SHEAR STRENGTH OF *Pinus* sp. JOINTS BONDED WITH DIFFERENT GRAMMAGES AND PRESSURES

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ABSTRACT – The main function of the adhesive is to promote adhesion between materials, as well as provide fluidity and fill in the gaps between joints. Information such as grammage and bonding pressure is fundamental when it comes to the execution of structures in glued laminated wood. In this sense, the objective of this study was to evaluate the shear strength in compression of bonded joints using a one-component polyurethane adhesive with cold curing at three different gram levels, being 150 $g.m^{-2}$, 200 $g.m^{-2}$ and 250 $g.m^{-2}$, with spreading on a single face, applied at two pressure levels, 0.7 MPa, and 1.0 MPa. The apparent density was determined, and with that, four blocks/density groups were obtained, which comprised four repetitions. In addition, the percentage of failure in the specimens after performing the shear test was analyzed. Statistical data analysis was carried out adopting a randomized design in a 2x3 factorial block to analyze the effects of grammage and bonding pressure on wood strength and failure The homogeneity and normality of the data were tested, and later the analysis of variance (ANOVA). The results showed that the joints' strength was not affected, both for weight and pressure levels. As for the wood failure percentage, the values obtained were low, with averages below 35%.

Keywords: Polyurethane adhesive; Resistance; Wood failure.

RESISTÊNCIA AO CISALHAMENTO DE JUNTAS DE Pinus *sp. COLADAS COM DIFERENTES GRAMATURAS E PRESSÕES*

RESUMO – A principal função do adesivo é promover aderência entre os materiais, bem como proporcionar fluidez e preencher os vazios entre as juntas. Informações como gramatura e pressão de colagem são fundamentais quando se trata da execução de estruturas em madeira lamelada colada. Nesse sentido, o objetivo deste trabalho foi avaliar a resistência ao cisalhamento na compressão de juntas coladas com adesivo poliuretano monocomponente de cura a frio em três níveis de gramatura, sendo de 150 $g.m^{-2}$, 200 $g.m^{-2}$ e 250 $g.m^{-2}$ com espalhamento em face única, aplicados em dois níveis de pressão, 0,7 MPa e 1,0 MPa. Determinou-se a densidade aparente, e com isso obtiveram-se quatro blocos/grupos de densidade que compuseram quatro repetições. Além disso, analisou-se a porcentagem de falha nos corpos de prova após a realização do ensaio de cisalhamento. Para analisar os efeitos da gramatura e pressão de colagem na resistência e na falha da madeira, realizou-se a análise estatística dos dados adotando o delineamento casualizado em bloco fatorial 2x3. Testou-se a homogeneidade e normalidade dos dados, e posteriormente a análise de variância (ANOVA). Os resultados obtidos demonstraram que as resistências das juntas não foram afetadas, tanto para os níveis de gramatura quanto para os níveis de pressão. Quanto ao percentual de falha na madeira, os valores obtidos foram baixos, com médias inferiores a 35%.

Palavras-Chave: Adesivo poliuretano; Resistência; Falha na madeira.

1. INTRODUCTION

Glued Laminated Wood (GLW) is a structural material obtained from the joining of small pieces of sawn wood. According to Segundinho et al. (2018), the lamellas can be glued on the face and on the top using adhesives and with the fibers arranged parallel to the length, in which it is possible to acquire pieces of different sizes and shapes. Longitudinal and transverse splices are responsible for providing products with greater lengths and widths (Pauli et al., 2021).

Adhesion is responsible for promoting the union of the wood and this process is a physical-chemical phenomenon in which there is a mechanism of interaction between the surfaces, that is, the adherent and the adhesive. Adhesive refers to the product that can maintain the connection between materials. Such a product has the function, in addition to the adhesion between materials, the fluidity and filling of empty spaces between the joints, causing a decrease in the distance between them (Bianche et al., 2017).

The main adhesion mechanisms are explained by the theory of mechanical, chemical and diffusion adhesion of polymers. Mechanical adhesion is based on the intertwining of the adhesive in the hardened state in the bonded joint and in the pores of the adherent, thus, mechanical adhesion takes place on porous surfaces, making the bonding process depend on the surface of the substrate, applied pressure and the adhesive viscosity (Carrasco et al., 2017). On the other hand, chemical adhesion involves primary, ionic, or covalent bonds, which are responsible for promoting strength and durability of the adhesive bond. Finally, the theory of polymer diffusion takes place at the molecular level, where adhesion occurs through the diffusion of segments of polymeric chairs (Albuquerque et al., 2005).

For Follrich et al. (2007), in addition to the chemical and physical properties of the adhesives, the physical and structural properties of the wood are also important to ensure the quality of the adhesive bond. Thus, high-density parts have low adhesive penetration since they do not have high porosity. This implies a thicker and more superficial glue line. On the other hand, in low-density woods, a “hungry” glue line may occur, in which there is a greater penetration of the adhesive into the substrate, which may cause a glue line lacking in adhesive.

The adhesive can cost around 50% of the total price, in the case of wood products, being one of the most important components with significant technical implications. Adhesives can be classified in different ways, such as: curing temperature, moisture resistance, chemical composition, among others (Carneiro et al., 2004).

As for chemical classification, adhesives can be organic and inorganic. Inorganic adhesives are usually based on silicates, which have connections with high mechanical strength. An example of an inorganic adhesive is cement. Organic adhesives are subdivided into two groups, synthetic and natural. Synthetics are the most used in wood-based products, classified as thermosets and thermoplastics (Campos and Lahr, 2004).

Still according to Campos and Lahr (2004), thermosets are characterized by adhesives that harden from chemical reactions, these being through temperature or catalysts. Thermosetting adhesives are: phenol-formaldehyde, urea-formaldehyde, resorcinol formaldehyde and polyurethanes. On the other hand, thermoplastic adhesives present reversible cure, that is, they present a change in their state with the increase in temperature, returning to a solid state when cooled. Such adhesives are extracted from animal and vegetable proteins, tannin, among others. Although synthetic adhesives are the most used for bonding wood, some are considered toxic to human health (Santiago et al., 2018).

The adhesive quantity used in gluing wood joints and the pressure applied are some of the parameters considered to promote a good bond. The resistance in the glue line can be affected if the grammage is greater or less than what is considered ideal, thus affecting the resistance of the product. When a low amount of adhesive is applied, strength is affected as it results in insufficient adherence and anchorage. Otherwise, when a higher amount is applied, there may be excess adhesive running around the edges, resulting in economic losses (Trianoski et al., 2020).

In this context, this work aimed to evaluate the shear strength in the glue line of joints of *Pinus* sp. glued with three levels of adhesive quantity and two levels of pressure, using monocomponent polyurethane adhesive, as well as the percentage of failure in the wood.

2. MATERIAL AND METHODS

The work was carried out at the Laboratory of Engineering Structures and Materials – LEME and at the Laboratory of Technology and Wood Structures – LATEM of the State University of Western Paraná – UNIOESTE, located in the municipality of Cascavel – PR.

For this research, *Pinus* sp. wood from reforestation, obtained from local commerce in the city of Cascavel - PR, was used in the form of boards, which were processed in the form of lamellae with a length of 50 cm, a width of 6 cm and a thickness of 2 cm. The initial set consisted of 92 lamellae, indicating a variation for the apparent density between 0.409 $g.cm^{-3}$ to 0.857 $g.cm^{-3}$. Of these, 48 lamellae were selected to be used in the experiment and 24 glued joints were made.

In turn, the adhesive used was a single-component, cold-curing polyurethane-based adhesive, also purchased commercially, from the Rendmelt brand.

2.1. Preparation of glued joints

The lamellae, free of defects, were selected according to their apparent density and anatomy. The apparent densities were separated into four groups, namely: low, medium low, medium high and high. The density of the pieces was determined when the moisture content of the wood was close to 12%, having weighed all the lamellae and determined, with the aid of a caliper, their dimensions.

Each density group represented one repetition, thus totaling four repetitions. Thus, we sought to obtain equivalent densities between treatments so that none of them was favored. In addition, we sought to obtain joints with anatomically similar lamellae in terms of the arrangement of the growth rings, which is illustrated in Figure 1.

To glue the joints, the lamellas were first processed on the trowel and on the planer, aiming at suitable surfaces. Afterwards, any residues were removed with the aid of an air compressor and a brush.

The adhesive was applied to only one side of each lamella, using a brush to facilitate spreading. A closed time of 10 minutes was adopted, since the PUR adhesive reacts with humidity, both in the air and in the wood, rapidly changing its viscosity. In this logic, still, the open time was established as being null. As for weight, 150 $g.m^{-2}$, 200 $g.m^{-2}$ e 250 $g.m^{-2}$ were used, levels compatible with what is recommended on the adhesive presentation label by the manufacturer, which involves the range between 100 $g.m^{-2}$ and 200 $g.m^{-2}$. Three joints were glued at a time and the average time consumed, from the launch of the adhesive to the placement in the press, was 8 minutes.

Pressing was performed manually with the aid of a digital torquemeter, previously calibrated, applying two desired pressure levels: 0.7 MPa or 1.0 MPa. After 20 minutes of the first tightening, the verification was carried out of the pressure. This was done since the adhesive, still fluid, flowed along the edges, which could cause some loosening in the press. After that, the joints were kept under pressure for a minimum period of 12 hours.

The joints were glued in a controlled environment, with an average temperature of 25.1 ºC and an average relative humidity of 32.25% during the days of bonding. Furthermore, the average humidity of the wooden pieces on the days of bonding was 11.31%.

After a minimum period of 5 days, the joints were processed in the dimensions established by ASTM D 905-08 (ASTM, 2013) and the specimens were extracted to be tested.

2.2. Compressive shear strength test

The shear strength test in compression was carried out according to the specifications of the ASTM D 905-08 standard (ASTM, 2013). 20 specimens per treatment were extracted and broken, totaling 120 specimens tested. Each specimen was subjected to increasing shear stress until failure. After rupture, the specimens were separated into two parts, one of which was destined for the oven, to obtain moisture for resistance correction purposes, as specified by NBR 7190 (ABNT, 2022), and the other part to evaluate the percentage of wood failure.

In Figure 1 (A to F), the treatments are illustrated, represented by a specimen of each joint, where the typical anatomy of this bonding can be observed, with a predominance of tangential or almost tangential planes. In the available batch, there were no planks with radial unfolding.

The test was carried out in a Universal Testing Machine – MUE available at LEME, using the specific

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Fonte: Autores.

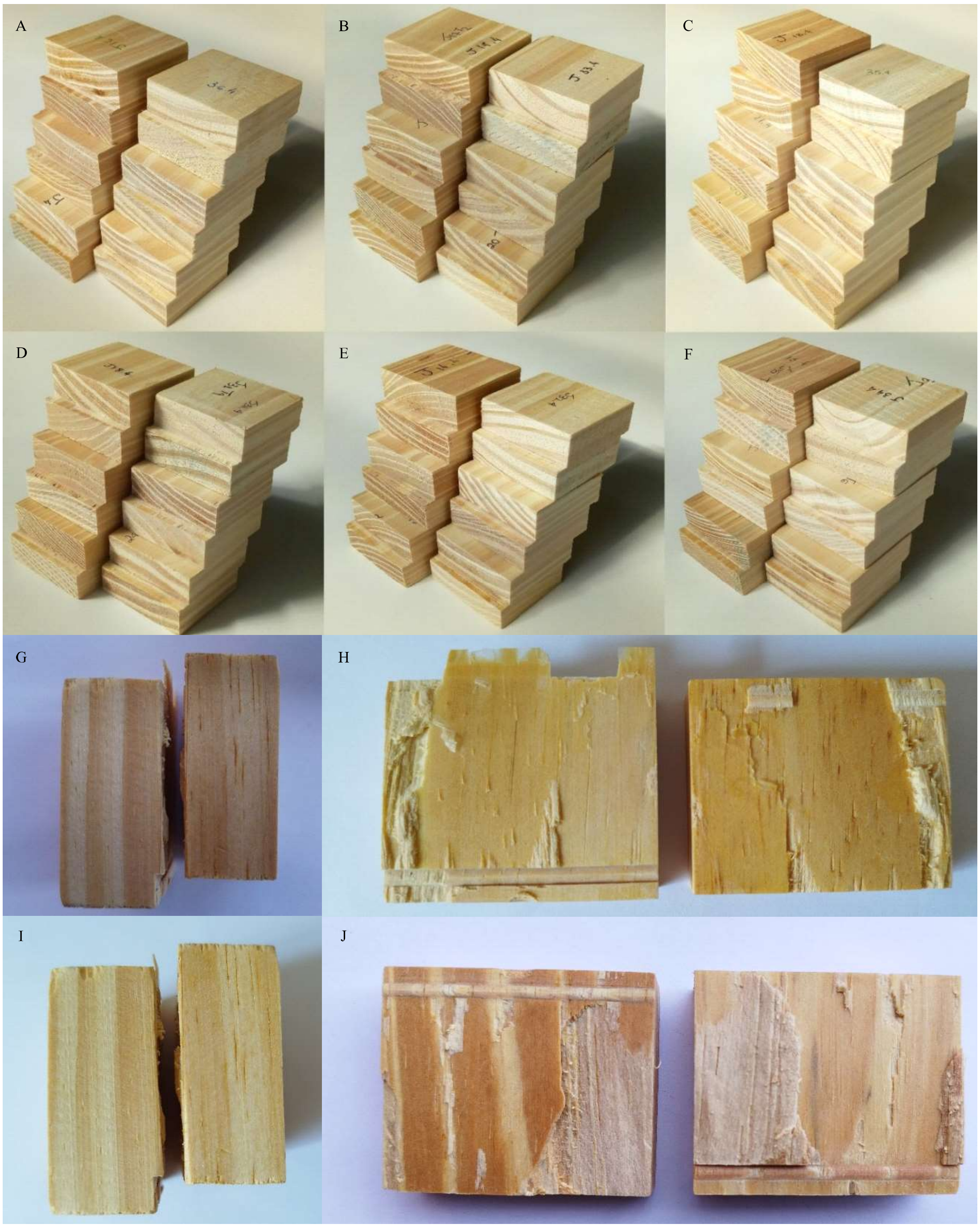

Figure 1 – Specimens for shear strength testing representing Treatment T1 (A), Treatment T2 (B), Treatment T3 (C), Treatment T4 (D), Treatment T5 (E), Treatment T6 (F); Specimens after rupture test (G and I) and their respective separate parts after rupture (H and J).

Figura 1 *– Corpos de prova para ensaio de resistência ao cisalhamento representando o Tratamento T1 (A), tratamento T2 (B), tratamento T3 (C), tratamento T4 (D), tratamento T5 (E), tratamento T6 (F); Corpos de prova após ensaio de ruptura (G e I) e suas respectivas partes separadas após a ruptura (H e J).*

apparatus and methodology proposed by ASTM D 905-08 (ASTM, 2013). It should also be noted that the bodies were tested after a minimum period of 10 days after bonding the joints.

2.3. Wood failure percentage

To evaluate the percentage of wood failure, the method specified by ASTM D 5266-99 (ASTM, 2005) was used. For this purpose, transparent and checkered slides were used to facilitate the identification of failure percentages.

This method was used by Pimentel et al. (2021), who evaluated the percentage of failure of seven species of tropical Amazonian wood bonded with PUR and PVA (polyvinyl acetate crosslink) adhesive. Bianche et al. (2017) also used this method to evaluate the percentage of failure in eucalyptus wood glued with six different types of adhesives, including castor oil-based bicomponent polyurethane.

Regarding the observation of failures, deep fractures were considered, with notorious pulling out of fibers or portions of wood, as well as shallow flaws, without significant alteration of the bonded plane, but with the presence of fiber parts. After that, the statistical analysis of the average percentage obtained was performed.

2.4. Statistical analysis of the data

In this work, the experiment was developed with a randomized design in 2x3 factorial blocks, with two levels of bonding pressure, three levels of grammage and four blocks/density groups that represented the repetitions, totaling 24 experimental units or glued joints. The blocks had the following average densities: 0.81 g.cm^{-3} (group 1); 0.75 g.cm^{-3} (group 2); 0.68 g.cm^{-3} (group 3); and 0.48 g.cm^{-3} (group 4). Each experimental unit/joint was subdivided into 5 specimens, according to ASTM D 905-08 (ASTM, 2013) providing replicas for better evaluation of the experiment.

For the analysis of the statistical model of shear strength, the averages of the three central specimens of the set of five replicates from the same joints were calculated. Thus, a reduced impact of information variability was achieved by excluding the two extremes (the highest and lowest strength of each joint). The same treatment was applied to the percentage of failure in the wood.

Consequently, being y_{ijk} the average resistance referring to the i-th pressure level (i = 0.7 or i = 1.0); j-th grammage (j = 150; j = 200 or j = 250) and k-th density group (k = 1, 2, ... 6), the resistance model was represented according to Equation 1.

$$y_{ik} = \mu + g_k + \alpha_i + \tau_j + (\alpha\tau)_{ij} + \varepsilon_{ijk} \quad \text{Eq. 1}$$

Where: μ is the overall average effect; g_k is the mean effect of the k-th group/block; α_i is the average effect of the i-th pressure; τ_j is the average effect of the j-th grammage; $(\alpha\tau)_{ij}$ is the average effect of the interaction between the i-th pressure and the j-th grammage; ε_{ijk} is the experimental error, with Normal distribution of mean zero and variance σ^2.

The assumptions in relation to the model were evaluated through graphic analyses, descriptive measures and statistical tests, and the normality of the residuals was verified using the Shapiro Wilk test and the homogeneity of variances using the Bartlett test.

After satisfying the assumptions for carrying out the analyses, the effects of interest (α_i, τ_j and $(\alpha\tau)_{ij}$), were evaluated using the F-test of analysis of variance and, when applicable, the Tukey test was used to compare means, with a significance level of 5%.

All the analyzes of this work were carried out in the *R software* (*R* Core Team, 2022), version 4.2.1, using the ggplot2 packages, for the construction of the graphs, and *ExpDes*, for the analysis of the experiment – ANOVA and Tukey tests.

3. RESULTS

In Table 1, the general results per studied treatment are presented. In the columns that inform the resistances and percentages of failure in the observed wood, the coefficients of variation – CV (expressed in percentage), obtained by treatment are also presented, between parentheses. It appears that the variation coefficients related to resistance varied between 3.89% and 14.25%, values considered of low dispersion, that is, there was low variability of the data in relation to its average. However, there is greater variability in the data regarding wood failure, which exhibit coefficients of variation between 34.17% and 55.36%.

It should be noted, as shown, that the average apparent densities per treatment were close, indicating success in terms of avoiding favoritism between treatments. As reported, after testing, a broken part of

Table 1 – Weight and pressure values per treatment, densities, and average values of resistance (MPa) and wood failures (%) per treatment and their respective coefficients of variation (%) in parentheses.
Tabela 1 *– Valores de gramatura e pressão por tratamento, densidades e valores médios das resistências (MPa) e falhas na madeira (%) por tratamento e seus respectivos coeficientes de variação (%) entre parênteses.*

Treatment	Grammage($g.m^{-2}$)	Pressure (MPa)	Average apparent density ($g.cm^{-3}$)	Average resistance, 12% moisture (MPa)	Average wood failures (%)
T1	150	0.7	0.688	13.69 (8.43)	27.25 (44.25)
T2	150	1.0	0.690	13.75 (11.41)	36.57 (34.17)
T3	200	0.7	0.694	13.05 (3.89)	19.64 (53.65)
T4	200	1.0	0.701	13.69 (14.25)	23.44 (54.31)
T5	250	0.7	0.697	14.02 (4.79)	28.75 (39.07)
T6	250	1.0	0.699	13.04 (14.24)	29.95 (55.36)

Source: Authors.
Fonte: Autores.

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Fonte: Autores.

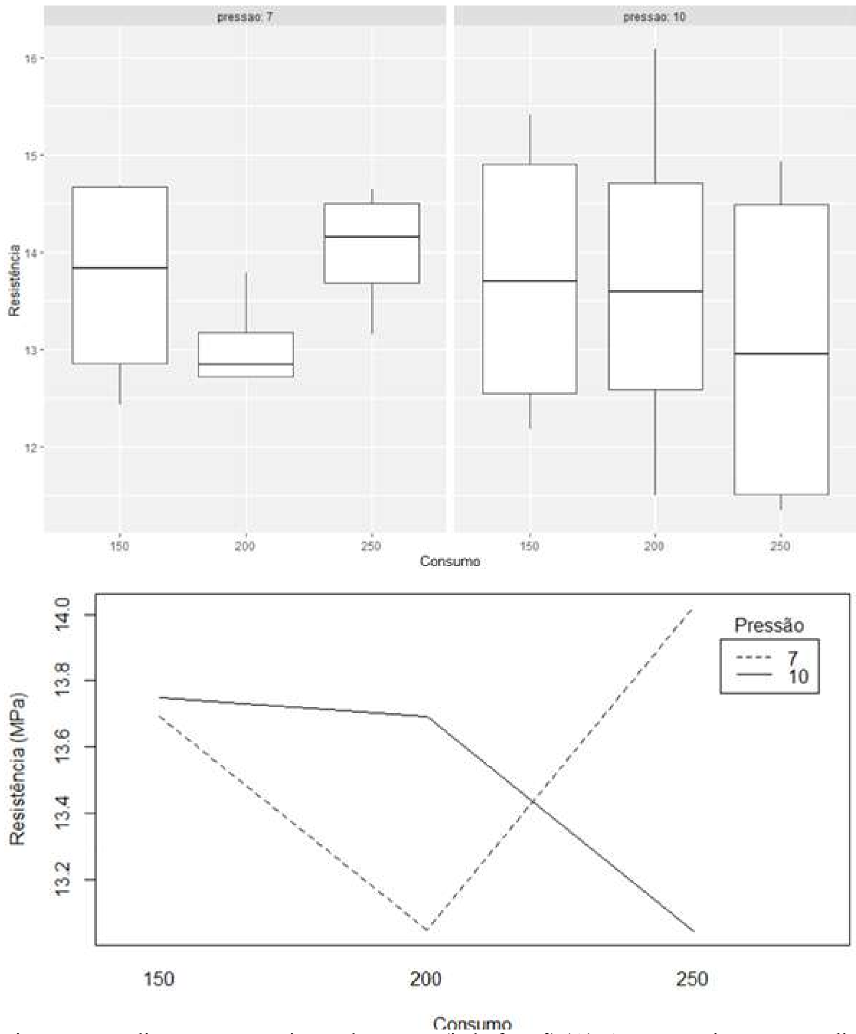

Figure 2 – Average resistance according to consumption and pressure (in $kgf.cm^{-2}$) (A); Average resistance according to consumption and pressure (in $kgf.cm^{-2}$) (B).
Figura 2 *– Resistência média de acordo com o consumo e pressão (em $kgf.cm^{-2}$) (A); Resistência média de acordo com o consumo e a pressão (em $kgf.cm^{-2}$) (B).*

Table 2 – Average values of resistance and percentage of failures (%), depending on pressure and grammage.
Tabela 2 *– Valores médios das resistências e do percentual de falhas (%), em função da pressão e da gramatura.*

Resistance				
Pressure (MPa)	Grammage (g.m^{-2})			
	150	200	250	Average
0.7	13.693	13.046	14.022	13.587
1.0	13.748	13.692	13.042	13.494
Average	13.72	13.369	13.532	13.540
Wood failure				
Pressure (MPa)	Grammage (g.m^{-2})			
	150	200	250	Average
0.7	27.251	19.644	28.725	25.207
1.0	36.575	23.445	29.950	29.99
Average	31.913	21.544	29.338	27.598

Source: Authors.
Fonte: Autores.

each specimen was weighed to determine the moisture content at the time of rupture. In this research, the humidity results varied between 10.5% and 13.7%, with a general average of 12.08% and coefficient of variation of 5.11%. In this sense, the experimental values also indicate good adequacy with the standard moisture content recommended by NBR 7190 (ABNT, 2022).

In Figure 2 (G and H) are shown specimens after rupture and in Figure 2 (I and J) are their respective separate parts. In Figure 2I, it is possible to notice a smaller splintering of the wood, that is, it presents an example of a shallow flaw on the surface of the wood. However, in Figure 2J, a higher percentage of wood failure is observed, demonstrating a deep failure.

When evaluating the average resistance obtained as a function of consumption and pressure (Figure 2A), it was possible to observe that there was a variation between a little more than 11.0 MPa and a little less than 16.5 MPa, with greater resistance variability when the pressure was 1.0 MPa. However, the average effects are very close, from just over 13 MPa to just over 14 MPa (Figure 2B). It is also possible to observe

Table 3 – ANOVA summary for the experimental results of shear and failure in wood.
Tabela 3 *– Resumo da ANOVA para os resultados experimentais de cisalhamento e falha na madeira.*

Variation Sources	GL	SQ	F-test	p-value
	Shear strength			
Groups/Density	3	14.903	3.658	0.037
Treatments				
Pressure	1	0.052	0.038	0.848
Consumption	2	0.494	0.182	0.835
Pressure: Consumption	2	2.713	0.999	0.391
Residue	15	20.37		
Total	23	38.531		
Coefficient of variation = 8.61%				
	Wood failure			
Groups/Density	3	1592.7	5.966	0.007
Treatments				
Pressure	1	137.3	1.542	0.233
Consumption	2	466.3	2.62	0.106
Pressure: Consumption	2	68.5	0.385	0.687
Residue	15	1334.7		
Total	23	3599.5		
Coefficient of variation = 34.18%				

Source: Authors.
Fonte: Autores.

in Figure 2A that when the pressure is 0.7 MPa, the resistance results were less variable for consumptions of 200 g.m^{-2} or 250 g.m^{-2}.

Table 2 presents the average values obtained per treatment for the resistances and the observed percentages of failure.

Conditions of normality and homogeneity of variances were not rejected for both response variables, strength and failure in the wood. Consequently, the analysis of variance was carried out. When evaluating the factors of interest in the research, using the F test (Table 3), none of the factors was significant, including the interaction between pressure and consumption. The exception, both for strength and percentage of wood failure, was the significant effect of the control variable blocks, which in this case represented different density groups. However, as density was treated as a control variable, its influence was not being investigated.

In Table 3, it can be observed that the coefficients of variation indicated less variability for the response variable associated with the strength of the glued joints.

4. DISCUSSION

As shown, there was no significant effect of the levels of the factors studied on the shear strength of the joints bonded with the PUR monocomponent adhesive. Regarding weight, considering that the weight range suggested by the manufacturer, between 100 and 200 g.m^{-2}, is compatible with the levels evaluated in this research (150, 200 and 250), which can be considered an expected result. Bianche et al. (2017), for example, evaluating the strength of glued joints in *Eucalyptus* sp., also found no significant effect for the same levels of consumption employed in this research, working with 6 different adhesives, including polyurethane adhesive based on castor oil, chemically similar to the one used in this work.

Regarding the shear strength of the glued joints, although there was no significant difference, the weight of 250 g.m^{-2} and pressure of 1.0 MPa indicated the lowest mean shear strength. According to Matos et al. (2019), pine wood is highly permeable, which leads to greater penetration of the adhesive as greater pressure is applied, resulting in a so-called hungry adhesive line, which may explain the resistance shown in this treatment. However, for this same grammage, but with a lower pressure level, 0.7 MPa, the highest mean resistance obtained between treatments is observed. According to Bianche et al. (2017), the high consumption of adhesive by the area favors fluidity, transfer, wetting and penetration of the wood.

Treatment T2, grammage 150 g.m^{-2} and pressure of 0.7 MPa, presented the second-best mean resistance, which means that this amount would be enough to guarantee resistance in the glue line. However, the adhesive weight of 150 g.m^{-2} presented greater difficulty in spreading when compared to the other weights. In this sense, although the manufacturer of this adhesive recommends, for example, grammage from 100 g.m^{-2}, this option may not be viable depending on the method used for spreading on the surface. However, considering the experience of this research, when using a brush, the weight of 150 g.m^{-2} may be the lower limit to be considered.

The average strength values found, around 13.5 MPa, can be considered satisfactory. Bianche et al. (2017) found an average resistance of 7.89 MPa for eucalyptus joints bonded with castor oil-based bicomponent adhesive. The wood used by the authors had an average basic density of 0.670 g.cm^{-3}. For seven Amazonian tropical wood species, studied by Pimentel et al. (2021), the average shear strength in the glue line, using PUR adhesive, ranged between 11.80 and 15.16 MPa, with an average of 13.39 MPa. In this research, the coefficients of variation of these resistances, using PUR, were between 9.53% and 26.14%, with an average of 17.94% and the wood densities varied between 0.550 g.cm-3 and 0.920 g.cm^{-3}. The authors used a grammage of 200 g.m^{-2} for all species. It can be observed that the average resistance, for the same grammage, obtained in the present study approached the value obtained by the authors. NBR 7190 (ABNT, 2022), for example, recommends that the coefficients of variation associated with shear strength be less than 28%. In this context, the variability found in this research can be considered satisfactory, as a maximum coefficient of variation of approximately 14% was obtained.

The bonding pressure factor, also investigated in this research, also did not turn to be significant in terms of altering the strength of the joints, at the two levels studied: 0.7 and 1.0 MPa. It seems appropriate to clarify that there is no guidance from the manufacturer in this regard. However, NBR 7190 (ABNT, 2022) started to explicitly recommend two minimum reference levels of pressure: 0.7 MPa and 1.2 MPa, respectively, for woods with densities of the order of 0.50 g.cm^{-3} or higher. Consequently, given that the average apparent density of the density groups established here, between 0.48 g.cm^{-3} to 0.81 g.cm^{-3}, would require the use of the two pressures recommended by the standard, it must be considered that the answers found here would not be conclusive and would require work with more levels of pressure. However, for the options studied, even with the variability in pinus density, no influence of pressure on strength was observed.

As for percentages of wood failure, the values found in this research were low, with an average of around 28% and high variation coefficients, between 34% and 55%. For the grammage of 200 g.cm^{-2}, regardless of the pressure, there was a decrease in the percentage of wood failure, with the lowest mean values for the variable wood failure. This result may be linked to the preparation of the glue line, the low mechanical and chemical bond between the adhesive and the wood and may also be associated with the evaluator's subjectivity. Both Lopes et al (2013) and Pimentel et al (2021) cite subjectivity as a factor that influences visualization, and that there is difficulty in visualizing whether the flaw is in the wood or in the glue line. In this aspect, it is necessary to consider whether the researcher is sufficiently prepared to observe differences between deep failure and shallow failure, the latter being more challenging to perceive.

The ASTM D 5266 – 99 standard (ASTM, 2005) mentions that one of the factors that make visualization difficult for the quantification of the percentage of failure in wood, mainly shallow failure, is the color of the adhesive approaching the color of the wood. Considering that, even after curing, the adhesive used in this study has a color similar to that of wood, as can be seen in Figures 2H and 2J, that is, in some specimens, it posed a difficulty in visually quantifying shallow failures.

The average percentage of wood failure was close to the value found by Pimentel et al. (2021), where they found an average value of 30%. The authors state that the density influences the interaction of the adhesive with the wood, and that the mechanical interlocking of the adhesive is affected due to the thicker cell wall. This statement was confirmed in the analysis of variance, in which it was noticed that the p-value was significant for Group/Density. However, as previously mentioned, this factor was not explored because it is a control variable.

According to Faria et al (2020), high percentages of wood failure are associated with greater efficiency of the adhesive. Furthermore, they indicate that the adhesive bonds are considered stronger than the wood itself, suggesting that there is good mechanical interlocking. However, when considering different types of adhesives, for example, resorcinol-based adhesives, show a higher percentage of wood failure, due to the type of film formed in the glue line by the adhesive. While resorcinolic adhesives form a rigid film, polyurethane-type adhesives such as PUR are considered flexible, therefore, they are more prone to undergoing deformations (Vital et al., 2006).

In the general context of very low results for percentages of failure in wood, in relation to expectations, there seems to be a need for broader research that considers, for example, the chemical nature of the new adhesives now being used. The chemical nature of new adhesives can affect their mechanical properties, such as their rigidity. In a failure event, even for satisfactory tensions, adhesives of lower rigidity may not be able to drag portions of wood and yield in their own plane, without affecting the adjacent substrate. However, under the conditions of development of this research, such questions could not be considered. Furthermore, chemical properties of new adhesives can characterize impediments to obtaining high and desirable levels for wood failure. Therefore, there may be a need to review previously accepted normative standards, meaning that low percentages of failure in wood, depending on the chemical base of a specific adhesive, do not necessarily indicate an obstacle to achieving strength and stability in bonds.

5. CONCLUSIONS

Based on the results, the average variation studied for the weight and pressure factors did not have significant effects on the shear strength of the glued joints, nor on the percentages of failure in the wood found.

Regarding wood failure, the percentage values found were low. Although it was not a variable of interest, a study on the influence of density groups on the percentage of wood failure is necessary. In general, the glued joints achieved satisfactory values for shear strength, however, the values of wood failure were lower than expected.

The non-influence of grammage is an interesting result from an economic point of view, since less adhesive consumption can be used in the gluing operation, with a possible reduction in adhesive costs.

AUTHOR CONTRIBUTIONS

Tomé, K.T. and Petrauski A. designed the research Project, performed the experiments, wrote the paper and obtained the statistical and experimental data. Possa, D.C. and Padilha, V.H.L. supported the research project design, performed the experiments and obtained experimental data. Petrauski, S.M.F.C. and Petrauski M.C. supported the research project design, performed the statistical procedures and reviewed the writing.

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