

# EFFECT OF THE HEAT TREATMENT OF *Hovenia dulcis* Thunb. WOOD ON THE PRODUCTION OF EGP PANELS WITH DIFFERENT ADHESIVES

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## Resumo

*Efeito da termorretificação da madeira de Hovenia dulcis Thunb. Na produção de painéis egp com diferentes adesivos.* O objetivo deste trabalho foi analisar a resistência ao cisalhamento de painéis colados lateralmente (EGP) fabricados a partir da madeira de *H. dulcis* Thunb. modificados termicamente pelo processo VAP HolzSysteme®. Primeiramente as amostras de *Hovenia dulcis* foram termorretificadas pelo processo VAP HolzSysteme®, em seguida foram coladas com adesivos Resorcinol-formaldeído (RF), Melamina-uréia-formaldeído (MUF), Emulsão polimérica de isocianato (EPI) e Polivinilacetato (PVAc) e submetidas a pré-tratamentos para ambiente seco, úmido e externo e sem pré-tratamento para avaliar a resistência ao cisalhamento, 5º percentil e falha na madeira. Observou-se queda na resistência ao cisalhamento da madeira de *H. dulcis* termorretificada para todos os adesivos. Todos os adesivos obtiveram resultados superiores ao mínimo exigido pela norma EN13354(2009) para a madeira sem pré-tratamento tanto para a madeira sem termorretificação como para a madeira termorretificada, podendo ser utilizados para fins não estruturais. No entanto, para ambiente externo (três ciclos) somente o adesivo MUF obteve valor que atendesse aos padrões mínimos da norma, desta forma sugere-se para colagem de painel EGP de *H. dulcis* sem termorretificação e com termorretificação a utilização do adesivo MUF o qual obteve melhor performance oferecendo maior resistência em ambientes secos, úmidos e externos.

*Palavras-chave:* Uva-do-japão. Cisalhamento. VAP HolzSysteme®.

## Abstract

The objective of this work was to analyze the shear strength of edge-glued panels (EGP) made from the *H. dulcis* Thunb. wood thermally modified by the VAP HolzSysteme® process. Initially, the *Hovenia dulcis* samples were heat-annealed by the VAP HolzSysteme® process, and then bonded with Resorcinol-formaldehyde (RF), Melamine-urea-formaldehyde (MUF), Isocyanate Polymer Emulsion (EPI) and Polyvinylacetate (PVAc) and submitted to pre-treatments for dry, humid and external environment and without pre-treatment to evaluate the shear strength, 5th percentile and failure in the wood. It was observed a decrease in the shear strength of the thermorectified *H. dulcis* wood for all adhesives. All adhesives obtained results superior to the minimum required by the standard EN13354 (2009) for the wood without pre-treatment as for the wood without thermoregulation as well as for the heat treated wood, and may be used for non-structural purposes. However, for the external environment (three cycles) only the MUF adhesive obtained value that meets the minimum standards of the standard, in this way, it is suggested to glue the EGP of *H. dulcis* without thermortification and with thermorectification using the MUF adhesive, which has achieved better performance offering greater resistance in dry, wet and external environments.

*Keywords:* Uva-do-japão. Shearing. VAP HolzSysteme®.

## INTRODUCTION

Heat treatment is a process of modifying wood pieces from the application of heat to high temperatures, which may vary between 180 and 260°C; below 140°C, the modifications occurred are irrelevant and, above 260°, the treatment starts to compromise the integrity of the samples (HILL, 2006). According to Cademartori *et al.* (2012), after 200°C, changes in physical and mechanical properties become more significant.

The heat treatment processes are those that have evolved the most in commercial terms in recent years. The success is probably due to the low cost of treatment when compared to other modifications that are based on the use of chemical compounds that make the final product more expensive (ESTEVES AND PEREIRA, 2009).

According to Hill (2006), among all the wood modification processes, heat treatment has the most commercially advanced technology, which proposes improvements in dimensional stability by reducing hygroscopicity, improving resistance to biodeterioration and weathering, in addition to changing the color of the

material. Therefore, the heat treatment is able to improve the qualities of commercial wood, producing alternative products for use and production of materials resistant to external use.

Moura and Brito (2011) added that the heat treatment of wood species of less economic value is an excellent example of adding value. Another process that has been generating higher value-added products is the production of side-glued panels (BELLON *et al.*, 2014).

The side bonding panels are panels produced from a set of wooden battens glued laterally, with or without top bonding by finger-joint splices, and their adhesion is performed with the help of adhesives (TIENNE *et al.*, 2011). Its production allows the use of narrow and short pieces, with small or light defects, residues from sawmills and other forest-based industries, thus increasing the yield through the reuse of a material that was discarded or burned as biomass for energy generation (DANAWADE *et al.*, 2014).

Generally, these two processes are used: heat treatment and panels glued laterally, in common species in Brazilian reforestations (pinus and eucalyptus). However, to reduce dependencies on pine and eucalyptus wood, the forest-based sector has invested in research in the areas of silviculture and wood technology in search of alternative species of rapid growth for wood production (IWAKIRI *et al.*, 2012). Likewise, Trianoski *et al.* (2013) highlight the need for studies related to the use of alternative species, in order to increase the diversity and volume of raw material offered to the timber market.

Thus, the species *Hovenia dulcis* Thunberg (uva-do-japão), emerges as a new species for the timber market. The "uva-do-japão" has been used in silvopastoral, silviagropecuária systems and as hedges, and may be destined to the sawmill, with approximately 20 years (CARVALHO, 1994). Selle (2009) suggests *H. dulcis* as one of the species that presents desirable conditions and characteristics for industrial use, being wood with good characteristics for use in furniture, floors, walls and frames and, in rural areas, in the form of fence posts as well as energy due to its energy potential. However, due to little knowledge of its technological properties, its wood is generally used as firewood in small rural properties (CARPANEZZI, 2010).

In this context, it is necessary to verify the technological behavior of the side glued panels manufactured from *H. dulcis* wood submitted to the heat treatment process, to test its viability regarding the use in high value products (HVP). Therefore, the aim of the present study was to analyze the bonding quality of EGP (*Edge-Glued Panel*) panels produced with *Hovenia dulcis* Thunb. wood without heat treatment and thermorectified bonded with four different adhesives.

## MATERIAL AND METHODS

### Wood collection and processing

Five *Hovenia dulcis* trees, 20 years old, from Irati-PR, Brazil (25° 28' 02" S and 50° 39' 04" O) were used. After cutting, the wood was sawn and dried to 12% moisture. Then, it was sectioned into 20 pieces with dimensions of 25.40 x 101.00 x 1000.00 mm (thickness, width and length), in which 10 pieces were directed to the making of test pieces without heat treatment and 10 pieces for making of thermorectified test pieces.

### Wood heat treatment – VAP HolzSysteme® hygrothermal process

Ten pieces with dimensions of 25.40 x 101.00 x 1000.00 mm (thickness, width and length) were subjected to VAP HolzSysteme® heat treatment. This process consists of heating the material to 110°C and maintaining the temperature for 25 minutes, then the temperature increases to 155°C for 45 minutes and finally it cools down inside the equipment. The heat treatment process followed the company's methodology, represented in Figure 1.

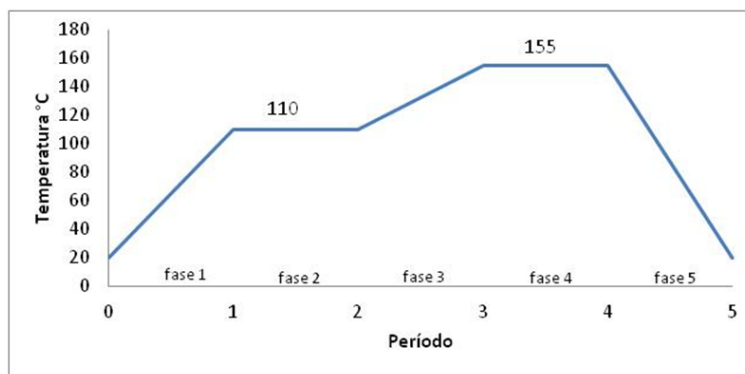


Figure 1. Program of VAP HolzSysteme® heat treatment process.

Figura 1. Programa do processo de termorreificação VAP HolzSysteme®.

## Wood processing and gluing

For the preparation of the shear specimens, samples of 25.00 x 60.00 x 310.00 mm (thickness, width and length, respectively) were produced from pieces of 25.40 x 101.00 x 1000.00 mm (thickness, width and length) of treated wood and treatment. Then, the samples were bonded with four adhesives: Polyvinyl Acetate Cross (PVAc), Emulsion Polymer Isocyanate (EPI), Melamine Urea Formaldehyde (MUF) and Resorcinol Formaldehyde (RF), all with weight and homogeneous distribution for the control of variables. The applied weight was 180 g/m<sup>2</sup> and after applying the adhesive, the battens were pressed with a manual press. The pressing time varied between the types of adhesive and followed the instructions of the manufacturer's technical bulletin, two hours for PVAc, one hour for EPI, eight hours for RF and five hours for MUF. After acclimatizing the glued joints, the specimens were made according to standard EN13354 (2009) for each adhesive within each wood treatment and pre-treatment as shown in Table 1.

Table 1. Experimental delimitation.  
Tabela 1. Delineamento experimental.

Treatment	Adhesive	Pressing time (hours)	Pre-treatment	No. of test pieces	
Wood without thermorectification	PVAc	2	Dry	10	
			Cold water	10	
	EPI	1	Dry	10	
			Cold water	10	
	RF	8	Dry	10	
			Cold water	10	
			Boiling 6h	10	
	MUF	5	Three cycles	10	
			Dry	10	
			Cold water	10	
	Thermorectified wood	PVAc	2	Boiling 6h	10
				Three cycles	10
EPI		1	Dry	10	
			Cold water	10	
RF		8	Dry	10	
			Cold water	10	
			Boiling 6h	10	
MUF		5	Three cycles	10	
			Dry	10	
			Cold water	10	
				Boiling 6h	10
				Three cycles	10
	Dry			10	

## Shear test pre-treatments

The samples were tested in simulation tests under extreme conditions, which seek to accelerate the process of deterioration of the adhesive joints (EN13354/2009 *Bondin quality – Test method*). In this way, the panels were classified based on the conditions of use (dry, humid or outdoor conditions), with pre-treatments determined for each class: without pre-treatment (dry shear), pre-treatment for dry environments (immersion in cold water), humid environments (boiling), external environments (three cycles).

In the condition without pre-treatment, the shear test was performed after the adhesive cured. The test pieces classified in dry environments were pre-treated, which consists of emerging them in water at a temperature of 20°C (± 3°C) for 24 hours and immediately after performing tests. The test pieces for humid environments were immersed in water, at boiling temperature for six hours. After this period, they were conditioned in cold water (20°C) for one hour and soon after the tests were performed.

The test pieces for external use were immersed in water at the boiling temperature for four hours, followed by drying in an oven at 60°C for 16 to 20 hours, returning to the boiling water for another four hours; and finally, one hour of cooling in water at 20°C (± 3°C) to immediately after performing the shear tests on the glue line.

The four adhesives (PVAc, EPI, RF and MUF) were used in the test without pre-treatment and in the test with pre-treatment in dry environments. Tests with wet pretreatment and external use were performed only with RF and MUF adhesives. The choice of each adhesive for each type of pre-treatment was based on the condition of use prescribed in the package insert for each adhesive.

### Shear strength test on the glue line

The tests were performed on the test pieces without heat treatment and thermorectified. The test pieces were submitted to the shear test on a universal EMIC testing machine, according to EN 13354 (2009). The results were compared with the minimum requirements established in the standard EN 13353 (2008) in which the glue line failure percentages and the lower 5th percentile were evaluated.

The wood failure was determined with the aid of a transparent checkered film placed over the shear bonded area. The glued area was visually divided into 10 rows x 10 columns, with each grid covering 1% of its surface during the evaluation. The parts that broke completely in the wood structure and not in the glue line received a maximum percentage of wood failure (100%).

### STATISTICAL ANALYSIS

The treatments were subjected to a test using a completely randomized design (CRD) with a 2x4 factorial arrangement scheme, two wood treatments (without thermal treatment and with thermal treatment) and four adhesives (PVAc, EPI, RF and MUF). First, the normality test was performed. Noting the normal data, the homogeneity of variances was tested by the Bartlett test and then applied to ANOVA to verify the existence or not of differences between the factors. If there was a statistical difference between the factors, the Tukey's average comparison test was applied at the 95% probability level. The programs used for the analyzes were Excel® 2007, Statgraphics Centurion XVII, and SISVAR 5.6.

### RESULTS

Table 2 contains the average values of maximum stress (MPa), wood failure (%) and the 5th lower percentile of resistance (MPa) of *Hovenia dulcis* without heat treatment and thermorectified without pre-treatment (dry) with the use of four different adhesives used for bonding the wood.

Table 2. Average results of the shear test on the glue line in the *Hovenia dulcis* wood performed after dry pre-treatment.

Tabela 2. Resultados médios do ensaio de cisalhamento na linha de cola na madeira *Hovenia dulcis* realizado após o pré-tratamento a seco.

Pre-treatment	Adhesive	Wood without thermorectification			Thermorectified Wood		
		Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)	Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)
Dry	PVAc	15.80 aA (0.69; 4.34)	40	15.07	8.65 bB (0.70; 8.10)	77	7.94
	EPI	12.96 bA (0.89; 6.88)	33	12.23	11.31 aB (1.05; 9.30)	90	10.14
	RF	10.55 cA (0.52; 4.93)	0	10.06	3.82 cB (0.43; 11.14)	25	3.40
	MUF	15.46 aA (0.89; 5.79)	49	14.58	11.31 aB (0.36; 3.19)	100	10.84
F				30,33*			

The averages followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test (5%). \* significant at the 5% probability level ( $01 = <p <0.05$ ). The values in parentheses correspond to the standard deviation and coefficient of variation (%), respectively.

According to Table 2, considering the specimens that did not receive heat treatment, without pre-treatment, it is observed that those made with the MUF and PVAc adhesive were statistically superior to the others, however for those that were heat-treated, MUF and EPI were superior. It may be noted that for both treatments the EGPs bonded with RF were statistically inferior to the others.

Table 3 shows the average values of maximum stress (MPa), wood failure (%) and the lower fifth percentile of resistance (MPa) of *Hovenia dulcis* without thermal treatment and with thermal treatment, for the pre-treatment with immersion in cold water (dry environments) with the use of four different adhesives used for bonding the wood.

Table 3. Average results of the shear test on the glue line in the *Hovenia dulcis* wood performed after immersion in cold water.

Tabela 3. Resultados médios do ensaio de cisalhamento na linha de cola na madeira *Hovenia dulcis* realizado após imersão em água fria.

Pre-treatment	Adhesive	Wood without thermorectification			Thermorectified Wood		
		Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)	Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)
Immersion in cold water	PVAc	4.91 bA (0.46; 9.32)	0	4.37	3.01 bcB (0.23; 7.49)	1	2.79
	EPI	9.74 aA (0.57; 5.83)	0	9.24	2.48 cB (0.10; 4.23)	3	2.35
	RF	10.52 aA (1.29; 12.26)	10	9.25	3.78 bB (0.46; 12.22)	14	3.19
	MUF	10.06 aA (0.28; 2.82)	20	9.71	7.89 aB (0.53; 6.67)	59	7.40
F		58.45*					

The averages followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test (5%). \* significant at the 5% probability level ( $01 = <p < 0.05$ ). The values in parentheses correspond to the standard deviation and coefficient of variation (%), respectively.

It is observed in Table 3, for the pretreatment in cold water for wood without thermal treatment, that the specimens made with the EPI, RF and MUF adhesives were statistically superior when compared to the PVAc adhesive; however, for heat-treated wood there was a significant difference between all adhesives, with MUF being the most resistant in the glue line (7.89 MPa) and EPI being the least resistant (2.48 MPa).

Table 4 shows the average values of maximum stress (MPa), wood failure (%) and the lower fifth percentile of resistance (MPa) of *Hovenia dulcis* without thermal treatment and with thermal treatment, for pre-treatment with boiling (humid environments) with the use of two different adhesives used for bonding the wood.

Table 4. Average results of the shear test on the glue line in *Hovenia dulcis* wood performed after boiling pre-treatment for RF and MUF adhesives.

Tabela 4. Resultados médios do ensaio de cisalhamento na linha de cola na madeira *Hovenia dulcis* realizado após o pré-tratamento em fervura para os adesivos RF e MUF.

Pre-treatment	Adhesive	Wood without thermorectification			Thermorectified Wood		
		Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)	Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)
Boiling	RF	8.31 aA (1.02; 12.27)	7	7.07	3.43 aB (0.41; 12.02)	47	3.03
	MUF	8.38 aA (0.84; 9.98)	22	7.55	4.3 aB (0.56; 13.05)	60	3.78
F		0.241 <sup>ns</sup>					

The averages followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test (5%). <sup>ns</sup> Not significant at the 5% probability level ( $01 = <p < 0.05$ ). The values in parentheses correspond to the standard deviation and coefficient of variation (%), respectively.

It may be seen in Table 4, in the pre-treatment with boiling (humid environments), that between the RF and MUF adhesives there was statistical equality both for wood without heat treatment and for thermorectified; however, within the same adhesive, between the treatments of wood without heat treatment and thermorectified

there was a significant difference, in which wood without Heat treatment was again more resistant to shear in the glue line.

Table 5 shows the average values of maximum stress (MPa), wood failure (%) and the 5th lower percentile of resistance (MPa) of *Hovenia dulcis* without heat treatment and thermorectified, for the pretreatment of three cycles (external environment) using two different adhesives used for bonding the wood.

Table 5. Average results of the shear test on the glue line in the *Hovenia dulcis* wood performed after the pretreatment in three cycles for RF and MUF adhesives.

Tabela 5. Resultados médios do ensaio de cisalhamento na linha de cola na madeira *Hovenia dulcis* realizado após o pré-tratamento em três ciclos para os adesivos RF e MUF.

Pre-treatment	Adhesive	Wood without thermorectification			Thermorectified Wood		
		Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)	Shear (MPa)	Wood failure (%)	5th low. perc. (MPa)
Three cycles	RF	3.69 bA (1.20; 32.41)	2	2.29	2.03 bB (0.43; 21.01)	23	1.50
	MUF	7.10 aA (0.89; 12.60)	10	6.21	3.31 aB (0.19; 5.82)	53	3.10
F				9.17*			

The averages followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test (5%). \* significant at the 5% probability level ( $01 = <p < 0.05$ ). The values in parentheses correspond to the standard deviation and coefficient of variation (%), respectively.

It may be seen in Table 5, in the pre-treatment three cycles for external environments that there was a statistically significant difference between the RF and MUF adhesives both for wood without heat treatment and for thermorectified wood and also within the same adhesive, between treatments of wood without Heat treatment and thermorectified, with the MUF adhesive on wood without Heat treatment with an average shear of 7.01 MPa.

## DISCUSSION

When analyzing each adhesive in the dry pretreatment in Table 2, it may be seen that, for all specimens tested without thermal treatment, they presented higher shear averages than the thermorectified ones. This fact probably happened due to the heat treatment exuding extracts for the wood surface, impairing the gluing efficiency and consequently the resistance to the shear test. Esteves and Pereira (2009) corroborate that the hygroscopic sites that absorb the humidity of the environment and increase the equilibrium humidity of the wood are also responsible for the chemical bond with the adhesive and, according to Carvalho *et al.* (2015), the decomposition of these sites hinders the mechanical bonding of the adhesive with the wood, reducing the shear strength after heat treatments with higher temperatures.

Iwakiri *et al.* (2013), in a study using *Eucalyptus benthamii* and PVAc adhesive, obtained values of 9.04 MPa for the shear strength, being lower than the present study in comparison with wood without thermal treatment and superior when compared with thermorectified wood. Plaster *et al.* (2012), using *Eucalyptus urograndis* wood and the PVAc and RF adhesives, found a lower performance for the shear strength in the glue line (11.33 MPa) with the use of PVAc when compared with *H. dulcis* wood without thermal treatment and higher when compared with the thermorectified *H. dulcis* wood.

Marchesan *et al.* (2018) in a study on the production of EGP with the *H. dulcis* wood, found shear values in the dry pretreatment for the PVAc and EPI adhesives of 6.33 and 12.60 MPa, respectively. It is noted that the PVAc adhesive showed a lower value than that found in the present study, while the EPI showed a similar value. The difference in the resistance values obtained for the same species and the same adhesive, may be related to the wood moisture, adhesive viscosity, glue line failure, among other factors.

Still with regard to dry pretreatment (Table 2), studies were found that showed similar results to those found in this research. Vital *et al.* (2006) found, for *E. saligna* and *E. grandis* wood glued with PVAc, shear strength values of 10.24 and 9.12 MPa, respectively. Iwakiri *et al.* (2013) found for *Eucalyptus benthamii* wood glued with PVAc, average shear value of 9.04 MPa.

Regarding wood failure, the standard EN 13353 (2003) establishes a minimum percentage of 40%. Thus, it may be seen in Table 2 that the wood without thermal treatment in the dry pre-treatment showed values according

to the standard for PVAc and MUF adhesives of 40% and 49% respectively, while for the EPI and RF adhesives, the wood failure values were lower than the stipulated by the standard (33 and 0% respectively).

For heat-treated wood in the dry pre-treatment, PVAc, EPI and MUF adhesives were in accordance with the standard (77, 90 and 100% respectively). The RF adhesive was found to be below the stipulated value of 40% of wood failure (25%). The MUF adhesive was the most efficient in relation to the strength of the glue line, both in untreated *H. dulcis* wood (49% wood failure) and in heat treated wood (100% wood failure).

Iwakiri (2016) also obtained better values for the MUF adhesive. However, it is clear that there is a wide range of variation in the results obtained for the wood failure in the present study, a fact that corroborates with studies performed by other authors such as Plaster *et al.* (2008) and Bila *et al.* (2016).

According to Bila *et al.* (2016), generally when the percentage of wood failure varies between 0-25% the result suggests low adhesive resistance and/or deficiency in the bonding process such as smooth surface, low applied weight, high surface humidity, among others; between 50-70% suggests a more adequate situation of the gluing process and properties of the adhesive and between 75% and 100%, stronger adhesion properties are found.

The conditions without thermal treatment, in the dry pre-treatment showed a higher maximum stress and less failure in the wood compared to the thermorectified wood. According to Esteves; Pereira (2009) and Kacikova *et al.* (2013) the heat treatment reduces the resistance of the wood due to the degradation of carbohydrates, however, the resistance of the adhesive remains the same, that is, it may increase or maintain the percentage of wood failure in conditions with heat treatment, a fact that was proven in the present work.

For the 5th lower percentile in which the standard EN 13353 (2003) establishes a minimum value of 2.5 MPa, Table 2 also shows that all adhesives in the dry pre-test for non-heat treated and thermorectified wood were within the value stipulated by the standard. In addition, it may be highlighted that the treatments without heat treatment showed higher values than those certified, when analyzing the same adhesive in the dry pre-treatment.

When comparing the two treatments (without heat treatment and with thermorectification) presented in Table 3 for pre-treatment in a dry environment, it is observed that again all adhesives applied to the wood without treatment were statistically superior to the wood with thermorectification.

Iwakiri *et al.* (2015) in a study on the resistance evaluation of joints bonded from the *Cryptomeria japonica* and *Sequoia sempervirens* woods with PVA and EPI adhesives in the pre-treatment in cold water immersion, obtained higher shear values than those of *H. dulcis* wood without heat treatment for the PVAc adhesive of 8.32 MPa for *C. japonica* and 9.35 MPa for *S. sempervirens*. For the EPI adhesive, the values may be considered close, 9.63 MPa for *C. japonica* and 10.39 MPa for *S. sempervirens*. In the case of thermorectified *H. dulcis* wood, both adhesives showed lower shear values than those presented by the authors.

For the result of wood failure, it is also observed in Table 3 that only the MUF adhesive used in the thermorectified wood was within the stipulated by the standard EN 13353 (2003) with an average of 59%. The others presented values well below the norm indicating that there were failures in the glue line, suggesting that the pre-treatment in cold water contributed to the degradation of the adhesives. Iwakiri *et al.* (2015) observed that the adhesive obtained better results from wood failures, a fact that did not occur in the present study. Iwakiri *et al.* (2016) and Bila (2016) also obtained values below 40% for the pretreatment in cold water immersion, confirming the results of the present study.

In relation to the lower 5th percentile (minimum value of 2.5 MPa), it is noted in Table 3 that only the EPI adhesive on the heat-treated wood was below that required by the standard EN 13353 (2003), the others were found above 2.5 MPa in the two treatments of the *H. dulcis*.

Iwakiri *et al.* (2015) found higher values of the 5th percentile for both species (*Cryptomeria japonica* and *Sequoia sempervirens*) and for the two adhesives studied (PVAc and EPI).

Following the parameter of side bonding quality, it may be said that in general the *H. dulcis* Thunb. wood, without heat treatment or thermorectified, presented satisfactory results with the tested adhesives, both without pre-treatment and in a dry environment (immersion in cold water). However, the EPI adhesive obtained a 5th percentile below the value determined by the standard for thermorectified wood.

According to Iwakiri *et al.* (2016) the shear tests of glued joints after wet pre-treatment (TABLE 4) are little performed as standard procedures for assessing the quality of glue. In a study performed with the species *Dinizia excelsa* Ducke and *Protium puncticulatum* J. F. Macbr using the PVAc, EPI and MUF adhesives, obtained lower average shear values than those found in this study in the wet pre-treatment for *H. Dulcis* wood without thermorectification, being 5.04 MPa for PVAc D3 adhesive, 3.18 MPa for PVAc D4, 3.62 MPa for EPI adhesive and 2.08 MPa for MUF adhesive. However, when compared to the values found for the *H. dulcis* thermorectified wood, the PVAc and EPI adhesives are close and the MUF is lower than the present study.

It is also noted in Table 4 that only the thermorectified wood was within the required by the standard for the wood failure value (40%) for the two adhesives. The wood without heat treatment had a wood failure of less than 40%, indicating that there were failures in the glue line, also suggesting that the boiling pretreatment for humid environments contributed to the degradation of the RF and MUF adhesives. Regarding the lower 5th

percentile, both the RF adhesive and the MUF in the two treatments of *H. dulcis* wood were approved with values above 2.5 MPa. The wood without heat treatment is highlighted with the MUF adhesive with 7.55 MPa.

Iwakiri *et al.* (2016) found in a study with *Dinizia excelsa* Ducke and *Protium puncticulatum* J. F. Macbr average values for the MUF of 1.24 MPa of 5° and 0% of wood failure, lower than those found in this study for the same adhesive in the wet pre-treatment.

Lima *et al.* (2008), using the RF adhesive, found a percentage of wood failure percentage of 61.23% in the wood of eucalyptus clones, higher than the average found for the same adhesive in the two wood treatments of *H. dulcis* (7 and 47%, respectively).

Table 5 shows that only the thermorectified wood glued with the MUF adhesive was within the standard required for the wood failure value (40%) with 53%, showing that there were flaws in the glue line and that the boiling pretreatment for outdoor environments contributed to the degradation of RF and MUF adhesives.

Regarding the lower 5th percentile, only the MUF adhesive in the two treatments of *H. dulcis* wood was approved with values above 2.5 MPa. Once again, the wood without heat treatment stood out with an average of 6.61 MPa.

## CONCLUSION

- The use of *H. dulcis* wood in the production of EGP panels is feasible, as it obtained results of resistance and failure in the wood accepted by the standard EN13354 (2009).
- It was possible to observe a decrease in the mechanical resistance of the wood to shear in the glue line with the use of thermally modified *H. dulcis* wood, also presenting a higher percentage of wood failure when compared to wood without thermal treatment.
- PVAc, EPI, RF and MUF adhesives obtained results higher than the minimum required by the standard EN13354 (2009) on wood without heat treatment and thermorectified, both without pre-treatment, and may be used for non-structural purposes.
- For dry environments (pre-treatment in immersion in cold water) only the EPI adhesive was below the standard EN13354 (2009) for *H. dulcis* thermorectified wood.
- For the pre-treatment of humid environments (boiling), both the RF and the MUF adhesive, in both treatments of *H. dulcis* wood, obtained values above the stipulated by the norm for the 5th percentile.
- In external conditions, only the MUF adhesive showed an adequate value for the standard for the 5th percentile in the two treatments of *H. dulcis* wood.
- It is suggested to glue the *H. dulcis* EGP panel, both without heat treatment and thermorectified, the use of MUF adhesive which obtained better performance offering greater resistance in dry, humid and external environments.

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