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# EVALUATION OF THE MECHANICAL AND SURFACE PROPERTIES OF BRAZILIAN FILM FACED PLYWOOD PANELS

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**Resumo**

*Avaliação das propriedades mecânicas e superficiais de painéis de compensado plastificado brasileiro*. Os painéis compensados plastificados representam uma importante solução para o setor da construção civil, especialmente na aplicação como fôrmas para concreto, devido à sua resistência, durabilidade e possibilidade de reutilização. Diante da relevância desse material e da necessidade de assegurar a qualidade dos produtos disponíveis no mercado, este estudo teve como objetivo avaliar o desempenho das propriedades dos painéis de compensados plastificados produzidos por quatro indústrias brasileiras, com foco em sua conformidade com os requisitos normativos para aplicação na construção civil. Os ensaios foram conduzidos conforme as normas ABNT NBR 17002 (densidade e flexão estática), ABNT ISO 12466 (resistência da linha de cola ao cisalhamento) e ABNT NBR 17001 (avaliação do filme fenólico). Os resultados demonstraram que todos os painéis atenderam aos requisitos mínimos exigidos, apresentando desempenho satisfatório nos diferentes ensaios. As variações observadas entre as indústrias evidenciam a influência de fatores como densidade, composição das lâminas e parâmetros de fabricação. Conclui-se que os painéis avaliados são tecnicamente adequados para aplicação na construção civil, desde que utilizados corretamente, sendo capazes de contribuir para maior eficiência, reutilização e desempenho das fôrmas de concreto.
*Palavras-chave:* Reutilização de fôrmas, construção civil, fôrma de concreto, filme fenólico, adesão.

**Abstract**

Film faced plywood panels represent an important solution for the civil construction industry, especially for use as concrete forms, due to their strength, durability, and the possibility of reuse. Considering the relevance of this material and the need to ensure the quality of products available on the market, this study aimed to evaluate the performance of film faced plywood panels produced by four Brazilian industries, focusing on their compliance with standards requirements for application in civil construction. The tests were conducted in accordance with ABNT NBR 17002 (density and static bending), ABNT ISO 12466 (glue line shear strength), and ABNT NBR 17001 (phenolic film evaluation). The results demonstrated that all panels met the minimum required standards, showing satisfactory performance across the different tests. The variations observed among the industries highlight the influence of factors such as panel density, veneer composition, and manufacturing parameters. It is concluded that the panels evaluated are technically suitable for use in civil construction, provided they are correctly applied, and can contribute to greater efficiency, reuse, and performance of concrete forms.
*Keywords*: Reusable formwork, civil construction, concrete form, phenolic film, adhesion.

## INTRODUCTION:

Civil construction represents one of the most important sectors of the Brazilian economy (Gonçalves *et al.*, 2022), playing a crucial role in the country's socioeconomic development, generating direct and indirect jobs, promoting the improvement of physical infrastructure with positive effects on connectivity, accessibility, commerce, and tourism, and meeting housing needs (IBGE, 2024). Data from the Brazilian Institute of Geography and Statistics and the Brazilian Tree Industry (IBÁ, 2024) indicate that the average share of civil construction in the national GDP over the last ten years is 5%.

According to the Brazilian Chamber of the Construction Industry (CBIC, 2024), a 4.1% growth in gross domestic product (GDP) was observed in the first three quarters of 2024, as well as a level of activity 21.20% higher than the pre-pandemic period. For 2025, a growth of 2.3% in the construction GDP is expected. Given this demand, wood consumption in this sector has been growing significantly.

In civil construction, wood is used both temporarily and permanently or definitively (Filho *et al.*, 2018; Pons; Knop, 2020; Menezes; Damineli, 2024). In temporary uses, it is applied as formwork or concrete forms, scaffolding, and shoring (Pons; Knop, 2020), collective protection, and fences (Kern *et al.*, 2018). Permanently, it is used in roof structures (Filho *et al.*, 2018; Pons; Knop, 2020; Oliveira *et al.*, 2024), and in frames (doors and windows) (Filho *et al.*, 2018).

Wood is used in construction both in its solid or sawn form and in the form of reconstituted products. Chiletto *et al.* (2024) add that the wood used in this sector can range from unprocessed elements (such as roundwood) to components with varying levels of processing, such as sawn, processed, and preservative-treated wood, and even highly industrialized materials, such as reconstituted panels. Among the various types of reconstituted panels, plywood panels stand out.

Brazil is a major producer of plywood panels, with a production of 2.7 million cubic meters in 2023, and in 2024, production until September was approximately 300 thousand cubic meters per month (ABIMCI, 2024), demonstrating the resumption of the increase in production evidenced until 2021. According to ABIMCI (2022), the woods used in production are conifers (*Pinus spp*.) and hardwoods (native tropicals, *Eucalyptus spp*., and Paricá).

The largest volume of national production is based primarily on *Pinus spp.* timber, whose plantations are concentrated in the southern states, where the largest installed production capacity is also located, especially in the states of Paraná and Santa Catarina. Brazilian production of *Pinus spp.* plywood ranks Brazil as the world's fourth-largest producer of coniferous plywood, with 4% of global production (3.4 million m³), and the largest exporter, with 27% (2.6 million m³). This results in domestic consumption of approximately 788,000 m³, meaning Brazil consumes approximately 23% of its production. Regarding hardwood plywood, and also based on 2021 data, Brazil has a more modest production, with 290 thousand m³, of which 43% is exported (124 thousand m³) and 57% is destined for national consumption (167 thousand m³) (ABIMCI, 2022).

It is also worth noting that, within the reported production statistics, some industries produce "combi" panels, which are a combination of conifers and hardwoods, especially a combination of *Pinus spp.* veneers with *Eucalyptus spp*. veneers, seeking improvements in the quality of the final product or specific properties. The benefit of this combination is corroborated by Iwakiri *et al.* (2012), who, in a study on the combination of *Pinus spp.* and *Eucalyptus spp*. veneers in plywood panels, concluded that the greater density of *Eucalyptus spp.* contributes significantly to the increase in modulus of rupture and elasticity in static bending—properties of extreme importance in the use of plywood panels in civil construction.

In civil construction, plywood panels are widely used as concrete formwork (NBR 15696, 2009; Sanches; Iwakiri, 2013; Pizzol *et al.*, 2017). Concrete forms are temporary structures used to mold fresh concrete, resisting all the actions of variable loads resulting from the pressures of fresh concrete placement, until the material becomes self-supporting (NBR 17001, 2021; NBR 15696, 2009). In addition to protecting new concrete, they limit water loss, prevent the escape of fines, allow for the achievement of predetermined surfaces, enable the positioning of other elements such as struts, and ensure the geometry of the piece (Pizzol *et al.*, 2017).

NBR 15696 (2009) establishes that the requirements for formwork, when industrialized wood is used, must present characteristics such as rigidity, compliance with the dimensions of the designed structures, watertightness between joints, surface finish, durability, mechanical resistance to rupture, low water absorption, and low adhesion of the material to the concrete.

Based on this context, and to improve the final quality of the concrete, as well as increase the durability of the forms, some industries began producing panels coated with phenolic film. Phenolic film is a paper impregnated with phenolic resin (Marra, 1992) in grammage ranging from 120 g/m² to 220 g/m². After the resin impregnates the paper, the films are bonded to the faces of the plywood panel through the application of heat and pressure, becoming coated and known as film faced plywood panels (Sanches; Iwakiri, 2013; Abimci, 2016). Their quality and performance are evaluated using the NBR 17001 standard, released by the Brazilian Association of Technical Standards for the first time in 2021.

The phenolic film coating provides the plywood panel with greater resistance, especially against moisture due to its waterproofing, in addition to offering a better finish to the concrete, leaving a smooth and regular surface, unlike sawn wood, which, due to wear and tear over time, leaves the concrete with irregularities (ABIMCI, 2023). Furthermore, the film faced plywood panel stands out for its high reuse rate (Sanches; Iwakiri, 2013), which consequently reduces construction costs.

The possibility of numerous uses, which can reach up to 20 (10 on each side of the panel), according to the ABIMCI (2015) Guidelines for the Use of Film Faced Plywood Panels, brings with it another great advantage for the construction industry, which is seen as a major generator of waste (Azambuja *et al.*, 2018). Increasing the reuse of materials in civil construction reduces waste generation, and according to Kern *et al.* (2018), it is a necessary measure to reduce the sector's environmental impact and improve sustainability.

Based on the importance of civil construction for the country and the lack of information on the performance of film faced plywood panels, this study aims to evaluate the physical-mechanical and surface properties of film faced plywood panels produced by four different industries.

## MATERIAL AND METHODS

This research used laminated plywood panels supplied by four different industries located in the state of Paraná, Brazil. Each industry provided 12 panels, which were randomly sampled according to the NBR 17002 (2021) standard for process control. The panels were produced with nominal dimensions of 2,440 mm × 1,220 mm × 18 mm, with wood veneers of *Pinus spp*. and *Eucalyptus spp*. Each panel was composed of 11 plies, glued with phenol-formaldehyde resin, and coated with phenolic film. Each manufacturer used different production parameters regarding the species or combination of species, ply thickness, and coating film weight. These variables are associated with the availability of forest plantations or timber in the region where the industry is located, as well as the final quality and intended use of the panel. The composition variables of the plywood panels are described in Table 1.

Table 1. Experimental design: composition of film faced plywood panels.
Tabela 1. Delineamento experimental: composição dos painéis de compensado plastificado.

| Industries | Veneer thickness (mm) | | Species | Phenolic film grammage (g/m²) |
|---|---|---|---|---|
| 1 | Face | 1,90 | *Pinus spp.* | 125 |
| | Glue Core | 1,90 | *Pinus spp.* | |
| | Dry Core | 1,90 | *Pinus spp.* | |
| | Back | 1,90 | *Pinus spp.* | |
| 2 | Face | 1,85 | *Pinus spp.* | 130 |
| | Glue Core | 1,85 | *Pinus spp.* | |
| | Dry Core | 1,85 | *Pinus spp.* | |
| | Back | 1,85 | *Pinus spp.* | |
| 3 | Face | 2,25 | *Pinus spp.* | 135 |
| | Glue Core | 2,00 | *Eucalyptus spp.* | |
| | Dry Core | 2,00 | *Pinus spp.* | |
| | Back | 2,25 | *Pinus spp.* | |
| 4 | Face | 2,50 | *Pinus spp.* | 120 |
| | Glue Core | 1,70 | *Eucalyptus spp.* | |
| | Dry Core | 1,50 | *Pinus spp.* | |
| | Back | 2,50 | *Pinus spp.* | |

After receiving the film faced plywood panels, they were checked and then sectioned to prepare the test specimens, according to the cutting plan recommended by NBR 17002 (2021). The test specimens were stored at a relative humidity of 65 ± 5% and a temperature of 20 ± 2 ºC.

The determination of the physical-mechanical properties included density and static bending tests, which were carried out according to the procedures described by NBR 17002 (2021), as well as shear strength in the glue line, which followed the methodology recommended by NBR ISO 12466:1 and 2 (2012). The test specimens underwent pre-treatment in cold water (20ºC) and boiling for 72 hours.

The chemical resistance and anchoring of the phenolic film were evaluated according to the procedures outlined in NBR 17001 (2021). Chemical resistance was determined through a curing test, in which the specimens were subjected to a 5% sodium hydroxide (NaOH) solution for two hours. The exposed area was then scratched in different directions with a spoon. Chemical resistance was assessed visually and classified according to the cure.

The evaluation of the anchoring of the phenolic film was carried out through the adhesion test, based on two different methods: cross-section and boiling. In the cross-section method, a utility knife was used to make parallel cross-sectional cuts in different directions on the surface of the specimens, followed by a visual assessment of the detachment of the phenolic film, free of wood fibers. In the boiling method, the specimens were boiled in water for 6 hours, and then visually assessed for surface bubbles. In both methods, anchoring was classified as having either good or poor adhesion.

The quantitative results of the panel properties were subjected to statistical analysis using *outlier* tests (*Grubbs*), data normality (Shapiro-Wilk), homogeneity of variance (Bartlett), and one-way analysis of variance. When the null hypothesis was rejected, Tukey's comparison of means was applied. All analyses were performed in Statgraphics at a 95% confidence interval.

## RESULTS

### Physical and mechanical properties of film faced plywoods panels

Flexural strength

Table 2 presents the average values of density, modulus of rupture (MOR), and modulus of elasticity (MOE) at static bending, in both the parallel and perpendicular directions of the panels, by production industry.

Table 2. Average results for density and modulus of rupture and elasticity in static bending of film faced plywood panels.
Tabela 2. Resultados médios da densidade e dos módulos de ruptura e de elasticidade à flexão estática nos painéis compensados plastificados.

| Industries | Density ($g/cm^3$) | Static Bending | | | |
|---|---|---|---|---|---|
| | | Parallel direction | | Perpendicular direction | |
| | | MOR (MPa) | MOE (MPa) | MOR (MPa) | MOE (MPa) |
| 1 | 0,59 d (3,47) | 41,35 a (16,93) | 4421,49 d (15,62) | 40,05 a (18,21) | 4572,19 c (20,49) |
| 2 | 0,63 b (4,23) | 41,18 a (21,45) | 4813,29 c (15,97) | 41,47 a (21,21) | 5338,53 b (18,16) |
| 3 | 0,65 a (4,42) | 46,59 a (20,94) | 6162,06 a (15,46) | 40,70 a (18,99) | 5797,65 a (12,24) |
| 4 | 0,61 c (5,01) | 39,86 b (21,51) | 5304,79 b (15,22) | 40,41 a (17,27) | 5088,90 b (16,73) |

MOR: Modulus of Rupture; MOE: Modulus of Elasticity. Means followed by the same letter in the same column are statistically equal according to Tukey's test at a 95% confidence interval. Values in parentheses refer to the coefficient of variation as a percentage.

The average apparent density results of the panels revealed significant statistical differences among all the industries analyzed. This variation may be related to several factors, such as species variation in industries 3 and 4 (*Pinus spp*. + *Eucalyptus spp*.), the age of the forests that produced the logs for veneering, the geographic location of the plantations, the forest growth site, and others.

The average results of the modulus of rupture (MOR) indicated a statistically significant difference only for the parallel direction, with values ranging from 39.83 to 46.59 MPa. In this case, the panels produced by industries 1, 2, and 3 exhibited statistically equal resistance to each other, and higher than that of industry 4. In the perpendicular direction, the values ranged from 40.05 to 41.47 MPa. Regarding the MOE values, the results indicated a statistically significant difference between the industries in both the parallel and perpendicular directions, with emphasis on company 3, which exhibited the highest values (6162.06 MPa in the parallel direction and 5797.65 MPa in the perpendicular direction).

Glue Line Shear Strength Resistance

Table 3 shows the average values of shear strength resistance of the glue line and wood failure for pre-treatment in cold water and boiling for 72 hours.

Table 3. Average glue line shear strength results for film faced plywood panels.
Tabela 3. Resultados médios da resistência da linha de cola ao cisalhamento em painéis compensados plastificados.

| Industries | **Shear strength of the glue line** | | | |
|---|---|---|---|---|
| | Cold Water | | Boiling 72 hours | |
| | RLC (MPa) | Failure (%) | RLC (MPa) | Failure (%) |
| 1 | 1,66 a (14,20) | 79 | 1,28 ab (23,35) | 32 |
| 2 | 1,55 ab (42,06) | 48 | 1,37 a (23,71) | 35 |
| 3 | 1,45 bc (52,70) | 42 | 1,20 b (20,32) | 37 |
| 4 | 1,33 d (57,71) | 41 | 1,09 c (30,00) | 36 |

RLC: Glue line resistance. Means followed by the same letter in the same column are statistically equal according to Tukey's test at a 95% confidence interval. Values in parentheses refer to the coefficient of variation as a percentage.

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The evaluation of glue line shear strength resistance (RLC) revealed statistically significant variations between industries. In the test after 24 hours of cold water immersion, Industry 1 presented the highest RLC value (1.66 MPa), statistically superior to Industries 3 and 4 (1.45 and 1.33 MPa, respectively). For the pre-treatment after 72 hours of boiling, a general reduction in the average RLC values was observed compared to cold water, with emphasis on Industry 2 (1.37 MPa), which was statistically superior to Industries 3 and 4. Industry 4, with 1.09 MPa, presented statistically inferior performance compared to the others. Regarding the percentage of wood failure, Industry 1 again stands out with the highest failure rate (79%) after cold water immersion, indicating efficient bonding. The other industries had failure rates ranging from 41% to 48%, with a predominance of glue line ruptures, demonstrating less efficient bonding. After boiling, the wood failure rates decreased in all industries, ranging from 32% to 37%.

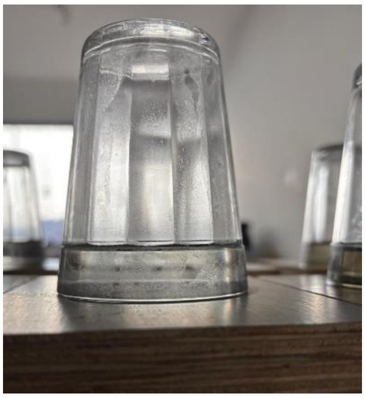
It is also worth noting that the panels produced by industries 3 and 4, from the combination of *Pinus spp.* and *Eucalyptus spp.* veneers, presented the lowest average RLC values in both pre-treatments, compared to the panels produced entirely with *Pinus spp*. veneers (industries 1 and 2).

**Phenolic film properties**

Resistance to Chemical Attack

The evaluation of the chemical resistance of phenolic films exposed to a 5% (NaOH) solution aimed to simulate the alkaline environment created by direct contact with cement. The results indicated differences in the quality performance of the films used by the four industries for coating plywood panels, as shown in Table 4.

Table 4. Results of the phenolic film's resistance to chemical attack.
Tabela 4. Resultados da resistência do filme fenólico ao ataque químico.

| Industries | Fully cured | Nearly fully cured |
|---|---|---|
| 1 | 83% | 17% |
| 2 | 100 % | 0% |
| 3 | 67% | 33% |
| 4 | 100 % | 0% |
| Solvent coloring (NaOH 5%) |  (a) |  (b) |
| Appearance of the tested surface |  (c) |  (d) |

Legend: (a) Fully cured solvent (b) Nearly fully cured solvent (c) Fully cured film (d) Nearly fully cured film

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The phenolic films applied to the panels from industries 2 and 4 showed superior performance, with 100% of the samples classified as "fully cured." This indicates that the solvent had a clear color and the surface was hard, smooth, and slightly whitish. Industry 1, on the other hand, showed 83% of the phenolic films as "fully cured" and 17% as "nearly fully cured." The "nearly fully cured" condition presented a slightly yellowish solvent hue and a slightly softened, slightly swollen, and yellowish surface. Industry 3 presented the lowest phenolic film coating performance, with 67% of the samples classified as "fully cured" and 33% as "nearly fully cured."

Phenolic Film Anchoring

The results demonstrated that, in general, the phenolic films exhibited satisfactory anchoring in both the cross-sectional and boiling tests.

In the cross-sectional method, all test specimens (100%) from all industries were classified as having good adhesion (Figure 1a), meeting the criteria established by the technical standard 17001 (2021). No removal of phenolic film particles from the panels was observed, and although removal of fibers or wood particles with the coating is permitted by the aforementioned standard, no such removal was evidenced.

In the boiling method, industries 1, 3, and 4 showed 100% of the test specimens with good adhesion, as shown in Figure 1b, with no bubbles on the surface. It is also worth noting that good adhesion or anchoring allows for small bubbles in the coating. Industry 2, however, showed 8% of the test specimens with poor adhesion (1 panel out of 12), with bubbles observed after boiling (Figure 1c).

Figure 1. Sample safter phenolic film anchoring tests: (a) good adhesion using the cross-section method, (b) good adhesion using the boiling method. (c) poor adhesion using the boiling method.
Figura 1. Corpos de prova após ensaios de ancoragem do filme fenólico: (a) boa adesão pelo método do corte transversal, (b) boa adesão pelo método de fervura. (c) má adesão pelo método de fervura.

(a) (b) (c)

## DISCUSSION

### Physical and mechanical properties of film faced plywoods panels

Static Bending

The density of the veneers (material) used in panel production, and consequently of the plywood itself, directly influences the production process and the final quality of the product. According to Marra (1992), less dense woods have greater porosity, which can lead to greater or excessive penetration of the adhesive into their structure (starved glue line), resulting in poor bonding quality. On the other hand, denser woods, as noted by the same authors, hinder the mobility of the adhesive within their structure and the formation of the adhesive bond. They can also undergo greater dimensional changes with variations in moisture content, generating increased tension in the glue line, which can favor delamination or debonding.

Regarding the final product, higher densities directly correlate with higher mechanical strength values, contributing to better performance when the product's end use demands this characteristic, as is the case with concrete forms. However, higher density can also result in greater stresses in the adhesive line when the plywood panel is subjected to concreting, as its moisture content changes with the deposition of fresh cement, especially in panels without a phenolic coating.

The higher average MOR and MOE values presented by Industry 3 can be explained, in part, by the higher density of the panels. According to Iwakiri *et al.* (2007), higher density directly reflects increased flexural strength. Another factor that may have contributed to the flexural results is the combination of species. Results obtained by Trianoski *et al.* (2024) indicated that "combi" panels, composed of *Pinus spp.* and *Eucalyptus spp.* veneers, showed that *Eucalyptus spp.* contributed to increased flexural strength. When used in combination with lower-density woods such as *Pinus spp., Eucalyptus spp.*, due to its higher wood density, tends to function as structural reinforcement, increasing the MOR and MOE values of the final product and making it more suitable for applications requiring high mechanical strength, such as temporary use in concrete structures.

According to the Abimci Technical Catalog (2002), the minimum recommended parameters for panels are 32.02 MPa for MOR in the parallel direction and 28.90 MPa in the perpendicular direction. For MOE, the reference values are 3433.20 MPa in the parallel direction and 3018.89 MPa in the perpendicular direction. The results obtained in this study indicate that all the evaluated panels presented MOR and MOE values higher than the reference parameters, both in the parallel and perpendicular directions.

High MOR and MOE (flexural strength) values are desirable in plywood panels used as concrete formwork because, during concrete placement, the forms are subjected to various stresses, such as hydrostatic pressure from the weight of fresh concrete, vibrations from the compaction process, and localized impacts during pouring (NBR 17001, 2021; NBR 15696, 2009). A high MOR ensures that the concrete formwork can withstand stresses up to the rupture point without structural failure or cracking. Similarly, a high MOE value is desirable because it indicates greater panel rigidity and less deformation under load, ensuring that the geometry of the molded element is accurately preserved. When the panel has good rigidity, it prevents deformations that could compromise the alignment and surface finish of the molded concrete part, resulting in flatter, smoother surfaces with less need for rework. Furthermore, high MOR and MOE values contribute to the durability of plywood over several use cycles, allowing for its reuse without significant loss of performance, which can lead to cost reductions on the construction site.

Glue Line Shear Strength Resistance

In general, all RLC values, for both cold and boiling water pre-treatments, obtained in this study meet the minimum requirement of 1.0 MPa established by ABNT NBR ISO 12466-2 (2012) for structural panels. This demonstrates that, regardless of the statistical variations observed between the evaluated industries, the adhesive systems employed show performance compatible with the technical standard criteria, demonstrating technical compliance for the use of the panels in formwork.

High shear strength values of the glue line are desired in plywood panels used as concrete formwork. During the concreting process, these forms are subjected to significant loads, pressure from fresh concrete, deformations, and vibrations resulting from compaction (NBR 15696, 2009), in addition to adverse environmental conditions, such as high humidity and temperature variations, especially those resulting from the exothermic reaction of cement, which releases heat and promotes the heating of the concrete mix.

The integrity of the glue line is essential to ensure the bond between the sheets, preventing delamination that could compromise the structural stability of the formwork. Furthermore, bonding performance for structural use is directly related to the durability and reusability of the panels, even after multiple uses.

This result is similar to, and can be justified by, Rocha *et al.* (2022), who report that the greater density of *Eucalyptus spp*. can hinder the absorption of the adhesive and the compaction of the panels, leading to lower resistance in the glue line.

**Phenolic film properties**

Resistance to Chemical Attack

The yellowish coloration of the solvent, and partially of the tested surface, classified as "nearly fully cured," occurs when the film does not reach a state of complete curing, with part of the phenolic resin remaining in its free form or with incomplete bonds. This makes it susceptible to extraction in an alkaline medium, such as cement or concrete.

The yellowish coloration observed in the solvent (Table 4b) and, to a lesser extent, on the tested surface (Table 4d), both classified as "nearly fully cured," indicates that the applied film has not reached the ideal curing state. This occurs due to the presence of phenolic resin still in its free form or with incomplete bonds, making it susceptible to extraction in alkaline environments, such as cement or concrete. In contrast, images "a" and "c" in Table 4, which represent the "fully cured" state, show no coloration in the solvent and no alteration to the surface, demonstrating greater resistance to the action of the alkaline environment and indicating complete curing of the film.

Despite variations in the performance of phenolic films against chemical attack, all evaluated panels from the four industries passed the criteria established by NBR 17001 (2021). It should also be noted that no phenolic panel or coating from any industry presented resistance to chemical attack as "overcured" (passed), "under-cured" (failed), or "fully under-cured" (failed).

When using plywood panels coated with phenolic films as concrete formwork, properly cured coatings, especially "overcured" or "fully cured", are desirable. Adequately or fully cured films provide greater panel durability, preserving their structural performance and ensuring the quality of the molded concrete. Conversely, when the phenolic film is inadequately cured or undercured, the coating will show signs of degradation, swelling, and delamination, as well as the risk of transferring particles or residue from the film to the surface of the molded or hardened concrete, compromising the finish and reducing the panel's service life or reuse.

Finally, considering the different grammages of phenolic films applied by different industries, as specified in Table 1, no direct relationship with resistance to chemical attack was observed. This result can be explained by the fact that, although higher grammages indicate better coating quality in terms of abrasion resistance, durability, and reuse, resistance to chemical attack depends primarily on the adequate time for pressing the film onto the panel, resulting in the complete curing of the phenol-formaldehyde resin present in the coating sheet.

Phenolic Film Anchoring

Poor adhesion or anchoring in a single panel in Industry 2 may be associated with specific causes, such as contamination of the panel surface prior to bonding the phenolic film, the presence of moisture or dust on the surface, primarily due to waiting time, storage, or handling of the panel still uncoated on the factory floor, or a possible defect in the phenolic film. The occurrence of this isolated failure, present in only one of the twelve panels evaluated, reflects the effectiveness of the quality control adopted by the industry, as the low frequency of the problem indicates that the manufacturing process is well monitored and consistent.

Additionally, it is important to consider that the performance of film faced panels is directly associated with the type of stress they are subjected to in their final use. In the case of panels intended for use as concrete formwork, there is constant exposure to moisture and water present in the cement mix, which can contribute to the progressive degradation of the coating. Krefta *et al.* (2022) emphasize that repeated contact with concrete and the action of water directly affect the panel surface, while Pizzol *et al.* (2017) argue that excessive moisture can alter the properties of the underlying wood and, indirectly, compromise the integrity of the adhesive bond between the sheets.

Therefore, good adhesion of the phenolic film to the film faced plywood is essential because it ensures the maintenance of the protective and finishing properties of the coated surface, allows the panel to withstand the conditions of use in civil construction, and, consequently, enables its main economic and practical benefit: the ability to be reused multiple times as concrete formwork (Krefta *et al.*, 2022).

## CONCLUSIONS

- All panels presented MOR and MOE values higher than those outlined by ABIMCI (2002), confirming their suitability for structural use in formwork. Panels with greater density, as well as the “combi” type panels with *Eucalyptus spp.* veneers, generally exhibited greater strength (MOR) and stiffness (MOE).
- The average resistance values met the minimum requirements set by ABNT NBR ISO 12466-2 (2012), both after pre-treatment in cold water and after 72 hours of boiling, demonstrating adequate bonding performance and confirming the quality of the panels for structural uses. Panels composed exclusively of *Pine spp.* demonstrated better results, possibly due to the lower density and better adhesive penetration.
- Regarding the properties of the phenolic film, it was observed that all panels met the minimum requirements for resistance to chemical attack and anchoring of the phenolic film, being approved according to the requirements of standard NBR 17001 (2021).
- In general, the film faced plywood panels produced by the four evaluated industries present satisfactory quality for use as concrete formwork.

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