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Influência da anatomia no desempenho da adesão de quatro espécies madeireiras

Influence of anatomy on the adhesion performance of four wood species

Influencia de la anatomía en el desempeño de adhesión de cuatro especies de madera

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Resumo

Avaliou-se a influência das características anatômicas no desempenho da adesão da madeira de Vatairea sp., Paulownia sp., Aspidosperma populifolium e Tectona grandis. De pranchas

orientadas tangencialmente, foram produzidos corpos de prova para as análises anatômica e físico-mecânica da madeira. Os tratamentos foram juntas coladas de peças de mesmo plano de corte (radial e tangencial), avaliados quanto a resistência ao cisalhamento e falha na linha de cola. A madeira de angelim apresentou a maior massa específica aparente (0,74 g cm-3) e a madeira de kiri (0,34 g cm-3) o menor valor. A espécie peroba mica apresentou a maior resistência ao cisalhamento na linha de cola nas faces tangencial e radial. As características anatômicas com maior influência no processo de adesão da madeira foram as células de raios e as fibras, que exibiram as maiores correlações com a resistência ao cisalhamento na linha de cola.
Palavras-chave: Adesivo; Linha de cola; Planos de corte; Resistência ao cisalhamento.

Abstract

The aim of this study was to evaluate the influence of anatomical characteristics on the adhesion performance of Vatairea sp., Paulownia sp., Aspidosperma populifolium and Tectona grandis wood. Specimens for anatomical, physical and mechanical analyzes were produced from tangentially oriented boards. The treatments were joint glued from pieces of the same anatomical orientation (radial and tangential), evaluated for shear strength and glue line failure. The Vatairea sp wood had the highest specific gravity (0.74 g cm-3) and the Paulownia sp (0.34 g cm-3) wood was smaller. Aspidosperma populifolium species showed the highest shear strength in the glue line in the tangential and radial faces. The anatomical variables with higher influence on the wood adhesion process were pith ray cells and especially fibers that exhibit the greatest correlation with the shear strength of the glue line.
Keywords: Adhesive; Glue line; Shear planes; Shear strength.

Resumen

Se evaluó la influencia de las características anatómicas en el rendimiento de adhesión de Vatairea sp., Paulownia sp., Aspidosperma populifolium y Tectona grandis. A partir de tablas orientadas tangencialmente, se produjeron muestras para el análisis anatómico y físico-mecánico de la madera. Los tratamientos fueron uniones encoladas de piezas del mismo plano de corte (radial y tangencial), evaluadas por resistencia al corte y falla de la línea de pegamento. La madera de Angelim tuvo la densidad aparente más alta (0,74 g cm-3) y la madera de kiri (0,34 g cm-3) el valor más bajo. Las especies de peroba mica mostraron la mayor resistencia al corte en la línea de pegamento en las caras tangencial y radial. Las características anatómicas con mayor influencia en el proceso de adhesión de la madera fueron las células y fibras de rayos, que exhibieron las mayores correlaciones con la resistencia al corte en la línea de pegamento.

Palabras clave: Adhesivo; Línea de pegamento; Planos de corte; Resistencia al corte.

1. Introduction

The anatomical characterization of the species contributes to subsidies on the relation of the microscopic structure with the other properties of the wood, among them the adhesion which facilitates processing and ensures the quality of the products. In several situations, inappropriate behavior of the wood is a reflection of the unknown (Hernández, 2010).

Adhesion refers to the interfacial phenomenon or the separation energy of two substrates that occurs between the wood and the adhesive. It depends on factors such as the characteristics intrinsic to the wood itself (anatomy, chemistry and physics), adhesive properties (chemical and physical) and the procedure adopted during bonding (Albino et al., 2010)

Variables such as size, arrangement and frequency of cellular cavities and pores are directed to the penetration effects of the adhesive into the interior of the wood piece (Carneiro et al., 2007). However, the age, tree growth conditions and intrinsic wood variability (Albuquerque e Latorraca, 2000) contribute to changes in the proportion of heartwood and sapwood, which significantly reduce the wood's permeability to adhesives and causes problems in bonded joints.

The type of adhesive to be used during the adhesion process should also be considered. For example, resorcinol formaldehyde is a widely used adhesive in structural parts because it gives bonded joints, resistance against mechanical stress, moisture and temperature, despite its high cost (Tienne et al., 2011; Albino et al., 2012). A strategy to reduce costs is the use of resorcinol in wood species with different anatomical structures, which provides an accurate diagnosis to adjust its behavior in the bonding.

Research on adhesives have been dedicated to optimizing adhesion in wood of some species, which promoted the development of intrinsic adhesives for bonding these materials (Vital et al., 2006). However, information on the effect of the wood's anatomical structures on the performance of bonded joints is still necessary (Albino et al., 2012), given the diversity of species with industrial potential.

In view of the above, the objective of this work was to evaluate the influence of the anatomical characteristics of the wood on the adhesion and shear strength performance of bonded joints in the radial and tangential planes of four wood species.

2. Material and methods

Evaluated species: the anatomical structure and the main use of the wood were considered in the triage of the species. Therefore, the Angelim (*Vatairea* sp.) species was selected for its proportion of parenchyma and use in frames, Kiri (*Paulownia* sp.) for its thin wall fibers and use in handicrafts and cashew, Peroba mica (*Aspidosperma populifolium*) for its vessel frequency and use in the construction and production of floors and finally Teak wood (*Tectona grandis*) due to its ring porosity and use in manufacturing furniture and boats. For all the mentioned uses, it is important to know the influence of the anatomical properties and the density on the behavior of the wood glue.

Test specimens were produced from tangentially oriented boards for all performed analyzes (Figure 1). The sawed pieces of Teak and Kiri came from the timber stock of the Machining and Processing Laboratory of Madeira (LUMber-UFES), while the Peroba mica and Angelim were acquired from the timber trade of the region.

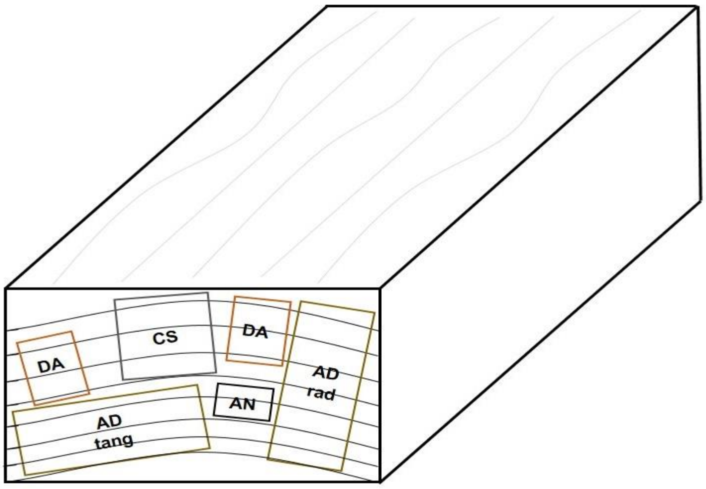

Figure 1. Sampling model of boards for removing the test samples for anatomy (AN), wood density (DA), shear (CS) and tangential (AD tang) and radial adhesion (AD rad).

Anatomical characterization of the wood: in the microscopic study of the wood of the four forest species, the recommendations of the Pan American Technical Standards Commission (Copant, 1974) were followed. The test specimens were 1.5 x 2.0 x 3.0 cm [tangential x radial x longitudinal (Figure 1)], to obtain histological sections (transverse, radial and tangential planes) in a slide microtome and to prepare macerates (1:1 solution of 30% hydrogen peroxide and glacial acetic acid) for individualization of the fibers.

Histological slides were assembled using the thin sections and the mass of individualized fibers, which were photomicrographed by a digital camera (7.1 mega pixel) coupled to an optical microscope. Axiovision 4.5 image analyzer software was used to measure the tangential diameter (μm) and frequency (mm^{-2}) of the vessels; the height (μm and number of cells), width (μm) and frequency (mm mm) of the rays; and the length, width and diameter of the lume (μm) of the fibers.

The wall thickness of the fibers was indirectly determined by half the difference between the width and the diameter of the lume and the wall fraction determined by the ratio of twice the wall thickness to the fiber width. The International Association of Wood Anatomists – IAWA (1989) was referenced for quantitatively evaluating the anatomical characteristics of the wood.

Apparent wood density: this physical property was evaluated according to the Brazilian Regulatory Standard - NBR 7190 (Associação Brasileira de Normas Técnicas, 1997). The specimens were stored in a climatic chamber (relative humidity of 65 ± 5% and temperature of 25 ± 2°C) until reaching equilibrium moisture, equivalent to 12%. After the air conditioning, the samples were weighed and their volumes measured by the hydrostatic balance method with the mercury replaced.

Wood shearing: this mechanical test was carried out for a later comparison between the strength values obtained in the solid wood and in the glue line of the bonded joints. The shear strength of the solid wood of the species was determined according to NBR 7190 (Associação Brasileira de Normas Técnicas, 1997).

Wood adhesion: in this test, the treatments were the joints bonded to pieces of the same cutting plane (radial x radial and tangential x tangential), obtained from the planks of the evaluated species (Figure 1).

To prepare the bonding face and subsequent formation of the joints, the pieces were properly planed (Figure 2 (A)) and sanded to the final dimensions of 2.0 x 30.0 cm (thickness x length). Their width was variable according to the species due to limitations in the nominal dimensions of sawn wood.

Figure 2. Wood adhesion testing. (A) Machining of the pieces (B) Mass weighing (weight) of adhesive applied on pieces; (C) adhesive dispersion with a spatula; (D) adhesive spread onto the pieces; (E) installation of joints; (F) Compression of the joints in a 15-ton hydraulic press.

The Cascophen RS-216-M adhesive was used to add 20% of the prepared hardener catalyst FM-60-M (powder) with cold glue and 5% ethyl alcohol to improve penetration. The viscosity (800 centipoise), the solids content (60%) and the pH (7.0) of the adhesive are in accordance with the parameters recommended by the manufacturer.

A weight of 300 g m^{-2} was used in the double-glue line recommended by the manufacturer [Figure 2 (B)]. The adhesive was prepared and spread over the surface of the samples with a spatula [Figure 2 (C) and (D)]. After 20 minutes, the gaskets were arranged in a hydraulic press and compressed for six hours at a pressure of 1.2 MPa at room temperature (Figure 2 (E) and (F)). After the bonding step, the pieces were acclimatized for a period of 30 days for complete curing of the adhesive.

Adhesion performance: the bonding performance of the treatments was evaluated by the parallel shear strength in the glue line, and by the failure percentage in the wood. The samples were prepared for determining the shear strength in the glue line according to the American Society for Testing and Materials (ASTM D-905) standard test by glued joint, totaling 25 samples per treatment.

The percentage of faults in the wood was evaluated in the bonded area, then submitted to shearing with the aid of a transparent and checkered film which had areas delimited in percentage, as proposed by ASTM D-5266 (ASTM, 2013).

Statistical analysis: the experiment was conducted under a completely randomized design. Four treatments were used (species) for the physical-mechanical characterization, and eight treatments were adopted in evaluating shear strength in the glue line and wood failure (species and cutting planes).

Data were submitted to analysis of variance (ANOVA) by the F-test and the means were compared by the Tukey test when the F-test was significant using a significance level of 5%. The Lilliefors and Cochran tests were used for the analysis of data normality and homogenization of variances, respectively.

The functional relationship between the anatomical variables, physical-mechanical properties and faults in the wood were evaluated using Pearson's linear correlation coefficient and its p-value.

3. Results and discussion

Solid wood properties: by analyzing the dimensions of vessels, fibers and rays (Table 1) according to IAWA (1989), species can be qualitatively classified as: a) vessels with a large tangential diameter (> 200 µm): Angelim; b) vessels of medium tangential diameter (100 to 200 µm): Kiri, Peroba mica and Teak; c) few vessels (<5 vessels mm-2): Angelim, Kiri and Teak; d) numerous vessels (20 to 40 vessels mm-2): Peroba mica; e) long fibers (≥ 1600 µm): Angelim and Peroba mica; (f) short fibers (900 to 1600 µm): Kiri and Teak; g) thin rays (<100 µm): angelim, Peroba mica and Teak; h) mean rays (100 to 300 µm): Kiri; (i) very uncommon rays (<4 mm-1 rays): Kiri and Teak; and j) light rays (4 to 12 mm-1 rays): Angelim and Peroba mica. Woody rays of all species were low (<1000 µm).

Due to the different anatomical structures, the apparent density and shear strength (Table 1) values of the evaluated species differed significantly. The highest and lowest values of these two properties were observed in Angelim and Kiri wood, respectively, resulting from the anatomical differences between them.

Table 1. Average values of the anatomical, physical and mechanical properties of the four species studied.

Anatomical. physical and mechanical properties		Species			
		Angelim	Kiri	Peroba Mica	Teca
Vessels/pores	Diameter (µm)	**248.35** (18.73)	**158.17** (20.88)	**109.20** (15.89)	**172.83** (25.17)
	Frequency (n° mm^{-2})	**1.65** (53.04)	**2.45** (30.99)	**21.75** (11.45)	**3.80** (21.93)
Fibers	Length (µm)	**1958.59** (11.49)	**1244.59** (16.12)	**1807.83** (13.29)	**1183.01** (13.49)
	Width (µm)	**29.00** (19.62)	**42.00** (16.37)	**34.00** (14.22)	**30.00** (14.84)
	Lume Diameter (µm)	**10.72** (28.26)	**34.51** (20.99)	**13.24** (30.56)	**20.25** (20.25)
	Wall thickness (µm)	**9.28** (25.58)	**3.97** (20.90)	**10.15** (13.71)	**4.89** (22.24)
	Wall fraction (%)	**63.32** (14.07)	**19.32** (28.80)	**61.05** (13.00)	**32.93** (21.05)
Rays	Height (µm)	**245.96** (32.51)	**577.75** (33.87)	**272.33** (25.35)	**309.50** (25.74)
	Height (n° cells)	**15.70** (12.42)	**13.15** (28.59)	**25.56** (24.08)	**24.52** (12.86)
	Width (µm)	**30.11** (27.53)	**113.08** (25.68)	**10.65** (26.61)	**23.10** (29.16)
	Frequency (n° mm^{-1})	**4.00** (16.22)	**2.70** (27.10)	**6.10** (14.95)	**3.75** (19.10)
Apparent Density (g cm^{-3})	12% moisture	**0.74 a** (3.16)	**0.34 d** (6.07)	**0.67 b** (1.88)	**0.63 c** (8.42)
Shearing (MPa)	12% moisture	**14.61 a** (6.03)	**7.01 d** (10.36)	**10.25 c** (15.11)	**12.01 b** (10.04)

Means of physical-mechanical properties followed by the same lowercase letter in each row are statistically the same (Tukey, $p < 0.05$); values in parentheses refer to the coefficient of variation (%).

The greater apparent density conferred by Angelim wood is explained by the wall length and thickness of its fibers, the smaller area occupied by vessels and by the greater proportion of axial parenchyma, which together contributed to the increase of this physical property. In a related way, the effect of long fibers in the apparent density can be noticed, which in joint action gave greater shear strength to the wood of this species.

The lower apparent density of Kiri wood is mainly related to the presence of thin-walled fibers. When considering the shear strength of the wood of this species, the lower value of this property may be directly associated with the apparent density and the smaller amount of fibers per area due to the greater dimensions of the woody rays (height and width).

Although the Peroba mica wood has thicker wall fibers, this species exhibited the second highest bulk density and the third highest shear strength. These properties were mainly affected by the high frequency of small diameter vessels (a common characteristic of this species), and by the remarkable occurrence of rays in the Peroba mica wood.

In addition to the fiber, vessel and ray morphology, the shear strength of the species may have been affected by the microfibril angle, grain deviations, juvenile and adult wood ratio, presence of reaction wood and the crystallinity degree of the cellulose (Lima & Garcia, 2010; Vito, 2013).

Shear strength variability was generally lower for the higher density wood, especially Angelim wood. An adverse outcome was observed by Plaster et al. (2008), where the variability of the mentioned property was shown to be higher for the higher density classes of *Eucalyptus* sp. wood. This distinction in the results probably results from the density variability itself, in which this variable ranged from 0.70 to 0.99 g.cm^{-3} in the cited work, being higher than in the present study.

Adhesion performance: Peroba mica wood (Table 2) provided the greatest shear strength in the glue line of the bonded joints in the tangential and radial shear planes. The lowest strength in the Kiri wood was observed in both directions, however, it was the wood with the highest homogeneity among the four evaluated species, as demonstrated by the low coefficient of variation values.

Table 2. Shear strength and wood faults percentage in the glue line of four evaluated species.

Species	**Shear strength (MPa, 12% moisture)**		**Wood failures (%)**	
	Tangential	**Radial**	**Tangential**	**Radial**
Angelim	**12.55 Ba** (12.26)	**9.71 Bb** (12.14)	**57.52 Ba** (48.01)	**62.64 ABa** (34.55)
Kiri	**5.62 Da** (9.44)	**5.50 Ca** (11.43)	**87.36 Aa** (19.32)	**67.68 Ab** (12.70)
Peroba Mica	**14.76 Aa** (12.24)	**14.03 Aa** (12.95)	**32.44 Cb** (77.56)	**48.32 Ba** (46.20)
Teca	**8.09 Ca** (20.9)	**6.50 Cb** (25.58)	**28.93 Cb** (64.64)	**48.96 Ba** (64.30)

Representation of the wood faults

Species	**Tangential**	**Radial**
Angelim		

Means followed by the same capital letter in each column are statistically the same (Tukey, P> 0.05);

Averages of each property in the cut planes followed by the same lowercase letter in the row are statistically the same (T-test, P> 0.05); values in parentheses refer to the coefficient of variation (%).

In the Angelim and Teak woods, the shear strength in the glue line differed significantly in the cutting planes of the pieces. The bonded joints formed between the tangential pieces were more resistant to shear in relation to the radial pieces. A greater homogeneity of this property in tangential and radial pieces was observed for Kiri wood.

In comparing shear strength, it was observed that it was higher in the solid wood (Table 1) when compared to the values of the bonded joints, except for the Peroba mica species (Table 2). According to ASTM D-2559 (2012a), when using wood by means of bonded joints for structural purposes such as in civil construction, its shear strength should be practically similar to that found for solid wood. However, it was observed that shear values were only close to those found for solid wood in the tangential direction.

Regarding the wood faults of the bonded joints in tangential and radial faces, smaller percentages were observed for Teak and Peroba mica, while the highest values were conferred by Kiri.

Efficient bonding occurs when the wood breaks along with the adhesive, and the shear bond strength of the bonded joint is equal to that of solid wood (Frihart & Hunt, 2010). This fact was mainly observed for Kiri wood, in which the average shear strength of the wood glued on the tangential (5.62 MPa) and radial face (5.50 MPa) was close to the value determined for solid wood (7.01 MPa), and had a high wood failure percentage for both faces.

The permeability conferred by the higher fiber diameters in the Kiri wood provided a qualitatively superior performance in relation to porosity (diameter and vessel frequency) in the adhesion of this wood (Figure 3).

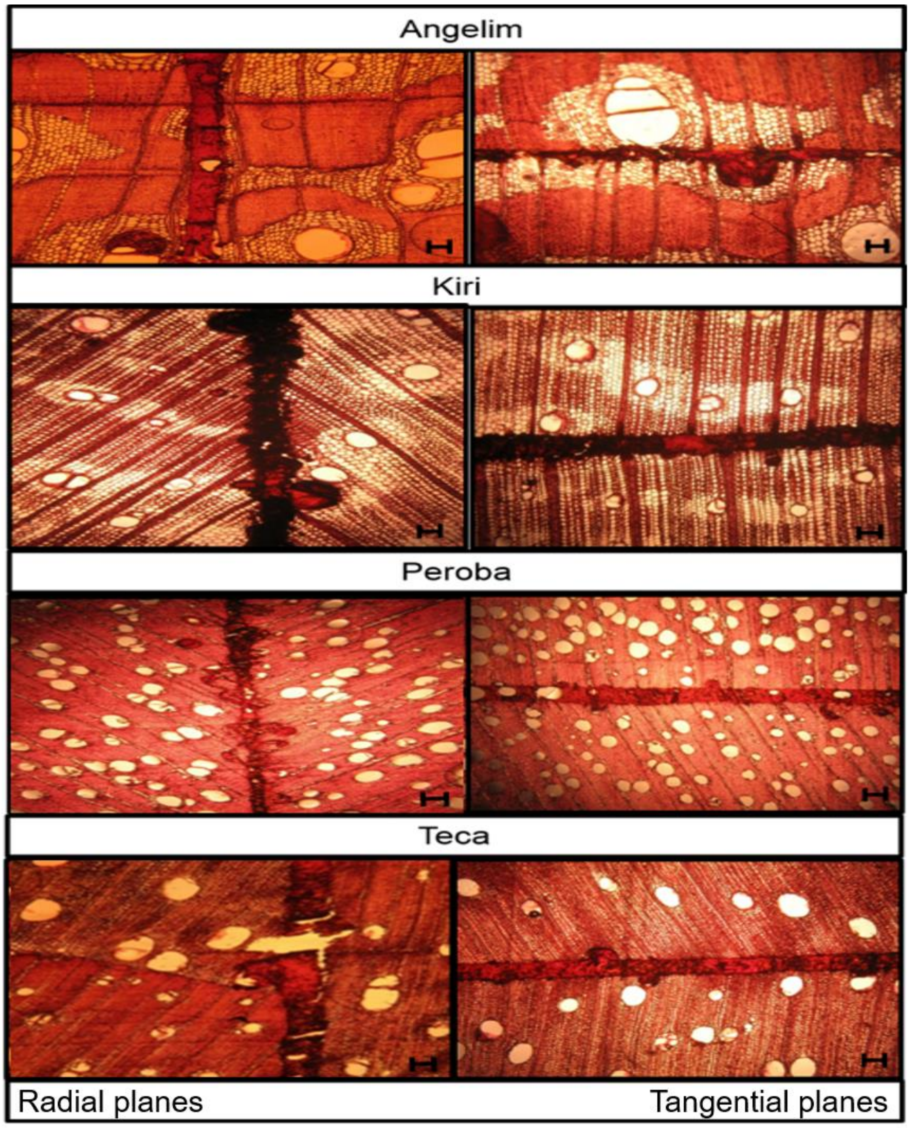

Figure 3. Microscopy of the glue line in the radial and tangential planes of the four studied species, arrow: main glue line (scale 100 micrometres).

There was penetration of the Cascophen RS-216-M adhesive into the vessel elements, the axial parenchyma cells and the fibers of the four studied species. Penetration also occurred in the radial parenchyma cells in the Angelim and Kiri species (Figure 3). The main glue line was thicker in the radial plane in species with larger vessel diameter (Table 1 and Figure 3), a fact observed for the Kiri, Angelim and Teak woods.

The greater the fiber diameter and ray width, the greater the adhesive penetration in the cells, and consequently the greater the adhesion between the wood pieces and the shear strength in the glue line (Albino et al., 2012). However, this fact was not observed for Kiri wood, which exhibited the lowest shear strength. In this way, Miranda e Castelo (2012) emphasize that thicker fiber walls have higher cellulose values than thinner walls. This chemical constituent is responsible for imparting resistance to wood.

The vessel diameter may provide greater interaction between the adhesive and the wood because of the better fluidity in the cells, thus increasing shear stress resistance. However, larger diameters of these elements may promote the appearance of a hung glue line and provide low resistance to bonded joints (Albino et al., 2012). In this case, the Peroba mica wood exhibited a smaller thickness of the main glue line in the radial and tangential planes (Figure 3) and demonstrated greater shear strength of the bonded joints (Table 2).

Regarding the glue line, the Angelim wood in the radial plane had the highest thickness, homogeneity and wood failure, while presenting a lower adhesive penetration and shear strength in the glue line. In the tangential plane, the opposite characteristics were observed in the radial, with the adhesive penetrating the rays, vessels, parenchyma and less perceptibly in the fibers.

For the Kiri species, greater failure and penetration of the adhesive in the radial plane were observed in the vessels and fibers, with less penetration in the radial and axial parenchyma. For the tangential plane, it exhibited less glue line failure and less adhesive penetration, with higher visual concentrations in the rays and less amount in vessels and fibers. The shear strength in the glue line and its thickness were similar between the two analyzed planes.

Regarding Peroba mica wood, the glue line in the radial plane was of smaller thickness and failure with greater adhesive penetration in the vessels by virtue of its greater frequency. In the tangential plane, a thicker and uniform glue line with greater failure and little adhesive penetration in the vessels and fibers. The shear strength in the glue line was similar between the two evaluated planes.

In Teak wood lower shear strength and glue line failure were observed in the radial plane, with greater thickness and adhesive penetration in the fiber vessels and radial parenchyma. In the tangential plane, greater shear strength and glue line failure were verified,

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being less thick and more uniform with greater adhesive penetration in the vessels and fibers, although less perceptible in the rays.

Relationship between wood properties and the bonding process: the anatomical characteristics of the forest species significantly correlated with the physical-mechanical properties, the glue line shear strength, and the tangential face failure percentage (Table 3).

Table 3. Pearson linear correlation coefficients among anatomical properties, physical-mechanical, shear strength in the glue line and wood failure percentages in the four species studied.

Variables	DAM	CMS	CLCT	CLCR	FMT	FMR
CR	**- 0.74***	**- 0.60***	**-0.59***	- 0.45*	0.41*	0.17^{ns}
LR	**- 0.88***	**- 0.68***	**-0.64***	**- 0.50***	**0.61***	0.28*
FR	**0.56***	0.15^{ns}	**0.66***	**0.77***	**-0.50***	-0.19^{ns}
CF	**0.59***	0.43*	**0.72***	**0.63***	-0.03^{ns}	0.08^{ns}
LF	**- 0.65***	**- 0.60***	-0.46*	- 0.22*	0.36*	0.17^{ns}
DLF	**- 0.88***	**- 0.68***	**-0.77***	**- 0.61***	0.45*	0.17^{ns}
EPF	**0.69***	0.42*	**0.74***	**0.76***	-0.33*	-0.08^{ns}
FP	**0.82***	**0.59***	**0.84***	**0.74***	-0.38*	-0.10^{ns}
DV	0.24*	**0.54***	0.01^{ns}	-0.25*	0.07^{ns}	0.26*
FV	0.34*	-0.11^{ns}	**0.66***	**0.87***	-0.35*	-0.15^{ns}
WAD	1	**0.80***	**0.78***	**0.59***	**- 0.52***	-0.19^{ns}
CMS		1	0.49*	0.18^{ns}	-0.27*	-0.05^{ns}
CLCT			1	**0.80***	-0.41*	0.07^{ns}
CLCR				1	- 0.39*	-0.07^{ns}
FMT					1	0.21^{ns}
FMR						1

DAM: wood apparent density; CMS: solid wood shear; CLCT: shear on the tangential glue line; CLCR: radial glue line shear; FMT: tangential wood failure; FMR: radial wood failure; CR: radius length; LR: ray width and FR: ray frequency; CF: length, LF: width, DLF: fiber lume diameter and EPF: wall thickness of fibers; FP: fiber wall fraction; DV: diameter and PV: frequency of vessels. * significant (P <0.05) and ns: not significant (P> 0.05).

The apparent density proportionally increased the wall fraction and thickness and fiber length; a relation corroborated by the existence of positive and significant correlations between the variables. However, the density and shear strength of the solid wood decreased with the increase in the length and width of the spokes, and the width and diameter of the flame of the fibers. The increase in the fiber wall fraction resulted in increased shear strength, given a positive, median and significant correlation coefficient.

The same trends observed for the relationship of density and shear strength with anatomical properties are a reflection of the strong, positive and significant correlation between these two properties.

For the shear in the glue line on the tangential and radial faces (CLCT and CLCR), the same characteristics of the previously mentioned correlations were observed for the wood apparent density with the anatomical properties. Except for the CLCT, vessel diameter exhibited a non-significant relationship, and a negative and significant correlation for CLCR.

In relation to the anatomical variables, FMT presented previously described contrary tendencies for the other evaluated characteristics. On the other hand, FMR showed only significant, weak and positive correlations with ray width and vessel diameter.

The higher the number of vessels in the wood, the greater the wood failure percentage due to the high resistance of the adhesive, which forms a more resistant glue line than the wood itself (Albino et al., 2012).

The wood bonding of Eucalyptus clones (14 years old) with urea-formaldehyde based adhesive was influenced by the frequency and dimensions of vessel and ray elements, which showed significant correlations with shear strength in the glue line and the wood failure percentage (Lima et al., 2007). This same behavior was observed for the four forest studied species, except FMR.

The vessel diameter, wall thickness, fiber width and length, and ray width of *Eucalyptus grandis* wood (18 years) positively influenced the shear strength, i.e. the higher the mean value of the anatomical parameters evaluated, the greater the strength of the cast joint. The vessel and ray frequency and the lume diameter of the fibers correlated positively and significantly with the wood failure percentage (Albino et al., 2012).

4. Conclusions

The anatomical variables that most influenced the adhesion performance of the bonded wood joints were the ray and fiber cells, with the latter being the one that most correlated with the shear strength in the glue line.

The pieces of joints bonded in the tangential cutting plane provided shear strength values closest to those verified for solid wood.

The highest failure percentage in the wood was obtained in the bonded joints of Kiri wood in both radial and tangential planes.

In general, the properties that confer greater shear strength to the bonded joints provided an inverse trend in relation to the failure percentage in the wood.

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