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PHYSICAL-MECHANICAL PROPERTIES OF MULTILAMINATED PLYWOOD PANELS PRODUCED WITH *Cecropia hololeuca* AND *Pinus elliottii*

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Abstract: The work aimed to evaluate the physical and mechanical properties of plywood panels produced with *Cecropia hololeuca* and *Pinus elliottii*, in different compositions of blades, phenol-formaldehyde rhein was used, with a solids content of the beat of 35%, weight of 160 g/cm³ in a single line, in the pressing cycle a pressure of 12 kgf/cm² and a temperature of 140 °C for 10 min. Based on the recommendations of ABNT standards, physical-mechanical tests of apparent specific mass were performed; water absorption; swelling in thickness; swelling plus recovery in thickness; moisture content, static bending and shear in the glue line. The panels produced showed physical-mechanical properties in accordance with the parameters defined by ABIMCI and ABNT. Some results obtained significant differences, with emphasis on the panels with pine veneers and those combined with pine on the cover.
Keywords: Embaúba, Phenol-formaldehyde, Native species.

INTRODUCTION

Multilaminated plywood panels generally have superior physical-mechanical properties compared to particulate wood panels. It still has better applicability to sawn wood, which is related to the dimensions that are produced. Being important characteristics for the sectors where they are destined, highlighting in Brazil the civil construction and the production of furniture. Multilaminated plywood can be used indoors when using the urea-formaldehyde adhesive and outdoor use or "waterproof" when the bonding is based on phenol-formaldehyde adhesive (IWAKIRI, 2005). Currently in Brazil, wood from fast-growing species such as pine, eucalyptus and, recently, paricá, a tropical species with a vast planted area in the north of the country, are used (PINTO and IWAKIRI, 2013).

The strategies indicated for the maintenance of the plywood companies in the market are the redirection to the domestic market, the European Union and the Middle East, being hampered by the strong competition from Asian countries, such as China, which makes it difficult to access international markets and consequently consumption of Brazilian production (SCHWAB et al. 2012). According to Iwakiri (2004), several species of pine have been researched for the production of sheets and plywood and that sheets of this species can be used in combination with hardwood species. This context requires from Brazilian companies greater investments in production technology that increase their productivity, as well as the search for new species of fast growth and good quality, which provide wood with a larger diameter in less time, in order to provide greater viability for the use of multi-laminated plywood panel, both in the domestic and foreign markets.

In order to seek new sources of raw material, some researches were developed evaluating the use of other species in the production of plywood panels. Iwakiri et al. (2013) analyzed the production of multi-laminated plywood panel using wood veneers of *Sequoia sempervirens* bonded with phenol-formaldehyde resin. Pinto and Iwakiri (2013) determined the quality of veneer plywood panels *Criptomeria japonica* bonded with phenol-formaldehyde and urea-formaldehyde resins. Other authors, such as Palma et al. (2012), Iwakiri et al (2011), Albino et al. (2011), Lima and Pio (2007) and Bortoletto Jr. and Belini (2002) used wood veneers of *Hevea brasiliensis; Schizolobium amazonicum* Huber ex*; Toona ciliata; Copaifera duckei e Eperua oleifera*; and *Schizolobium parahyba* Vell. Blake, respectively.

According to Iwakiri et al (2010), in the northern region of the country, specifically in Pará, erect trees of *Cecropia hololeuca*

(Embaúba), without ramifications, reaching up to 15 m in height, with very light and whitish wood, with a specific mass of 0.43 g/cm³. And they conclude that the species has technically viable potential for agglomerate production. In another study, Iwakiri et al. (2012) also concluded that the wood of the species is suitable for use in wood-cement panels.

According to Barichello and Foelkel (1975), embaúba wood is very light and whitish. Its most common uses are: boxes, cellulose, matchsticks and when burned, charcoal is recommended as excellent for the manufacture of gunpowder. The authors concluded that the species produces cellulose sulfate of reasonable quality.

Thus, researching the use of wood from alternative species and the combination of wood from different species for the production of plywood means expanding the supply of raw material for the wood sector and, at the same time, contributing to environmental preservation. With this, arousing the interest of giving yet another application to the wood of *Cecropia hololeuca,* this study aims to evaluate the use of wood veneers of the species and in mixture with *Pinus elliottii* for the production of multi-laminated plywood panels.

MATERIAL AND METHODS

MATERIAL COLLECTION

Two species of wood were used, the *Cecropia hololeuca* (Embaúba) and *Pinus elliottii* (pinus), three logs per species were used. Embaúba wood comes from forests aged between 16 and 19 years (basic density of 0.33 g/cm³), located in Dom Eliseu - PA, at coordinates 04º 17' 06" S/ 47º 30' 18" W, and were provided by a company in the region, later transported to Irati - PR 25º 27' 56" S/ 50º 37' 51" W.*Pinus elliottii*, aged 14 years (basic specific mass of 0.55 g/cm³), were taken from commercial plantations of a company in the region of Irati-PR. Being processed the steps of lamination, drying and preparation of the slides for both species in this region.

PRODUCTION OF BLADES AND PANELS

The logs were laminated on a defoliator lathe with a spindle traction system, brand Thoms Benato, with the following adjustment: knife sharpening angle of 21°, knife angle of 90°30', horizontal opening of 1.35 mm and vertical opening of 0.75 m. Blades measuring 1.70 m wide and 1.5 mm thick were produced. Immediately after turning, the blade mat was sectioned into 1.70 x 1.35 m blades.

The slides were dried in a dryer with roller system, Benecke, at a temperature of 130°C and a speed of 21 m/min, leaving them with a final moisture content of 11%. After drying, the blades were cut into four pieces measuring 0.60 x 0.60 m using an Indumec square saw. The dry and cut veneers were classified using the classification criteria for hardwood and coniferous plywood panels, according to Standards NBR ISO 2426/1:2006 (ABNT, 2006a), NBR ISO 2426/2:2006 (ABNT, 2006b) and NBR ISO 2426/3:2006 (ABNT, 2006c). The sheets used for the core in the panels, which had an average moisture content of 11%, were dried at a temperature of 50°C for one hour in an oven with ventilation forced, with an average moisture content of 6%. Then, they underwent a 20-minute cooling period.

The manufacture of the panels was carried out in the Wood Technology laboratory at UNICENTRO, which had dimensions of 60x60 cm, with seven layers of sheets with 1.5 mm thick each.

For the production of the panels, only Class E veneers were used. Phenol-formaldehyde (FF) resin was used, with 54% solids content. In the beating of glue, a proportion of 67.3% of adhesive, 16.35% of wheat flour and 16.35% of water was adopted, so that the mixture reached a solids content of 35% and a viscosity of 40 to 60 seconds. The application of the adhesive was performed manually with a spatula, with a weight of 160 g/cm² in a single line. The panel assembly was carried out by overlapping sheets, following the concept of cross lamination. The panels underwent an assembling period of 30min and then taken to hot pressing, in a pressing cycle of 10 minutes, pressure of 12 kgf/cm² and temperature of 140°C.

OUTLINE

The variable of interest analyzed was the combination of wood veneers, totaling four treatments with three replications each, according to the experimental design presented in Table 1.

After pressing, the panels were squared and conditioned in the climatization chamber at a temperature of 20±2ºC and relative humidity of 65±5% until stabilization. Subsequently, the physical-mechanical properties were determined, namely: apparent specific mass of the panel (NBR 9485/2011), moisture content (NBR 9484/2011), water absorption (NBR 9486/2011), swelling and swelling plus thickness recovery (NBR 9535/2011), modulus of rupture and modulus of elasticity in static bending, parallel and perpendicular to the fibers of the cover sheet, (NBR 9533/2012), shear strength in the glue line, after wet treatment (immersion of the bodies for 24 hours in water at room temperature) and boiling (immersion of the specimens for 6 hours in boiling water and then for 1 hour in water at room temperature) NBR ISO 12466/1 and NBR ISO 12466/2.

STATISTICAL ANALYSIS OF RESULTS

The average values of the physical-mechanical properties of the panels were compared with the requirements described in the ABIMCI technical catalogs and with the ABNT standards. To analyze the properties of the panels, satisfying the prerogatives of homogeneity of variances and normal distribution, ANOVA was applied in a completely randomized design, with a 5% error probability, for the factor and its interactions. If there were significant differences between treatments, Tukey's test was performed to compare the means.

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES

Table 2 shows the average values of the physical properties of the panels (apparent specific mass, moisture content, water absorption, swelling, swelling and thickness recovery).

Treatment	Cover/Back Cover - 4 blades	Brain- 3 blades	Repetitions
T1	Embaúba	Embaúba	3
T2	Embaúba	Pinus	3
T3	Pinus	Pinus	3
T4	Pinus	Embaúba	3
Total of pannels			12

Table 1 – Experimental design.

Treatments	MEA (g/cm³)	TU (%)	AA (%)	I (%)	IR (%)
Embauba/Embauba	0,50 b	13,24 a	74,10 a	6,71 a	0,55 a
Embauba/Pinus	0,51 b	13,10 ab	71,13 a	7,01 a	0,91 a
Pinus/Pinus	0,61 a	12,12 c	56,27 b	8,29 a	1,93 a
Pinus/Embauba	0,52 b	12,89 b	61,02 b	7,02 a	0,66 a
F calc	31,5810*	38,9302*	23,6089*	1,7506 ns	2,4555 ns

Notes: Means followed by the same letter do not differ statistically from each other. The Tukey Test was applied; *: significant at 5% error probability; ns: not significant; MEA: Apparent specific gravity; TU: Moisture content; AA: Water absorption; I: Swelling; IR: Swelling and recovery in thickness.

Table 2- Average values of the physical properties of plywood panels.

The results for apparent specific mass ranged from 0.49 to 0.61 g/cm³. The pure pine panels had a high apparent specific mass, above the quality standards, which is 0.59 g/cm3. On the other hand, the composite panels with embaúba veneers had an apparent specific mass below the recommended minimum, which is 0.52 g/cm3, as described in the ABIMCI Technical Catalog (2002).

There was a statistically significant difference between the results of apparent specific mass, the panels composed only of pine veneers showed higher values than the others. Since these results are related to the basic density of the species used in this study, it was observed that the mixture of veneers provided a balance in the values of this property, equaling the pure embaúba panels. In the studies by Albino et al. (2011), differences were also observed in the apparent specific mass values between the mixed panels produced with sheets of *Pinus* sp./*Toona ciliata* and pure composition of *Toona ciliata,* where the results were related to the difference in the basic density between the species studied.

The average moisture content of the panels ranged from 12.12 to 13.24%, in accordance with the maximum value of 18% for packaged panels, as described by ABIMCI (2009). There is a statistical difference between the panels, noting that the panels containing embaúba veneers presented higher values of moisture content, which may be linked to the difference in the physical and chemical properties of the wood. For Jankowski and Galvão (1979), extractives act as filling material (occupying places that would be available for the adsorption/desorption of moisture from the cell wall), the inherent factors of wood that condition the adsorption of moisture are the cellulose content and the crystallinity of this cellulose, because water freely enters the amorphous regions of the cellulose, where it is adsorbed by the available hydroxyl groups and, in the crystalline region, the water is adsorbed only on the surface, due to its inability to penetrate the interlacing of crystals of crystalline molecules of cellulose.

The variation of the averages of the water absorption results was from 56.27 to 74.10%. The results found in this study are similar to those of Albino et al. (2011), who observed a variation from 56.67 to 84.67% in panels with veneers of Toona ciliata (wood with a basic density of 0.32 g/cm³) and mixed with Pinus sp (wood with a basic density of 0.5 g/cm³).

A statistical difference was observed between the water absorption results, as the panels containing embaúba veneers on the cover presented higher values, which may be associated with the difference in the basic specific mass between the species and consequently have different porosities that influence water occupation. free. For Guimarães et al. (2009), the material with the lowest specific mass has the potential to present greater porosity and, consequently, can be occupied with a greater amount of free water. Albino et al. (2011) also stated that panels composed of low density veneers absorbed more water.

No statistically significant difference was observed in the results of swelling and swelling plus recovery in thickness, where the mean values for swelling in thickness ranged from 7.00 to 8.09% and swelling plus recovery in thickness from 0.66 to 1.54 %.

Almeida et al. (2012), produced multi-laminated plywood panels with an average value for specific mass of 0.413 g/cm³, using wood veneers of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* (basic density of 320 g/cm³), using a pressing cycle of specific pressure of 8 kgf/cm², temperature of 150ºC and two pressing times of 8 and 12 minutes, found average values of 4.32% for swelling in thickness and 0.66% for swelling plus recovery in thickness. These values are lower than those found in this study, which can be explained by variations in the panel production methodology, such as pressure and temperature. The compressed and thermomechanically treated material suffers the accumulation of internal compression stresses, which when placed in water release these stresses, in addition to the swelling of the wood itself (ARRUDA, 2012).

MECHANICAL PROPERTIES

STATIC BENDING

Table 3 shows the average values of static bending, as follows: modulus of rupture (MOR) and modulus of elasticity (MOE) both in the perpendicular and parallel directions to the fibers of the cover sheet.

The perpendicular and parallel MOR values ranged from 29.28 to 30.91 MPa and 40.76 to 53.49 MPa respectively, being above 18.04 MPa for the perpendicular direction and 25.79 MPa for the parallel direction according to the ABIMCI (2002).

A statistically significant difference was observed only in the results for MOR in the parallel sense. Where the pure pine panel has better results in relation to composite panels with embaúba veneers on the cover, as the

Treatments	MOR (MPa)		MOE (MPa)	
	Perpendicular	Parallel	Perpendicular	Parallel
Embauba/Embauba	29,28 a	42,48 b	2463,97 b	6476,72 a
Embauba/Pinus	30,08 a	40,76 b	2818,35 ab	6397,12 a
Pinus/Pinus	30,91 a	53,49 a	3274,27 a	6330,34 a
Pinus/Embauba	30,60 a	49,25 ab	3210,26 a	6560,46 a
F calc	0,1132 ^{ns}	6,6543*	4,3917*	0,0667 ^{ns}

Notes: Means followed by the same letter do not differ statistically from each other. The Tukey Test was applied; *: significant at 5% error probability; ns: not significant; MOR: modulus of rupture; MOE: modulus of elasticity.

Table 3 – Average values by treatments for MOR and MOE in the parallel and perpendicular direction of the panels.

pine wood has a higher basic specific mass than the embaúba, consequently providing greater mechanical properties to the panels. The mixed panel with pine cover equaled its value with the pure pine panel, as it has four pine blades, being the same on the cover and back cover, region where the rupture stresses are higher.

In the perpendicular and parallel MOE values, the variation was from 2463.97 to 3274.27 MPa and 6330.34 to 6560.46 MPa respectively, meeting the minimum values of 2129.91 MPa for perpendicular MOE and 4734.85 MPa for parallel MOE described in ABIMCI (2002). There was a statistically significant difference only for the perpendicular MOE, with better results for the composite panels with pine veneers in the cover in relation to the panels composed only of embaúba.

Both results were influenced by the higher basic specific gravity of pine, which provided greater mechanical strength. According to Mello (2012), the use of wood veneers with higher specific mass produces more mechanically resistant panels.

COLLAGE QUALITY

The average values of averages per treatment for wet and post-boil shear stress and respective failures in the wood are presented in Table 4.

For the wet treatment of the specimens, the results ranged from 1.15 to 1.57 MPa for tensile strength and 57.50 to 66.66% for wood failures. For the boiling treatment of the specimens, the results ranged from 0.82 to 0.97 MPa for failure stress and 29.17 to 53.33% for wood failures. Having the pure composition of pine after boiling with results in disagreement with the requirements of NBR ISO 12466-2 (2006).

There was a statistically significant difference in the average values of wet shear, obtained for the different compositions of the panels, where the panels composed only of pine veneers had better results in relation to the pure composition of embaúba. The difference in mechanical properties between the blades influenced the results, with greater resistance being attributed to the difference in basic density between the species used in this research. Anatomical properties may also have influenced, as species with low density tend to be more porous and consequently absorb more adhesive, leaving a hungry glue line.

According to Iwakiri et al. (2013), the low values of shear strength found in the *Sequoia sempervirens* are attributed to the low density

Treatments	**Wet**		**Boil**	
	RLC (MPa)	**FM (%)**	**RLC (MPa)**	**FM (%)**
Embauba/Embauba	1,15 b	57,50 a	0,95 a	44,17 a
Embauba/Pinus	1,52 ab	61,67 a	0,97 a	46,67 a
Pinus/Pinus	157 a	66,66 a	0,82 a	29,17 a
Pinus/Embauba	1,42 ab	57,50 a	0,90 a	53,33 a
F calc	3,2177*	0,6155 ^{ns}	0,8902 ^{ns}	2,4211^{ns}

Notes: Means followed by the same letter do not differ statistically from each other. The Tukey Test was applied; *: significant at 5% error probability; ns: not significant; RLC: shear stress; FM: wood failure.

Table 4 – Mean values per treatment for wet and post-boil shear stress and respective wood failures.

of the wood, due to the greater absorption of the adhesive, resulting in a reduction in the thickness of the glue line and, consequently, in the strength of the adhesive bond between the sheets.

CONCLUSION

The wood of *Cecropia hololeuca* presents potential for the production of multilaminated plywood panels, despite the panels having low values of apparent specific mass, they reached values above the minimum required by ABIMCI and ABNT for all physical-mechanical properties analyzed.

The inclusion of blades *Pinus elliotti* on the panels of *Cecropia hololeuca* exerted a positive influence on some physical and mechanical properties of the panels, such as reduced water absorption, increased modulus of rupture in the parallel direction, modulus of elasticity in the perpendicular direction and wet shear stress.

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