Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Bonding quality of plywood with Cupressus lusitanica Mill. Wood

Qualidade da colagem de painéis compensados com a madeira de Cupressus lusitanica Mill. Wood

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Submission: February 15, 2024 | Acceptance: February 3, 2025

ABSTRACT

The state of Santa Catarina occupies a prominent position in national exports of coniferous plywood and whose production is highly dependent on pine wood. With a view to expanding the possibilities of including new raw materials in this segment, the study aimed to evaluate the quality of gluing plywoods made with *C. lusitanica* wood veneers and its combination with *P. taeda* wood and compare performance with panels composed only of *P. taeda* and with the requirements stipulated for Pine plywood by the National Wood Quality Program (PNQM). Panels with 17 mm thick, glued with phenolic resin at a amount of adhesive of 328 g/m², consolidated in a press at a temperature of 135 ºC and specific pressure of 12 kgf/cm² were evaluated for the quality of the bondline upper, central and lower by the shear strength test after basic and additional pre-treatments for gluing classes 2 and 3. It was observed that the raw material did not influence the average shear stress of the plywoods produced and the quality of the gluing between the gluelines, and attended the average shear resistance for pine plywoods with similar characteristics by PNQM, with the exception of panels resulting from the mix of the species *C. lusitanica* and the species *P. taeda*, after pre-treatment “BDB”. The use of *C. lusitanica* wood resulted in pannels with gluing quality equivalent to that obtained for *P. taeda* panels and could be an option to be introduced in the plywood panel segment, without the need to adapt to the already consolidated manufacturing process for the plywoods of *P. taeda*.
KEYWORDS: Shear strength. Bondline. Alternative species. Conifer.

RESUMO

O estado de Santa Catarina ocupa uma posição de destaque nas exportações nacionais de compensado de coníferas e cuja produção é altamente dependente da madeira de pinus. Com vistas a ampliar as possibilidades de inclusão de novas matérias-primas nesse segmento, o estudo teve como objetivo avaliar a qualidade da colagem de painéis compensados confeccionados com lâminas da madeira de *C. lusitanica* e combinação desta com a madeira de *P. taeda* e comparar o desempenho com painéis compostos apenas desta última e com os requisitos estipulados para compensado de Pinus pelo Programa Nacional de Qualidade da Madeira (PNQM). Os painéis com 17 mm de espessura, colados com resina fenólica na gramatura de 328 g/m², consolidados em prensa à temperatura de 135 ºC e pressão específica de 12 kgf/cm² foram avaliados quanto à qualidade da colagem das linhas de cola superior, central e inferior pelo ensaio de resistência ao cisalhamento após pré-tratamentos básico e adicional para classes de colagem 2 e 3. Observou-se que a matéria-prima utilizada não promoveu influência na tensão média ao cisalhamento dos painéis compensados produzidos e na qualidade da colagem entre as linhas de cola, bem como houve atendimento dos mesmos à resistência média ao cisalhamento para painéis de pinus de característica similar estipulado pelo PNQM, com exceção dos painéis resultantes da mistura da espécie *C. lusitanica* à espécie *P. taeda*, após o pré-tratamento “BDB”. A utilização da madeira de *C. lusitanica* resultou em chapas

com qualidade da colagem equivalente à obtida para painéis de *P. taeda*, podendo ser uma opção a ser introduzida no segmento de painéis de madeira compensada, sem necessidade de adaptação ao processo de manufatura já consolidado para a madeira de *P. taeda*.
PALAVRAS-CHAVE: Cisalhamento. Linha de cola. Espécie alternativa. Conífera.

INTRODUCTION

According to data from the 2022 report of the Brazilian Tree Industry (IBÁ 2023), in that year the cultivated tree sector in Brazil generated 2.6 million direct and indirect jobs and achieved a gross revenue of R$ 260 billion. This results from the harvesting and replanting of an area of 9.94 million hectares composed of a few species, almost entirely eucalyptus, that covers 76% of this planted area, followed by pine, with 19% of the total, and the remaining 5% represented by rubber trees, teak, and acacia.

According to the Santa Catarina Association of Forestry Companies (ACR 2022), in 2021 the state of Santa Catarina had a total of 1.03 million hectares of planted area, approximately 69% of which was composed of pine trees, responsible for supplying the sawn wood, wood panel, cellulose, paper, doors, frames, and furniture segments, which are highly dependent on this raw material and in which the state is among the leading exporters.

In this sense, research initiatives aimed at expanding the possibilities of supplying alternative raw materials for the timber sector have been emerging in the state of Santa Catarina. One example is the study conducted by DOBNER JÚNIOR (2021), which observed for the species *Cupressus lusitanica* Mill., growing in the mountainous region of Santa Catarina, productivities of up to 31 m³ ha-1 year-1 at ages between 16 and 18 years, therefore comparable to that recorded for the Pinus genus in the state.

In this sense, considering the growth potential already reported for this species in the state of Santa Catarina, the high dependence of the timber sector on pine wood, and the need to meet the growing demand for exports of coniferous plywood, driven by the high added value of this type of product, in which the state ranks second nationally, this study was developed with a view to verifying the possibility of including the species *C. lusitanica* as a raw material in the coniferous plywood segment.

Regarding the technical feasibility of using C. lusitanica wood in the physical and mechanical properties of plywood panels, MODES et al. (2023), evaluating the same panels as in the present study, concluded that the use of *C. lusitanica* wood in pure form or combined with *P. taeda* wood in the manufacture of the panels resulted in lighter panels with dimensional stability and static bending strength equivalent to that obtained for panels made only with *P. taeda* wood. Based on these technical characteristics, it could become an option to be considered in the plywood industry. Therefore, in order to complement the investigation into the potential of the *C. lusitanica* species to meet the requirements of the plywood segment, it is important to evaluate the effect of the interaction of the species with the industrial process to which it was subjected on the quality of the bonding and, consequently, on the degree of consolidation of the final product for adequate performance in use.

According to LIMA et al. (2011), the glue line will only cause problems and lead to defects in the final product if factors such as the quality and viscosity of the adhesive, the moisture content of the veneers, and the degree of surface cleanliness are not

taken into account during the gluing process. In addition to what the authors reported, there are also aspects related to the hot pressing stage of the panels, such as temperature, pressure, and pressing time, the latter being responsible for the adequate transfer of heat from the surface layers of the panel, in direct contact with the heated plate of the press, to the innermost glue line, and maintaining it for the time necessary for the evaporation of moisture and curing of the resin.

In this sense, it is important to verify whether the operational aspects already established for *P. taeda* wood in the plywood panel industry meet the industrialization requirements for *C. lusitanica* wood, so that the latter can be introduced into this segment in the form of pure panels or combined with *P. taeda* wood. Thus, this study aimed to evaluate the bonding quality of plywood panels made with veneers of *C. lusitanica* wood and a combination of this with *P. taeda* wood, and to compare the results obtained with panels made only with *P. taeda* wood, as well as with the minimum requirements stipulated for Pinus plywood by the National Wood Quality Program (PNQM).

MATERIALS AND METHODS

For this study, industrially produced plywood panels were evaluated by a company in the sector located in the municipality of Presidente Getúlio, SC, using wood veneers from the species *Pinus taeda L.* and *Cupressus lusitanica* Mill. under three configurations: panels composed exclusively of *P. taeda* wood veneers (treatment 1), panels composed exclusively of *C. lusitanica* wood veneers (treatment 2), and panels composed of a combination of *P. taeda* and *C. lusitanica* veneers (treatment 3). For the latter, the wood veneers of *C. lusitanica* were oriented longitudinally in the composition of the panels. Three panels per treatment were evaluated, each composed of seven veneers bonded with phenolic resin at a basis weight of 328 g/m² and a total thickness of 17 mm, consolidated in a press at a temperature of 135 ºC, a pressing time of one minute for each mm of nominal panel thickness, and a specific pressure of 12 kgf/cm².

Phenol-formaldehyde resin was used for bonding the veneers, with a solids content of 34%, a pH of 11 to 13, and a Brookfield viscosity of 120 to 200 cP. The adhesive mixture was prepared with the following composition: 320 kg of phenol-formaldehyde resin, 90 kg of extender (wheat flour), and 90 kg of water.

Thirty samples were made from each panel, for a total of 90 test specimens for each panel configuration. Of this total, the test specimens were divided into two batches of 45 specimens each, consisting of 15 specimens for evaluating the bonding at the central glue line, 15 specimens for evaluating the upper glue line, and 15 specimens for evaluating the lower glue line. To this end, the test specimens were notched with a saw cut into the layer corresponding to the glue line to be evaluated.

One of the batches was subjected to the basic pre-treatment "24 h Cold Immersion," which consisted of immersing the test specimens for 24 hours in water at a temperature not lower than 17 °C (Figure 1A), followed by the shear test on the glue line. The other batch was subjected to the additional "BDB" pre-treatment, which consisted of immersing the test specimens for 4 hours in boiling water, drying in a drying oven for 16 to 20 hours at a temperature of 60 ± 3 °C, immersion in boiling water

for 4 hours, followed by cooling in water at a temperature below 30 °C for at least 1 hour before performing the test (Figures 1A, 1B and 1C). Before the pre-treatments, the length and width of the shear area of the test specimens were measured with a digital caliper. The preparation of the test specimens, the methodology for the pre-treatments, and the execution of the shear test on the glue line (Figure 1D) followed the recommendations of the Brazilian Standard NBR 12466-1 (ABNT 2012a). The criteria for interpreting the results regarding the bonding requirements, specifically the average shear stress and the average apparent cohesive failure in the wood, followed the recommendations of NBR 12466-2 (ABNT 2012b).

The properties obtained from the panels of each treatment were compared with each other and with the requirements for 18 mm pine plywood established by the National Wood Quality Program (PNQM) of the Brazilian Association of Mechanically Processed Wood Industry (ABIMCI 2002).

Figure 1. Steps for carrying out pre-treatments on the specimens before the shear strength test at the glue line. Specimens immersed in cold water (A), Specimens immersed in boiling water (B), Drying of specimens in a drying oven (C); Specimens subjected to the shear test at the glue line on a universal mechanical testing machine (D).

The average shear stress values at the glue line of the different plywood panel compositions were statistically analyzed using a Completely Randomized Design (CRD) and the Sisvar software. The normality of the data was determined by the Shapiro-Wilk test, and the homogeneity of variances was checked using Bartlett's test. The shear stress results at the glue line between treatments and within the same treatment were subjected to analysis of variance, and if the null hypothesis was rejected by the F-test, the Tukey test was applied at a 5% significance level to identify these differences.

RESULTS AND DISCUSSION

Table 1 shows the results of the shear test on the glue lines evaluated in each treatment (panel composition) after application of the basic (24 h cold immersion) and additional (BDB) pre-treatments.

Table 1. Average values of shear strength in the upper, central and lower glue lines and overall average of the panels in each treatment.

Treatment/Pre-treatment	24-hour cold immersion Glue line				BDB Glue line			
	U	C	L	Average	U	C	L	Average
	N/mm²							
P. taeda	1.68A (0.41)	1.66A (0.61)	1.65A (0.51)	1.67a* (0.51)	1.38A (0.30)	1.51A (0.42)	1.44A (0.46)	1.44a (0.39)
C. lusitanica	1.76A (0.45)	1.66A (0.60)	1.74A (0.27)	1.72a (0.44)	1.42A (0.39)	1.53A (0.45)	1.41A (0.37)	1.45a (0.40)
P. taeda x C. lusitanica	1.52B (0.35)	1.96A (0.37)	1.50B (0.43)	1.66a (0.38)	1.29A (0.38)	1.39A (0.26)	1.30A (0.40)	1.32a (0.34)

*averages followed by the same lowercase letter vertically and uppercase letter horizontally do not differ significantly from each other according to Tukey's test at a 5% probability of error; Values in parentheses refer to the standard deviation; 24 h Cold immersion: immersion of the test specimens for 24 h in water at a temperature not lower than 17 °C; BDB: immersion of the test specimens for four hours in boiling water, drying in a drying oven for 16 to 20 hours at a temperature of 60 ± 3 °C, immersion in boiling water for four hours, followed by cooling in water at a temperature below 30 °C for at least one hour before performing the test; U: Upper glue line; C: Central glue line; L: Lower glue line.

It can be observed that there is no statistical difference in the average resistance of the glue line to shear stress between the plywood panels of different configurations, that is, the type of raw material used did not influence the bonding quality of the panels evaluated after the application of both pretreatments, which is a comparative advantage of introducing the alternative species *C. lusitanica* into the already consolidated industrialization process of the company that manufactures the panels. Regarding the shear stress between the glue lines evaluated within the same treatment, it is observed that, with the exception of the treatment resulting from the mixture of the species *P. taeda* and *C. lusitanica* after the "24 h cold immersion" pre-treatment, all others did not show a difference in this parameter between the evaluated glue lines. Regarding the "*P. taeda* x *C. lusitanica*" treatment, it was observed that the central glue line, although considered the most critical in terms of bonding quality, was the one that performed best, with an average value that was statistically superior to those recorded for the upper and lower glue lines.

Regarding the "24-hour cold immersion" pre-treatment, it is observed that the average resistance of the panels and that presented by each glue line in all treatments exceeded the average value of 1.37 N/mm² for the wet test, stipulated for pine plywood panels with similar characteristics (seven layers with 18 mm thickness), as stated in the Technical Catalog for Pine Plywood Panels of the Brazilian Association of the Mechanically Processed Wood Industry (ABIMCI 2002). As for the "BDB" pre-treatment, this criterion was not met by the treatment resulting from the mixture of species, both in relation to the overall average and in the upper and lower glue lines, with values falling short by 3.65%, 5.84% and 5.11%, respectively.

Regarding the minimum value of 0.78 N/mm² defined by the same document, it was observed that of the specimens subjected to the "24-hour cold immersion" pre-treatment, only one specimen out of the 45 evaluated in each treatment, which included all the glue lines tested, did not reach the minimum value. In those samples subjected to the "BDB" pre-treatment, 2 test specimens in each treatment showed a shear stress lower than the minimum value.

NBR 12466-2 (ABNT 2012b), which deals with the requirements for evaluating bonding quality, establishes that each pre-treatment must be applied to a set of no fewer than five test specimens per glue line and that, of the total evaluated, a minimum of 10 test specimens per glue line tested must satisfy the combination of the criteria of average shear stress and the average apparent cohesive failure in the wood. The same document also states that there is no need to assess the percentage of apparent cohesive failure of the wood when the average shear stress is greater than 1,0 N/mm². In this sense, the present study did not analyze the percentage of cohesive rupture of wood in the sheared area, since of the total of 15 test specimens evaluated per glue line in each pretreatment, the minimum number of test specimens mentioned by the normative document regarding the average shear stress greater than 1.0 N/mm² was met.

CONCLUSION

There was no influence of the use of *C. lusitanica* wood and its mixture with *P. taeda* wood on the average shear strength of the plywood panels produced, nor was there any compromise in the quality of the bonding between the glue lines.

With the exception of the plywood panels resulting from the mixture of the *C. lusitanica* and *P. taeda* species evaluated after the "BDB" pre-treatment, the produced panels met the average shear strength of the glue line in a wet test for plywood panels of similar characteristics stipulated by the Technical Catalog for Pine Plywood Panels proposed by the Brazilian Association of the Mechanically Processed Wood Industry.

The use of *C. lusitanica* wood, either in its pure form or combined with *P. taeda* wood, resulted in panels with bonding quality equivalent to that obtained for panels made solely with *P. taeda* wood; it could be an option to be introduced into the plywood panel segment, without the need for adaptation to the manufacturing process already established for *P. taeda* wood.

AUTHOR'S CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Karina Soares Modes, Magnos Alan Vivian and Alexsandro Bayestorff da Cunha; software and validation, Karina Soares Modes and Magnos Alan Vivian; investigation, Karina Soares Modes, Alexsandro Bayestorff da Cunha and Vitoria Cozer; resources and data curation, Karina Soares Modes, Vitoria Cozer and Mario Dobner Junior; writing - original draft preparation, Karina Soares Modes and Vitoria Cozer; writing - review and editing, Karina Soares Modes; visualization, Karina Soares Modes; supervision, Karina Soares Modes and Alexsandro Bayestorff da Cunha; project administration, Karina Soares Modes and Mario Dobner Junior; funding acquisition, Mario Dobner Junior. All authors have read and agreed to the published version of the manuscript.

FINANCING
This work was not supported by any funding agency.

STATEMENT OF THE INSTITUTIONAL REVIEW BOARD
Not applicable to studies that do not involve humans or animals.

INFORMED CONSENT STATEMENT
Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT
The data can be made available upon request.

ACKNOWLEDGEMENTS
The authors thank G13 Compensados company for the manufacturing and transportation of the evaluated plywood panels.

CONFLICTS OF INTEREST
There are no conflicts of interest to declare.

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