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IMPROVEMENT OF GLUING PARAMETERS IN EDGE GLUED PANELS

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ABSTRACT

Faced with the need for innovation and waste reduction that the market demands, the high consumption of adhesive in the furniture industry led to the need and interest in studying ways to reduce this consumption, through changes in the bonding process without compromising the mechanical properties of the bonded material. The collage is carried out to form Edge Glued Panels of *Pinus taeda* (loblolly pine), using PolyVinyl Acetate adhesive with an average weight of 205 g/m². If lower weights are used, using the current application method (roller), mechanical strength problems begin to arise. The objective of this work was to study the feasibility of applying glue by another method (spray) with weights and, consequently, shorter pressing times, to evaluate the conservation of the mechanical properties of the panels through shear and traction tests. For that, samples were made according to the standards with the current situation of bonding (weight of 205 g/m² and pressing time of 80 s), to obtain reference results in the tests, and in the proposed situations (adhesive weights of 125 g/m² and 80 g/m² and pressing times of 70 s and 75 s), in an attempt to reach the established reference values. Regarding the results, it was feasible to conclude that the current method could be replaced by the proposed one, using the spray together with an adhesive weight of 125 g/m² and pressing times of 75 s and 70 s, with no statistically significant difference for the current method.

Keywords: Edge glued panels, mechanical properties, *Pinus taeda*, shear strength, traction strength.

INTRODUCTION

In recent years, wood, as a raw material, has been increasingly used to create new groups of products, to meet the demands of innovation, performance, quality and sustainability imposed by the market. To keep up with this evolution, it is necessary to create and improve industrial processes and to seek the best use of the materials involved in these processes, to reduce waste (Sandberg 2016).

Classified inside the group of wood products with higher added value, panels, both reconstituted wood and mechanically processed wood, are the most relevant in the classification. Data from the international furniture scene indicate that Latin America has a share of up to 7 % in supplying the main importing countries (UNECE FAO 2021) and, specifically about production of solid wood panels, production growth between 2000 and 2019 was 105 %, with an increase in demand forecast for the coming years (Funchal 2021).

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In the furniture industry, the EGP (Edge Glued Panel), which a panel made by gluing battens (wooden slats) on the side, is one of the most used in furniture manufacturing. In terms of bonding, it is important to point out that the world timber industry is the largest user of adhesives and resins, using 70 % of the total produced (Sandberg 2016) and that adhesive consumption is present in more than 70 % of products made from wood (Biazzon 2016).

Considering the relevance of adhesives in this type of industry, linked to the increase in market demand and the need for processing innovation, it is necessary to carry out research to seek improvements in this field. With this in mind, a study was carried out to reduce the consumption of adhesive in a furniture industry that manufactures EGP, in which the problem presented was the high consumption of glue, approaching the average of 60 t/year.

As decreasing only the amount of adhesive implies a reduction in the mechanical performance of the panel, it was hypothesized that by changing the method of applying the glue, the panel could present the same ease with less glue applied. As a result of reducing the amount of glue deposited, the pressing time could also be reduced, due to the shorter time required for the adhesive to solidify.

The new method of application of the proposed adhesive was the spray, as it is already used in the furniture industry for other purposes, because there is familiarity with the process. The findings on the applicability of the spray on wood and the possibility of forming a thinner layer of glue and reducing waste were also considered (Hazir and Koc 2021).

To verify the maintainability of the mechanical performance of the panels (Leggate *et al.* 2022) with the new bonding proposal, the adhesive joints must be evaluated, mainly, by the traction, flexion and shear properties (Green *et al.* 1999, Bolgenhagen 2018). As this work does not include EGP panels with a finger joint, flexion was not tested.

In summary, this research aims to evaluate the mechanical performance (traction and shear) of the EGP wood panel glue line type in the current production situation and in the proposed situations, changing the adhesive application method, the quantity of glue deposited and pressing time. The intention is to use statistical methods to find out if there is a significant difference between the current situation and the proposed situation, through the use of the performance values obtained. If one or more of the proposed situations are validated, the possibility of manufacturing EGP with a decrease in material consumption will be confirmed. In addition, the research may serve as a guiding basis for the readjustment of similar processes in other companies in the same field that seek the same kind of improvement.

MATERIAL AND METHODS

Regarding the materials used, the wood was from the loblolly pine (*Pinus taeda* L.) species, from reforestation and subjected to the same preparation process for bonding that is normally done, for greater reliability in the results. An emulsion of polyvinyl acetate (PVAc), classified as D3 in DIN EN 204 (2016), was used as an adhesive.

The process studied was the lateral gluing of wooden battens to make EGP panels. The process includes the steps of applying glue to the surface to be glued, laying the battens side by side and pressing them sideways at high frequency.

Regarding the experiments, the mechanical properties of traction and shear of the glued wooden panels in the current manufacturing situation (SA) and the proposed situations (SPn) were evaluated, to verify the possibility of reaching the values found in the current situation. For the organization of traction and shear tests in all proposed conditions, the experimental design was used (Table 1).

Table 1: Experimental planning schematization.

Variables/Process conditions	Current situation	Proposed situations			
Application method	Roller application	Spray application			
Glue spreading rate (g/m²)	205	125		80	
Pressing time (s)	80	75	70	75	70
Abridgment	SA	SP1	SP2	SP3	SP4

The ASTM D5751-99 (2005) standard was used for the shear strength test, which determines three pre-treatments for carrying out the test: dry, in which the specimens are initially exposed to room temperature until reach the humidity between 8 % and 10 %; due to exposure to high temperature, which preheats the parts to 104 °C ± 3 °C; and by immersion in water, in which the specimens are first submerged in water at room temperature (between 19 °C and 27 °C) for four hours and then dried in an electric oven at 41 °C ± 3 °C, repeating it twice. The equipment used was the EMiC universal testing machine.

For the traction strength test, the ABNT NBR 7190 (1997) standard was used, which determines that the specimens are subject to normal force contrary to the glue line, by previously designed equipment. The equipment used was the Schenck Trebel universal testing machine.

Concerning the samples used in the tests, initially, panels of the EGP type (Figure 1a) were made for the extraction of specimens for the shear test (Figure 1b) and the traction test (Figure 1c). The total quantification of samples is shown in Figure 2.

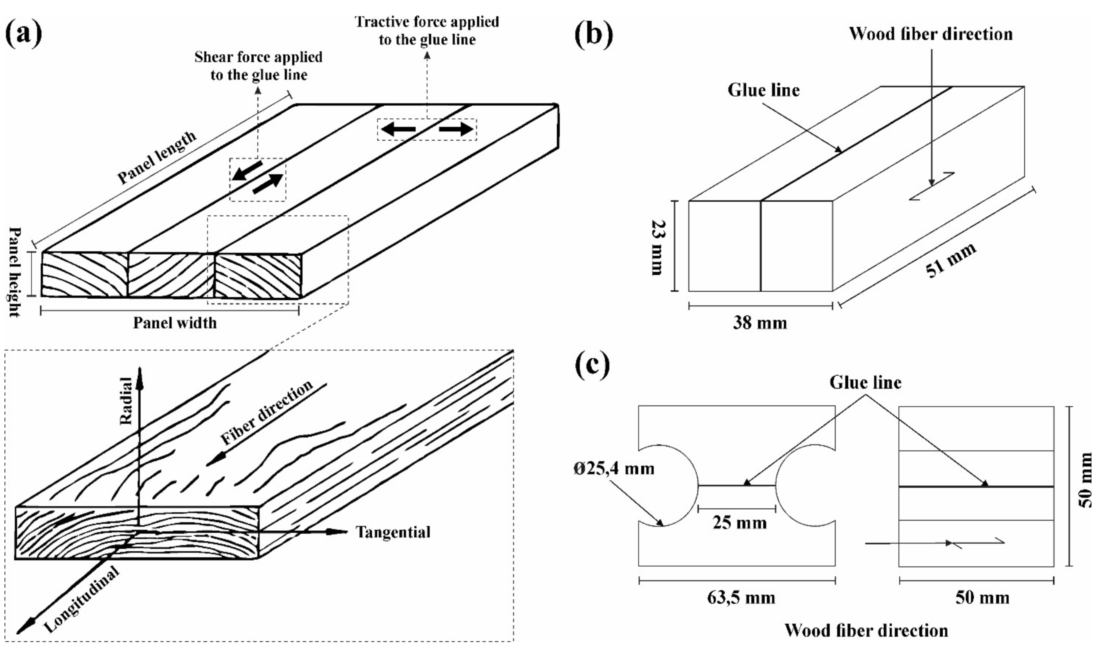


Figure 1: (a) Illustration of the EGP panel, (b) The specimen for the shear test and (c) The specimen for the traction test.

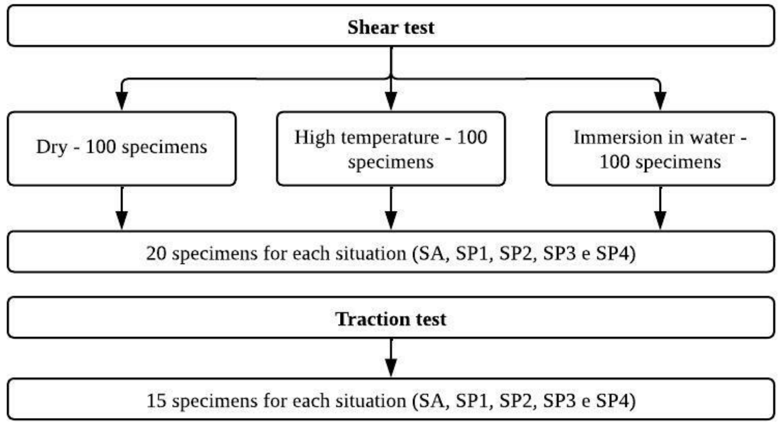


Figure 2: Sample quantification scheme.

For the application of the glue in the sample preparation, a roller (SA) and a spray (SPn) were used. The automatic application with a roller is typical of the gluing equipment and for the application of the spray, an Anest Iwata gravity spray gun, model W-400-182G, with a 1,8 mm diameter nozzle, application pressure of 2 bar was used and a flow rate of 320 ml/min. In summary, the weights were defined as follows:

• for SA, average weight of 205 g/m² and average application time of 1,6 s per meter, with roll application;

• for SP1 and SP2, average weight of 125 g/m² and average application time of 4,8 s per meter, with spray application;

• for SP3 and SP4, an average weight of 80 g/m² and an average application time of 3,2 s per meter with spray application.

For the pressing properties, the time was adjusted between 80 s, 75 s and 70 s as already demonstrated and the average pressure of 4650 ± 740 kPa was maintained.

For the statistical analysis, planning was carried out to treat the data in a complete factorial type, with a 2 x 3 x 3 arrangement (two methods of applying glue, three times of pressing and three grammages). As the intention was to evaluate the significant difference between the proposed situations (SPn) about the current situation (SA), there was only a comparison between SA and each of the SP, not analyzing the relationship among the proposed situations (Figure 3).

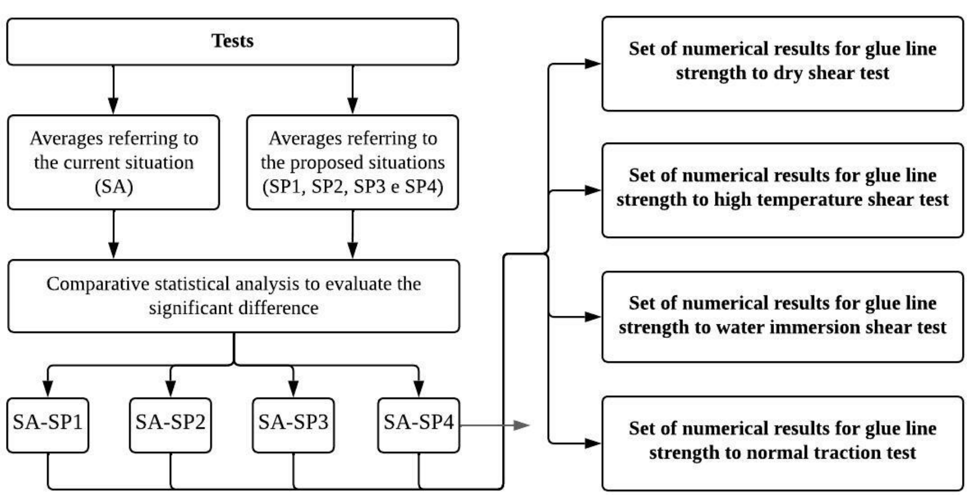


Figure 3: Comparison procedure scheme among the averages.

Regarding the treatment of data, initially, the averages and standard deviations were obtained for each condition, for purposes of comparison with results in the literature. Finally, to carry out each of the comparative analyses, the Minitab 18 software used the ANOVA analysis of variance, aided by the Tukey test at a 95 % liability level, to assess the existence or not of a significant difference between the compared values.

RESULTS AND DISCUSSION

The first analysis to be carried out refers to the averages obtained for the resistance of the glue line to normal traction and to shear. The average and its standard deviation of each experiment combination can be consulted in Table 2, and then the discussion with results obtained from the literature.

Table 2: Average values of shear and traction strength of the glue line.

Variables/Process conditions		Current situation	Proposed situations				Standard used for the test
		Roller application	Spray application				
Glue spreading rate (g/m²)		205	125		80		
Pressure time (s)		80	75	70	75	70	
Shear strength	Dry test (kPa)	10180 ± 430	11310 ± 760	9630 ± 460	8610 ± 780	7820 ± 1080	ASTM D5751-99 (2005)
	High temperature test (kPa)	4160 ± 380	4530 ± 230	3700 ± 190	3010 ± 440	2560 ± 720	
	Immersion in water test (kPa)	3760 ± 350	4050 ± 580	3990 ± 300	2100 ± 530	1600 ± 360	
Normal traction strength test (kPa)		1390 ± 80	1350 ± 210	1340 ± 160	1190 ± 190	1020 ± 120	ABNT NBR 7190 (1997)

At first, it is important to highlight that the averages were obtained only for specimens that broke in the glue line, since the intention was to test its strength and performance.

Regarding normal traction, three of the five averages obtained (SA, SP1 and SP2) are within the established range of results from 1220 kPa to 3690 kPa (Amparado 2008, Bolgenhagen 2018). In addition, only the averages of these two proposed situations were statistically equal, also making situations SP3 and SP4 invalid.

Regarding the variables that were adjusted for the tests, the first author used a weight of 200 g/m², cold pressing for at least 48 h and the adhesive was applied by brush, in addition to using blue gum (*Eucalyptus saligna* Sm.) wood, with higher density and the same sticker.

The second author, on the other hand, when using a weight of 220 g/m², pressing at high frequency in cycles of 89 s at 4000 kPa, pine wood and, as an adhesive, the polymeric emulsion of isocyanate (EPI) applied by roller, obtained values superior results in all adjusted conditions (slat size, moisture content and wood finishing process). This may be a consequence of the combination of greater grammage, but kept within the recommended range, with the adhesive used, which has better behavior in adhesive joints wood (Iwakiri *et al.* 2015).

Tests with lower levels of adhesive weight were also carried out, such as the research by (Becker 2011), which obtained maximum values of normal traction to the fibers in the range of 680 kPa to 1580 kPa, considering the highest weight values (130 g/m²), pressing time (90 s) and pressing pressure (390 kPa), using slash pine (*Pinus elliottii*) wood and PVAc adhesive. It can be seen that the range of values was closer to those found in this research because the first two properties were used at similar levels.

Regarding shear, it is essential to point out that it is the main test to which glued wood splices are submitted when the intention is to test their strength and performance. The standard used determines minimum values for approval of 4690 kPa (dry), 3120 kPa (at high temperature) and 2350 kPa (by immersion in water). So, according to normative values, only SA, SP1 and SP2 exceed the established minimum limits.

Of the conditions tested in this work, the averages of the SA and SP1 situations were within the range proposed by (Iwakiri *et al.* 2015), considering the dry test. Considering the statistically significant similarity, the SP2 situation can also be considered in the range. Regarding the other shear test conditions, only the SP1 and SP2 conditions were able to reach values significantly equal to the SA situation, with the SP3 and SP4 conditions already invalidated.

The studies found on glue line shear were based on the observation of several properties. (Bolgenhagen 2018), with the processing conditions previously highlighted, obtained results in the range of 8560 kPa to 14650 kPa, alternating according to the batten size adjustment, moisture content and mechanical processing, and varying for smaller values and greater than those found in the different combinations imposed here. This corroborates the understanding that gluing depends on many factors of different natures.

The results of the research by (Yusoh *et al.* 2021) demonstrated the relationship between wood with higher densities (lower porosity) and the glue spreading rate, in which the species with density of 434 kg/m³ and 480 kg/m³ obtained better resistance indexes to shear with weight of 300 g/m², while the species with densities of 700 kg/m³ and 770 kg/m³ had better behavior with weight less. As lower densities are more porous, the adhesive flows more easily, decreasing the amount on the bonded surface. If the heavier weight were applied to the other species, a smaller amount of adhesive would penetrate, causing the thick layer of glue to interfere with the adhesive-substrate connection.

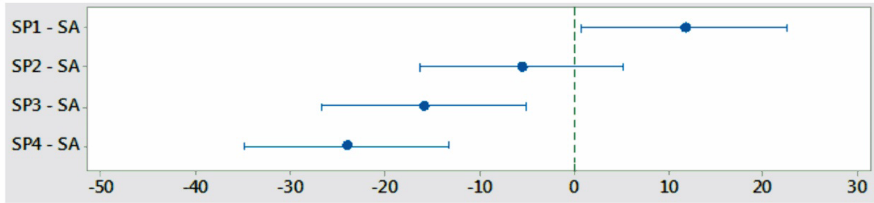
Martins (2011), when evaluating the property with camden white gum (*Eucalyptus benthamii*) wood Maiden et Cambage and PVAc and polyurethane adhesives, varying the pressing pressure (cold) from 700 kPa to 1000 kPa with the duration of 360 min and 90 min, obtained higher values with the second adhesive and the higher pressing pressure, reaching an average of 11530 kPa. Considering that cold pressing was performed, pressure can be considered an important factor, even when the adhesive cures naturally and it is not accelerated, as in high-frequency pressing.

Using the pressing types as one of the controllable variables, (Endo *et al.* 2017) found ranges from 5040 kPa to 5630 kPa for the dry test, 3280 kPa to 7170 kPa in immersion and air conditioning and 670 kPa to 2150 kPa only in immersion. The values below the common can be explained by the use of low pressing pressure (7000 kPa), since the grammage of 200 g/m² is indicated for loblolly pine (*Pinus taeda* L.) wood using PVAc. The pressing times using cold pressing (45 min) and high frequency pressing (3 min) provide similar results, indicating that the two processes are effective, as long as they are applied within the appropriate limits. Another research with similar behavior is that of (Bianche 2014), in which, in the pressing, carried out cold for 24 h, a pressure of 12000 kPa was applied. The results obtained indicated dry shear strength in the range of 4510 kPa to 4760 kPa and in the wet condition of 230 kPa to 360 kPa, using PVAc adhesive from 150 g/m² to 250 g/m² in pine wood.

For the main discussion of the results regarding the possibility of using one or more proposed situations, the statistical analyzes are shown in Table 3, where the four types of tests performed and the respective statistical comparisons of each proposed situation are represented (SPn) with the current situation (SA). For each comparison, there is a confidence interval (CI), illustrated by the blue horizontal lines, which determines the probable range that the statistical value obtained from the comparison may be when considering a certain degree of probability or confidence. If there is an intersection between this interval and the green vertical line, it averages that there is no significant difference between the compared values, graphically representing what is indicated in columns p.

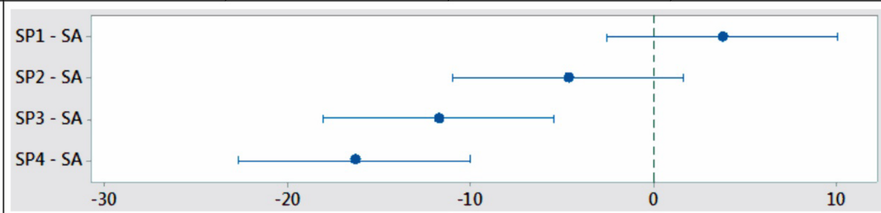
Table 3: Statistical analysis of the significant difference between the current situation and proposals, for the four tests performed. Analyzes were performed with a liability level of 95 %, that is, p values ≤ 0,05 indicate a significant difference between the compared values.

Glue line strength to dry shear test



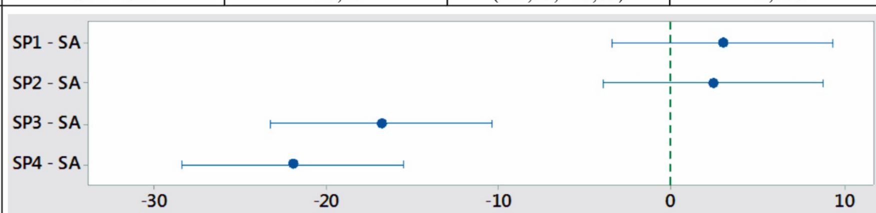
Compared situations	Average differences	95 % CI	p
SP1 - SA	11,60	(0,78; 22,41)	0,030
SP2 - SA	-5,54	(-16,36; 5,27)	0,585
SP3 - SA	-15,99	(-26,81; -5,18)	0,001
SP4 - SA	-24,04	(-34,85; -13,22)	0,000

Glue line strength to high temperature shear test



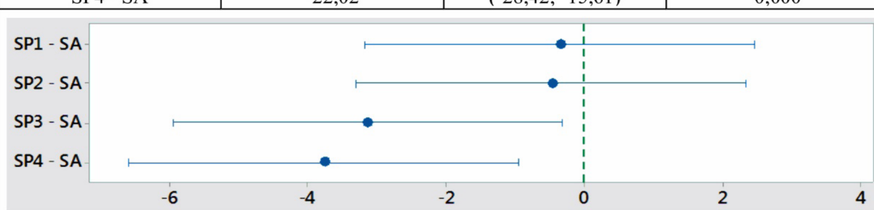
Compared situations	Average differences	95 % CI	p
SP1 - SA	3,72	(-2,61; 10,05)	0,453
SP2 - SA	-4,68	(-11,01; 1,65)	0,231
SP3 - SA	-11,80	(-18,13; -5,47)	0,000
SP4 - SA	-16,40	(-22,73; -10,07)	0,000

Glue line strength to water immersion shear test



Compared situations	Average differences	95 % CI	p
SP1 - SA	2,94	(-3,46; 9,35)	0,679
SP2 - SA	2,41	(-3,99; 8,81)	0,814
SP3 - SA	-16,87	(-23,27; -10,47)	0,000
SP4 - SA	-22,02	(-28,42; -15,61)	0,000

Glue line strength to normal traction test



Compared situations	Average differences	95 % CI	p
SP1 - SA	-0,37	(-3,18; 2,46)	0,995
SP2 - SA	-0,49	(-3,31; 2,34)	0,986
SP3 - SA	-3,15	(-5,97; -0,33)	0,023
SP4 - SA	-3,79	(-6,60; -0,97)	0,005

Through the data shown in Table 3, it is possible to corroborate the discussion raised above. At first, in the comparison between the proposed situations and the current one, for validation of an alternative proposal in dry shear values, note the average of SP1 and its interval to the right of the vertical line delimited at zero. This means a significant difference however, as the average includes a value greater than SA, this becomes valid. Still, the SP2 value of $p > 0,05$, indicates statistical similarity and perhaps the possibility of using the proposed situation. The same applies to the other two shear tests (dry and at high temperature) and the normal traction test to the glue line, which confirm the significant similarity compared to the current situation (SA).

With these findings, it is possible to establish the relationship between the numerical results obtained and the properties modified for carrying out the tests. Note the greater influence of the weight of the adhesive applied about the pressing time demonstrated by the better behavior of SP1 and SP2, but this last property also has its importance. This can be observed in Table 2 by the significant similarity pointed out between the means of SP2 and SP3 in the dry shear test and between the values found in SP1, SP2 and SP3 in the normal traction test, in which only the combination of the longer pressing with the lowest grammage was able to obtain this statistical range.

Another pertinent point of discussion is the overcoming or approximation (in the case of traction) of the average result of the current situation, even using smaller weights and pressing times than those commonly used in the literature. By this condition, it is understood that the glue application method, which was another modified property, also has a significant influence on the results.

Among the surveys studied, there are several methods of applying glue used, which may be related to the practicality of each one. Reports range from the most common methods in this type of process, involving spray, brush and roller (Lima 2016, Hazir and Koc 2021), to less recurrent uses (when considering production speed as a decisive factor), such as application by tube, immersion and spatula (Martins 2011, Kläusler *et al.* 2014).

In his research on the quality of EGP bonding, (Amparado 2008) points out that the brush application method was chosen to ensure that the glue spreads over the entire surface of the wood substrate to be fixed. In this sense, the reason for the existence of the observed variety of procedures for spreading the adhesive may be the supply of a thinner layer of glue, the high viscosity and malleability of the adhesive, availability of tools and machinery, among others.

The need for glue application on the entire surface to be glued, uniformly and without excess, corroborated by (Iwakiri *et al.* 2021), raises the discussion of the comparison between the two methods tested here, illustrated in Figure 4.

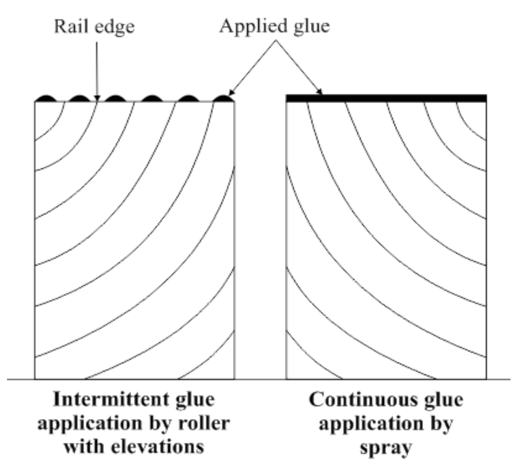


Figure 4: Comparative illustration of the adhesive deposited by the two glue application methods (current and proposed).

The current procedure adopted involves the application of the glue with a slightly toothed roller, which ends up resulting in an uneven application of the adhesive, with the thickness of the layer. What ends up spreading the material until the formation of the adhesive layer is the pressing process, however, if there is not enough glue for uniform distribution over the entire surface, deficient regions of binding material will appear and it will consequently compromise the mechanical performance of the joint. This phenomenon may explain the inefficiency of using lower adhesive weights while maintaining the current application process.

In addition, a factor that may be related to this possible failure in spreading is the behavior of the adhesive at high temperatures, as mentioned by (Stoeckel *et al.* 2013). PVAc, as well as other adhesives that use water as a solvent, tend to solidify more quickly due to the loss of this solvent, which is more intense in jobs at high temperatures, such as high-frequency pressing. This property can lead to pre-gelatinization, that is, the adhesive solidifies ahead of time, impairing the formation of a uniform glue layer and, consequently, the strength of the adhesive joint.

In this sense, research such as those by Bekhta *et al.* (2012) and Tong *et al.* (2013) emphasize the qualities of spray application such as: versatility to substrate coverage, ease of adaptation to different conditions and relatively low cost. Therefore, the authors recommend this method be studied in more detail so that it is increasingly improved.

Involving these three favorable conditions that spraying offers, for the installation of the new application method in the studied process, in addition to the implementation of the spraying equipment, structures similar to removable and relocatable gutters would be installed to retain the adhesive that end up not being deposited on the surface, as demonstrated in the Figure 5.

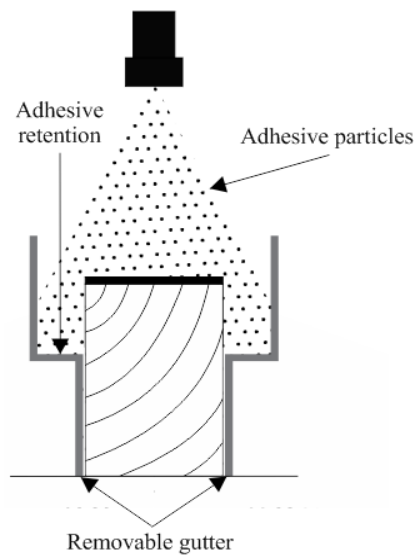


Figure 5: Layout of the structure for the new application method.

As an initial solution, the adhesive deposited in these gutters would be removed and sent back to the supplier (as is currently done) for better disposal. Promising alternatives for treatments without return to the supplier can be seen in studies such as that of (Gong *et al.* 2019), which demonstrate possibilities for dissolving PVAc such as the use of CO_2 at high pressure, returning to liquid form, being reusable. However, it is essentially necessary to make sure that the dissolved adhesive retains the same properties as the first application.

About material losses, the current application method in the company reaches maximum loss rates of approximately 28 %, varying according to the thickness of the wooden batten to be glued, with greater waste when the battens are thinner. To the spray, the first tests showed a loss rate close to 16 %, as the equipment regulates the application area and directs the flow of applied material. Once implemented, the new system will be constantly evaluated so that improvements can be made to reach a minimum loss rate.

CONCLUSIONS

In summary, among the proposed situations, SP1 and SP2 were the ones that obtained the best averages in the four tests carried out, that is, the weight variable was more influential in determining the results than the pressing time. This behavior could be visualized in the study of the geometry of the rupture region in the traction test specimens, where the best interaction between adhesive and wood substrate was remarkable.

Another factor that may be related to the success of gluing using the spraying method is the interaction between the adhesive particles among themselves and between them and the wood substrate, since deposition by atomization (which is what happens in spraying) provides a geometric of different adhesive particles. Although this geometry makes the formation of a uniform layer of adhesive more complex, by pre-polymerizing the adhesive (since atomization provides more dispersed particles), this application can facilitate the access of the adhesive to points on the wood surface where the adhesive applied by other application methods are not able to reach. However, to make this a valid statement, a more in-depth study using more specialized techniques and equipment would be necessary.

In the statistical comparison between the proposed situations and the current one, it was possible to perceive the absence of significant difference between SA and SP1 and SA and SP2, that is, the two proposed situations can be used as substitutes for the current situation. As SP2 has the shortest pressing time (70 s), this could be chosen for effective replacement due to the shortest process time. To carry out the replacement of the application method, it would be necessary to carry out an entire study to adapt and improve the machinery, equipment and materials, in addition to evaluating the processing conditions to guarantee the greater efficiency of the new process.

A factor that had a strong influence on these results was the spread of the adhesive over the entire surface, resulting from the spray application. The current method, which contemplates the intermittent application by roller combined with the properties of the process and the adhesive, can contribute to the incorrect or insufficient application of the glue, resulting in the deficiency of the glue line, if the adhesive is applied in smaller quantities.

Authorship contributions

D. G. L.: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, writing - original draft, writing, review & edition, software. C. L. I.: Supervision, validation. W. H.: Visualization, funding acquisition.

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