

Potential use of *Pinus patula* wood for frames and edge glued panels

Potencial de utilização da madeira de Pinus patula para molduras e painéis colados lateralmente

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Abstract

Wood and engineered wood products can be used to replace non-renewable materials in construction and furniture, contributing to a more sustainable society. This study aimed to assess the potential of *Pinus patula* wood for the production of frames and edge glued panels, and to maximize production process variables, adhesive weight, and pressure, in order to generate a product with adequate quality at the lowest cost. Fingerjointing and edge gluing were performed. The finger joint gluing was carried out industrially using PVA adhesive. Edge gluing was carried out on a laboratory scale under 18 experimental conditions: 16 with *Pinus patula* and 2 with *Pinus taeda* (control). The variables studied were the glue type (PVA and EPI), grammage (160, 180, 200, and 220 g.m⁻²), and pressure (7 and 10 kgf.cm⁻²). The finger joint gluing quality was assessed by flexural and tensile tests (ASTM, 2019) and edge bonding by shear strength (ES, 2009). The results showed that *Pinus patula* has potential for the production of frames and edge glued panels, and that process variables can be maximized when using EPI adhesive.

Keywords: Engineered wood products. Bonding quality. Finger joint. Edge gluing.

Resumo

A madeira e os produtos de madeira engenheirada podem ser utilizados na substituição de materiais não renováveis na construção civil e mobiliário, contribuindo para uma sociedade mais sustentável. Este estudo objetivou avaliar o potencial da madeira de *Pinus patula* para a produção de molduras e painéis colados lateralmente, bem como, maximizar as variáveis do processo produtivo gramatura de adesivo e pressão, de forma a gerar um produto com qualidade adequada ao menor custo. Foram realizadas colagens finger joint e lateral. A colagem finger joint foi efetuada industrialmente com adesivo PVA. A colagem lateral foi realizada em escala laboratorial e compreendeu 18 condições experimentais, sendo 16 com *Pinus patula* e 2 com *Pinus taeda* (testemunha). As variáveis estudadas foram o tipo de adesivo (PVA e EPI), gramaturas (160, 180, 200 e 220 g.m⁻²), e pressão (7 e 10 kgf.cm⁻²). A qualidade de colagem finger joint foi avaliada segundo ensaios de flexão e tração (ASTM, 2019) e a colagem lateral por meio da resistência ao cisalhamento (ES, 2009). Os resultados demonstraram que o *Pinus patula* possui potencial para a produção de molduras e painéis colados lateralmente e as variáveis de processo podem ser maximizadas se utilizado o adesivo EPI.

Palavras-chave: Produtos de madeira engenheirada. Qualidade de colagem. Finger joint. Colagem lateral.

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Introduction

Currently climate change is a major global concern, which, according to Zhang, Zhang and Zhu (2024), represents a major threat to human life and biological ecosystems. This concern reflects the importance of forests and the search for sustainable materials with less environmental impact.

Among their many benefits, forests store carbon. According to Confederation Européenne des Industries du Bois (2019), for the production of 1 m³ of wood, 1 ton of carbon dioxide (CO₂) is absorbed from the atmosphere and 0.7 tons of oxygen (O₂) are released, and in this sense, wood plays a leading role as it is a natural, renewable, and adaptable material.

Brazil has the second largest forest area in the world, with around 495 million hectares - mi/ha (12% of the world total), of which 485.4 mi/ha (98.1%) is a native forests and 9.5 mi/ha (1.9%) by is planted forests. Of the latter, 7.5 mi/ha are *Eucalyptus* (78 %), 1.7 mi/ha are *Pinus* (18%), and 0.4 mi/ha are other species (4%) (Abimci, 2022). Although they make up less than 2% of total forests, forest plantations provide more than 90% of the wood consumed in industrial processes (Ibá, 2022).

The majority of *Pinus* forest plantations are concentrated in the south of Brazil, with 1.7 mi/ha (85%), with *Pinus taeda* being the most widely used (Abimci, 2022). On the other hand, in some regions, *Pinus taeda* plantations suffer from attacks by capuchin monkeys (*Sapajus nigritus*), which remove the bark to feed on the elaborated sap. This damage can be of the “window” type, where only one face of the stem is damaged, or of the “ringed” type, where the peeling covers the entire circumference of the trunk, compromising tree growth, causing stress and promoting pest attack (Mikich; Liebsch, 2009).

In this context, some reforestation companies and industries have sought to plant other species of this genus in order to avoid selective attacks by capuchin monkeys, increase and diversify the raw material, and improve the quality of forest-based products. One example is the introduction of *Pinus patula* into forest plantations in Paraná, which originates from Mexico and, unlike *Pinus taeda*, has not suffered selective attack by capuchin monkeys, probably due to lower levels of glucose and fructose and higher concentrations of phenolic compounds in the months when attacks are most prevalent (Almeida, 2013). *Pinus patula* wood has sapwood that varies from white to light yellow, while the heartwood is pinkish and often indistinguishable, the growth rings are very distinct, brown in color, slightly thick and irregular in texture, with straight and spiral grain, it has low resin production, is considered light, easy to work, dry and impregnate (Melchiorretto; Eleotério, 2003). On the other hand, this species has demanded research into the quality of its wood and its possible applications in solid form or engineered products.

FAO (2022), in its report “Perspectives for the Global Forestry Sector 2050,” states that wood and its products and by-products can be used to replace non-renewable materials, as well as Verkerk *et al.* (2022). Longue and Colodette (2013) reinforce the replacement of products from non-renewable sources with wood, primarily petroleum derivatives such as fuels and plastics, and Araujo *et al.* (2017) add that products manufactured from wood are fundamental to modern society, thus promoting sustainability.

With current technology and knowledge, the range of wood products, solid or engineered, is vast, offering a wide range of applications in civil construction, for decorative purposes, and for furniture. One engineered wood product worth highlighting for its characteristics and multiple applications is the edge glued panel (EGP).

EGP is a panel made from wooden battens joined together using edge gluing, which may or may not have a finger joint. Its main advantages are the reuse of by-products from sawmills, such as wood slabs, increased performance thanks to the use of narrow or short pieces that would otherwise be discarded, improved dimensional stability compared to solid wood, good mechanical resistance, size flexibility, pleasant texture, color, and appearance, and a relatively simple production process compared to other wooden panels, among others. It finds applications in civil construction, both structurally and decoratively, in floors, door and window frames, and mainly in furniture (Trianoski; Iwakiri, 2020).

Many factors influence the production process of this panel, such as the wood species and its properties, the preparation of the wood for gluing, the type of adhesive and weight applied, the pressing pressure, etc. Therefore, when evaluating a new species for this product, studies must be conducted in order to generate a product that complies with the regulatory requirements of the consumer market or that has adequate properties, as well as maximize the process in order to generate a compliant product at the lowest possible cost.

In this context, the aim of this study is to evaluate the suitability of *Pinus patula* wood for the production of frames and edge glued panels, as well as to maximize the variables of the production process, adhesive

grammage, and pressure, in order to generate a product with adequate quality to meet regulatory requirements and with the lowest possible cost and environmental impact.

Materials and methods

The *Pinus patula* wood used in this research comes from an 18-year-old forest plantation located in Bituruna – PR (26°09'39" S 51°33'10" W and 900 m altitude), belonging to Remasa Reflorestadora. In this region, the climate is subtropical (Cfb), with an average temperature between 12 °C and 22 °C, hot summers and winters with frequent frosts, an average annual precipitation of 1600 mm, and predominantly soils being oxisols soils.

Trees totaling approximately 15 m³ of logs were collected for multiple studies to assess wood quality and applications. To evaluate the suitability of the species in edge glued panels, approximately 10 m³ of the logs were unfolded into 1 and 2 inch boards and dried to a final moisture content of 10–12% in a local wood industry.

Top gluing was carried out industrially; the boards were transformed into battens with dimensions of 35 x 140 mm and 35 x 55 mm (thickness x width) and variable length to eliminate defects, then milled to obtain non-structural joints (length: 7 mm, width: 3.7 mm, and tooth tip width: 1.7 mm). Top bonding was carried out with Polyvinyl Acetate (PVA) adhesive, which was applied on a roller conveyor to reach at least 75% of the teeth. The battens were then assembled and pressed with a specific pressure of 20 kgf.cm⁻² (± 2 MPa or N/mm²) in an automatic press, generating pieces with dimensions of 35 x 55 x 2000 mm and 35 x 140 x 2000 mm (thickness, width, and length). The volume of material totaled approximately 2 m³.

Edge gluing was carried out on a laboratory scale, where industrially dried boards were conditioned to reach or maintain a humidity of 12%. They were then sampled to understand all the natural variability of the wood and cutting planes, and transformed into battens with dimensions of 25 x 60 x 310 mm. After sizing, they were measured to determine their apparent density.

The experimental design included the study of the use of adhesives, grammages, and pressures, as shown in Table 1, generating a 2x4x2 factorial arrangement. As a reference, treatments were produced with *Pinus taeda* wood, a species traditionally used for EGP panels and frames, which followed the industrial gluing conditions normally adopted for this species.

Table 1 - Experimental design of edge gluing of *Pinus patula* and *Pinus taeda* wood

Treatment	Adhesives	Grammage (g.m ⁻²)	Pressure (kgf.cm ⁻²)
1 - P _{patula} /PVA/160g.m ⁻² /7kgf.cm ⁻²	PVA	160	7
2 - P _{patula} /PVA/180g.m ⁻² /7kgf.cm ⁻²	PVA	180	7
3 - P _{patula} /PVA/200g.m ⁻² /7kgf.cm ⁻²	PVA	200	7
4 - P _{patula} /PVA/210g.m ⁻² /7kgf.cm ⁻²	PVA	220	7
5 - P _{patula} /PVA/160g.m ⁻² /10kgf.cm ⁻²	PVA	160	10
6 - P _{patula} /PVA/180g.m ⁻² /10kgf.cm ⁻²	PVA	180	10
7 - P _{patula} /PVA/200g.m ⁻² /10kgf.cm ⁻²	PVA	200	10
8 - P _{patula} /PVA/210g.m ⁻² /10kgf.cm ⁻²	PVA	220	10
9 - P _{patula} /PVA/160g.m ⁻² /7kgf.cm ⁻²	EPI	160	7
10 - P _{patula} /PVA/180g.m ⁻² /7kgf.cm ⁻²	EPI	180	7
11 - P _{patula} /PVA/200g.m ⁻² /7kgf.cm ⁻²	EPI	200	7
12 - P _{patula} /PVA/210g.m ⁻² /7kgf.cm ⁻²	EPI	220	7
13 - P _{patula} /PVA/160g.m ⁻² /10kgf.cm ⁻²	EPI	160	10
14 - P _{patula} /PVA/180g.m ⁻² /10kgf.cm ⁻²	EPI	180	10
15 - P _{patula} /PVA/200g.m ⁻² /10kgf.cm ⁻²	EPI	200	10
16 - P _{patula} /PVA/210g.m ⁻² /10kgf.cm ⁻²	EPI	220	10
17 - P _{taeda} /PVA/180g.m ⁻² /7kgf.cm ⁻²	PVA	180	7
18 - P _{taeda} /EPI/180g.m ⁻² /7kgf.cm ⁻²	EPI	180	7

Note: P_{patula}: *Pinus patula*; P_{taeda}: *Pinus taeda*; PVA Polyvinyl Acetate class D3; EPI: Emulsion Polymer Isocyanate; 7 kgf.cm⁻² = $\pm 0,7$ MPa or N/mm²; 10 kgf.cm⁻² = $\pm 1,0$ MPa or N/mm².

The adhesive was applied with a foam roller on a simple glue line, and each grammage was controlled on a precision scale. After glue application, the joints were pressed with a manual press. Pressure was calibrated and controlled with a digital load cell and torque meter. Pressing time was 1 hour for both adhesives, as recommended by the manufacturers, and the environmental conditions of the pressing environment were 18 to 20 °C and a relative humidity of 70/75%.

A total of 18 treatments were carried out, 16 under experimental conditions with *Pinus patula* and 2 with *Pinus taeda*. For each treatment, 7 joints were glued, and each joint generated 10 specimens, for a total of 70 specimens per gluing condition.

After full curing of the adhesive and air conditioning, the edge glued joints, as well as the finger joint gluing samples, were sectioned to prepare the test specimens. The evaluation of the finger joint gluing quality was conducted in accordance with the D5572 standard (ASTM, 2019) through bending and tension tests, and the specimens underwent dry, high temperature and triple cycle pre-treatments. Edge gluing was evaluated based on the shear resistance test. Following the methodology recommended by standard EN 13354 (ES, 2009) with pre-treatment indicated for SWP/1 type panels, which are used in dry conditions, samples were immersed for 24 hours in water at a temperature of 20 ± 3 °C, in addition to the dry test carried out as a control. In the tensile and shear strength test specimens, wood failure was also analyzed.

The results were subjected to statistical analysis using tests for outliers, normality, homogeneity of variance, analysis of simple and factorial arrangement variance within each adhesive (4x2: 4 grams x 2 pressing pressures), and comparison of Tukey means, all at 95% reliability and in the statistical program Statgraphics XVII. The performance results of *Pinus patula* were compared with the normative requirements of D 5572 (ASTM, 2019) and EN 13353 (ES, 2022) and with those of *Pinus taeda*.

Results and discussion

Wood density

The apparent density of *Pinus patula* and *Pinus taeda* wood were 0.432 g.cm^{-3} (Coefficient of variation - CV: 15.34%), and 0.444 g.cm^{-3} respectively (CV: 10.69%). No statistically significant difference was found between the two means. Like *Pinus taeda*, *Pinus patula* wood was classified as light or low density. According to Sellers (1994), low-density wood is easier to glue as it does not require high strength or performance adhesives, facilitates the mobility of the adhesive in its structure, and does not require special procedures during the gluing process. On the other hand, according to Marra (1992), due to their greater porosity, they absorb a greater amount of adhesive and can even generate a "hungry" glue line.

Based on this result, one can expect that *Pinus patula* present similar behavior to the reference species in terms of wood processing for gluing panels, as well as adhesive consumption, without substantially altering the current parameters of the industrial process.

Finger joint gluing

The average finger joint gluing results, presented in Table 2, showed that *Pinus patula* wood met the minimum requirements of the D 5572 (ASTM, 2019) standard for static bending in all pre-treatments.

Likewise, the tensile test showed satisfactory results and complied with the minimum requirements of the aforementioned standard, which recommends a value of 13.8 MPa in the dry test and 6.9 MPa in the high temperature and triple cycle tests. Wood failures ranged from 75 to 95%, which is higher than the minimum value of 60% for the dry test and 30% for the test after the triple cycle. Furthermore, wood flaws can be considered high, indicating good adhesion.

Table 2 - Average results of Finger joint gluing

Test condition	Static bending (MPa)	Traction	
		Strength (MPa)	Wood failure (%)
Cured/Dry	39.46 (23.78)	22.09 (32.74)	95
Elevated temperature	28.04 (25.05)	21.19 (29.86)	75
Three-cycle soak	37.07 (23.30)	22.71 (28.59)	93

Note: values in parentheses indicate CV (%).

Based on these results, it can be stated that *Pinus patula* wood has potential or aptitude for manufacturing frames or finger joint gluing for EGP panels, and, considering that the experiment was carried out industrially, the same process parameters can be adopted as for *Pinus taeda*. Therefore it is also possible to maximize them while reducing production costs

In a brief comparison of the results of finger joint gluing of *Pinus patula* with other research that used *Pinus taeda*, the results obtained are similar to those of Prata (2010), who found values of 33.19, 41.44, and 47.81 MPa for the flexural strength dry, high temperature, and triple cycle tests, respectively, and 24.54, 25.52, and 27.85 MPa for tension under the same test conditions. Lau (2017) obtained values for the flexural strength test of 28.53, 14.05, and 7.39 MPa, and for the traction test of 20.79, 9.71, and 12.02 MPa, both for the respective conditions of dry test, high temperature, and triple cycle, such results being inferior to those obtained here.

Edge gluing

Bonding with Polyvinyl acetate

The edge gluing resistance average results to shear of joints bonded with Polyvinyl Acetate adhesive (Table 3) ranged from 6.82 to 7.76 MPa in the dry test and from 1.24 to 2.41 MPa in the test after 24h of immersion in water (wet), with a significant statistical difference being found only in the second condition. In the dry test, high values for wood failure were observed, as well as for the lower 5th percentiles. In the pre-treatment with cold water, mandatory for internal use, none of the gluing conditions proposed with this adhesive reached the minimum requirement of standard EN 13353 (ES, 2022) of 2.50 MPa (2.50 N/mm²), in addition to zero or close to zero wood failure recorded.

The unsatisfactory bonding results with PVA adhesive in this research, and often observed in other publication, can be justified, in part, by the composition and classification of the adhesive itself, which is D3, which tends to exhibit high resistance in dry environments; however, major limitations for use in humid environments (Frihart; Hunt, 2010), including easy degradation under temperature and/or humidity conditions (Claub; Joscak; Niemz, 2011).

In comparison with *Pinus taeda* wood, it appears that in the dry test, regardless of pressure, *Pinus patula* presented lower average shear strength values but higher 5th percentile values. In the wet test, which truly defines compliance with the regulatory requirement, *Pinus patula* presented similar behavior to *Pinus taeda*.

When analyzing the effect of the grammage of the PVA adhesive, a significant statistical difference was observed only for the wet test, with the grammage of 160 g.m⁻² being lower than all the others. This result is in agreement with Marra (1992), who reports that very low grammages imply lower resistance due to poor adhesion and anchoring. It should be noted that the grammages adopted in this research ranged from 160 to 220 g.m⁻², and the adhesive industry traditionally recommends grammages of 180 to 220 g.m⁻², therefore, the grammage of 160 g.m⁻² was studied with the aim of exploring cost reduction in the process and is below what is suggested. On the other hand, it is noteworthy that not even the largest grammages reached the resistance of 2.50 MPa in the 5th lower percentile, indicating that it is insufficient for gluing *Pinus patula* with this adhesive, since no excess adhesive leakage was observed at the edges of glued joints.

Regarding the pressure factor, significant statistical differences were found for both the dry and wet tests. Despite the low resistance in the second test condition mentioned, there is an increase in resistance with increasing pressing pressure. Probably, the application of greater pressure, associated with the greater plasticity of the wood generated by humidity, promoted greater contact between the wooden pieces, resulting in greater resistance.

Bonding with polymeric isocyanate emulsion

The results obtained for bonding with the Emulsion Polymer Isocyanate adhesive (Table 4) showed that the average shear strength varied from 6.92 to 9.40 MPa in the dry test and from 5.01 to 6.98 MPa in the wet test, with a significant statistical difference observed in both conditions. All treatments presented lower 5th percentile values higher than the value of 2.50 MPa required by EN 13353 standard (ES, 2022) for product approval, as well as wood failure values higher than 40% for wood with a density of up to 0.6 g.cm⁻³.

A better gluing performance of treatments with EPI adhesive was observed when compared to treatments bonded with PVA adhesive, a fact explained by the chemical composition of the adhesive. According to Frihart and Hunt (2010), EPI adhesive has high resistance to water and temperature, good stability, and faster curing, but has the disadvantage of higher cost.

In comparison with the treatment produced with *Pinus taeda* wood, it appears that in the dry test, the values of shear resistance, wood failure and 5th percentile were similar between the two species. In the wet test, *Pinus patula* presented higher mean values of shear resistance and wood failure than *Pinus taeda*, and in the lower 5th percentile, 8 of the 7 treatments presented higher percentiles. In the specific analysis between treatments Ppatula/EPI/180g.m⁻²/7kgf.cm⁻² and Ptaeda/EPI/180g.m⁻²/7kgf.cm⁻², it appears that the species object of this study presented higher average values in relation to its control, indicating its potential for this purpose. These results allow us to affirm that *Pinus patula* can be used as a complementary raw material for the EGP panel industry, and if wood is available to supply this manufacturing process, as a main raw material.

Table 3 - Average results of edge gluing with Polyvinyl Acetate (PVA) adhesive

Treatment	Dry test (Cured)			Wet test (24h immersion in water)		
	Shear (MPa)	Wood failure (%)	5 th lower percentile (MPa)	Shear (MPa)	Wood failure (%)	5 th lower percentile (MPa)
P _{patula} /PVA/160g.m ⁻² /7kgf.cm ⁻²	7.06 (19.21)	93	5.26	1.24 c (24.72)	1	0.86
P _{patula} /PVA/180g.m ⁻² /7kgf.cm ⁻²	6.82 (21.65)	94	4.75	1.40 bc (27.67)	1	0.90
P _{patula} /PVA/200g.m ⁻² /7kgf.cm ⁻²	6.83 (22.27)	88	4.76	1.32 bc (27.14)	2	0.96
P _{patula} /PVA/220g.m ⁻² /7kgf.cm ⁻²	7.58 (22.68)	88	5.40	1.47 bc (22.94)	0	0.93
P _{patula} /PVA/160g.m ⁻² /10kgf.cm ⁻²	7.76 (22.73)	96	5.32	1.56 b (24.23)	0	1.01
P _{patula} /PVA/180g.m ⁻² /10kgf.cm ⁻²	7.70 (22.91)	95	5.88	2.21 a (21.96)	0	1.37
P _{patula} /PVA/200g.m ⁻² /10kgf.cm ⁻²	7.17 (27.07)	96	5.49	2.28 a (22.19)	1	1.63
P _{patula} /PVA/220g.m ⁻² /10kgf.cm ⁻²	7.46 (19.91)	89	5.30	2.41 a (16.74)	0	1.85
	p=0.1057			p=0.0000		
P _{taeda} /PVA/180g.m ⁻² /7kgf.cm ⁻²	8.09 (20.31)	83	2.67	1.96 (34.21)	0	0.98
Effect of grammage						
160 g.m ⁻²	7.42 (21.66)	94	5.28	1.40 b (27.08)	1	0.91
180 g.m ⁻²	7.32 (22.91)	94	5.00	1.81 a (33.01)	2	1.01
200 g.m ⁻²	7.00 (24.89)	92	4.82	1.80 a (36.02)	2	0.99
220 g.m ⁻²	7.52 (21.22)	88	5.30	1.94 a (30.82)	2	0.97
	p=0.2519			p=0.0000		
Effect of pressure						
7 kgf.cm ⁻²	7.10 b (21.74)	91	4.83	1.36 b (26.25)	1	0.90
10 kgf.cm ⁻²	7.52 a (23.17)	94	5.41	2.11 a (26.03)	0	1.20
	p=0.0353			p=0.0000		

Note: Ppatula: *Pinus patula*; Ptaeda: *Pinus taeda*; PVA Polyvinyl Acetate class D3; 7 kgf.cm⁻² = ± 0,7 MPa or N/mm²; 10 kgf.cm⁻² = ± 1,0 MPa or N/mm². Means followed by the same letter in the same column (between treatments or effects) are statistically equal according to the Tukey test at 95% reliability; Values in parentheses indicate the coefficient of variation in %.

Table 4 - Average results of lateral bonding with the adhesive Emulsion Polymer Isocyanate (EPI)

Treatment	Dry test (Cured)			Wet test (24h immersion in water)		
	Shear (MPa)	Wood failure (%)	5 th lower percentile (MPa)	Shear (MPa)	Wood failure (%)	5 th lower percentile (MPa)
P _{patula} /EPI/160g.m ⁻² /7kgf.cm ⁻²	6.92 c (24.53)	92	5.04	4.22 c (15.47)	47	3.38
P _{patula} /EPI/180g.m ⁻² /7kgf.cm ⁻²	8.05 abc (18.23)	98	5.71	4.46 bc (16.17)	55	3.70
P _{patula} /EPI/200g.m ⁻² /7kgf.cm ⁻²	7.67 bc (24.22)	92	5.42	4.74 abc (20.37)	42	3.75
P _{patula} /EPI/220g.m ⁻² /7kgf.cm ⁻²	7.59 bc (23.09)	85	5.01	4.48 bc (21.46)	42	3.56
P _{patula} /EPI/160g.m ⁻² /10kgf.cm ⁻²	9.17 a (26.78)	82	5.94	4.17 c (23.85)	57	2.76
P _{patula} /EPI/180g.m ⁻² /10kgf.cm ⁻²	9.40 a (19.02)	86	6.98	4.97 ab (13.74)	44	4.20
P _{patula} /EPI/200g.m ⁻² /10kgf.cm ⁻²	8.41 ab (23.96)	91	5.47	5.10 ab (17.61)	52	3.98
P _{patula} /EPI/220g.m ⁻² /10kgf.cm ⁻²	8.08 abc (27.13)	87	5.18	5.19 a (19.03)	45	3.97
	p=0.0000			p=0.0000		
P _{taeda} /EPI/180g.m ⁻² /7kgf.cm ⁻²	7.72 (12.25)	96	6.52	4.03 (16.09)	13	3.11
Effect of grammage						
160 g.m ⁻²	8.04 ab (29.61)	87	5.16	4.20 b (19.79)	52	2.97
180 g.m ⁻²	8.72 a (20.17)	92	6.01	4.72 a (15.71)	49	3.79
200 g.m ⁻²	8.04 ab (24.37)	91	5.41	4.92 a (19.23)	46	3.76
220 g.m ⁻²	7.83 b (25.34)	86	5.14	4.83 a (21.38)	41	3.62
	p=0.0417			p=0.0000		
Effect of pressure						
7 kgf.cm ⁻²	7.55 b (22.89)	92	5.12	4.47 b (18.94)	45	3.51
10 kgf.cm ⁻²	8.76 a (24.76)	86	5.61	4.86 a (20.05)	49	3.23
	p=0.0000			p=0.0003		

Note: P_{patula}: *Pinus patula*; P_{taeda}: *Pinus taeda*; EPI: Emulsion Polymer Isocyanate; 7 kgf.cm⁻² = ± 0,7 MPa or N/mm²; 10 kgf.cm⁻² = ± 1,0 MPa or N/mm². Means followed by the same letter in the same column (between treatments or effects) are statistically equal according to the Tukey test at 95% reliability; Values in parentheses indicate the coefficient of variation in %.

When evaluating the effect of grammage on bonding quality, it is noted that there was no clear trend towards increasing resistance with the amount of adhesive applied between all treatments in both the dry and wet tests. A significant statistical difference was found in the two test conditions, but, with emphasis on the wet test, which is a mandatory normative condition for SWP/1 type panels, it can be seen that the grammage of 160 g.m⁻² proved to be statistically lower than the others. However, even though this grammage had a lower performance than the others, the average values of the lower 5th percentile and wood failure were higher than the minimum regulatory requirements, which indicates that the gluing is compliant and may even allow for a further small reduction in grammage, such as 150 g.m⁻², which would directly imply a greater reduction in adhesive costs and in potential environmental impact. This becomes quite interesting and attractive, considering that the adhesive is an expensive component of the production process and, according to Carneiro *et al.* (2004), can represent up to 50% of the final value of the finished product.

Regarding the effect of the pressing pressure factor, significant statistical differences were observed for both the dry and wet tests, and behavior was similar to that seen when gluing *Pinus patula* wood with PVA adhesive. Likewise, the greater pressure must have promoted better contact between the battens as well as contributed to better penetration of the adhesive into the wood structure. The manufacturer recommends pressures of 6 to 12 kgf.cm⁻² (± 0.6 to 1.2 MPa) for edge gluing of wood, depending on its density. Therefore, considering the possibility of greater maximization of the process through using a grammage even smaller than those tested in this study (for example, 150 g.m⁻²), the adoption of a pressure of 11 or 12 kgf.cm⁻² may be viable since low grammages allow higher pressures without adhesive leakage through the sides.

In general, the performance presented in the different treatments produced with *Pinus patula* and glued with the EPI adhesive demonstrates that the species has potential or aptitude for the production of EGP panels. *Pinus patula* experimental materials also tend to present similar or superior gluing quality compared to the species traditionally used for this product and even reduce production process costs, especially in the adhesive, which is one of the biggest costs in the process.

Conclusions

Based on the development of this research it is possible to conclude that:

- (a) *Pinus patula* wood was classified as light or low density and is similar to the density of *Pinus taeda* wood;
- (b) the finger joint gluing of *Pinus patula* wood with PVA adhesive reached the minimum tensile and flexural requirements of D 5572 (ASTM, 2019);
- (c) the EPI adhesive showed superior performance compared to the PVA adhesive in the evaluation of the edge gluing of *Pinus patula* wood, and met the requirement of standard EN 13353 (ES, 2022);
- (d) there was no clear trend in the effect of increasing grammage on the shear strength of edge gluing of *Pinus patula* wood; however, the grammage of 160 g.m⁻² proved to be superior to the others in the wet test of both adhesives tested;
- (e) the increase in pressure contributed to improving the resistance of the edge gluing of *Pinus patula* wood;
- (f) *Pinus patula* presented similar or superior gluing quality compared to *Pinus taeda*, which is the main species currently used by the frames and EGP panel industry; and
- (g) *Pinus patula* has potential for the production of frames and EGP panels and can replace other non-renewable materials in civil construction such as skirting boards and door frames, as well as in the production of furniture.

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