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Properties of multi-laminated plywood produced with *Hovenia dulcis* Thunb. and *Pinus elliottii* wood under different pressing pressures

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ABSTRACT. This study aimed at evaluating the effect of different pressing pressures and the influence of the wood features on the properties of plywood produced with sapwood and heartwood *Hovenia dulcis* combined with *Pinus elliottii*. To support the discussion, the anatomical and physical characterizations of the wood were carried out. The panels were produced by applying three different press pressures (0.88, 1.18 and 1.47 MPa) and with six combinations of wood veneers. Phenol-formaldehyde resin was employed, 160 g m^{-2} in a simple line and 35% solid content. The anatomical analysis revealed that the sapwood is more permeable than the *H. dulcis* heartwood. The *H. dulcis* wood basic density it was higher than that of the *P. elliottii*. Increased press pressure raised the values of the apparent density, thickness swelling and thickness swelling plus recovery of the plywood and water absorption reduction. The panels produced with *H. dulcis* veneers presented higher apparent density, MOR, MOE and bonding line resistance, as well as lower water absorption and moisture content, than those produced with *P. elliottii* veneers. No difference was noticed regarding the plywood properties when the main effects were evaluated in relation to the use of *H. dulcis* heartwood and sapwood veneers.

Keywords: wood panels, japanese raisin tree, wood veneers, phenol-formaldehyde resin.

Propriedades de painéis compensados multilaminados produzidos com madeira de *Hovenia dulcis* Thunb. e *Pinus elliottii*, em diferentes pressões de prensagem

RESUMO. O estudo avaliou o efeito do uso de diferentes pressões de prensagem e a influência das características da madeira nas propriedades dos painéis compensados produzidos com lâminas de alburno e de cerne da madeira de *Hovenia dulcis*, e em combinação com *Pinus elliottii*. Para subsidiar a discussão, foi realizada a caracterização anatômica e física da madeira. Os painéis foram produzidos sob três pressões (0,88, 1,18 e 1,47 MPa) e em seis combinações de lâminas de madeira. Utilizou-se resina fenol-formaldeído, na gramatura de 160 g m^{-2} em linha simples e teor de sólidos de 35%. A análise anatômica mostrou que a madeira de alburno de *H. dulcis* é mais permeável que a de cerne e que a densidade básica de ambas foi maior que a de *P. elliottii.* O aumento da pressão de prensagem causou aumento da densidade aparente, do inchamento e do inchamento mais recuperação em espessura e redução da absorção d´água dos painéis. Os painéis produzidos com lâminas de *H. dulcis* tiveram maior densidade aparente, MOR, MOE e resistência da linha de cola, e menor absorção d´água e teor de umidade, do que os produzidos com *P. elliottii*, não se verificando diferenças entre cerne e alburno de *H. dulcis*.

Palavras-chave: painéis de madeira, uva do Japão, lâminas de madeira, resina fenol-formaldeído.

Introduction

The physical mechanical properties of multi-laminated plywood can be better than those of wood particle panels. When compared to sawn wood, they present better applicability due to the dimensions in which they are produced. These characteristics are important for the destination sectors of these panels, mainly building industry and furniture production in Brazil. Plywood might be used inside buildings when the glue urea-formaldehyde is applied and externally or 'water proof' when employing a phenol-formaldehyde based glue (Iwakiri, 2005).

In Brazil, multi-laminated plywood is produced with fast growing wood species such as slash pine, eucalyptus and more recently the *paricá*, a tropical species with large planted area in the north of the country (Pinto & Iwakiri, 2013).

Hovenia dulcis is a fast growing pioneer species, and studies have been developed on its plantation to implement reforestation and characterize this wood. The wood is moderately heavy, with basic density values ranging between 0.58 and 0.62 g cm^{-3} (Napoli, Sanches, Iwakiri, & Hillig, 2013). The authors confirmed that the timber is suitable for producing particleboards when mixed with eucalyptus wood, providing panels with good dimensional stability.

The wood presents few pores, with small and low frequency rays, short fibers with walls varying from thin to thick. Its basic density of 0.577 g cm^{-3} is considered medium, 7.68% tangential, 4.36% radial, and 11.76% volumetric shrinkage and 1.77 tangential to radial shrinkage ratio. (Motta, Oliveira, Braz, Duarte, & Alves, 2014).

When evaluating the natural durability of tree species of *Eucalyptus* sp. and *H. dulcis* woods submitted to a deterioration test in two environments, field and forest, *H. dulcis* wood presented lesser deterioration probability in both environments (Carvalho et. al., 2016). However, its wood was considered not resistant to fungal attack from *Gloeophyllum trabeum* and *Trametes versicolor* species (Carvalho, Santini, Gouveia, & Rocha, 2015).

The specie *H. dulcis* is considered invasive, due to its easy dispersion through several means and high adaptability (Lima, Dechoum, & Castellani, 2015). It is found widespread in Brazilian subtropical forests, however, no differences were found between plant communities invaded and non-invaded by *H. dulcis* at three different succession stages according to Dechoum et al. (2015).

The region of Irati, in the state of Paraná, is one of the places where there is great dispersion of this species. Considering that the region presents large part of its wood sector comprising plywood industries, this sector might become an important consumer of this wood.

Regarding plywood production, Iwakiri (2005) explains that the hot pressing aims to finish the interaction adhesive-wood, through physical and chemical reactions and its variables are pressure, temperature and time. The pressure aims at transferring the glue from one veneer to the other and keeping suitable contact between the veneers. For panels made of several species veneers, the pressure must be adjusted taking into consideration the lowest density wood, since high pressure in light woods might result in reduction in the thickness of the panels and volumetric loss.

When considering species, the differences observed in the glue quality might be explained by the intrinsic qualities of the plywood structure material, highlighting those related to the wood anatomical and physical constitution (Guimarães Júnior, Mendes, Mendes, & Guimarães, 2012). The wood anatomical characteristics influence adhesion, taking as an example the difference in porosity observed in early wood and late wood, heartwood and sapwood, and juvenile and adult wood (Albuquerque & Latorraca, 2005).

The heartwood might present higher density, higher concentration of 'strange' materials such as oil, fat and phenolic compounds when compared to the sapwood, which affect permeability and consequently the adhesive movement, and can also interfere in the chemical reactions of the adhesive curing process (Iwakiri, 2005). The author also recommends the use of lower pressure when the plywood is produced with high gluing rates in the process, aiming to prevent the transfer of adhesive to the external veneer surface and leakage through the panel sides.

According to Vital, Maciel and Della Lucia (2006), the adhesive differentiated behavior on each wood species is possibly due to the variability in density and permeability of each kind of wood.

Research has been developed to evaluate the viability of using alternative species in the production of plywood with phenol-formaldehyde resin. The production of multi-laminated plywood using *Sequoia sempervirens* wood veneers was studied by Iwakiri et al. (2013) and the quality of plywood made of *Schizolobium amazonicum* Huber ex veneers was evaluated by Iwakiri et al. (2011). *Hevea brasiliensis* veneers were used by Palma, Escobar, Ballarin and Leonello (2012). The yield in lamination and quality of plywood made of *Criptomeria japonica* veneers were evaluated by Pinto and Iwakiri (2013). Veneers of the species *Toona ciliate* were used by Albino, Sá, Bufalino, Mendes and Almeida (2011).

This study aimed at evaluating the effect of wood characteristics and the use of different press pressures on the properties of multi-laminated plywood, produced with *H. dulcis* sapwood and heartwood veneers in combination with *Pinus elliottii* veneers.

Material and methods

Material

Two wood species were used, the *H. dulcis* Thunb. and the *P. elliottii* (slash pine), with three trees per species. *H. dulcis* trees have an invading origin and are situated at the Campus of the Midwestern State University, Irati, Paraná State, coordinates 25º 27' 56" S/ 50º 37' 51" O, and the age of the trees is estimated to be between 14 and 18 years old. The *P. elliottii* trees, which were 14 years old, were extracted from commercial plantations belonging to a company in the region.

Wood characterization

The *H. dulcis* and the *P. elliottii* sapwood and heartwood basic density was determined according to the standard NBR 11941/2003 (Associação Brasileira de Normas Técnicas [ABNT], 2003).

The qualitative anatomic analysis of the *H. dulcis* heartwood and sapwood was carried out in permanent micro sections produced according to the methodology described by Burger and Richter (1991). Blocks measuring 1 x 1 x 1 cm were used, extracted from the heartwood and sapwood from four discs of each tree. Photographs of the permanent micro sections were taken by employing an electronic microscope with coupled digital camera with 50 x resolution.

Producing veneers and plywoods

The logs were turned into veneers in a logs turning lathe with a fuse traction system, branded Thoms Benato, with the following adjustment: knife sharpening angle 21°, knife angle 90°30', horizontal opening 1.35 mm and vertical opening 0.75 m. The veneers produced were 1.70 wide x 1.5 mm thick. The sheet was cut into a 1.70 x 1.35 m veneer.

The *H. dulcis* wood veneers were separated according to their position in the log, and comprised 38.32% sapwood veneers, 32.83% heartwood veneers and 28.75% mixed veneers. For the panel production, the sapwood and heartwood veneers were used separately.

The veneers were dried in a roll drier system, branded Benecke, at 130°C and 21m min.$^{-1}$ speed, resulting in a 5% final moisture content.

Phenol-formaldehyde (PF) resin was used to produce the panels, with 54% solid content. The gluing was carried out with 67.3% adhesive, 16.35% wheat flour and 16.35% water, so that the mixture reached a 35% solid content and 40 to 60 second viscosity. The gluing was applied manually at a rate of 160 g m^{-2} (simple line), using a spatula across the surface of the veneer, and 30 minutes assembling time.

The relevant variables under analysis were the hot press specific pressure and the combination of wood veneers, totaling 18 treatments with three replications each, according to the experimental design presented in Table 1.

The panels produced measured 60 X 60 cm and had five-veneer layers, 1.5 mm thick each, obeying to the cross lamination assembling principle, pressed at 140°C for 7.5 minutes.

After being pressed the panels were cut and placed in the air-conditioned chamber at 20 ± 2°C and 65 ± 5% relative moisture up to stabilization. The physical and mechanical properties were determined according to the NBR standards (Associação Brasileira de Normas Técnicas [ABNT], 2011a; 2011b; 2011c; 2011d; 2012; 2006a; 2006b).

Table 1. Experimental Design

Treat.	Pressure (MPa)	Plywood Composition (cover-2/core-3)	Replic.
1	0.88	Pine	3
2	0.88	S Hd	3
3	0.88	H Hd	3
4	0.88	S Hd/H Hd	3
5	0.88	S Hd/Pine	3
6	0.88	H Hd/Pine	3
7	1.18	Pine	3
8	1.18	S Hd	3
9	1.18	H Hd	3
10	1.18	S Hd/H Hd	3
11	1.18	S Hd/Pine	3
12	1.18	H Hd/Pine	3
13	1.47	Pine	3
14	1.47	S Hd	3
15	1.47	H Hd	3
16	1.47	S Hd/H Hd	3
17	1.47	S Hd/Pine	3
18	1.47	H Hd/Pine	3
Panels Total			54

Note: S Hd = *H. dulcis* sapwood veneers; H Hd = *H. dulcis* heartwood veneers.

The properties under analysis were: the log basic density (NBR 11941, Associação Brasileira de Normas Técnicas [ABNT], 2003); the panel apparent density (NBR 9485, ABNT (2011), moisture content (NBR 9484, ABNT, 2011), water absorption (NBR 9486, ABNT, 2011), thickness swelling and thickness swelling plus recovery (NBR 9535, ABNT, 2011)[1], static bending (modulus of rupture, MOR and modulus of elasticity, MOE), parallel and perpendicular to the cover veneer (NBR 9533, ABNT, 2012), bonding quality (bonding line resistance), after humid treatments (immersion of samples in room temperature water for 24h) and boiling water (sample immersion in boiling water for 6h followed by immersion in room temperature water for 1h) NBR ISO 12466/1(ABNT, 2006a) and bonding quality: requirements NBR ISO 12466/2 (ABNT (2006b). The panel thickness was also determined and evaluated.

The panel properties were analyzed after the variance homogeneity and normal distribution prerogatives were satisfied. The factorial ANOVA was applied, with 5% error probability for the main factors and their interactions. When difference was found between the factors, the Tukey test was carried out to compare the averages.

[1]The equation used to calculate thickness swelling was modified to match the concepts supplied by the standard NBR.

Results and discussion

Log basic density

The *H. dulcis* sapwood and heartwood presented 0.50 g cm^{-3} and 0.57 g cm^{-3} basic density, respectively, which was higher than the one presented by the *P. elliottii,* 0.42 g cm^{-3} on average. In general, the timber up to 0.50 g cm^{-3} is preferred for the plywood production, with the sapwood and heartwood presenting the proposed limit and above it, respectively. These results are similar to those found by other authors. *H. dulcis* basic density values of 0.58 g cm^{-3} were found by Motta et al. (2014). Basic density values of 0.41 g cm^{-3} for 13-year old *P. elliottii* wood were found by Santini, Haselein and Gatto (2000).

Anatomical characteristics of the *H. dulcis* wood.

Figure 1 shows photographs of permanent anatomical micro sections of *H. dulcis* wood sample in transversal, radial longitudinal and tangential longitudinal cuts.

The *Hovenia dulcis* heartwood presented higher amount of extractives, apparently smaller pores and rays with fewer cell rows, when compared to the sapwood. Also, differences were found in pore distribution, since the sapwood presented multiple distributions up to three and the heartwood up to two. These differences revealed that the *Hovenia dulcis* sapwood is more permeable than the heartwood.

Plywood apparent density, thickness and moisture content

In Table 2, the apparent density average values factorial analysis, thickness and moisture content for each level of factor under study can be observed.

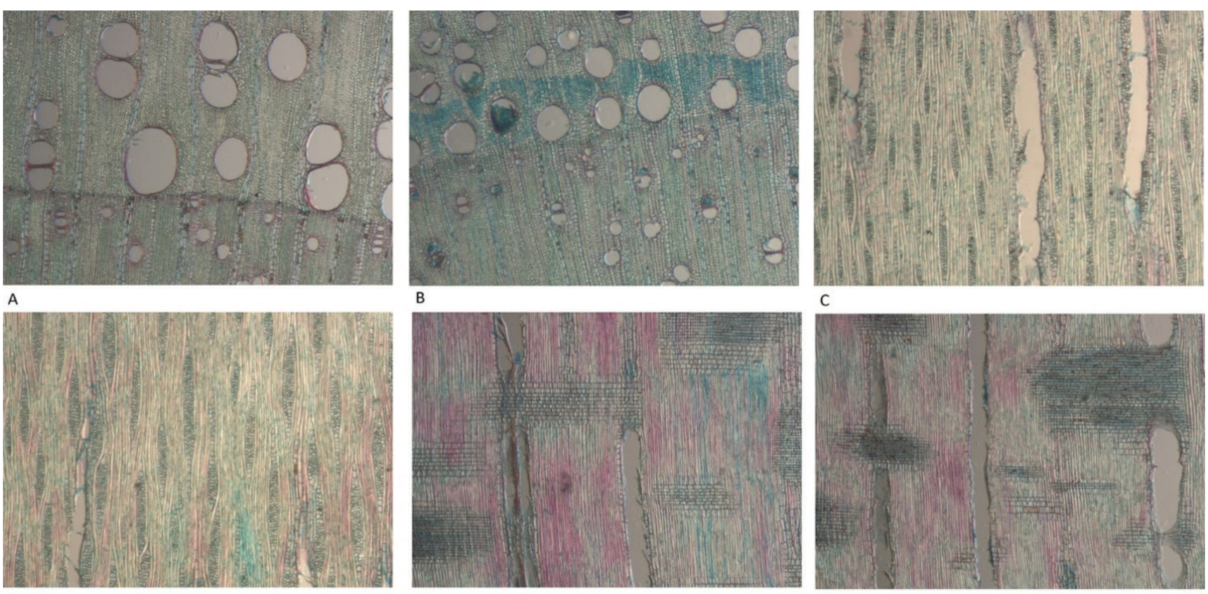

Figure 1. Photographs of *H. dulcis* permanent anatomical micro sections: A) transversal cut (sapwood); B) transversal cut (heartwood); C) tangential longitudinal cut (sapwood); D) tangential longitudinal cut (heartwood); E) radial longitudinal cut (sapwood); F) radial longitudinal cut (heartwood).

Table 2. Influence of press pressure and veneer composition on the plywood apparent density, thickness and moisture content.

Factors		AD (g cm^{-3})	T (mm)	MC (%)
Press pressure (MPa)	0.88	0.65 b	7.25 a	10.87 a
	1.18	0.66 b	7.12 ab	10.96 a
	1.47	0.68 a	6.98 b	10.89 a
	Calculated F	9.22*	9.10*	1.25^{ns}
Plywood Composition	P	0.59 c	7.10 a	11.38 a
	S-Hd	0.70 a	7.10 a	10.72 c
	H-Hd	0.72 a	7.28 a	10.56 c
	S-Hd / H-Hd	0.71 a	7.13 a	10.60 c
	S-Hd / P	0.61 c	7.05 a	11.08 b
	H-Hd / P	0.65 b	7.03 a	11.09 b
	Calculated F	48.90*	1.91^{ns}	32.22*
Interaction	Calculated F	0.39^{ns}	0.92^{ns}	0.50^{ns}

Note: Averages followed by the same letter are not statistically different. The Tukey test was applied; *: significant at 5% error probability; ns: non-significant; AD: apparent density; T: plywood thickness; MC: moisture content; P: *P. elliottii* veneers; S-HD: *H. dulcis* sapwood veneers. H-HD: *H. dulcis* heartwood veneers.

The press pressure influenced the apparent density and thickness of the panels. Thus, the use of 1.47 MPa pressure was not advantageous to the species under study, since it produced heavier plywood and presented higher plywood thickness reduction when compared to the application of 0.88 MPa. The use of 0.88 or 1.18 MPa pressure provided panels with lower apparent density than the use of 1.47 MPa. The application of high pressure on low density wood results in reduction in the plywood thickness (Iwakiri, 2005).

Regarding plywood composition, the compositions with *H. dulcis* veneers presented higher apparent density values when compared to the mixed and pine compositions. The plywood apparent density variation is related to the basic density of the species used in this study.

The pine plywood was verified to reach higher moisture content, followed by the mixed plywood (*H. dulcis* and pine) and the panels made of *H. dulcis* veneers only. This fact is related to the physical and chemical characteristics of each wood species.

Dimensional stability

Table 3 shows the average values of dimensional stability properties for each level of factor under study.

Table 3. Influence of press pressure and veneer composition on the panel water absorption, thickness swelling and thickness swelling plus recovery.

Factors		WA (%)	TS (%)	TSR (%)
Press Pressure (MPa)	0.88	61.88 a	6.85 c	0.68 b
	1.18	55.14 b	7.97 b	0.99 ab
	1.47	53.52 b	9.11 a	1.43 a
	Calculated F	48.86*	20.61*	5.45*
Plywood Composition	P	64.80 a	7.30 a	1.41 a
	S-Hd	54.41 b	8.32 a	0.71 a
	H-Hd	45.66 d	7.67 a	1.03 a
	S-Hd/H-Hd	50.28 c	8.15 a	0.58 a
	S-Hd/P	63.70 a	7.85 a	1.27 a
	H-Hd/P	62.21 a	8.57 a	1.22 a
	Calculated F	77.76*	1.72^{ns}	2.10^{ns}
Interaction	Calculated F	2.42*	1.44^{ns}	1.12^{ns}

Note: Averages followed by the same letter are not statistically different. The Tukey test was applied; *: significant at 5% error probability; ns: non-significant; WA: water absorption; TS: thickness swelling; TSR: thickness swelling plus recovery; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

Regarding water absorption, statistical difference was observed in the average values obtained from different pressures and compositions used in the plywood, which revealed factor interactions. Plywood thickness swelling (TS) and thickness swelling plus recovery (TSR) only presented statistical difference for the factor pressure.

There was reduction in water absorption by the panels produced at 1.18 MPa pressure when compared to those produced at 0.88 MPa. This fact was ascribed to the reduction of empty spaces in the wood due to compression, an effect that did not occur when the pressure was increased from 1.18 to 1.47 MPa.

The factor composition revealed that the panels produced with *H. dulcis* heartwood veneers presented the lowest water absorption, followed by the mixed (sapwood and heartwood), sapwood and pine. The flow of liquids through the woody structure is related to its porosity; this fact can be explained by the anatomical characteristic differences between the *H. dulcis* sapwood and heartwood, as well as by the wood basic density difference between pine and *H. dulcis*.

Table 4 presents average values of each treatment resulting from the combination of factors such as plywood composition and press pressure on water absorption.

It was seen that the increase in pressure from 0.88 to 1.18 MPa was efficient to reduce water absorption in all panels that contained pine veneers and in those only made of *H. dulcis* heartwood. For panels only produced with *H. dulcis* sapwood veneers, the water absorption reduction only occurred with 1.47 Mpa pressure, while in the mixture heartwood with sapwood there was no water absorption reduction with the pressure increase.

Regarding thickness swelling and thickness swelling plus recovery, results revealed that averages were higher when the pressure 1.47 MPa was applied to the panel production process, since with pore and fiber compaction there was increase in the panel apparent density and in the internal compression tensions.

Mechanical properties

Static bending

Table 5 shows the modulus of rupture (MOR) and modulus of elasticity (MOE) average values in static bending, parallel and perpendicular to the cover veneer, for each level of the factors under study.

Table 4. Interaction of press pressure with plywood composition in the panel water absorption property (%).

Press pressure	Veneer composition					
(MPa)	P	S-Hd	H-Hd	S-Hd / H-Hd	S-Hd / P	H-Hd / P
0.88	73.64 aA	58.08 aC	51.57 aC	51.96 aC	69.67 aAB	66.36 aB
1.18	60.46 bAB	54.54 abBC	42.83 bD	50.74 aC	62.88 bA	59.39 bAB
1.47	60.30 bA	50.62 bB	42.59 bC	48.14a BC	58.55 bA	60.88 bA

Note: averages followed by the same letter were not statistically different (capital letter in lines and small letter in columns), according to the Tukey test at 5% error probability; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

Table 5. Influence of factors on the MOR and MOE static bending, both parallel and perpendicular.

Factors		MOR (MPa)		MOE (MPa)	
		Per	Par	Per	Par
Press pressure (MPa)	0.88	35.00 a	74.21 a	1958.2 c	6830.9 c
	1.18	37.47 a	79.76 a	2449.5 a	8817.0 a
	1.47	35.55 a	81.31 a	2235.2 b	7711.5 b
	Calculated F	1.66^{ns}	1.87^{ns}	20.32*	30.44*
Plywood Composition	P	25.82 b	55.64 b	1609.2 c	6350.4 c
	S-Hd	42.73 a	83.92 a	2439.7 b	7761.8 ab
	H-Hd	43.53 a	86.19 a	2630.6 ab	8730.6 a
	S-Hd/H-Hd	44.79 a	87.54 a	2858.5 a	8273.2 ab
	S-Hd/P	28.42 b	77.70 a	1851.3 c	7482.2 b
	H-Hd/P	30.75 b	79.57 a	1896.5 c	8120.5 ab
	Calculated F	36.25*	9.29*	41.47*	10.44*
Interaction	Calculated F	1.58^{ns}	0.75^{ns}	3.47*	1.07^{ns}

Note: Averages followed by the same letter were not statistically different. Tukey test was applied; *: significant at 5% error probability; ns: non-significant; MOR: modulus of rupture; MOE: modulus of elasticity; Per: perpendicular; Par: parallel; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

The perpendicular and parallel MOR results analyzed revealed statistical difference in average values obtained for the different panel compositions. Regarding perpendicular and parallel MOE, the panel composition and different pressures applied influenced the results, and interaction between composition and pressure factors was also observed in the perpendicular MOE results.

The 0.88 MPa pressure might not have been enough to transfer the adhesive from one veneer to the other, and at 1.47 MPa excessive absorption of the adhesive by the veneer might have occurred, both influencing the panel rigidity. Thus, the plywood with the highest elasticity module was produced at 1.18 MPa press pressure.

Panels produced with *H. dulcis* venners presented greater parallel MOR and MOE than panels produced with pinus. Panels only made of *H. dulcis* veneers that presented higher apparent density (Table 2) and higher perpendicular MOR and MOE when compared to the others. Better MOR and MOE static bending results in panels with higher apparent density were also observed by Albino et al. (2011). This is an important factor for the panel structural uses since they require the increased strength and rigidity.

The interaction of plywood composition and press pressure in the perpendicular MOE results can be seen in Table 6.

Panels containing *H. dulcis* heartwood veneers obtained increase in the elasticity module (MOE) when pressure above 1.18 MPa was applied, since they present more obstructed pores and need higher pressure for adhesive transfer. In the composition containing only *H. dulcis* sapwood veneers and in the mixture of sapwood and pine, the 1.47 MPa press pressure caused reduction in MOE values, probably due to the excessive adhesive absorption by the panel veneers.

Table 6. Interaction of press pressure with plywood composition in perpendicular MOE (MPa).

Pressure (MPa)	Plywood Composition					
	P	S-Hd	H-Hd	S-Hd/ H-Hd	S-Hd/ P	H-Hd/ P
0.88	1507.9 aC	2393.1 abA	2120.8 bAB	2523.6 bA	1495.7 bC	1708.2 bBC
1.18	1694.7 aC	2735.4 aA	2818.7 aA	2930.4 abA	2116.9 aBC	2400.9 aAB
1.47	1625.0 aBC	2190.8 bB	2952.2 aA	3121.5 aA	1941.2 abBC	1580.4 bC

Note: Averages followed by the same letter were not statistically different (capital letter in line and small letter in column), according to the Tukey test at 5% error probability; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

In mixed panels made of *H. dulcis* heartwood and pine veneers, the use of 1.18 MPa in the press process was enough to distribute the adhesive, and the application of 1.47 MPa might have resulted in uneven distribution between veneers, due to the higher impermeability of the *H. dulcis* heartwood when compared to pine, which caused higher adhesive absorption by the latter.

In the panels only made of pine wood, the application of 0.88 MPa in the press process was enough and provided efficient gluing, agreeing with Iwakiri (2005) which recommends the use of lower pressure when the plywood is produced with high gluing rates.

Bonding quality

Table 7 shows the bonding line resistance average values, after the sample treatments using the humid and boiling methods, for each level of factor under study.

Table 7. Influence of press pressure and plywood composition on the bonding line resistance (BLR).

Factors		BLR (MPa)	
		Humid	Boiling
Pressing pressure (MPa)	0.88	1.36 a	1.12 a
	1.18	1.34 a	1.15 a
	1.47	1.36 a	1.13 a
	Calculated F	0.06^{ns}	0.11^{ns}
Plywood Composition	P	1.25 b	0.99 b
	S-Hd	1.39 ab	1.20 ab
	H-Hd	1.65 a	1.32 a
	S-Hd/H-Hd	1.44 ab	1.23 ab
	S-Hd/P	1.29 b	1.05 b
	H-Hd/P	1.11 b	1.00 b
	Calculated F	5.54*	4.64*
Interaction	Calculated F	1.36^{ns}	3.52*

Note: Averages followed by the same letter were not statistically different. The Tukey test was applied; *: significant at 5% error probability; ns: non-significant; BLR: bonding line resistance; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

According to the NBR ISO 12466/2 (Associação Brasileira de Normas Técnicas [ABNT], (2006b) - bonding quality requirements, for BLR equal to or over 1.0 MPa there is no need to determine the percentage of wood failure in the bonding quality test. Since the average values are around this minimum or more, the evaluation of bonding quality was carried out according to the bonding line resistance values only.

The pressing pressure factor did not influence the bonding line resistance (BLR) results. Statistical difference was observed in the BLR after humid treatment average values, obtained for the different panel compositions. For BLR after boiling, there was statistical difference regarding the factor composition as well as interaction between the factors.

The panels produced with *H. dulcis* heartwood veneers presented better BLR results when compared to the panels that contained pine veneers in their composition. The anatomical characteristics between the species influenced gluing, since the *H. dulcis* wood has short fibers, small and scarce rays, with smaller pores in the heartwood, absorbing less adhesive than the pine.

According to results obtained by Albino, Mori and Mendes (2012), when pore diameter dimension, the width and the fiber length and ray width are too high, they might result in a thick glue line since more adhesive is absorbed.

The interaction between plywood composition and press pressure in the BLR after boiling results is presented in Table 8.

Table 8. Interaction of pressing pressure and the plywood composition in the bonding line resistance (BLR) after boiling.

Press pressure (MPa)	Plywood Composition					
	P	S-Hd	H-Hd	S-Hd/ H-Hd	S-Hd/ P	H-Hd/ P
0.88	1.17 aAB	1.40 aA	1.28 aAB	0.82 bB	1.09 aAB	0.94 aAB
1.18	0.93 aA	1.27 abA	1.24 aA	1.39 aA	1.03 aA	1.01 aA
1.47	0.87 aB	0.93 bB	1.44 aA	1.49 aA	1.02 aAB	1.04 aAB

Note: Averages followed by the same letter were not statistically different (capital letter in the lines and small letter in the columns), Tukey test at 5% error probability; P: *P. elliottii* veneers; S-Hd: *H. dulcis* sapwood veneers; H-Hd: *H. dulcis* heartwood veneers.

For panels produced with *H. dulcis* sapwood veneers, BLR after boiling was reduced with the application of 1.47 MPa, while for panels produced with mixture of the sapwood and heartwood veneers the inverse occurred. For other compositions there was no statistical difference between the pressures used.

Since it was found that the sapwood is more permeable than the heartwood, the use of less pressure to this type of veneer prevents high absorption of adhesive. The mixture veneer composition of heartwood and sapwood for the use of 0.88 MPa did not provide a good adhesive absorption for the heartwood veneers, damaging the bonding.

Conclusion

The plywood composition with *H. dulcis* veneers resulted in heavier panels than those containing pine. The 1.47 MPa press pressure led to increase in the plywood density and thickness reduction, and the 1.18 MPa pressure was the most suitable, since it was enough to reduce water absorption and maintaining the resistance and rigidity.

The plywood properties were higher for *H. dulcis* veneers, except for thickness properties, and there was no difference of heartwood and sapwood veneers.

The *H. dulcis* wood presents potential for use in structural multi-laminated plywood panels, mainly in uses that require greater resistance to static bending.

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