Scientific Article

SHEAR STRENGTH OF PINE WOOD BONDED JOINTS WITH DIFFERENT ANGLES OBTAINED USING COMPRESSION AND TORSIONAL TESTING METHODS

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[1] Received on 15.02.2023 accepted for publication on 04.08.2023.
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ABSTRACT – Glued Laminated Timber technology allows the construction of wooden structural components bonded with adhesive. This technology enables the creation of large-scale structures, with technological control over the material, and in a competitive industrial system. Focusing on the structural application of wood, the present study assessed the strength of bonded joints with different angles between the fibers of *Pinus* sp. wood, joined with a two-component polyurethane adhesive based on vegetable oils. The bonded joints were fabricated with angles of 0°, 10°, 20°, 30°, 45°, 60°, 70°, 80°, and 90°, and were evaluated for shear strength under compression and torsion. When regression analysis was performed, shear compression values showed compliance with *Hankinson's* equation, with an R^2 value close to 0.76. However, shear torsion results yielded R^2 values near 0.17. Thus, *Hankinson's* equation was unsuitable as an estimator for torsional shear strength values. The specimens showed a different mechanical response to shear when tested in compression compared to those tested in torsion.

Keywords: Adhesion; Mechanical performance; Reforested wood.

RESISTÊNCIA AO CISALHAMENTO À COMPRESSÃO E À TORÇÃO DE JUNTAS COLADAS DE PINUS E ADESIVO POLIURETANO CONFECCIONADAS COM DIFERENTES ÂNGULOS

RESUMO – A tecnologia da Madeira Lamelada Colada permite a execução de peças estruturais em madeira unidas com adesivo. Com o emprego desta tecnologia é possível gerar estruturas de grande porte, com controle tecnológico do material e em sistema industrial competitivo. Com ênfase ao emprego estrutural da madeira, o presente trabalho avaliou a resistência de juntas coladas com diferentes ângulos entre as fibras da madeira de ***Pinus*** *sp. e unidas com o adesivo poliuretano bicomponente a base de óleos vegetais. As juntas coladas foram confeccionadas com a formação dos ângulos de 0°, 10°, 20°, 30°, 45°, 60°, 70°, 80º e 90° e avaliadas em ruptura por esforço de cisalhamento à compressão e cisalhamento à torção. Quando realizada a análise de regressão, os valores de cisalhamento à compressão apresentaram adequação com a fórmula de* ***Hankinson****, apresentando valor de R^2 próximo a 0,76. Porém, os resultados de cisalhamento sob torção apresentaram valores de R^2 próximos a 0,17. Desta maneira, a fórmula de* ***Hankinson*** *não se mostrou propícia como estimadora dos valores de resistência para o cisalhamento à torção. Os corpos* *de prova apresentaram resposta mecânica diferente ao cisalhamento quando ensaiados à compressão comparativamente aos ensaiados à torção.*

Palavras-Chave: Adesão; Desempenho mecânico; Madeira de reflorestamento.

1. INTRODUCTION

Reforestation wood is a renewable material with social and environmental benefits and its carbon cycle is close to zero, noting that all the carbon in the wood was previously removed from the atmosphere by the plant's biological cycle (Barata et al., 2020). With long-term utilization in mind, the environmental benefits are increased with the formation of "carbon reserves", where the carbon removed from the atmosphere will be stored for long periods within the chemical composition of the wood (Silva et al., 2015; Susaeta et al., 2017).

In terms of the life cycle, wood has a lower energy cost and lower environmental liabilities compared to other materials used in civil construction, such as steel and concrete (Demarzo and Porto, 2007). Thus, the utilization of wood in the construction industry becomes a crucial topic for discussion in reducing carbon emissions and ensuring the sustainability of construction systems. Wood can be employed on a permanent basis in the formation of structural systems, contributing to the broader goal of carbon reduction and sustainable construction practices.

The application of structural systems in wood, in a competitive way in the market, requires the use of constructive techniques that allow the industrialization of the structural elements. With the use of industrial processes in construction, it is possible to increase reliability and minimize material waste, employing strict quality controls and accelerating construction processes (Tam et al., 2007).

The manufacturing process of Glued Laminated Timber (glulam) is one such technique that enforces rigorous quality control while facilitating the production of large-scale structural elements using reforested wood (Carrasco et al., 2020).

Glulam is obtained by joining laminated wood, using a bonding process, so that its fibers are parallel to each other (Szucs et al., 2015). Glulam structural elements should provide resistance similar to solid wood elements, enabling the transfer of stresses between the glued veneers, ensuring the satisfactory performance of the structural connection (Segundinho et al., 2021).

The Brazilian standard NBR 7190 (ABNT, 2022) only allows the gluing of wood with the pieces arranged with their fibers parallel to each. However, since 1983 it has been known that the strength of glued joints at different angles can be estimated, for example, by Hankinson's equation (De Paula, 1983).

Concerning the origin of the shear stresses, structural connections may be subject to both shear stresses due to normal loads, such as in compression, and shear stresses due to torsional loads. The shear stresses with both origins can act at the same time on the connection, both being relevant for the design of structural connections (Petrauski et al., 2020; Stringari et al., 2020; Possa et al., 2022). In this regard is relevant to point that these different loads lead to different orientations of the stress in relation to the wood fibers in the connection.

Couri Petrauski (1999) and Petrauski (2000) executed and tested glulam trusses and obtained satisfactory results, showing the possibility of making connections at different angles, using only adhesives. However, truss systems fundamentally work under normal loads (tension or compression), with a small incidence of bending moments and shear forces.

Recent research has been conducted to evaluate the performance of glulam three-hinged frames, confirming the strong structural performance of bonded connections with inclined fibers (Couri Petrauski et al., 2016; Stringari et al., 2020; Filippini, 2020; Possa et al., 2022). These studies on frames have been significant in verifying the behavior of bonded joints, particularly when the primary force acting on the structure joints is bending moment.

In this context, Petrauski et al. (2020) demonstrated that when a bonded joint is subjected to shear under compression, its strength is significantly affected by the angle between the wood fibers in the joint and can be estimated using Hankinson's equation. Additionally, the authors confirm that when a bonded joint is subjected to torsional moment (bending moment in the frame), its strength is less sensitive to the angle between the fibers and differs from the strength of bonded joints subjected to normal loads. As a result, the researchers proposed a new testing method for evaluating the strength of bonded joints under torsion.

Couri Petrauski et al. (2022) analyzed the results of five independent basic research studies related to wood bonding using two distinct adhesives. The researchers highlighted that, when bonded joints are sheared under compression, the strength for different bonding angles can be estimated using Hankinson's equation. Furthermore, the research found that torsional shear strength differs from shear strength under compression.

In assessing the quality of adhesion in glulam techniques, Segundinho et al. (2018) characterized glued laminated Eucalyptus sp. wood produced using resorcinol-phenol-formaldehyde and polyurethane adhesives. The study obtained bonded joint strength values similar to solid wood. Thus, the polyurethane adhesive exhibited strength values suitable for structural use under dry conditions.

In this context, the aim of this research was to evaluate the compressive shear strength in comparison to the torsional shear strength of Pinus sp. glued with polyurethane adhesive, performing the bonding with nine different angles. Additionally, the use of Hankinson's equation was evaluated as an estimator of shear strength in compression and in torsion of glued joints under different angles.

2. MATERIAL AND METHODS

The studied wood was Pinus sp. acquired in a batch of 1.46 m^3 in the form of boards in the city of Cascavel, Paraná, Brazil. The lot was stored until hydroscopic equilibrium, so that the pieces presented moisture content values close to 12%.

The adhesive used was a bicomponent polyurethane based on vegetable oils, manufactured by Kehl Indústria e Comércio Ltda, commercialized in the form of isocyanate and polyol components. Throughout the research, the adhesive was applied in proportions of 1:1.5 of isocyanate and polyol and spread only on one surface of the wood with the aid of a brush. Also, a bonding pressure of 1.0 MPa was applied in all joints using press with threaded steel bars. The amount of adhesive applied was 300 g/m^2, the closed assembly time was less than 20 minutes, and the pressing time was at least 12 hours. In the bonding environment, efforts were made to maintain the laboratory temperature was maintained at approximately 23°C.

The wood batch was divided according to apparent density, to avoid biasing the test results regarding the type of test and the bonding angles. For this, the experiment was carried out in subdivided plots with a randomized block design, due to the variability found in the density of the lot. The woods were separated into 8 groups, whose mean density values were: G1= 0.694 g/cm^3; G2 = 0.624 g/cm^3; G3 = 0.592 g/cm^3; G4 = 0.559 g/cm^3; G5 = 0.563 g/cm^3; G6 = 0.531 g/cm^3; G7 = 0.512 g/cm^3 and G8 = 0.427 g/cm^3.

To carry out the research, glued joints were fabricated at 9 different angles. In this way the joints were generated with angles of 0°, 10°, 20°, 30°, 45°, 60°, 70°, 80° and 90° in relation to the wood fibers.

The bonding process involved placing wood strips with approximate dimensions of 2.1 x 6 x 12 cm (thickness, width, length) onto strips measuring 2.1 x 14 x 15 cm, according to the intended angle. Each strip was bonded to another with a similar density, forming homogeneous test specimens. The surface of each strip composing the bonded joint underwent its final processing on the day of bonding to expose the wood fibers for adhesive application. For this procedure, the thickness of the bonded strip was reduced using a planer and subsequently mechanically cleaned with compressed air and a brush.

On the right side of Figure 1, two paired specimens were extracted from each glued joint, one for shear under compression testing (C) and the other for shear under torsion testing (T).

All specimens extracted and intended for testing by shear under compression (C) were manufactured and tested according to ASTM D 905 (2013) guidelines, subjected to load in a universal testing machine. For a better quantification of the force, a load transductor of 50 kN was used. The strength

Source: Author, 2023.
Fonte: Autor, 2023.

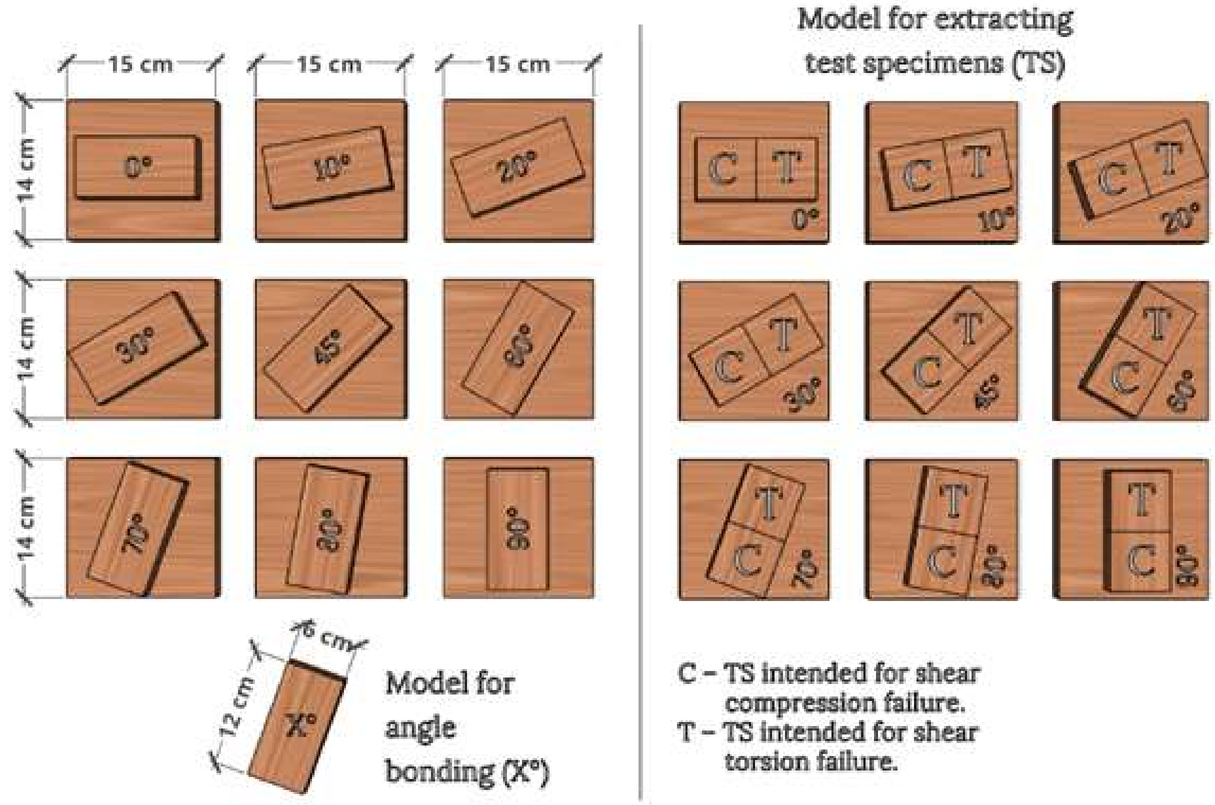

Figure 1 – Method of bonding and extraction of specimens, dimensions in cm.
***Figura 1** – Método de colagem e extração de corpos de prova, dimensões em cm.*

values were corrected for a moisture content of 12%, according to NBR 7190 (ABNT, 2022).

The specimens intended for shear under torsion were tested according to the methodology proposed by Petrauski et al. (2020), being configured with an effective circular cross section in the glued surface. The load for the torsional shear test was applied in a universal testing machine and obtained using a 50 kN load transductor. This methodology consists of using an apparatus that induces the glued surface to pure torsional effort.

For each of the studied angles, eight specimens were made for compressive shear and eight specimens for torsional shear. Consequently, the experiment with nine bonding angles, eight repetitions per angle (density groups) and two test types, resulted the total amount of 144 specimens. All specimens were tested at least 10 days its fabrication for the adhesive to cure properly.

Thus, the statistical model for shear strength (y_{ijk}) was assumed to be:

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

Where, in the j-th test type of the k-th group:

μ is the overall mean effect.

g_k is the effect of the k-th group/block.

α_i is the effect of the i-th angle.

e_{ik} is the effect of the error at the plot level, with Normal distribution of mean zero and variance $\sigma^1{}_2$.

τ_j is the effect of the j-th test type;

$\alpha\tau_{ij}$ is the effect of the interaction between the i-th angle and the j-th test type.

ε_{ijk} is the experimental error associated with subplots, with Normal distribution of mean zero and variance $\sigma^2{}_2$;

i= 1, 2, ..., 9.

j= 1 or 2.

k=1, 2, ..., 8.

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

Once the conditions were met, the effects of interest (α_i,τ_j e) were evaluated using the F test of analysis of variance (ANOVA) and when a significant difference was identified between the levels of the factor, the Tukey test was applied to compare means.

The nominal level of significance in all tests was 5%; therefore, if the descriptive level (p-value) was less than 0.05, the null hypothesis can be rejected, that is, in the ANOVA it was stated that there is a significant difference between the levels of the analyzed factor(s).

To study the levels of the angle factor in each of the tests, the non-linear Hankinson model described by the following expression was adjusted:

$$\overline{y_{ij.}} = \frac{f_{w0_j} \cdot f_{w90_j}}{f_{w0_j} \cdot (sen(\alpha_i))^{b_j} + f_{w90_j} \cdot (cos(\alpha_i))^{b_j}} + e_{ij.} \quad \text{Eq. 2}$$

Where:

$\overline{y}_{ij}$ represents the average strength at the i-th angle in the j-th test type.

f_{w0j} is the value of the asymptotic average strength of the j-th test type as the angle tends to zero degrees.

f_{w90j} is the value of the asymptotic average strength of the j-th test type as the angle tends to ninety degrees.

b_j is the coefficient of strength decay.

e_{ij}. is the experimental error, and the remaining variables are as defined in the previous equation.

The quality of the Hankinson model fit was assessed through graphical and statistical analyses, considering the residual sum of squares of the models and the coefficient of determination (R^2). This coefficient indicates how much of the variance in the response variable is explained by the variance in the explanatory variables.

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

When evaluating the strength obtained according to the density groups, the type of test and the bonding angles, it was possible to observe that specimens with higher density values resulted in greater strength. The strength results were, on average, higher in the shear under compression test for angles between 0° and 45°; for the other angles, the shear under torsion tests showed higher average strength results. Both tests showed a decrease in resistance as the angle increased (Table 01). In addition, it is possible to

Table 1 – Average shear strengths, including standard deviation, by test and bonding angles, and average shear strength and average density of test specimens by test and group.
Tabela 1 *– Resistências médias ao cisalhamento, incluso desvio padrão, por ensaio e ângulos de colagem, e resistência média ao cisalhamento e densidade média dos corpos de prova por ensaio e grupo.*

Angles	Average shear strengths from shear tests (MPa)		Groups	Average strength and average density per group and shear test			
	Compression	Torsion		Compression		Torsion	
				Mpa	g.cm^{-3}	Mpa	g.cm^{-3}
0°	10.46± 1.58	7.13 ± 1.54					
10°	10.22± 2.38	6.60 ± 2.10	G1	9.32	0.70	7.27	0.69
20°	9.87± 2.17	6.61 ± 1.24	G2	7.98	0.63	6.94	0.62
30°	8.44 ± 1.45	6.78 ± 1.65	G3	6.95	0.60	5.74	0.59
45°	6.40 ± 1.45	6.03 ± 1.68	G4	7.07	0.56	7.91	0.55
60°	5.10 ± 1.13	5.97 ± 1.52	G5	6.61	0.56	5.38	0.57
70°	4.39 ± 0.84	5.99 ± 1.33	G6	6.54	0.53	5.19	0.53
80°	4.22 ± 1.18	5.50 ± 0.82	G7	6.02	0.51	4.56	0.51
90°	3.90 ± 1.37	4.52 ± 1.20	G8	5.51	0.43	6.04	0.43

Source: author, 2023.
Fonte: autor, 2023.

observe the variability (standard deviation) of the results, and at the 10° angle the greatest dispersions in resistance were found for both the shear under compression and torsion tests.

Despite obtaining standard deviations ranging from 0.82 to 2.38 MPa across the treatments, the assumption of normality and homogeneity of variances was not rejected. When evaluating the factors of interest in the research using the ANOVA F-test, it was found that there is a significant interaction between the type of test and the bonding angle. In other words, as the angle and the type of test change, the trend in strength also changes significantly. In this experiment, the coefficient of variation in the first part of the test was 17.75%, and in the second part, it was 17.21%.

When performing the factor angle breakdown within the test, it was found that there was a significant difference between the angles, considering whether the test was shear under torsion or shear under compression.

Therefore, based on the Tukey multiple comparisons test, in the shear under compression tests, angles 0°, 10°, and 20° do not differ significantly in average, the same occurring among angles 10°, 20°, and 30°, which form group b; 45° and 60° are in group c with statistically non-different means, and angles 60° to 90° form group d. Thus, for this test, we can conclude that 0° differs significantly only when the angle is 30° or higher; 30° differs for angles of 45° or higher; 45° differs when the angle is 70° or higher. For the shear under torsion tests, most angles did not show statistically different mean results, except for the 90° angle, which differs from angles between 0° and 30°.

With the breakdown of the test type factor within the angle, Table 2 shows that there is a significant difference between the types of tests when the angle is 0°, 10°, 20°, 30°, 70°, and 80°.

Therefore, based on the Tukey multiple comparisons test, it can be concluded that at angles 0°, 10°, 20°, and 30°, the average strength in the shear under compression test is statistically higher than the average in the shear under torsion test. At 70° and 80°, the results reverse, with the average strength in the torsion test being statistically higher compared to the average in the compression test. Among the average values, the shear under compression test exhibits a decreasing and sigmoidal behavior as the angles increase. In contrast, the shear under torsion test yields more average results with a slight decrease.

When modeling the Hankinson curve, the following equation for the shear under compression test was obtained:

$$\hat{y}_{iC} = \frac{10.43 \times 3.97}{10.43\left(sen(\alpha_i)\right)^{2.35} + 3{,}97\left(cos(\alpha_i)\right)^{2.35}} \quad \text{Eq. 3}$$

For the shear under torsion test, the following equation was obtained:

$$\hat{y}_{iT} = \frac{6.79 \times 5.20}{6.79\left(sen(\alpha_i)\right)^{2.19} + 5{,}20\left(cos(\alpha_i)\right)^{2.19}} \quad \text{Eq. 4}$$

In Figure 2, you can observe the curve along with the sample points and the mean values. Despite the fit appearing adequate for both tests, the coefficient of determination was extremely low for the shear under torsion test (T), with R^2_c=0,756 and R^2_T=0,172.

Table 3 presents the estimated coefficients for the Hankinson model, their respective confidence intervals, and determination coefficients.

Table 2 – ANOVA summary given the deployment of the test factor within angle.
Tabela 2 *– Resumo da ANOVA dado o desdobramento do fator ensaio dentro de ângulo.*

Sources of Variation	df	Sum of squares	F-Test	p-value
Test / angle: 0°	1	44.57	34.67	**<0.001**
Test / angle: 10°	1	52.44	41.06	**<0.001**
Test / angle: 20°	1	42.49	33.27	**<0.001**
Test / angle: 30°	1	11.01	8.62	**0.004**
Test / angle: 45°	1	0.55	0.43	0.511
Test / angle: 60°	1	3.04	2.38	0.128
Test / angle: 70°	1	10.30	8.07	**0.006**
Test / angle: 80°	1	6.55	5.12	**0.027**
Test / angle: 90°	1	1.55	1.21	0.274
Error (subparcel)	63	80.46		

Source: author, 2023.
Fonte: autor, 2023.

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Fonte: autor, 2023.

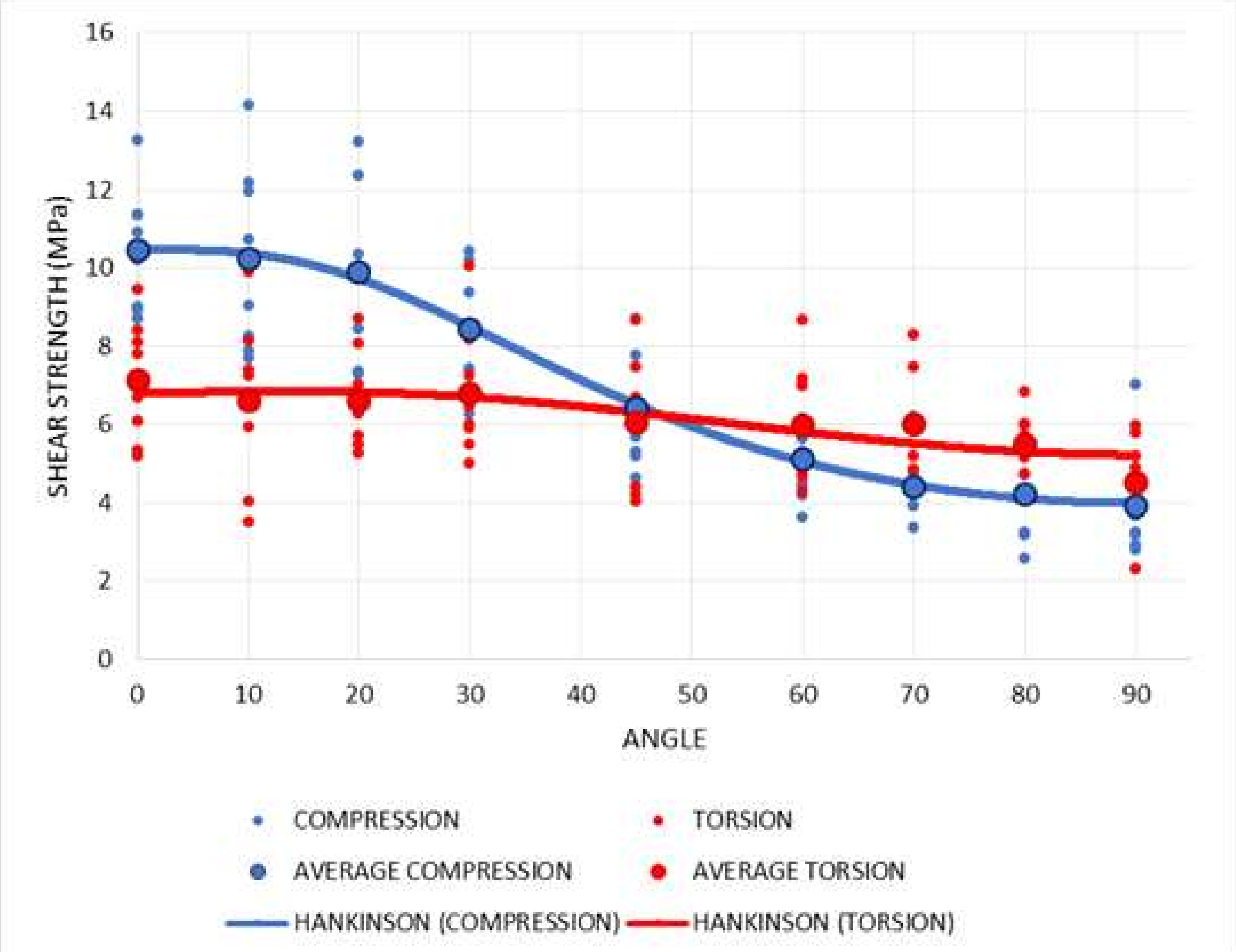

Figure 2 – Fitting of the Hankinson model according to the test. The smaller points represent the values of sample strength, and the larger points represent the average strength.
Figura 2 *– Ajuste do modelo de* ***Hankinson*** *de acordo com o ensaio. Os pontos menores são os valores da resistência amostral e os maiores são a resistência média.*

Table 3 – Estimated coefficients in the *Hankinson* model and their respective confidence intervals and coefficient of determination.
Tabela 3 *– Coeficientes estimados no modelo de* ***Hankinson*** *e seus respectivos intervalos de confiança e coeficiente de determinação.*

Rehearsal	Parameters			
	$\hat{f}_{w0j}$	$\hat{f}_{w90j}$	$\hat{b}_j$	R_j^2
C	10.43 [9.63; 11.26]	3.97 [3.43; 4.53]	2.35 [2.00; 2.71]	0.756
T	6.79 [6.08; 7.56]	5.20 [4.59; 5.85]	2.19 [1.74; 2.64]	0.172

Source: author, 2023.
Fonte: autor, 2023.

4. DISCUSSION

The batch of pine wood acquired for this research exhibited a wide range of apparent density, with average values for the established groups ranging from 0.43 to 0.69 g.cm^{-3}. Density, adopted in this study as one of the control factors, appeared to influence the strength of the bonded joints, especially when the shear test was conducted under compression. Glulam specimens with higher density tended to have higher strength values compared to lower-density ones. In the case of the shear under compression test, a correlation coefficient of 0.96 was obtained between apparent density and joint strength. The positive correlation between wood density and its mechanical properties has long been known and widely documented (Kollmann and Côté, 1968; Wood Handbook, 2021). However, it seems interesting to highlight this fact regarding bonded joints. For example, Stringari et al. (2020) and Possa et al. (2022), testing glulam structures, also found a strong correlation between the density of the structures and their strengths. In the production of glulam structures, it seems convenient to perform a preliminary selection based on the density of the available material.

Considering one of the main objectives of this work, the two regression models studied, based on Hankinson's equation, indicated a decrease in strength with the variation of the bonding angle, with the highest values near the 0° angle (parallel to the wood fibers) and the lowest values near the 90° angle (perpendicular to the wood fibers). The decrease in the joint strength was better evidenced in the shear under compression test.

Additionally, a statistical difference in the strengths obtained between the two types of tests conducted was observed. These differences were greater at the beginning and end of the angle series (near 0° and 90° angles), but they did not show statistical differences in the center of the series, near the 45° angle. This seems normal since, as Hankinson's equation itself establishes, there is a decrease in strength with increasing bonding angle, and near the center of the series, the shear under compression results become equivalent to the shear under torsion results. Similar results with the same general trend were obtained by Petrauski et al. (2020) using eucalyptus wood and two adhesives: resorcinol formaldehyde and castor oil-based polyurethane. In their research, however, the equivalence of strengths for shear under compression and shear under torsion tests occurred at a 30º angle.

For angles close to 0°, the average shear under torsion strength was statistically lower than the average shear under compression strength, a fact also observed by Petrauski et al. (2020). In a real application of a bonded structural joint, this may suggest safety risks if the joint is exclusively designed based on shear under compression test values, and it mainly suffers torsional loads (bending moment in the beam).

Hankinson's equation was able to estimate the strength values for the shear under compression test, presenting a coefficient of determination of the order of R^2=0.756 and b coefficient in a confidence interval of [2.00; 2.71]. Couri Petrauski et al. (2022), studying the same phenomenon and presenting results from five independent works with eucalyptus, obtained coefficients of determination for adjustments of Hankinson's equation that ranged from 0.67 to 0.86, with a mean of 0.79. Also, the coefficient *b* found by the researchers ranged from 1.82 to 2.18, with an average of 2.02.

The coefficient *b*, which is the exponent of the sine and cosine terms in Hankinson's equation, represents the rate of decay of the strength concerning the variation of the angle. In other words, a smaller coefficient indicates a faster decrease in strength with angle variation. In this regard, the coefficient $b = 2$ suggested by NBR 7190 (ABNT, 2022) has proven to be appropriate and falls within the confidence interval found in the study. It's worth noting, however, that this normative suggestion is intended for obtaining estimates of mechanical properties of wood that, in the current state of the art, do not consider bonded joints at angles.

The studied model, based on Hankinson's equation, did not prove to be suitable for estimating strength when tested by shear under torsion. Therefore, in the analysis of bonded joints subjected to torsion, it seems appropriate, for the sake of safety, to use performance results at 90 degrees. This is justified because, in this study, the 90° angle presented the lowest strength values.

The resistance curves obtained in this study resemble those presented in the works of Petrauski et al. (2020) and Couri Petrauski et al. (2022). These researchers used eucalyptus wood and, more frequently, resorcinol formaldehyde adhesive. In the present study, similar evidence was obtained for pine wood and polyurethane adhesive. It's worth to note that the polyurethane adhesive differs chemically from the resorcinol formaldehyde adhesive and is currently used in a significant number of applications that involve wood bonding, including the execution of glulam structures.

The difference between the strengths of bonded joints in shear under compression and under torsion, obtained in this and other similar research, seems to indicate the need for further studies aimed at establishing design criteria for bonded joints involving different structural arrangements.

5. CONCLUSIONS

The variation of the angle between the wood fibers results in changes in the shear strength of the bonded joint. A higher angle leads to lower strength in standardized tests.

The shear under compression strength can be estimated using Hankinson's equation. However, the shear under torsion strength cannot be estimated using the same model and exhibits a graphical pattern which is more similar to a simple linear behavior.

When comparing the strength values throughout the angle series, the difference in the mechanical response of the joint to the type of test becomes evident. Thus, the study provided evidence of differences in shear strength of bonded joints when the bonded surface is subjected to shear forces from compression (normal force) compared to shear forces from bending (torsional moment).

Nevertheless, it seems important to develop standardized solutions that facilitate the structural design of bonded joints subjected to torsional moments, including methodologies for obtaining the shear strength and standard prescriptions for bonding at angles.

The authors also suggest conducting similar research using different wood species and adhesives to verify the mechanical response trends of bonded joints with respect to the stresses acting in the bonded surface.

AUTHOR CONTRIBUTIONS

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

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