associated with the manufacturing process of the panels.

Table 3 shows the mean values, the range of the coefficients of variation (CV), and Tukey's test results for physical properties evaluated.

The P values of the normality tests and homogeneity of variances for physical properties ranged in the intervals of 0.105 to 0.526 and 0.086 to 0.722, respectively, validating Tukey's test results.

Table 3 shows that, for moisture content (MC), the mean values for all evaluated treatments are within the ranges recommended by normative codes. According to European code EN 312 [28], the required moisture content must be between 5 and 13%, whereas according to the Brazilian normative code ABNT NBR 14810-2 [29], the MC for particleboards must be between 5 and 11%. Comparing the results obtained in this study with the related literature, the mean values are in conformity. Besides that, according to the technical report of the Technological Research Institute (IPT) [28], the moisture content for the OSB produced and marketed in Brazil is $7.8 \pm 3\%$.

For thickness swelling after 2 h (TS2h) and 24 h (TS24h) of water immersion, the highest mean values were obtained for the OSB manufactured with *Pinus* sp. and Paricá wood species. EN 300 [9] normative code only mentions TS24h. Comparing the mean values shown in Table 2 with those recommended by normative code, it could be observed that the OSB made from *Pinus* sp. and Paricá wood species reached mean values of 25.9 and 28.74, respectively. These values are higher than the maximum permitted value (25%) for OSB type 1 (panels intended for application in dry conditions).

On the other hand, the OSB manufactured with Cambará wood species and wood from the thinning operations presented lower values than that recommended by normative code, being categorized as OSB type 4 (boards for use in humid conditions) and type 2 (boards for use in dry conditions), respectively.

Mean values for TS24h obtained in this study are consistent when confronted with related studies in which were evaluated resins from the same nature. Nascimento et al. [25] obtained TS24h of 14.4% for the OSB manufactured with *Piptadenia moniliformis* Benth. and castor oil-based polyurethane resin; Akrami et al. [1] for the OSB with *Populus tremula* and *Fagus sylvatica* wood species together with isocyanate resin (polymeric methylene diphenyl diisocyanate (pMDI)) obtained mean values of TS24h between 10.0% and 28.0%.

Due to the absence of properties such as TS2h and water absorption after 2 h (WA2h) and 24 h (WA24h) of water immersion in normative codes, the mean values resulting from this study were compared to the literature. Thus, the results obtained indicated physical performances consistent with those of Mendes et al. [30] for TS2h of 31.9%, WA2h of 91.5%, and WA24h of 102.4% for the OSB made with *Pinus oocarpa* wood species with phenol formaldehyde resin. Saldanha [31] obtained mean values for TS2h of 28.0%, WA2h of 58.6%, and WA24h of 74.2% for the OSB produced with *Pinus taeda*. Saldanha and Iwakiri [32] obtained mean values for TS2h of 31.3%, WA2h of 72.3%, and WA24h of 82.3% when panels were made with MUF (melamine-modified urea formaldehyde) resin.

As can be observed in Table 3, wood species influenced significantly on all OSB physical properties analyzed. For all of them, the panel made with Cambará wood species presented better performances, that is, lower mean values of thickness swelling and water absorption for the evaluated periods.

According to Hsu [33], thickness swelling and water absorption parameters are the sum of three components, that is, reversible swelling of the wood itself, spring back of compressed wood, and separation of furnish. Besides that, low-density woods tend to have greater porosity, consequently, greater water absorption in relation to the high-density woods. At the same target density, a lower wood density resulted on higher compression ratio; consequently, it will increase the water absorption and thickness swelling values. The stress inside the panel is particularly released when submitted to water immersion.

Comparing only low-density wood species, it could be observed that the OSB manufactured with thinning wood presented better performance in relation to the panels made with Pinus and Paricá wood species. This is mainly related to the strand's particle geometry obtained for each wood species. Strand generation from wood from the thinning operations resulted in a large amount of fines, which up to a certain amount improves the performance of these properties, once these assist in filling panel empty spaces, reducing the amount of water absorbed.

Table 4 shows the mean values, the range of the coefficients of variation (CV), and Tukey's test results for mechanical properties evaluated. P values of the normality tests and homogeneity of variances for mechanical properties varied between 0.291 and 0.876 and between 0.233 and 0.524, respectively, validating Tukey's test results.

It can be observed in Table 4 that the mean values of MOEpar ranged from 5463 for the OSB manufactured with Cambará wood species up to 8238 MPa for the OSB made

Table 4: Mechanical property results in MPa.

Properties	Cambará (Ca)	Pinus (Pi)	Paricá (Pa)	Thinning (Wt)	CV (%)
MOEpar	5463 c	8237 a	6932 b	6395 b	8.21; 17.74
MORpar	30.20 b	54.77 a	52.90 a	36.40 b	8.39; 35.23
MOEper	1638 bc	2437 a	1366 c	1818 b	2.88; 17.03
MORper	12.16 c	22.50 a	18.63 ab	13.94 bc	10.58; 22.47
IB	0.66 b	1.58 a	0.54 b	0.77 b	24.63; 0.22

with Pinus. For MOEpar property, all OSBs reached the minimum value (4800 MPa) recommended by EN 300 [9] for OSB type 4 (special panels for structural purposes). Regarding MORpar, mean values ranged from 31 MPa (Cambará) up to 55 MPa (Pinus). In addition, all conditions obtained the minimum value (30 MPa) recommended by EN 300 [9] for OSB categorized as type 4.

The mean values of all experimental conditions evaluated were consistent with those of 5080 MPa and 38.5 MPa for MOE and MOR in the major axis, respectively, reported in IPT technical report [34].

In Table 4, it also could be observed that, for MOEper, mean values varied between 1367 MPa for the OSB manufactured with Paricá and 2437 MPa for the OSB made with Pinus. In addition, only panels made with Pinus wood reached the minimum value of 1900 MPa recommended by normative code [9] for OSB type 4. Regarding the other treatments, it reached the minimum value of 1400 MPa recommended for OSB types 2 and 3 (both load-bearing boards). For MORper property, mean values ranged from 12 MPa (Cambará) up to 22 MPa (Pinus). According to EN 300 [9], panels made with Cambará and thinning wood reached the minimum value of 11 MPa required for OSB type 3, while panels made with Pinus and Paricá reached the required value of 16 MPa for categorization as type 4. However, both panels are intended for structural application.

Comparing the mean values of MOEper and MORper obtained in this study with results of the literature, it was observed that there is consistency between them. Surdi et al. [3], for the OSB produced with hybrids of Pinus and phenol formaldehyde resin, obtained mean values of 992 MPa and 15.3 MPa for MOEper and MORper, respectively. Neimsuwan [35], for the OSB made with MDI resin, obtained mean values of 1381 MPa for MOEper and 13.5 MPa for MORper.

From Table 4, it could also be observed that the mean values for internal bonding (IB) ranged from 0.54 MPa (Paricá) to 1.54 MPa (Pinus). For IB, all treatments analyzed reached the minimum of 0.5 MPa value recommended for OSB type 4 [9].

Mean values of this study are consistent with those results reported in the literature for the OSB made with phenol formaldehyde resin and castor oil-based polyurethane resin. For example, Saldanha and Iwakiri [32], for the OSB with *Pinus taeda* L, obtained mean values of 0.39 MPa for IB; Nascimento et al. [25], for panels made with wood from Caatinga-Brazilian northeast regions such as Marmeleiro (*Croton sonderianus* Muell. Arg.) with the bulk density of 750 kg/m^3 to 850 kg/m^3, Jurema-branca (*Piptadenia stipulacea* (Benth.) Ducke) with the bulk density of 750 kg/m^3 to 900 kg/m^3, and Catanduva (*Piptadenia moniliformis* Benth.) with the bulk density between 800 kg/m^3 and 940 kg/m^3 obtained mean values of 0.45 MPa, 0.58 MPa, and 0.68 MPa, respectively.

For all properties, it was observed that wood species is a significant factor in panel performance, being the best one obtained for the panels manufactured with lower density woods. Panels manufactured with higher density wood species presented deficiency in adhesion, especially when considered that more dense woods present difficulties in the resin penetration.

However, Paricá and wood from the thinning operations are also lower density woods, and the OSB produced with these species presented lower mechanical performance when compared to Pinus species. The lower mechanical behavior may be associated with the strand's particle geometry, since during particle generation, a great amount of fines were obtained. The large amount of fines interfere in the mechanical behavior since the longitudinal properties of the wood contribute effectively to panel properties [36].

4. Conclusion

Results obtained in this study attest the viability of OSB production with some Brazilian species such as Cambará and Paricá and, besides that, the feasibility of using Pinus wood from first thinning and castor oil-based polyurethane resin. Panels produced could be introduced in Brazilian market, once they reach the code requirements. OSB is among the three main panels produced in Brazil with perspective of increase because it has more possibilities of use when compared to the other panels, such as MDF (medium-density fiberboards) and plywood, in civil construction and furniture industry.

For physical properties, wood species was an influence factor. It was observed that the lowest mean values, that is, better performance, were obtained for higher density woods such as Cambará, once those higher density woods tend to have lower porosity, and consequently, water absorption in relation to the lower density woods is smaller. Besides that, the OSB made with Pinus wood from first thinning presents better performance than the OSB made with Paricá and Pinus (all low-density species). This is the result of strand geometry, since that during particle generation from thinning wood were obtained a large amount of fines.

Regarding mechanical properties, it was observed that the wood species was a significant factor in panel performance. The better performance was obtained for OSBs made with low-density woods such as Pinus, due to the possible higher resin penetration in the wood. Even though they are manufactured with low-density woods, the OSB made with Paricá and wood from thinning operations presented worse properties than that made with Pinus. This is due to the strand geometry because the large amount of fines interfere in the mechanical property behavior, since the longitudinal properties of the wood contribute effectively to panel properties.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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