EVALUATION OF THE PHYSICO-MECHANICAL PROPERTIES OF PLYWOOD PANELS AND LAMINATED VENEER LUMBER OF *Pinus glabra Walt.*

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Resumo

Avaliação das propriedades físico-mecânicas de painéis compensados e de lâminas paralelas de Pinus glabra Walt. Este trabalho teve como objetivos avaliar o potencial da espécie *Pinus glabra* para a produção de painéis laminados, bem como, o efeito da densidade das lâminas e sua combinação sobre a qualidade do produto. Os painéis compensados e de lâminas paralelas foram produzidos a partir de duas classes de densidade de lâminas e da combinação entre elas, sendo: painéis com lâminas de 0,33 a 0,40 g/cm^3; painéis com lâminas de 0,41 a 0,48 g/cm^3; e, painéis com lâminas de 0,33-0,40 g/cm^3 na camada interna e 0,41-0,48 g/cm^3 na camada externa, originando 6 tratamentos. O adesivo utilizado foi o fenol-formaldeído, cuja formulação foi de 100 pp de adesivo, 20 pp de extensor, 10 pp de material de enchimento e 20 pp de água, e aplicado em gramatura de 180 g/m^2. Os parâmetros de prensagem foram pressão de 1 MPa e temperatura de 160ºC por 8 minutos. A avaliação da qualidade dos painéis foi realizada por meio de ensaios de massa específica aparente, flexão estática e resistência da linha de cola ao cisalhamento, segundo as normas europeias. Os resultados demonstraram que a produção dos painéis a partir da classificação de lâminas por densidades e combinação entre elas proporciona ganhos em resistência e rigidez, e que o direcionamento paralelo das lâminas (em PLP) proporcionou ganhos de resistência e rigidez quando comparado aos painéis produzidos com lâminas perpendiculares entre si (compensados), sendo, portanto, os mais indicados para uso estrutural. Por fim, conclui-se que a espécie *Pinus glabra* apresenta potencialidade para produção de painéis laminados.
Palavras-chave: LVL. Adesivos fenólicos. Painéis de madeira. Classificação de lâminas. Densidade de lâminas.

Abstract

This work evaluated the potential of the species *Pinus glabra* for the production of laminated panels, as well as the effect of the density of the veneers and their combination on the quality of the product. The plywood and laminated veneer lumber were produced from two veneer density classes and the combination between them, namely: panels with veneers from 0.33 to 0.40 g/cm^3; panels with veneers ranging from 0.41 to 0.48 g/cm^3; and panels with veneers of 0.33-0.40 g/cm^3 in the inner layer and 0.41-0.48 g/cm^3 in the outer layer, resulting in 6 treatments. Phenol-formaldehyde was used as adhesive, whose formulation was 100 pbw of adhesive, 20 pbw of extender, 10 pbw of filler and 20 pbw of water, and applied at a grammage of 180 g/m². The pressing parameters were 1 MPa and temperature of 160ºC for 8 minutes. The evaluation of the quality of the panels was performed through tests of apparent specific gravity, static bending and glue line shear strength, according to European standards. The results presented that the production of panels, from the classification of veneers by densities and combination between them, provides gains in strength and stiffness. The parallel direction of the veneers (in LVL) provided gains in strength and stiffness when compared to panels produced with veneers perpendicular to each other (plywood), being, therefore, the most suitable for structural use. Finally, we have the conclusion that the species *Pinus glabra* has potential for producing laminated panels.
Keywords: LVL; Phenolic Adhesives; Wood panels; Veneer classification; Veneer density.

INTRODUCTION

The species *Pinus glabra Walt.* is native to the United States and is prevalent in the states of South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana. Its dendrometric characteristics are the height of 30 meters and the diameter at breast height can reach 100 centimeters. The trunk can present different characteristics such as curves, twists or be naturally straight; in well managed plantations these characteristics are controlled, without major obstacles. The ideal place for its development is in the sandy alluvium and in the mesic forest of the coastal plains of the Atlantic and the Gulf, at 150 meters above sea level, with a cold resistance limit between -6.7°C and -12.1°C (AMERICAN CONIFER SOCIETY, 2018).

Its heartwood has a reddish brown color, while the sapwood is similar to yellowish white and, in addition, has a medium texture and straight grain. Its basic density varies between 0.42 and 0.52 g/cm³. It can be used for light civil construction and furniture because it has a density compatible with the species most used for this purpose. In general, the wood of *Pinus glabra* has great potential for use, standing out in terms of stability, classified as excellent. Another positive point is the low content of extractives and ash, which benefit its mechanical processing, pulping and burning. However, for services where high mechanical strength is required, its use must be cautious because its natural durability and workability are respectively low and reasonable (MEIER, 2015).

Since its introduction in Brazil until today, there is a lack of research related to this species. The most recent studies were by Dobner *et al.* (2018), which evaluated the growth of the species in southern Brazil, such as Vivian *et al.* (2020) who evaluated the physical, chemical and anatomical characteristics of wood, aiming at its use in the production of cellulosic pulp and paper, comparing it with *Pinus taeda*, which is currently the most used conifer species in the Brazilian softwood segment.

Using the research by Dobner *et al.* (2018) the potential for commercial use of *Pinus glabra* in southern Brazil was proven, therefore, it is an interesting alternative to commonly used species. Productions above 30 m³/ha/year can be expected at 24 years of age, as well as the production of dominant individuals with 30 cm in diameter at 15 years of age.

With advances in wood technology and the search for renewable materials around the world, the use of products from planted forests emphasizes their quality, sustainability, aesthetic beauty and durability, in addition to being able to replace materials and products widely used today. Therefore, wood panels have great relevance in the development and improvement of industries, allowing the generation of more jobs in the civil construction and furniture sectors, moving this and other sectors of the economy.

Among the wooden panels, laminates stand out, among the plywood and the laminated veneer lumber. Plywood is the most frequently produced and used panel. It consists of interspersing wooden veneers previously unrolled on a lathe and glued together with adhesive and pressure, so that one veneer overlaps the other, perpendicular to the fibers of the adjacent veneers. This positioning and gluing leads to movement compensation allowing for dimensional stability and a more uniform mechanical strength than solid wood, eliminating some negative attributes of the wood itself (ALMEIDA *et al*., 2013).

Brazil is a major producer of plywood panels, with worldwide prominence (TRIANOSKI *et al.*, 2015). Complementing the importance of this type of panel, Eisfeld and Berger (2012) state that it is a product of high value and quality, but with a relatively high cost compared to its competitors. Its uses and applications are multiple and varied, but the ones with the greatest purpose and visibility are those used as concrete forms in civil construction, industrial packaging and in the furniture sector.

With similar characteristics, the laminated veneer lumber (LVL), differs from the plywood panel by the parallel arrangement of its veneers, that is, all veneers are oriented in the longitudinal direction of the piece (KILIÇ, 2011). The advantages of this type of product include - as in the plywood panel: elimination of negative characteristics of wood resulting from any external factors or genetic structure (KILIÇ, 2011), large pieces with a homogeneous structure, superior mechanical properties when compared to solid wood (BAL; BEKTAS, 2012), good dimensional stability, better stress distribution, in addition to being biodegradable (TENÓRIO *et al.*, 2011). According to Faria *et al.* (2019), in Brazil its production is still incipient and does not occur on an industrial scale, but its application is gradually inserted in civil construction.

In addition to the type of product, there are other factors that affect the properties of laminated panels, such as the species used, the properties of its wood, the thickness of the veneers, the type of adhesive and its weight, the pressing parameters, the classification and position of the veneers, among others.

Thus, wood density stands out, which substantially affects the quality of laminated panels. This property must be carefully observed, as the veneers are obtained from different parts of the log, that is, great variation and little uniformity in density. Iwakiri *et al.* (2013) report that the limitations related to the low density of wood can be minimized with the use of gluing technologies, for example, in the manufacture of reconstituted wood products, such as laminated products. This reported low density is easily noticed in fast-growing planted forests, and in young trees with small diameters at breast height, which occur in abundance in Brazil.

A practice to take advantage of species or veneers of low density or even lower quality is to position them in the inner layer of the panel, ensuring that species or veneers of higher density are used in the outer layers. This practice aims to circumvent the problems arising from the variability of the wood without harming the final quality of the product, as the surface veneers are the ones that suffer the most tensions when subjected to mechanical stresses, especially during the static bending test (H`NG *et al*., 2010; LIMA *et al.*, 2013). Iwakiri *et al.* (2012) validated this information by studying structural plywood panels with different veneer compositions of *Eucalyptus saligna* and *Pinus caribaea*, where they observed a significant increase in the values of strength and stiffness (parallel) in the composition of the panels with veneers of *Eucalyptus saligna* - higher density - in the covers and with veneers of the three varieties of *Pinus caribaea* - lower density - interspersed in the inner layers.

In this context, where the study of species that are technologically and industrially little known in Brazil is extremely important, and knowing that the natural variability of wood, normally due to its genetics and abiotic factors and/or biotic interactions during its formation, it is a great difficulty for the uniformity of the final products, arises the need to work with different densities within the same species, in order to obtain a final result adequate to the requirements and that meets the current demand. Thus, the objective of this work was to evaluate the potential of the species *Pinus glabra* for the production of laminated panels, as well as the effect of the density of the veneer and its combination on the quality of the product.

MATERIAL AND METHODS

Obtaining the Wood

The wood used in this research came from an experimental plantation at the Experimental Station of Rio Negro at UFPR, located in the rural area of Rio Negro, on the banks of the BR-116 at km 200. Planting was carried out in 1995, with a spacing of 1.6 x 2.5 meters, the stand underwent a systematic thinning of 50% in 2009 and a selective thinning in 2016 of 20 to 25% at the time it was collected for this experiment. The Region has a climate classified as Cfb throughout the year; in general the temperature ranges from 9°C to 28°C and is rarely lower than 4°C or higher than 31°C.

Confection and Design

The lamination process was carried out at the Laboratory of Wood Panels at UFPR, where ten logs were laminated with a nominal thickness of 3.0 mm, and then dried to a moisture content close to 12%, being finally sectioned with dimensions of 500 x 500 mm (length and width). The logs did not undergo heating nor was the yield analysis performed.

After drying and stabilization, all slides had their apparent specific gravity determined. Weighing was performed on an analytical balance and the width and length dimensions were obtained with a measuring tape. The average thickness was determined by measuring four points on the sides of the veneers using a digital caliper. After the determination of the apparent specific mass, the slides were separated into two classes. The specific gravity ranged from 0.33 to 0.48 g/cm³, therefore, a class from 0.33 to 0.40 g/cm³ was established, and another from 0.41 to 0.48 g/cm³ for the elaboration of the experimental design of laminated panels, as presented in Table 1.

Table 1. Experimental design of the plywood and LVL.
Tabela 1. Delineamento experimental dos painéis compensados e de lâminas paralelas.

Treatments	Specific gravity of veneers (g/cm³)	Panel
T1	0.33 – 0.40	Plywood
T2	0.33 – 0.40	LVL
T3	0.33 – 0.40 (inner layer) / 0.41 – 0.48 (outer layer)	Plywood
T4	0.33 – 0.40 (inner layer) /0.41 – 0.48 (outer layer)	LVL
T5	0.41 – 0.48	Plywood
T6	0.41 – 0.48	LVL

Legenda: LVL, laminated veneer lumber.

The plywood and the laminated veneer lumber were produced with dimensions of 1.2 x 50 x 50 cm, 5 veneers and in triplicate, totaling 6 treatments and 18 panels (9 plywood and 9 LVL's). In treatments T3 and T4, the inner layer consisted of 3 veneers and the outer layer consisted of 1 veneer on each side (cover and back cover).

The resin used in the bonding was phenol-formaldehyde and the adhesive was formulated with the addition of wheat flour (extender), coconut shell (filling material) and water, in proportions of 100, 20, 10 and 20 parts by weight, respectively. The grammage applied was 180 g/m² in a single glue line. The panels were consolidated in a Siempelkamp hot press at a specific pressure of 10 kgf/cm² with a temperature of 160ºC, pressing time of 8 minutes and assembly time of 50 minutes.

After acclimatization, the panels were sectioned to obtain the specimens for the static bending tests and glue line shear strength stresses. The static bending test followed the EN 310 standard procedures to determine the modulus of rupture (MOR) and modulus of elasticity (MOE) in the parallel and perpendicular directions for the plywood panels, and in the *flatwise* and *edgewise* directions for the unidirectional panels.

The shear strength of the glue line was evaluated by the methodology proposed by EN 314-1 and EN 314-2, and the specimens underwent dry pre-treatment, cold water (24h), boiling (6h), boiling (72h) and the boiling cycle (4h of boiling, 16 to 20h of oven at 60°C, 4h of boiling and 1h in cold water). It is noteworthy that this test was performed only from specimens removed from the plywood panels (by traction) due to the thickness of the panels. Additionally, the apparent specific gravity was determined from the static bending specimens (prior to this test) and, according to the EN 323 standard, adapted to the dimensions of the samples.

Figure 1 presents: a) the static bending and shear specimens separated in plastic bags; b) Emic model DL2000 equipment with a maximum capacity of 20kN, used for the static bending and shear tests of the glue line; c) dry glue line shear specimen; d) shear specimen of the wet glue line; e) wet specimen after shear test, where a visual evaluation of the wood failure was performed.

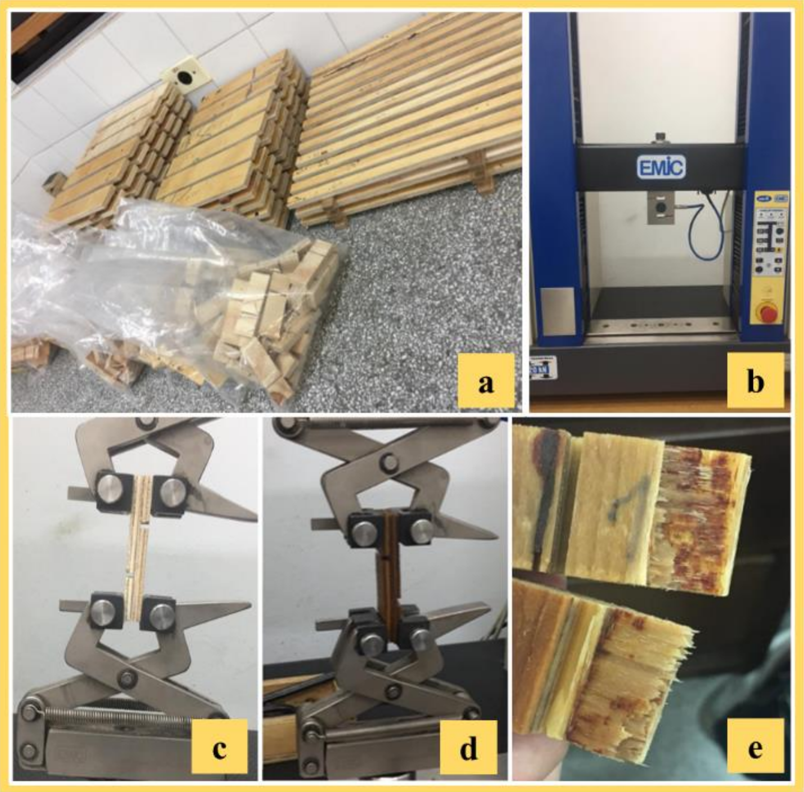

Figure 1. Demonstration of tests on samples under different conditions.
Figura 1. Demonstração dos ensaios nos corpos de prova em diferentes condições.

Statistical Analysis

Data were submitted to statistical analysis using *outliers* tests, Bartlett's homogeneity of variance, analysis of variance and Tukey's averages comparison; all at 95% of confidence interval (CI) using Statgraphics *software*.

RESULTS

The results related to the apparent specific gravity of *Pinus glabra* veneers are in Table 2, which ranged from 0.335 to 0.480 g/cm^3.

Table 2. Results of the specific gravity of the veneers of *Pinus glabra.*
Tabela 2. Resultados da massa específica aparente das lâminas de *Pinus glabra.*

Property	**Mean value**
Average specific gravity (g/cm³)	0.406
Minimum specific gravity (g/cm³)	0.335
Maximum specific gravity (g/cm³)	0.480
Coefficient of variation (%)	7.97

Table 3 presents the average results referring to the apparent specific gravity of the panels, as well as the average results of strength and stiffness to static bending of plywood and LVL's. For comparative purposes, reference values from the *Pinus* plywood technical catalog obtained by the ABIMCI National Wood Quality Program (2007) are also included.

Table 3. Average results of physical and mechanical properties of *Pinus glabra* multilaminate panels.
Tabela 3. Resultados médios das propriedades físico-mecânicas dos painéis multilaminados de *Pinus glabra*.

Plywood						
Treatment	**Specific gravity of veneers***	**ASG 12% (g/cm³)**	**Static bending (MPa)**			
			MOR Parallel	**MOE Parallel**	**MOR Perpendicular**	**MOE Perpendicular**
T1	0.33-0.40 g/cm^3	0.490 c (3.98)	37.03 b (17.04)	3142.12 c (17.43)	18.93 b (13.51)	1151.76 b (26.39)
T3	0.33-0.40 g/cm^3 e 0,41-0.48 g/cm^3	0.521 b (3.64)	39.95 b (20.84)	4546.33 b (13.17)	21.76 b (12.10)	1256.45 b (12.75)
T5	0.41-0.48 g/cm^3	0.563 a (3.90)	49.39 a (14.46)	5212.72 a (6.08)	25.14 a (10.89)	1983.27 a (12.41)
Minimun*		0.476	27.38	3100.72	20.58	1762.9
Average*		0.552	45.36	5139.78	32.05	2590.96
Maximum*		0.641	63.58	7063.29	45.27	4047.22
Laminated Veneer Lumber						
Treatment	**Specific gravity of veneers***	**ASG 12% (g/cm³)**	**MOR Flatwise**	**MOE Flatwise**	**MOR Edgewise**	**MOE Edgewise**
T2	0.33-0.40 g/cm^3	0.497 b (5.11)	45.70 b (13.48)	4822.26 b (19.84)	46.69 b (18.23)	5300.07 b (18.19)
T4	0.33-0.40 g/cm^3 e 0,41-0.48 g/cm^3	0.528 a (5.42)	55.87 ab (33.75)	7075.57 a (16.82)	50.35 ab (19.74)	6471.14 a (13.16)
T6	0.41-0.48 g/cm^3	0.541 a (6.20)	68.49 a (17.34)	7685.32 a (17.08)	58.14 a (17.93)	6937.42 a (12.02)

Legend: ASG, Apparent specific gravity; MPa, MegaPascal; MOR, Rupture Module; MOE, Elasticity Module; (*), Static bending strength values of pine plywood with 5 veneers and 12 mm; Averages followed by the same letter within the same column and panel type are statistically equal by Tukey's test at 95% CI; Values in parentheses refer to the coefficient of variation.
*In panels T3 and T4, the density of the veneers along the panels is in accordance with Table 1, as well as described below.

In order to evaluate the effect of the orientation of the veneers (Parallel Plywood and LVL *flatwise*) in the different specific gravity classes on the strength properties, Table 4 presents the average results of MOR and MOE at static bending of the plywood panels in the parallel direction and of the LVL panels in the *flatwise* direction.

Table 4. Average results of the effect of the orientation of the veneers (products) on static bending.
Tabela 4. Resultados médios do efeito da orientação das lâminas (produtos) sobre à flexão estática.

Tratamento	**Specific gravity of veneers***	**Static bending (MPa)**			
		MOR Parallel Plywood	**MOR *Flatwise* LVL**	**MOE Parallel Plywood**	**MOE *Flatwise* LVL**
T1 e T2	0.33-0.40 g/cm^3	37.03 a (17.04)	45.70 b (13.48)	3142.12 a (17.43)	4822.26 b (19.84)
T3 e T4	0.33-0.40 g/cm^3 e 0,41-0.48 g/cm^3	39.95 a (20.84)	55.87 b (33.75)	4546.33 a (13.17)	7075.57 b (16.82)
T5 e T6	0.41-0.48 g/cm^3	49.39 a (14.46)	68.49 b (17.34)	5212.72 a (6.08)	7685.32 b (17.08)
General		42.12 a (23.21)	56.69 b (27.34)	4300.39 a (23.04)	6527.72 b (25.43)

Legend: LVL, Laminated Veneer Lumber; MOR, Rupture Module; MOE, Elasticity Module; averages followed by the same letter on the same line and within the same property (MOR or MOE) are statistically equal by Tukey's test at 95% CI; Values in parentheses indicate the coefficient of variation in percentage.
* In panels T3 and T4, the density along the panels is in accordance with Table 1, as well as described below.

Table 5 presents the average results of the evaluation of the bonding quality by the glue line shear strength test of the plywood panels, as well as the minimum normative requirements of the EN 314-2 standard and the values obtained by the PNQM of ABIMCI from tests with industrial plywood panels made of *Pinus*.

Table 5. Average results of the glue line shear strength.
Tabela 5. Resultados médios da resistência da linha de cola ao cisalhamento.

Treatment/ Specific gravity of veneers*	Dry		Water 24h		Boiling 6h		Boiling 72 h		Boiling cycle 25h – 29h	
	GLSS (MPa)	Failure (%)	GLSS (MPa)	Failure (%)	GLSS (MPa)	Failure (%)	GLSS (MPa)	Failure (%)	GLSS (MPa)	Failure (%)
T1 – 0.33-0.40 g/cm^3	1.86 a (21.46)	79	1.17 ab (17.39)	55	1.02 a (24.83)	71	0.93 ab (19.78)	53	1.04 a (23.81)	69
T3 – 0.33-0.40 g/cm^3 e 0,41-0.48 g/cm^3	1.50 b (23.94)	88	1.02 b (25.48)	61	0.96 a (26.02)	40	0.78 b (34.56)	81	0.90 a (16.28)	59
T5 – 0.41-0.48 g/cm^3	1.94 a (15.44)	70	1.31 a (18.89)	49	1.08 a (17.94)	39	1.06 a (24.66)	47	0.95 a (26.98)	25
Minimun*	-	-	-	-	-	-	0.68	34.83	-	-
Average*	-	-	-	-	-	-	1.07	63.93	-	-
Maximum*	-	-	-	-	-	-	1.47	86.83	-	-

Legend: GLSS, glue line shear strength; MPa, MegaPascal; (*), Strength values of the pine glue line with 5 veneers and 12 mm from the 2007 pine plywood technical catalog; averages followed by the same letter within the same column and panel type are statistically equal by Tukey's test at 95% CI; Values in parentheses refer to the coefficient of variation. Minimum requirements for approval according to EN 314-2: > 1.0 MPa (no minimum failure required); Strength ≥ 0.6 and < 1.0 MPa failure ≥ 40%; Strength ≥ 0.4 and < 0.6 MPa failure ≥ 60%; and Strength ≥ 0.2 and < 0.4 MPa failure ≥ 80%.
* In panels T3 and T4, the density of the veneers along the panels is in accordance with Table 1, as well as described below.

DISCUSSION

In relation to what was observed in Table 2, the average value of the apparent specific gravity of the veneers was 0.406 g/cm³, classifying the wood of *Pinus glabra* as having low density. Considering *Pinus taeda*, a species widely used by the lamination and plywood industries in southern Brazil, in the literature values from 0.320 to 0.400 g/cm³ are found for basic specific gravity of *P. taeda* from 12 years of planting (TAVARES *et al.*, 2020). In a 17- and 18-year-old *P. taeda* plantation, Trianoski *et al.* (2014) obtained a value of 0.527 g/cm³ for apparent density and basic density in 35-year-old trees Mendes *et al.* (2013) found a value of 0.473 g/cm^3. In this way, the result is close to the densities commonly used for the lamination process, allowing the species to be evaluated among the initial parameters for the production of the referring panels.

As for other species of the genus, emphasis is placed on those planted in Brazil, which have practically the same territory of origin as P. glabra. In light of this, Trianoski *et al.* (2014) found apparent specific gravity values for 7 tropical pine species of 17 and 18 years of age ranging from 0.435 to 0.577 g/cm³, being them the *P.c. bahamensis* – 0.491 g/cm³, *b.w. caribaea* – 0.435 g/cm³, *b.w. hondurensis* – 0.502 g/cm³, *P. oocarpa* – 0.552 g/cm³, *P. chiapensis* – 0.435 g/cm³, *P. maximinoi* – 0.533 g/cm³ and *P. tecumannii* – 0.577 g/cm³. In research with a hybrid of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* (PEE x PCH) of seven years, Almeida *et al.* (2012) found a value of 0.320 g/cm³ for basic specific mass; Tavares *et al.* (2020) found basic density values between 0.300 and 0.350 g/cm³ for the 12-year-old *Pinus patula* species.

In the panels produced, Table 3 presents the apparent specific gravity varying between 0.490 and 0.563 g/cm³, and for LVL between 0.497 and 0.541 g/cm³, both increasing according to the different compositions of the specific gravity of the sheets. Statistically, there was a significant difference between the three treatments of the plywood panels (T1, T3 and T5), in relation to the lamianted veneer lumber, this difference was observed only between T2 *versus* T4/T6.

In this property, both the plywood panels and the unidirectional panels were similar to those described in the ABIMCI Technical Catalog (2007), whose average value for 5-ply phenolic panels is 0.552 g/cm^3 with a variation from 0.476 to 0.641 g/cm^3. Regarding the apparent specific gravity of laminated panels obtained by other researchers, especially for the species *Pinus taeda*, the values were 0.716 g/cm^3 (MENDES *et al.*, 2013) and 0.426 to 0.542 g/cm^3 (TAVARES *et al.*, 2020). In the hybrid (PEE x PCH), the value obtained was 0.413 g/cm^3 (ALMEIDA *et al.*, 2012), whereas for the species *Pinus oocarpa*, Lima *et al.* (2013) obtained an average value of 0.663 g/cm^3, and Tavares *et al.* (2020) found values from 0.430 to 0.472 g/cm^3 for laminates of *Pinus patula*.

As for the static bending results of the plywood panels, the increases in both strength and stiffness according to the increase in the density of the veneers/panels are notorious. For the MOR, in both test directions, a statistically significant difference was found between the T1 and T3 panels in relation to the T5, with the first two being statistically equal to each other, but inferior to the last. As for the MOE, the T5 treatment, produced with denser veneers, was statistically superior to the other two.

In comparison with the values of MOR and MOE presented by the PNQM of ABIMCI for industrial phenolic panels, it appears that the average values of the properties of MOR and MOE in the parallel sense are similar to those presented by this association; in the perpendicular direction, they were generally slightly inferior.

When evaluating tropical pine plywood panels Iwakiri *et al.* (2009) obtained values from 51.26 to 81.48 MPa for MOR and from 4627 to 7843 MPa for MOE, slightly higher than those found in this research, however, in relation to Almeida *et al.* (2012) who found from hybrid plywood panels (PEE x PCH), average values of 44 MPa and 20 MPa, and, 1397 MPa and 3394 MPa, respectively for parallel and perpendicular MOR and MOE, and also, Mendes *et al.* (2013) whose values were 48.5 and 33.6 MPa for parallel and perpendicular MOR and 7923 and 2243 MPa for parallel and perpendicular MOE from *Pinus taeda* plywood panels, a similarity between the values is stated.

The results of the flexural properties of the laminated veneer lumber followed the same trend of the plywood panels, where both MOR and MOE tended to increase with increasing density. A statistically significant difference was found only for panels produced with veneers of higher density - 0.41-0.48 g/cm^3 (T6) in relation to panels produced with veneers of lower density 0.33-0.40 g/cm^3 (T2). The T4 treatment, produced with lighter veneers in the inner layer and with higher density in the outer layer, were statistically equal to the treatment with the best bending performance (T6).

This result can be considered very interesting, as a tree has veneers of different qualities and densities depending on the position obtained. This combination makes it possible to maximize the performance, without, however, considerably reducing the mechanical resistance, as well as constituting an economic advantage in the production of these panels.

Regarding the quality of experimental LVL panels produced in Brazil, since production on an industrial scale is still incipient, the values found in the literature were: 48.1 MPa and 7139 MPa for MOR and parallel MOE of *Pinus taeda* panels and 54.7 MPa and 7136 MPa for *Pinus patula* panels (TAVARES *et al.*, 2020) and 74.49 MPa and 5338.95 MPa for MOR and MOE of *Pinus oocarpa* panels (LIMA *et al.*, 2013).

The average results presented in Table 4 refer to the evaluation of the effect of the orientation of the veneers on the static bending of the final product or type of laminated panel. They presented that, for both MOR and MOE between plywood and LVL (Parallel x *Flatwise*), statistically significant differences were found for all treatments (veneers density variations), where the LVL were superior in relation to the plywood panels.

In composite laminated panels with veneer density of 0.33-0.40 g/cm^3 there was a gain of 23.41% in MOR and 53.47% in MOE, in the composition that used veneers of 0.33-0.40 g/cm^3 in the inner layer and 0.41-0.48 g/cm^3 on the covers, the gain in MOR was 39.84% and 55.63% in MOE. Finally, for panels produced with veneers with a density of 0.41-0.48 g/cm^3 the gain in MOR was 38.67% and MOE of 47.43%. Regarding only the different panels, excluding the different classes of specific gravity of the veneers, the gain observed in the MOR was 34.59% and in the MOE it was 51.79%. Thus, it is evident that the orientation of the veneers always in the longitudinal direction and that characterize the LVL have greater strength and stiffness, and when this property is desired or greater strength is sought in structural products, this is the best configuration.

For the evaluation of the bonding quality through the glue line shear test, the results presented, from the dry pre-treatment, statistically significant differences between them, where the T3, produced with denser layers in the layers and less dense in the inner layer, was statistically inferior to the others. In this test condition, all treatments reached the minimum approval requirement of 1.0 MPa, as well as high wood failure values. It is also noteworthy that the standard does not require dry tests, which are performed as a control.

The shear results after pre-treatment in cold water indicated higher average strength of the T5 treatment, but statistically superior only in relation to the T3. All presented strength superior to the EN 314-2 minimum requirement of 1.0 MPa. For the test after boiling 6h, the values ranged from 0.96 to 1.08 MPa, all being statistically equal to each other. In this test condition, all treatments met the minimum normative requirement of 1.0 MPa without wood failure requirement (T1 and T5), or when they presented strength ≥ 0.6 and < 1.0 MPa, the wood failure was 40%.

For the pre-treatment of 72h of boiling, the shear strength values ranged from 0.78 to 1.06 MPa. A statistically significant difference was observed between treatments T3 and T5. The minimum requirement for bonding approval according to EN 314-2 was achieved for all treatments, through a minimum strength of 1.0 MPa (T5), or a combination of strength and minimum failure (T1 and T3) . For the boil cycle pre-treatment, the strength ranged from 0.90 to 1.04 MPa, all being statistically equal to each other. The T5 treatment, with a strength of 0.95 MPa, presented a low percentage of wood failure (25%), failing the minimum normative requirement.

This occurrence reveals the association of greater wood failure with wood density. When this interaction is exposed to a more drastic condition, it manifests itself in a more intense way. Therefore, it is known that denser woods have a greater amount of cellulose and/or late wood, and these are responsible for the phenomenon of contraction and swelling. Probably because of this greater contraction, as well as the boiling and drying sequence, the tensions in the glue line occur in an exacerbated way, preventing the tracheoids from supporting the forces and also allowing greater failure.

The quality of collage in the research by Tavares *et al.* (2020) reveals similarity with the values in this presented where they obtained shear strength of 1.01 MPa, 0.99 MPa, 0.90 MPa and 0.78 MPa, respectively for wet test (24h) and boiling of phenolic plywood panels of *Pinus taeda* and *Pinus patula*. Mendes *et al.* (2013) found moderately higher values, being 2.90 MPa and 1.63 MPa for dry shear and boiling test of plywood panels of *Pinus taeda*; in the same way as Iwakiri *et al.* (2009) where they obtained values from 1.79 to 2.16 MPa for the dry test and from 0.88 to 1.42 MPa for the boiling test in tropical pine plywood panels.

When comparing the results obtained in this research with the values presented by the PNQM of ABIMCI, for industrial panels and evaluated under the pre-treatment of boiling 72h (0.68 to 1.47 MPa and failure of 34 to 86%), it is stated that the results are compatible and that the species *Pinus glabra* has good gluing quality, that is, a significant potential for gluing veneers for the production of laminated panels.

CONCLUSIONS

- The apparent density of the plywood panels varied from 0.490 to 0.563 g/cm³, according to the different density compositions of the veneers.
- The production of plywood and unidirectional panels, based on the classification of veneers by classes of apparent specific gravity and the combination between them, provides gains in strength and stiffness (MOR and MOE in static bending).
- The parallel direction of the veneers (in LVL) provided gains in strength and stiffness when compared to panels produced with veneers perpendicular to each other (plywood).
- The apparent density of the veneers did not markedly affect the glue line shear strength of the plywood panels.
- The results presented that the species *Pinus glabra* has potential for the production of laminated panels.

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