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BONDING QUALITY OF *Melia azedarach* WOOD FOR THE PRODUCTION OF EDGE GLUED PANELS

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Resumo

Qualidade de colagem da madeira de Melia azedarach para a produção de painéis colados lateralmente. *Melia azedarach* é uma espécie nativa da Asia que apresentou boa adaptação edafoclimatica no Brasil. Seu rápido crescimento associado a qualidade da madeira, tornam esta espécie uma excelente opção para plantios florestais, contribuindo para a geração de matéria prima para indústria de base florestal e para novos produtos. Neste contexto, o objetivo desta pesquisa foi avaliar a qualidade de colagem da madeira de *Melia azedarach* para a produção de paineis colados lateralmente. A madeira utilizada é proveniente de um plantio florestal localizado em Corupá - SC. Das árvores coletadas foram obtidas amostras para determinação de propriedades físico-químicas e para a avaliação da qualidade de colagem lateral. A colagem foi realizada com os adesivos acetato de polivinila (PVA) e emulsão polimérica de isocianato (EPI), em cinco gramaturas (140, 160, 180, 200 e 220 g/m^2), sob pressão de 7 kgf/cm^2, e em temperatura ambiente por uma hora. A avaliação das juntas coladas seguiu os procedimentos das normas EN 13353 e EN 13354. A análise estatística adotada foi um delineamento em arranjo fatorial (2x5: adesivo x gramatura). Como testemunha foi utilizada a madeira de *Pinus taeda* colada conforme parâmetros industriais. Os resultados das propriedades físico-químicas mostraram-se adequadas para painéis colados lateralmente, o adesivo emulsão polimérica de isocianato apresentou melhor performance quando comparado ao adesivo acetato de polivinila no ensaio úmido, e a gramatura não apresentou efeito significativo, podendo-se recomendar a gramatura de 140 g/m^2. Conclui-se que a madeira de *Melia azedarach*, no contexto avaliado apresenta características físicas e químicas que permitem seu emprego como matéria-prima para a produção de painéis colados lateralmente.
Palavras-chave: Cinamomo, colagem da madeira, painéis EGP, adesivos para madeira.

Abstract

Bonding Quality of Melia azedarach Wood for the Production of Edge Glued Panels. Melia azedarach, a species native to Asia, has demonstrated good soil and climate adaptation in Brazil. Its rapid growth, coupled with the quality of its wood, makes it an excellent option for forest plantations, contributing to the generation of raw material for the forest-based industry and new products. In this context, the aim of this research was to evaluate the bonding quality of *Melia azedarach* wood for the production of edge-glued panels. The wood used was sourced from a forest plantation in Corupá, Santa Catarina. Samples were obtained from harvested trees to determine their physical-chemical properties and assess the bonding quality. Bonding was performed using polyvinyl acetate (PVA) and isocyanate polymer emulsion adhesives, at five application rates (140, 160, 180, 200, 220 g/m²), under a pressure of 7 kgf/cm², and at ambient temperature for 1 hour. The evaluation of the glued joints followed the procedures outlined in the EN 13353 and EN 13354 standards. A factorial design (2x5) was adopted for statistical analysis. *Pinus taeda* wood, glued according to industrial parameters, was used as a control. The results of the physical-chemical analysis showed that the wood is suitable for edge-glued panels. The isocyanate polymer emulsion adhesive performed better than the polyvinyl acetate in the wet test. The grammage did not have a significant effect, and a grammage of 140 g/m² can be recommended. In conclusion, *Melia azedarach* wood has potential for use as a raw material in the production of edge-glued panels.
Keywords: Cinamomo, wood bonding, EGP, wood adhesives.

INTRODUCTION

The species Melia azedarach belongs to the family Meliaceae, is native to Asia, and is widely distributed in China (SIVARAJ *et al.*, 2018; FENG *et al.*, 2022), and in other parts of the world such as the Middle East, Africa, the Americas, the Caribbean, and many islands of the Pacific region.

It is a fast-growing and high-quality species, also a good nectar plant and a botanical pesticide (HAN *et al.*, 2022). Its roots, bark, flowers, and fruits are of high medicinal value, being extensively employed in traditional folk medicine, and their pharmacological properties involve anticancer, antiviral, antimalarial, antibacterial, and antifeedant activities (TAN *et al.*, 2010).

From an economic standpoint, Melia azedarach has economic and industrial importance, including global significance (FENG *et al.*, 2022; MOHAPATRA *et al.*, 2024). Chen *et al.* (2014) report the good attributes of its wood, which is applied for multiple uses, such as construction, agricultural tools, boats, vehicles, and the manufacture of musical instruments, and Han *et al.* (2022) add that, due to its resemblance to mahogany, it is used for furniture.

The rapid growth associated with wood quality make Melia azedarach an excellent option for forest plantations in Brazilian territory. According to Vivan *et al.* (2005), this species showed a high degree of climatic adaptation in the South, being able to contribute to the supply of raw material for the numerous forest-based industries established in this region and justifying investment in forest plantations.

Among the various forest-based industries, the reconstituted panel industry stands out, producing plywood, MDP, MDF, OSB, EGP, among others. EGP panels are panels composed of sawn wood slats joined by lateral bonding, which may or may not be joined at the top by finger joints (IWAKIRI *et al.*, 2021). Their main advantages include the reuse of sawmill processing residues, such as slabs and non-conforming pieces, which would otherwise be discarded or used for energy generation; the use of small-diameter logs, including those from thinning operations; the increase in industrial yield by using narrow or short pieces that would be discarded; improved dimensional stability; good mechanical resistance; flexibility in the final product size with a wide range of dimensions; relatively low equipment costs and a simpler and more easily controlled production process, compared to other reconstituted panel industries (TRIANOSKI; IWAKIRI, 2020). The main application of this type of panel is in the furniture industry (LANHE *et al.*, 2024).

In the production of EGP panels, several factors can affect the quality of the final product, namely the wood species and its characteristics or properties, wood preparation for bonding, moisture content, pressing parameters, adhesive type and spread rate, among others (FRANÇA *et al.*, 2020).

The most commonly used adhesives in EGP panel production are polyvinyl acetate (PVA) and polymeric isocyanate emulsion (EPI) (ROJAS *et al.*, 2020; TRIANOSKI; IWAKIRI, 2020). PVA is an adhesive resulting from the polymerization of vinyl acetate, and presents high mechanical resistance of products bonded with it in dry environments, however, limitations of use in environments with high temperatures and relative humidity (PIZZI, 2018). The EPI adhesive, in turn, is composed of a polyvinyl acetate base and a polymeric isocyanate, whose function is to catalyze the curing of the adhesive, which occurs through the reaction of isocyanate groups with the hydroxyl groups of wood, allowing high resistance to water and temperature, good stability, rapid curing, but presents as a disadvantage a higher cost (FRIHART; HUNT, 2021).

During the application of adhesives to the slats for EGP panel production, the spread rate must be controlled, which according to manufacturers ranges between 180 to 220 g/m2. Very low spread rates can lead to low resistance due to insufficient adhesion and anchoring. Conversely, with high spread rates, excess adhesive may leak through the panel edges, resulting in economic losses (MARRA, 1992).

In this context, when evaluating a new species for application in EGP panels, studies must be conducted in order to develop a product that conforms to the normative requirements of the consumer market or with adequate properties, as well as to maximize the production process in a way that generates a conforming panel at the lowest possible cost. Thus, considering the scarcity of studies on this species and the technology of its use, the objective of this study is to evaluate the bonding quality of Melia azedarach wood for the production of edge glued panels (EGP).

MATERIAL AND METHODS

For the development of this research, *Melia azedarach* (Cinamomo) wood from experimental plantations aged 18.5 years, located in the Corupá region – SC (26º23'19.32''W, 49º16'50.74''S) at an altitude of 68 m, mesothermic climate, mean annual temperature of 22ºC and precipitation of 2,200 mm.

Five trees were selected, felled, and sectioned according to commercial height, obtaining samples at relative positions of 0%, 25%, 50%, 75%, and 100% of the stem for the evaluation of physical and chemical properties, and logs at these intervals. Basic density was determined according to the procedures of the COPANT 461/1972 standard. The chemical properties evaluated were total extractives (TAPPI 204:2017), pH (TAPPI 252:2022), and inorganic materials (TAPPI 211:2022).

The logs were sawn into planks, which underwent natural drying and were subsequently cut into boards. The boards were conditioned until reaching equilibrium moisture content in a climate chamber with controlled environmental conditions (20±2 °C and 65±5% RH), and then converted into slats with dimensions of 310x60x25 mm. The slats had their apparent density determined by the stereometric method, and were then paired in order to ensure that each treatment had similar conditions to each other, thus eliminating any effect arising from wood variability.

The bonding quality of *Melia azedarach* wood for interior or dry uses was evaluated through lateral bonding using Polyvinyl Acetate (PVA) class D3 and Polymeric Isocyanate Emulsion (EPI) adhesives, combined at five spread rates, 140, 160, 180, 200, and 220 g/m², with 3 replicates per treatment, according to the experimental design presented in Table 1, totaling 10 treatments. For each treatment, 30 test specimens were obtained.

Table 1. Experimental design of edge bonding quality of *Melia azedarach* wood.
Tabela 1. Delineamento experimental da qualidade de colagem lateral da madeira de *Melia azedarach.*

Treatment	**Adhesive**	**Grammage (g/m²)**
1 - *Melia azedarach/*PVA/140	PVA	140
2 - *Melia azedarach/*PVA/160	PVA	160
3 - *Melia azedarach/*PVA/180	PVA	180
4 - *Melia azedarach/*PVA/200	PVA	200
5 - *Melia azedarach/*PVA/220	PVA	220
6 - *Melia azedarach/*EPI/140	EPI	140
7 - *Melia azedarach/*EPI/160	EPI	160
8 - *Melia azedarach/*EPI/180	EPI	180
9 - *Melia azedarach/*EPI/200	EPI	200
10 - *Melia azedarach/*EPI/220	EPI	220
11 - *Pinus taeda/*PVA/180	PVA	180

PVA: Polyvinyl Acetate; EPI: Polymeric Isocyanate Emulsion.

The adhesives were applied with a foam roller in a single glue line and each spread rate was controlled with a precision balance. After adhesive application, the joints were pressed in a manual press with a pressure of 7 kgf/cm², which was calibrated and controlled with a digital load cell and torque wrench. The pressing time was 1 hour for both adhesives, as recommended by the manufacturers, and the environmental conditions of the pressing environment were 18 to 20ºC and relative humidity of 70/75%.

As a reference parameter (control), a treatment was produced with *Pinus taeda* wood, which followed the standard industrial bonding conditions for this species, being bonded with PVA adhesive at a spread rate of 180 g/m², pressure of 7 kgf/cm² and a pressing time of 1 hour.

After complete curing of the adhesive and conditioning, the lateral bonding joints were sectioned to produce the test specimens. Bonding quality was evaluated based on the glue line shear resistance test and followed the methodology recommended by standard EN 13354 (2009) with the pre-treatment indicated for panels of the SWP/1 type (*Solid Wood Panel* 1), whose use is in dry conditions, and consisted of immersing the samples for 24h in water at a temperature of 20±3°C, in addition to the dry test, performed as a control. For each test condition, 15 test specimens were used.

The results were subjected to statistical analysis through outlier, normality, and variance homogeneity tests, analysis of variance in a factorial arrangement (2x5: 2 adhesives x 5 spread rates), and Tukey mean comparison, all at 95% confidence level using the Statgraphics XVII software. The bonding performance results of *Melia azedarach* wood were compared with the normative requirements of the EN 13353 (2022) standards, and with the control treatment produced with *Pinus taeda*.

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RESULTS

Wood properties

Table 2 presents the mean results of the physicochemical properties of *Melia azedarach*.

Table 2. Average results of the physical-chemical properties of *Melia azedarach* wood.
Tabela 2. Resultados médios das propriedades físico-químicas da madeira de *Melia azedarach.*

Properties	Average values
Basic density (g/cm^3)	0.488 (4.05)
Apparent density (g/cm^3)	0.567 (6.09)
Total extractives (%)	4.41 (0.87)
pH	5.50 (0.46)
Inorganic materials (%)	0.52 (0.31)

Values in parentheses represent the coefficient of variation (%) of the samples.

Lateral bonding quality

Table 3 shows the mean results of bonding quality based on the glue line shear resistance test of *Melia azedarach* wood, as well as of the control treatment produced with *Pinus taeda.*

Table 3. Average results of bonding quality of *Melia azedarach* wood (Interactions).
Tabela 3. Resultados médios da qualidade de colagem da madeira de *Melia azedarach* (Interações).

Treatment	Dry			Wet		
	Shear (N/mm^2)	Failure (%)	5th LP (N/mm^2)	Shear (N/mm^2)	Failure (%)	5th LP (N/mm^2)
1 - *Melia azedarach*/PVA/140	10.45 abc (14.92)	78	8.16	6.52 bc (17.12)	1	4.83
2 - *Melia azedarach*/PVA/160	10.84 ab (14.05)	91	8.62	5.93 c (16.51)	1	4.35
3 - *Melia azedarach*/PVA/180	11.39 a (11.22)	79	9.00	6.64 b (16.69)	0	4.99
4 - *Melia azedarach*/PVA/200	9.12 c (13.86)	71	6.95	5.46 c (20.86)	1	4.02
5 - *Melia azedarach*/PVA/220	10.35 abc (13.64)	53	8.30	5.95 c (20.98)	0	4.23
6 - *Melia azedarach*/EPI/140	9.48 bc (16.74)	79	6.78	8.83 a (11.24)	19	7.60
7 - *Melia azedarach*/EPI/160	9.85 abc (11.32)	83	8.30	8.14 a (15.51)	10	6.18
8 - *Melia azedarach*/EPI/180	10.44 abc (11.21)	94	8.85	7.90 a (21.24)	4	5.33
9 - *Melia azedarach*/EPI/200	10.27 abc (13.62)	99	8.33	7.81 a (9.49)	7	6.82
10 - *Melia azedarach*/EPI/220	9.71 abc (13.64)	93	5.00	8.11 a (11.83)	17	6.69
p-value	0.0010			0.0000		
11 - *Pinus taeda*/PVA/180	8.09 (20.31)	83	2.67	1.96 (34.21)	0	1.28

5th LP: 5th lower percentile; Means followed by the same letter within the same column, are statistically equal by the Tukey Test at 95% confidence level; Values in parentheses indicate the coefficient of variation in percentage.

The statistical analysis indicated a significant difference for both the dry and wet tests. In the dry test, the treatment *Melia azedarach/*PVA/180 stood out, being statistically superior to the treatments *Melia azedarach/*EPI/140 and *Melia azedarach/*PVA/200. In the wet condition, the treatments bonded with the EPI adhesive, regardless of the spread rate, were statistically superior in relation to the treatments bonded with the PVA adhesive. High wood failure values were observed in the dry test, but, in contrast, the values decreased in the wet test.

Table 4 presents the results of the effect of the factors adhesive type and spread rate on the bonding quality of *Melia azedarach*.

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Table 4. Effect of adhesive and grammage factors on the bonding quality of *Melia azedarach* wood.
Tabela 4. Efeito dos fatores adesivo e gramatura sobre a qualidade de colagem da madeira de *Melia azedarach*.

Tratamento	Dry			Wet		
	Shear (N/mm^2)	Failure (%)	5^{th} LP (N/mm^2)	Shear (N/mm^2)	Failure (%)	5^{th} LP (N/mm^2)
Adhesive						
PVA	10.43 a (15.77)	76	7.82	6.07 b (18.91)	0	4.07
EPI	9.96 a (13.01)	90	6.48	8.14 a (14.75)	11	6.10
p-value	0.0598			0.0000		
Grammage						
140	9.97 ab (16.28)	79	7.46	7.67 a (20.42)	10	5.41
160	10.35 ab (13.56)	87	8.03	7.03 a (22.45)	5	4.85
180	10.92 a (13.97)	87	8.76	7.17 a (21.90)	2	5.31
200	9.70 b (14.77)	85	7.13	6.63 a (22.26)	4	4.11
220	10.08 ab (14.77)	73	5.51	7.06 a (21.85)	8	4.47
p-value	0.0203			0.1448		

5th LP: 5th Lower Percentile; Means followed by the same letter in the same column. per variable. are statistically equal by the Tukey Test at 95% confidence level; Values in parentheses indicate the coefficient of variation in percentage.

No significant statistical difference was found in dry shear resistance when the adhesive type was evaluated as the study variable, however, for the wet test, the EPI adhesive proved to be statistically superior in relation to PVA. For the spread rate variable, and in the dry condition, only the spread rates of 180 and 200 g/m^2 showed significant statistical differences between them, with the former being superior to the latter. In the wet test, all spread rates proved to be statistically equal.

DISCUSSION

Wood properties

The wood density of *Melia azedarach* is classified as low to medium, falling within the range below 0.550 g/cm^3 (low for basic density) and from 0.550 g/cm^3 to 0.720 g/cm^3 (medium for apparent density). Low-density woods are more porous and permeable, consequently facilitating adhesive mobility within their structure, allowing greater anchoring and not requiring the application of high pressure during pressing. On the other hand, woods with this characteristic tend to cause excessive adhesive absorption, resulting in a starved and fragile glue line, and consequently poor bonding quality (MARRA, 1992; FRIHART; HUNT, 2021; TRIANOSKI; IWAKIRI, 2020). Thus, to avoid this problem, adhesives with adequate viscosity must be used.

Regarding the chemical properties, the values of total extractives (4.41%) and pH (5.50) proved to be adequate and in accordance with the variation range described in the literature, indicating the absence of probable problems or negative interactions between adhesive and wood. According to Marra (1992), when these chemical components are elevated or outside the standard range, inhibition of the chemical polymerization reactions of the adhesive may occur, impeding fluidity, wettability, and absorption, thus impairing the development of adequate resistance and cohesion of the glue line. Beyond bonding, extractives may be released at different processing stages, for example, during the machining of slats, extractives may adhere to the cutting tool, hindering planing and the milling of finger joints, and may also alter or compromise the use of paints and varnishes in the final finishing.

Regarding the inorganic material content, the obtained value (0.52%) is low and consistent with the literature. Low proportions are desirable for the production of EGP's because these components consist of minerals, which cause wear of cutting tools during the preparation of slats for bonding and during panel planing, as well as of the abrasives (sandpapers) used in the surface finishing (TRIANOSKI; IWAKIRI, 2020).

Bonding quality

The bonding quality results of *Melia azedarach* wood in the dry test showed good performance for both adhesives, with all treatments in this condition meeting the minimum shear resistance requirement of 2.5 N/mm^2 for the 5th lower percentile, and minimum wood failure of 40% for species with density up to 0.60 g/cm^3, as required by standard EN 13353 (2022). Regarding the tests carried out in the wet condition, all treatments achieved the minimum resistance requirement for the 5th lower percentile (2.5 N/mm^2), whose values ranged from 5.46 to

8.83 N/mm^2, however, none of the treatments showed wood failure above 40%. The low wood failure values obtained in the wet test may reflect possible deficiencies in the bonding process, such as high surface moisture, contaminated surface, and adequate adhesive mobility within the wood structure.

In comparison with the control treatment, produced with *Pinus taeda* wood and bonded with PVA adhesive at a spread rate of 180 g/m^2, it can be observed that in the dry test, the results were similar for shear resistance and wood failure, and lower for the 5th lower percentile. In the wet test, the control presented mean results considerably lower than the treatments produced with *Melia azedarach*, including results that did not meet the minimum requirements for the 5th lower percentile and wood failure prescribed by standard EN 13353 (2022).

Regarding the main effect of adhesive type, the better performance of EPI compared to PVA, especially in the wet test, is associated with the chemical composition, which, according to Almeida *et al.* (2017) plays a fundamental role in hydrolysis resistance. The PVA adhesive results from the polymerization of vinyl acetate in aqueous dispersion, and products bonded with this adhesive present high resistance in dry environments, but great limitations of use in humid environments (PIZZI, 2018; FRIHART; HUNT, 2021), degrading easily under temperature and/or humidity conditions (CLAUB *et al.*, 2011; ALMEIDA *et al.*, 2017). The EPI adhesive, in turn, despite also containing polyvinyl acetate in its composition, includes a polymeric isocyanate (diphenylmethane diisocyanate), which is added as a catalyst and functions to catalyze the adhesive curing reaction that occurs through the reaction of isocyanate groups with the wood hydroxyl groups (SELLERS, 1994). As a result, it develops greater resistance to temperature, water, and solvents compared to PVA (FRIHART; HUNT, 2021), however, as a disadvantage, it has a higher cost.

Regarding the spread rate factor, no increase in resistance or bonding quality was evidenced with the increase of this variable, and the shear resistance and 5th lower percentile results were similar among the spread rates studied. This result can be considered quite interesting, since a lower adhesive spread rate during panel manufacturing leads to savings in this input, which normally presents a high cost in the production process. Furthermore, and corroborating the statements of Marra (1992) and Lanhe *et al.* (2024), a lower adhesive spread rate can result in a shorter pressing time, since there is a smaller quantity of water and/or solvents to be evaporated from the glue line. The savings in production cost as a function of adhesive quantity can be enhanced especially when this step is carried out in high-frequency presses and the elimination of these solvents occurs through the use of energy.

CONCLUSION

The development of this research allows the following conclusions to be established:

- *Melia azedarach* wood presents adequate physicochemical properties to be used as raw material in the production of edge-glued panels (EGP).
- The adhesive that showed the best bonding quality performance was the Polymeric Isocyanate Emulsion (EPI), however, both EPI and PVA presented high shear resistance values and 5th lower percentile values, meeting the minimum requirement of 2.5 N/mm^2 required by the European standard.
- No significant effect of the spread rate increase on the improvement of bonding quality was observed, therefore, to reduce adhesive cost, a spread rate of 140 g/m^2.
- *Melia azedarach*, under the technical conditions, limitations, and industrial contexts evaluated in this study, demonstrated physical and chemical characteristics that allow its use as raw material in the production of edge glued panels, as per the results obtained in the tests performed.

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