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Potential for using tropical solid wood waste from the Amazon for the production of edge glued panels

Corresponding author
Josiane Fernandes Keffer
Federal University of Paraná
kefferjf@gmail.com

Rosilani Trianoski
Federal University of Paraná

Rogério Antonio dos Santos
Federal University of Mato Grosso

Setsuo Iwakiri
Federal University of Paraná

Esoline Helena Cavalli Zamarian
Federal Technological University of Paraná

Abstract. The objective of this study was to evaluate the potential use of solid wood waste of the following species *Cedrela odorata*, *Enterolobium schomburgkii*, *Erisma uncinatum*, and *Qualea paraensis* for the manufacture of edge glued panels. The quality of the finger joint and edge bonding with PVA and EPI adhesives, respectively, with spreading rates of 180 g.m^{-2}, was evaluated through static bending, parallel tensile, and shear tests, using ASTM D 5572, EN 13353, and EN 13354 standards. A total of 1,460 test specimens exposed to dry, high temperature, triple cycle, and wet pre-treatments were tested for glue line resistance. The results of all tests for all pre-treatments of finger joints and edge bonding demonstrated the potential of wood waste for the manufacture of edge glued panels for interior use in dry environments. There was a tendency for resistance values to be balanced in splices and joints combined with mixtures of species, possibly due to the densities of the wood pieces. Wet pre-treatment delivered excellent lower 5th percentile results, highlighting the potential of Amazonian tropical solid wood waste for the production of edge glued panels.

Keywords: Wood waste, edge glued panels, products with higher added value, bonding quality, EGP panels.

Introduction

The wood sector is one of the most economically important for the Amazon region (Lima & Silva, 2016). However, most local sawmills predominantly produce pieces of wood that have not been processed, and therefore have low added value (Valdiones et al., 2022), which implies the generation of a large volume of wood waste (Hummel et al., 2010; Ramos et al., 2017).

The use of waste from wood processing in sawmills in the Amazon region is still very incipient (Bila et al., 2016), which results in an underutilization of this material. As natural resources are finite, the adoption of practices that contribute to reducing the waste of natural raw materials is increasingly necessary (Zhang et al., 2014).

Initiatives focused on the use of tropical wood waste to generate higher value-added products, such as wooden panels, for example, are urgent (Valdiones et al., 2022). One of the alternatives for using solid wood waste is the manufacture of edge glued panels (EGP) (Trianoski & Iwakiri, 2020).

EGP panels are produced by joining battens glued on the edge using adhesives, and may or may not have top bonding (Tienne et al., 2011). They are characterized by not using coatings, as the main differentiator of this type of panel is the enhancement of the natural aesthetic aspect of the wood (Trianoski & Iwakiri, 2020).

The most commonly used species in the production of EGP panels are *Pinus taeda*, *Eucalyptus* sp., and *Tectona grandis* (Almeida, 2013). These panels are produced industrially with unique species. Bonding is influenced by several wood characteristics, such as density, anisotropy, and extractives, among others (Frihart & Hunt, 2010; Almeida, 2015). The density is the property that most influences the physical and mechanical properties of EGP panels (Rojas et al., 2020).

In this sense, the main challenge in using tropical solid wood waste for the manufacture of EGP panels is the heterogeneity of species that make up this material. Despite this, the use of wood waste to generate products with higher added value is possible and can contribute to the generation of work and income, in addition to reducing environmental impacts through carbon sequestration (Rivela et al., 2006).

Because of this, intending to subsidize the improvement of the use of tropical solid wood waste in sawmills in the Amazon region, as well as adding value to this resource, it is necessary to investigate the feasibility of using solid wood waste of different species and compositions for the production of EGP panels. Thus, the objective of this work was to evaluate the potential for using solid wood waste from four Amazonian species for the production of EGP panels by evaluating the bonding quality of finger joints and edge glued.

Material and Methods

Characterization of the material

The waste used in this study consisted of logs, shavings and wood scraps from the splitting of logs of the species *Cedrela odorata*, *Enterolobium schomburgkii*, *Erisma uncinatum* and *Qualea paraensis* from the Sustainable Forest Management Plan, and donated by the company Rovermader (coordinates 11°55’52” S and 61°59’52” W, Alta Floresta D’Oeste-RO, Brazil).

Waste from five trees of each species (diameter at overall average breast height of 55 cm) was collected and converted into battens measuring 30 mm x 60 mm x 400 mm in thickness, width, and length, respectively. This material was kept under cover for approximately 90 days for outdoor drying. It was then transported to the Wood Panels Laboratory at the Federal University of Paraná, Curitiba-PR, where experimental procedures were carried out.

Manufacture of finger joints and edge glued

The battens were dried in an oven with forced air circulation at 40 ºC until a humidity content of 12%. They were subsequently resawed and planned to final dimensions of 22 mm x 55 mm x 310 mm for edge bonding and 25 mm x 55 mm x 200 mm (thickness, width, and length, respectively) for finger joints. The latter were also machined at the ends using finger joints to create the teeth.

The bonding’s were carried out individually by species and in mixtures between them, making a total of 10 treatments for each type of bonding (Table 1). For finger joint, Polyvinyl Acetate (PVA D3) adhesive was used with a spreading rate of 180 g.m^{-2} and pressure of 0.3 MPa for 30 seconds, and for edge bonding, the adhesive Emulsion Polymer Isocyanate (EPI) was used with a spreading rate of 180 g.m^{-2} and pressure of 0.8 MPa for 60 minutes. The stickers were applied with the help of a brush on a simple glue line and the battens were joined in pairs.

Table 1. Experimental plan for finger joint and edge bonding

Treatments	Species	Adhesives	
		Finger joint	Edge bonding
1	*C. odorata*	PVA D3	EPI
2	*E. schomburgkii*	PVA D3	EPI
3	*E. uncinatum*	PVA D3	EPI
4	*Q. paraensis*	PVA D3	EPI
5	*C. odorata* x *E. schomburgkii*	PVA D3	EPI
6	*E. uncinatum* x *C. odorata*	PVA D3	EPI
7	*E. uncinatum* x *E. schomburgkii*	PVA D3	EPI
8	*E. uncinatum* x *Q. paraensis*	PVA D3	EPI
9	*Q. paraensis* x *C. odorata*	PVA D3	EPI
10	*Q. paraensis* x *E. schomburgkii*	PVA D3	EPI

EPI: Emulsion Polymer Isocyanate; PVA D3: Polyvinyl Acetate

To characterize the wood, the apparent density was determined at 12% humidity following NBR 7190 (ABNT, 1997). For this purpose, the battens prepared for gluing were used.

Wood densities were classified based on studies by Melo et al. (1990); Coradin et al. (2010) and Silveira et al. (2013), who define wood with values lower than 0.50 g.cm^{-3} as low density, or light; medium density wood with values between 0.50 g.cm^{-3} and 0.72 g.cm^{-3}; and high density, or heavy, wood with values greater than 0.72 g.cm^{-3}.

Bonding quality

After the adhesive stabilization and curing period (seven days), test specimens were produced from the finger joints and edge bonding following the specifications of ASTM D 5572 (ASTM, 2019) and EN 13354 (EN, 2008). To evaluate the quality of the finger joints, 20 specimens from each treatment were tested in the static bending test and 12 in the parallel tensile test, in each of the pre-treatments established by the ASTM D 5572 standard (ASTM, 2019): dry (test specimens at 12% humidity), high temperature (test specimens exposed to 104 ± 3 °C for 6 hours) and triple cycle (specimens immersed in water at room temperature for 4 hours, followed by oven drying at 41 ± 3 °C for 19 hours, procedure was repeated for two more cycles). For edge bonding, 20 specimens from each treatment were tested in the glue line shear test in the dry (specimens at 12% humidity) and wet pre-treatments (test specimens immersed in water at 20 ± 3 °C for 24 hours).

After the shear and parallel tensile tests, the percentages of failure in the wood were evaluated and the 5th lower percentile was calculated for edge gluing according to EN 326-1 (EN, 1994). The test results were compared with the minimum requirements established by EN 13353 (EN, 2008) and ASTM D 5572 (ASTM, 2019) standards.

Statistical analysis

The experimental design was entirely randomized. Data normality and variance homogeneity were previously verified using the Shapiro-Wilk and Bartlett tests, respectively. The collected data were statistically analyzed by one-way analysis of variance (ANOVA) ($p = 0.05$) to investigate the effects of species on the quality of finger and edge bonding. When significant by the F test, differences between the experimental data means were evaluated using the Tukey test ($p = 0.05$). The Sivar software (version 26) (Ferreira, 2011) was used for the statistical analysis.

Results and discussion

Apparent density (12%)

Table 2 presents the average apparent density values (12%) for wood from *C. odorata*, *E. schomburgkii*, *E. uncinatum*, *Q. paraensis* and their combinations.

Table 2. Apparent density at 12% humidity *C. odorata*, *E. schomburgkii*, *E. uncinatum*, *Q. paraensis*, and their studied combinations

Species	ρ 12% (g.cm^{-3})	CV (%)	Density classification
C. odorata	0.51 d	4.06	Low
E. schomburgkii	0.78 a	1.28	High
E. uncinatum	0.56 c	3.09	Low
Q. paraensis	0.79 a	1.27	High
C. odorata x E. schomburgkii	0.66 b	1.52	Medium
E. uncinatum x C. odorata	0.54 cd	1.08	Low
E. uncinatum x E. schomburgkii	0.67 b	2.29	Medium
E. uncinatum x Q. paraensis	0.66 b	0.87	Medium
Q. paraensis x C. odorata	0.66 b	2.62	Medium
Q. paraensis x E. schomburgkii	0.77 a	0.00	High

ρ 12% = apparent density at 12% humidity in g.cm^{-3}. CV (%) = coefficient of variation in percentage. Means followed by the same letters in the column do not differ from each other using the Tukey test at 95% reliability.

The species *E. schomburgkii*, *Q. paraensis*, and the combination between them presented the highest average apparent density values, with no statistical difference between the two. While the lowest average value of apparent density was observed for *C. odorata*. The average apparent density values for the studied species varied from 0.51 g.cm^{-3} for *C. odorata* to 0.79 g.cm^{-3} for *Q. paraensis*.

Previous studies (Kamke & Lee, 2007; Hasset al., 2011; Musah et al., 2021) have suggested that anatomical characteristics such as porosity, which is directly related to density, early/late wood transition, and cell types, influence the penetration of the adhesive into the wood and consequently the quality of the gluing.

Finger joints resistance

The static bending results of the butt splices were statistically different only in the dry and triple cycle pre-treatments (Table 3). While for parallel tensile, there was a statistical difference in all pre-treatments.

In the static bending test *E. schomburgkii*, *and Q. paraensis* as well as the mixture between them showed resistances that were statistically equal to each other, but higher than the other treatments in the dry pre-treatment. In the triple cycle pre-treatment *E. schomburgkii* and *Q. paraensis* were also statistically equal to each other and superior to other treatments. All species and their mixtures met the minimum requirements for these two pre-treatments (13.8 MPa – Dry; 6.9 MPa – triple cycle), according to ASTM D 5572 (ASTM, 2019).

In the parallel tensile test, dry pre-treatment, *Q. paraensis* x *E. schomburgkii* was statistically superior to the other treatments. In high temperature and triple cycle pre-treatments, *E. schomburgkii* presented superior resistance to other treatments. Considering only the resistance value, all species and their mixtures met the minimum requirements (dry: > 13.8 MPa; triple cycle and high temperature: > 6.9 MPa) of the ASTM D 5572 standard (ASTM, 2019). As for wood failure, *E. schomburgkii*, *C. odorata* x *E. schomburgkii*, *Q. paraensis* x *C. odorata*, and *Q. paraensis* x *E. schomburgkii* did not reach the minimum requirement (30%) in dry pre-treatment. While in pre-treatments high temperature and triple cycle *Q. paraensis* x *E. schomburgkii* and *E. schomburgkii* did not reach the minimum requirement (15%) for wood failure.

Table 3. Resistance to static bending and parallel tensile of the finger joints, glued with PVA adhesive with a spreading rate of 180 g.m^{-2}, for each pre-treatment of *C. odorata*, *E. schomburgkii*, *E. uncinatum*, and *Q. paraensis* wood individually and in mixture

Pre-treatments	Species	Static bending	Tensile	WF
		(MPa)		(%)
Dry or cured	*C. odorata*	48.43 (10.77) ab	22.90 (11.93) abc	37
	E. schomburgkii	53.17 (11.99) a	26.58 (28.32) abc	12
	E. uncinatum	36.53 (20.42) d	20.34 (22.73) c	62
	Q. paraensis	53.61 (15.89) a	22.42 (14.65) bc	31
	C. odorata x *E. schomburgkii*	50.53 (10.54) ab	24.14 (19.33) abc	27
	E. uncinatum x *C. odorata*	39.41 (20.28) cd	24.63 (24.01) abc	52
	E. uncinatum x *E. schomburgkii*	48.54 (17.34) ab	24.43 (20.06) abc	54
	E. uncinatum x *Q. paraensis*	45.08 (14.02) bc	22.96 (28.44) bc	55
	Q. paraensis x *C. odorata*	49.19 (13.45) ab	28.76 (26.05) ab	23
	Q. paraensis x *E. schomburgkii*	52.96 (11.53) a	31.35 (24.72) a	18
High temperature	*C. odorata*	29.84 (38.19) a	31.25 (34.87) ab	33
	E. schomburgkii	29.32 (35.11) a	33.93 (28.91) a	26
	E. uncinatum	31.10 (32.37) a	21.80 (23.51) b	72
	Q. paraensis	33.39 (38.37) a	25.44 (25.67) ab	35
	C. odorata x *E. schomburgkii*	28.64 (29.07) a	27.98 (14.93) ab	20
	E. uncinatum x *C. odorata*	30.83 (28.31) a	27.63 (16.94) ab	49
	E. uncinatum x *E. schomburgkii*	32.02 (35.31) a	26.69 (13.54) ab	41
	E. uncinatum x *Q. paraensis*	28.50 (33.01) a	24.87 (17.03) ab	43
	Q. paraensis x *C. odorata*	23.83 (43.64) a	30.87 (22.25) ab	15
	Q. paraensis x *E. schomburgkii*	28.38 (34.59) a	29.35 (25.45) ab	10
Triple cycle	*C. odorata*	52.63 (9.84) ab	30.51 (21.65) abc	22
	E. schomburgkii	55.29 (14.03) a	35.86 (17.40) a	13
	E. uncinatum	37.70 (28.44) d	23.13 (25.38) cd	55
	Q. paraensis	56.23 (12.10) a	32.47 (19.39) ab	28
	C. odorata x *E. schomburgkii*	53.23 (14.17) ab	31.02 (21.79) abc	45
	E. uncinatum x *C. odorata*	40.00 (26.71) cd	21.76 (22.66) d	38
	E. uncinatum x *E. schomburgkii*	48.10 (21.57) abc	28.61 (21.43) abcd	48
	E. uncinatum x *Q. paraensis*	44.61 (21.72) bcd	24.63 (24.68) bcd	37
	Q. paraensis x *C. odorata*	50.57 (20.49) ab	30.55 (17.94) abc	27
	Q. paraensis x *E. schomburgkii*	51.76 (13.18) ab	27.93 (27.96) abcd	23

WF (%) = percentage of the wood failure. Means followed by the same letter in the same column for each pre-treatment are statistically equal according to the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

In general, a tendency toward resistance balancing was observed in the dry pre-treatment. For example, the *E. uncinatum* x *Q. paraensis* bonding combination resulted in an average static flexural resistance of 45.08 MPa, average parallel tensile resistance of 22.96 MPa, and average wood failure of 55%. While in individual bonding these species presented an average static flexural resistance of 36.53 MPa, an average parallel tensile resistance of 20.34 MPa, and average wood failure of 62% (*E. uncinatum*), and an average static flexural resistance of 53.61 MPa, average parallel tensile resistance of 22.42 MPa and average wood failure of 31% (*Q. paraensis*). The same behavior for these properties was observed for the top splices of *C. odorata* in combination with *E. schomburgkii*.

As for the other pre-treatments, the high temperature did not present a clear pattern of behavior, which was evidenced by the statistical analysis performed; and, in the triple cycle, the highest average static bending resistances were observed for *Q. paraensis*, *E. schomburgkii*. and *C. odorata*, as well as for their combinations. While for parallel tensile resistance, a balancing trend was observed again, with the combination of *E. uncinatum* x *Q. paraensis* showing an average value of 24.63 MPa, and the glued joints of the individual species average values of 23.13 MPa (*E. uncinatum*) and 32.47 MPa (*Q. paraensis*). Similar behavior was observed for the combination of *C. odorata* x *E. schomburgkii*, in which the top seams presented an average parallel tensile resistance of 31.02 MPa, while in individual gluing these species presented an average parallel tensile resistance of 30.51 MPa (*C. odorata*) and 35.86 MPa (*E. schomburgkii*).

Even though the vast majority of gluing operations are considered unique, due to the different variables involved in the process, such as species, wood properties, adhesives, gluing parameters, among others (Hunt et al., 2019), the results obtained in this research were satisfactory and compatible with those observed for the most industrially used woods in the production of EGP panels pine and eucalyptus.

Iwakiri et al. (2021) also using PVA D3 adhesive in a spreading rate of 180 g.m^{-2}, found resistances to static bending of the butt seams for *Eucalyptus badjensis* of 48.89, 41.31 and 11.44 MPa in the dry, high temperature and triple cycle pre-treatments, respectively. For *P. taeda*, Lau (2017) using the same gluing parameters found average values of static bending resistance of

28.53, 14.05 and 7.39 MPa in the dry, high-temperature, and triple cycle pre-treatments, respectively.

For *E. badjensis*, Iwakiri et al. (2021) found average tensile values of 26.78; 24.85 and 19.88 MPa in the dry, high temperature and triple cycle pre-treatments, respectively, and an average wood failure of 25 to 97%. While for *P. taeda*, Lau (2017) found 20.79, 9.71 and 12.02 MPa in the dry, high temperature and triple cycle pre-treatments, respectively, and average wood failure of 13 and 58%. It is worth highlighting the superiority of the resistances obtained in this study, for all species combinations in all pre-treatments, with pine and eucalyptus wood, which demonstrates the suitability of waste from *C. odorata*, *E. schomburgkii*, *E. uncinatum* and *Q. paraensis* for the production of EGP panels.

Edge bonding

The average shear results differed statistically between the species and their mixtures evaluated in both pre-treatments (Table 4). Average shear values for dry pre-treatment ranged from 7.68 MPa (*E. uncinatum*) to 14.26 MPa (*Q. paraensis* x *E. schomburgkii*). The lowest shear values during this pre-treatment were observed for *C. odorata*. *E. uncinatum*. *E. uncinatum* x *C. odorata*. and *E. uncinatum* x *Q. paraensis*. While *Q. paraensis*. *E. schomburgkii*. as well as their mixtures, presented statistically superior results. Despite this, all treatments met the minimum requirements of the lower 5th percentile and wood failure according to the EN 13353 standard (EN. 2008).

In the wet pre-treatment, shear values varied from 4.30 MPa (*Q. paraensis*) to 9.03 MPa (*E. schomburgkii*). The lowest shear values during this pre-treatment were observed for *Q. paraensis* and *E. uncinatum*. While *E. schomburgkii*. *C. odorata* x *E. schomburgkii*. *E. uncinatum* x *E. schomburgkii*. *Q. paraensis* x *C. odorata* and *Q. paraensis* x *E. schomburgkii* presented statistically better results. However, all treatments also met the minimum requirements of the bottom 5th percentile and wood failure in this pre-treatment. It is also worth highlighting the excellent results of the lower 5th percentile found in wet pre-treatment, which demonstrated the approval of all species and combinations.

Table 4. Resistance of the glue line to shear (RLS) of wood from *C. odorata*, *E. schomburgkii*, *E. uncinatum* and *Q. paraensis* glued individually and in a mixture with EPI adhesive at a spreading rate of 180 g.m^{-2}

Species	Dry or cured			Wet		
	RLS	5th LP	WF	RLS	5th LP	WF
	(MPa)		(%)	(MPa)		(%)
C. odorata	8.85 c (8.79)	7.89	80	6.88 bc (7.29)	6.32	52
E. schomburgkii	14.15 a (12.77)	11.88	47	9.03 a (10.84)	8.00	19
E. uncinatum	7.68 c (28.34)	4.75	62	5.11 cd (23.55)	3.78	44
Q. paraensis	13.16 ab (19.39)	10.11	60	4.30 d (21.40)	3.59	2
C. odorata x *E. schomburgkii*	10.77 bc (11.02)	9.26	91	7.85 ab (18.40)	6.20	54
E. uncinatum x *C. odorata*	8.56 c (8.61)	7.82	96	6.33 bcd (6.53)	6.02	76
E. uncinatum x *E. schomburgkii*	10.77 bc (10.63)	9.65	92	7.51 ab (7.06)	6.93	55
E. uncinatum x *Q. paraensis*	9.14 c (17.35)	7.01	95	6.57 bc (10.44)	6.01	58
Q. paraensis x *C. odorata*	10.04 bc (10.24)	8.99	91	7.71 ab (6.56)	7.13	60
Q. paraensis x *E. schomburgkii*	14.26 a (7.77)	12.91	59	7.44 ab (9.74)	6.57	8

RLS = Resistance of the glue line to shear. 5th LP = lower percentile. WF = wood failure. Means followed by the same letter in the same column for each pre-treatment are statistically equal according to the Tukey test at 95% reliability. Values in parentheses refer to the coefficient of variation in percentage.

In general, as seen in the finger joints, in the dry pre-treatment it was also possible to observe a balance in the shear resistance of the glue line. For example, joints glued with a combination of the species *E. uncinatum* and *Q. paraensis* showed an average RLS of 9.14 MPa, while in individual bonding these species showed an average shear of 7.68 MPa (*E. uncinatum*) and 13.16 MPa (*Q. paraensis*). Similar behavior was shown by the glued joints of *C. odorata* in combination with *E. schomburgkii*, which showed an average shear of 10.77 MPa. While in individual gluing, these species showed an average shear of 8.85 MPa (*C. odorata*) and 14.15 MPa (*E. schomburgkii*).

However, when observing the wet pre-treatment, which is most important for determining the bonding quality, a more interesting trend of behavior was observed. In general, low-density woods (*C.*

odorata and *E. uncinatum*) glued in combination with higher-density species (*Q. paraensis*) produced joints with a higher average value of shear resistance compared to the resistance of the species glued individually. For example, the combination of *E. uncinatum* x *Q. paraensis* resulted in joints glued with an average shear of 6.57 MPa, which was higher than *E. uncinatum* (5.11 MPa) and *Q. paraensis* (4.30 MPa) glued individually. Similar behavior was observed for glued joints from *C. odorata* in combination with *Q. paraensis*. which presented average shear resistance of 7.71 MPa. While in individual gluing, these species showed average shear of 4.30 MPa (*Q. parensis*) and 6.88 MPa (*C. odorata*). On the other hand, even though it is a species with greater density, *E. schomburgkii* did not show the same behavior when combined with lower-density species, which may indicate that other factors, in addition to density, may govern the shear resistance of this species, which was superior when glued individually.

As observed with top gluing, the results obtained with edge gluing were satisfactory and compatible with those observed in the literature for other tropical species and for pine and eucalyptus wood. *For P. taeda*, for example, glued with EPI adhesive with a spreading rate of 200 g.m^{-2}, Lopes et al. (2013) obtained a shear resistance of 7.63 MPa in dry condition and 2.91 MPa in wet pre-treatment. For *Eucalyptus sp.* using EPI adhesive at a spreading rate of 180 g.m^{-2}, França et al. (2020) found a shear resistance of 12.77 MPa in the dry condition and 8.84 MPa in the wet condition. While Iwakiri et al. (2021) using the same adhesive and spreading rates for *E. badjensis* found average values of 12.66 MPa and 5.23 MPa in dry and wet pre-treatments, respectively.

For other tropical species, Bila et al. (2016) observed that shear resistance varied from 7.66 MPa for *Manilkara amazonica* to 13.76 MPa for *Eschweilera coriacea* in wet pre-treatment, also glued with EPI adhesive, but with a spreading rate of 200 g.m^{-2}. Rojas et al. (2020) obtained shear values of 5.19 MPa for *Cariniana domestica*, 5.23 MPa for *Copaifera paupera*, and 4.31 MPa for *Cedrelinga cateniformis* in wet pre-treatment, using the same adhesive and spreading rates as in the present study. These authors also evaluated the quality of bonding of joints with mixtures of species, obtaining approval according to the requirements of EN 13353 (EN, 2008) standard, only for the combinations of *C. domestica* x *C. cateniformis* (5.62 MPa) and *C. paupera* x *C. cateniformis* (5.22 MPa). They associated the results obtained with density values, stating that higher density provides greater resistance to the glue line.

The variation from 7.68 MPa (*E. uncinatum* - Dry) to 14.26 MPa (*Q. paraensis* x E. *schomburgkii* - Dry) in shear resistance suggests that, among other factors, the density of wood is possibly the property that exerts the greatest influence on these differences. It is known that the density of wooden pieces can influence the bonding quality due to differences in the porosity and permeability of their structure (Albuquerque et al., 2020), which can, in this case, have been balanced in the seams and glued joints, since the density of a glued seam/joint was represented by the average between the densities of the two battens of different species joined in the bonding.

In this sense, Musah et al. (2021) reported that mixing species with different anatomical features can reduce the negative effects of some features that would be accentuated in gluing with a single species. Therefore, these findings expand the discussion on the use of mixtures of species in the production of hybrid wood panels (Musah et al., 2021) which becomes even more prominent for tropical Amazonian species.

Conclusion

Single-species and mixed-species butt and edge glued joints have met the prerequisites of ASTM D 5572 and EN 13353 standards for dry use. Wet pre-treatment showed excellent results in the lower 5th percentile. Therefore, solid wood waste, mainly from the following species combinations: *E. schomburgkii*, *C. odorata* x *E. schomburgkii*, *E. uncinatum* x *E. schomburgkii*, *Q. paraensis* x *C. odorata* and *Q. paraensis* x *E. schomburgkii*, present potential for producing EGP panels for interior use with higher value-added products, such as furniture and frames, enabling better use and valorization of this raw material.

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References

ALBUQUERQUE, C. E. C.; IWAKIRI, S.; KEINERT JÚNIOR, S.; TRIANOSKI, R. Adesão e adesivos. *In*: Iwakiri, S.; Trianoski, R. (eds.). Painéis de madeira reconstituída. Curitiba: FUPEF, 2020. p. 10-36.

ALMEIDA, V. C. Avaliação do potencial de uso de resíduos de madeira tropical para produção de painéis colados lateralmente – EGP. Tese (Doutorado em Engenharia Florestal) - Universidade Federal de Paraná. Curitiba, p. 122, 2013.

ALMEIDA, C. C. F. Avaliação da qualidade da colagem da madeira de *Cupressus lusitânica* Miil. para a produção de painéis colados lateralmente (Edge glued panel - EGP). Dissertação (Mestrado em Engenharia Florestal) - Centro de Ciências Agroveterinárias, Universidade do Estado de Santa Catarina. Lages, p. 142. 2015.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM). Standard specification for adhesives used for finger joints in nonstructural lumber products - D 5572. West Conshohocken, p. 17, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). Projetos de estruturas de madeira – NBR 7190. Rio de Janeiro, p 107, 1997.

BILA, N. F.; IWAKIRI, S.; TRIANOSKI, R.; PRATA, J. G. Avaliação da qualidade de juntas coladas de seis espécies de madeiras tropicais da Amazônia. Floresta, v. 46, n. 4, p. 455-464, 2016. https://doi.org/10.5380/rf.v46i3.36311

CORADIN, V. T. R.; CAMARGOS, J. A. A.; PASTORE, T. C. M.; CHRISTO, A. G. Madeiras comerciais do Brasil: chave interativa de identificação baseada em caracteres gerais e macroscópicos. Serviço Florestal Brasileiro, Laboratório de Produtos Florestais: Brasília, 2010. Disponível em: < https://lpf.florestal.gov.br/en-us/chave-interativa-de-identificacao >. Acesso em: 14 ago. 2023.

EUROPEAN STANDARD (EN). Wood-based panels – Sampling, cutting and inspection – Part 1: Sampling and cutting of test pieces and expression of test results – EN 326-1. Bruxelas, p. 11, 1994.

EUROPEAN STANDARD (EN). Solid wood panels (SWP) – Requirements – EN 13353. Bruxelas, p. 10, 2008.

EUROPEAN STANDARD (EN). Solid wood panels – Bonding quality – Test Method – EN 13354. Bruxelas, p.11, 2008.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia, v. 35, n.6, p. 1039-1042, 2011. https://doi.org/10.1590/S1413-70542011000600001

FRANÇA, M. C.; ZEN, L. R.; JUIZO, C. G. F.; CREMONEZ, V. G.; TRIANOSKI, R.; IWAKIRI, S. Production of joints of *Eucalyptus* sp. to obtain Edge Glued Panels. Floresta e Ambiente, v. 27, 2020. https://doi.org/10.1590/2179-8087-FLORAM-2018-0004

FRIHART, C. R.; HUNT, C. G. Adhesives with wood materials: bond formation and performance. Wood handbook: wood as an engineering material: chapter 10. Centennial ed. General technical report FPL; GTR-190. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 2010. p. 10.1-10.24.

HASS, P.; WITTEL, F. K.; MENDOZA, M.; HERRMANN, H. J.; NIEMZ, P. Adhesive penetration in beech wood: experiments. Wood Science and Technology, v. 46, n. 1-3, p. 243-256, 2011. https://doi.org/10.1007/s00226-011-0410-6.

HUMMEL, A. C.; ALVES, M. D. S. PEREIRA, D.; VERÍSSIMO, A.; SANTOS, D. A atividade madeireira na Amazônia brasileira: produção, receita e mercados. Belém: Imazon, 2010. p. 20.

HUNT, C. G.; FRIHART, C. R.; DUNKY, M.; ROHUMAA, A. Understanding wood bonds–going beyond what meets the eye: a critical review. *In*: MITTAL, K. L. (Ed.). Progress in adhesion and adhesives. Beverly: Wiley-Scrivener, 2019. p. 353-419. https://doi.org/10.1002/9781119625322

IWAKIRI, S.; TRIANOSKI, R.; ZUNTA, R. R.; PEREIRA, G. F.; ROSA, T. S. Avaliação dos efeitos do adesivo, gramatura e pressão na qualidade de painéis EGP de *Eucalyptus badjensis*. Scientia Forestalis, 49:e3437, 2021. https://doi.org/10.18671/scifor.v49n129.20

KAMKE, F. A.; LEE, J. N. Adhesive penetration in wood - a review. Wood and Fiber Science, v. 39, n. 2, p. 205-220, 2007.

LAU, P. C. Produção de painéis de colagem lateral-EGP com madeira de *Populus deltoides*. Dissertação (Mestrado em Engenharia Florestal) - Universidade Federal do Paraná. Curitiba, p. 66. 2017.

LIMA, J. B.; SILVA, J. M. P. Dinâmicas econômicas e ordenamentos territoriais dos grandes projetos de mineração no estado do Pará, 2009-2014: o caso de Paragominas. GEOSABERES, v. 6, n. 3, p. 402-416, 2016.

LOPES, M. C.; MUNIZ, G. I. B.; MATOS, J. L. M.; TANOBE, V. O. A.; CHINASSO, C. A. F.; ROSSO, S. Resistência da linha de cola de painéis de *Pinus taeda* colados lateralmente com diferentes adesivos. Cerne, v. 19, n. 4, p. 613-619. 2013. https://doi.org/10.1590/S0104-77602013000400011

MELO, J. E.; CORADIN, V. R.; MENDES, J. C. Classes de densidade para madeiras da Amazônia brasileira. In: CONGRESSO FLORESTAL BRASILEIRO, 6., 1990, Campos do Jordão. Anais... Campos do Jordão, 1990. v. 3. p. 695-705.

MUSAH, M.; WANG, X.; DICKINSON, Y.; ROSS, R. J.; RUDNICKI, M.; XIE, X. Durability of the adhesive bond in cross-laminated northern hardwoods and softwoods. Construction and Building Materials, v. 307, 2021. https://doi.org/10.1016/j.conbuildmat.2021.124267.

RAMOS, W. F.; RUIVO, M. L. P.; JARDIM, M. A. G.; PORRO, R.; CASTRO, R. M. S.; SOUSA, L. M. Análise da indústria madeireira na Amazônia: gestão, uso e armazenamento de resíduos. RBCIAMB, n.43, p. 1-16, 2017. https://doi.org/10.5327/Z2176-947820170057

RIVELA, B., HOSPIDO, A., MOREIRA, T., FEIJOO, G. Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector (8 pp). The International

Journal of Life Cycle Assessment, v. 11, p. 106-113, 2006. https://doi.org/10.1065/lca2005.05.206

ROJAS, J. C. C.; IWAKIRI, S.; TRIANOSKI, R.; MORA, H. E. G. Uso de residuos de procesos de transformación secundaria de tres especies tropicales en la fabricación de paneles encolados lateralmente. Scientia Forestalis, v. 48, n. 125, e3168, 2020. https://doi.org/10.18671/scifor.v48n125.20

SILVEIRA, L. H. C.; REZENDE, A. V.; VALE, A. T. Teor de umidade e densidade básica da madeira de nove espécies comerciais amazônicas. Acta Amazônica, v. 43, n. 2, p.179 – 184, 2013. DOI: 10.1590/S0044-59672013000200007

TIENNE, D. L. C.; NASCIMENTO, A. M.; GARCIA, R A.; SILVA, D. B. Qualidade de adesão de juntas de madeira de *Pinus* coladas em condições simuladas de serviço interna e externa. Floresta e Ambiente, v. 18, n. 1, p. 16-29, 2011. https://doi.org/10.4322/floram.2011.0191

TRIANOSKI, R.; IWAKIRI, S. Painéis colados lateralmente - EGP. *In*: Iwakiri, S.; Trianoski, R. (eds.). Painéis de madeira reconstituída. Curitiba: FUPEF, 2020. p.118-135.