

PRODUCTION OF PLYWOOD WITH VENEERS OF *Maquira coriacea* (Karsten) C.C. Berg

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Resumo

O presente estudo avaliou a qualidade dos painéis compensados produzidos com lâminas de *Maquira coriacea* (Karsten) C.C. Berg. Foram produzidos painéis com cinco lâminas de 60 cm x 60 cm, colados com resina ureia-formaldeído, com 65% de sólidos, utilizando três formulações de cola: A (Resina: 100, Extensor: 20, Catalisador: 1,5, Água: 20), B (Resina: 100, Extensor: 40, Catalisador: 1,7, Água: 40) e C (Resina: 100, Extensor: 60, Catalisador: 1,9, Água: 60), e gramaturas de 220 g/m² e 260 g/m². Os painéis foram prensados com pressão específica de 10 kgf/cm², temperatura de 120 °C e tempo de 10 minutos. Foram avaliados MOR e MOE em flexão estática paralela e perpendicular, e resistência da linha de cola ao cisalhamento. Os painéis produzidos com formulação A e gramatura de 260 g/m² apresentam maior resistência à flexão estática paralela, com MOR de 43,51 MPa e MOE de 4576 MPa, e perpendicular, com MOR de 21,88 MPa e MOE de 2129 MPa, bem como cisalhamento na linha de cola (seco: 2,42 MPa e úmido: 1,90 MPa). A formulação com maior teor de sólidos influenciou positivamente o MOR e MOE perpendicular e paralelo, enquanto a gramatura apenas na perpendicular. A resistência ao cisalhamento da linha de cola atendeu aos requisitos da norma EN 314-2 (1993), e demonstrou que a interação entre gramatura e formulação não é significativa. Pode-se concluir que os painéis compensados com *Maquira coriacea* apresentam propriedades de resistência satisfatórias para uso interno; recomenda-se a utilização da formulação C e gramatura de 220 g/m² para otimização da relação custo-benefício.

Palavras-Chave: Lâminas de Madeira; Capinuri; Ureia Formaldeído; Formulação; Gramatura.

Abstract

In the present study, the quality of plywood made with veneers of *Maquira coriacea* (Karsten) C.C. Berg, was evaluated. Plywoods of five 60 cm x 60 cm veneers, glued with urea formaldehyde resin with 65% solids, were made using adhesive formulations A (Resin:100, Extender: 20, Catalyst:1.5, Water:20), B (Resin:100, Extender:40, Catalyst:1.7, Water:40) and C (Resin:100, Extender:60, Catalyst:1.9, Water:60) and grammages of 220 g/m² and 260 g/m². Panels were pressed at specific pressure of 10 kgf/cm², temperature at 120 °C and pressing time of 10 minutes. MOR and MOE in static bending were evaluated in the parallel and perpendicular to the grain as well as the glue line shear strength. Plywood made with formulation A and 260 g/m² grammage shows greater resistance to static bending parallel, with a 43.51 MPa MOR and 4576 MPa MOE, and perpendicular to the grain with a 21.88 MPa MOR and 2129 MPa MOE, as well as the glue line shearing strength (dry: 2.42 MPa and wet: 1.90 MPa). Likewise, the formulation positively influences the MOR and MOE perpendicular and parallel to the grain, while the grammage only in the perpendicular. Shear strength in the glue line meets the requirements of the correspondent standard, finding that the interaction between the amount of glue used and the formulation is not significant. It is concluded that the plywood of *Maquira coriacea* shows satisfactory resistance properties for indoor use, being recommendable to use, to reduce costs, the formulation C and a grammage of 220 g/m².

Keywords: Veneers; Capinuri; Urea-Formaldehyde; Formulation; Grammage.

INTRODUCTION

In 2015 and 2016, 67.6% and 72.3% of the production of plywood panels in Peru were with the species *Maquira coriacea* (Karsten) C.C. Berg, commercially called "capinuri", due to its abundance and lower price compared to the *Chorisia integrifolia*, a species known with the trade name "lupuna", currently scarce and which for decades was the most used in its manufacture (SERFOR, 2016; SERFOR, 2018). However, there are few technical studies conducted with *Maquira coriacea* in terms of their suitability for use, in addition to optimizing the variables of the production process that result in economic gains and quality of the panels.

In Peru, the plywood panels are marketed based on the quality of the faces, so that the veneers used for the outer layers, of better quality, are 1.5 mm thick for better use of logs for this purpose.

The *Maquira coriacea* belonging to the Moraceae family, also known as "Muiratinga" in Brazil, has a basic specific mass of 0.42 g/cm³. It is a wood that in dry air conditions presents sapwood and indistinct heartwood, yellowish white color, undifferentiated growth rings, right to cross, average texture and absent brightness (CHAVESTA, 2018). Its wood is mainly used in the production of plywood panels as well as coatings.

The plywood panel is produced by gluing an odd number of veneers, with a direction of grain perpendicular between the adjacent layers. The restriction imposed by the glue line to the different physical and mechanical behaviors of the individual layers gives the panel a structural balance through a balanced construction (IWAKIRI, 2005).

The most used adhesives in the production of plywood panels are urea and phenol-formaldehyde. These adhesives are composed of a base polymer that provides resistance to the adhesive to join the two substrates: solvents, additives, accelerators or catalysts and extenders. Its function is to reduce adhesive costs, in addition to conferring adhesive properties. (FRIHART, 2013).

Urea-formaldehyde (UF) adhesives have several determining positive aspects: low cost, non-flammable, very fast curing speed and light color. On the downside, the adhesives are not waterproof and formaldehyde continues to be emitting after bonding. UF adhesives are the largest class of amino resins and are the most used for the production of particle boards and fibers for indoor use, not recommended for use outdoors or at extreme temperatures (FRIHART, 2013).

The quality of the bonding depends on the factors inherent to wood (species, cutting direction, initial wood and late wood, heartwood and sapwood), resin type and formulation (solids content, addition of fillers and other additives, surface tension of the liquid phase of the adhesive) and processing parameters (assembly time, temperature, time and pressing pressure) (GAVRILOVIC-GRMUSA, et al., 2008)

Other factors that may interfere with adhesive curing during the pressing phase of the panel are the extractives and pH of the wood. Certain extractives present on the veneers, when subjected to high temperatures during pressing, migrate to the surface and physically block the adhesive's contact with wood. The pH of the wood varies according to the species and usually varies from 3 to 6, and pH changes may occur within a piece of wood, due to the migration of extractives from the inner layers to the surface layers, changing the bonding conditions (IWAKIRI, 2005; FRIHART, FRIHART; HUNT, 2010).

The formulation of the adhesive is defined based on the type of resin, type of wood, surface quality of the veneer and plywood. The components, as well as the quantity, in parts by grammage of each of them, are depending on the formulation of the glue to be applied. In addition, the grammage or quantity of adhesive to be applied (grammage) varies according to the quality class of the panel, type of adhesive and thickness of the veneer; the larger the thickness of the veneer, the greater the grammage, taking into account the higher stresses generated in the glue line; veneers with smooth surfaces require smaller grammages (IWAKIRI, 2005; THOEMEN et al., 2010).

In view of the above, the objective of this work was to evaluate the quality of plywood produced with wood veneers of the species *Maquira coriacea*, in three glue formulations and two grammages, aiming at applications for internal use.

MATERIAL AND METHODS

Collect of veneers

In this research we used wood veneers of *Maquira coriacea*, collected at the company Industrial Ucayali SAC, located in the city of Pucallpa-Ucayali, Peru, laminated according to industrial processing conditions.

The veneers with 1.5 mm (outer layers) and 3.0 mm (internal layers) of thickness were collected after drying at the average moisture content of 8%, being sectioned in final dimensions of 60 cm x 60 cm, and transported to the Panel Laboratory of the Universidad Nacional Agraria La Molina, Lima, Peru.

Anatomical, physical and chemical characteristics of wood

The evaluation of the anatomical characteristics of the wood was carried out according to the procedures mentioned in the standards of the IAWA Bulletin - International Association of Wood Anatomists (1989). The basic specific mass of the wood was determined in samples of 20 mm x 300 mm, obtained from the veneers used in the study. Chemical properties were determined according to TAPPI 204 (2017) for total extractives and TAPPI 252 (2016) for wood pH.

Production of plywood panels

The plywoods were produced with urea-formaldehyde resin with 65% solids, viscosity of 400 cP and pH of 8.3, ammonium sulfate as catalyst, with three glue formulations and two grammages, as set forth in Table 1. The panels were pressed with specific pressure of 10 kgf/cm², temperature of 120 °C and time of 10 minutes. Four panels were produced per treatment.

Tabela 1. Delineamento experimental
Table 1. Experimental design

Treatment	No. panels	Formulation	SC (%)	Grammage (g/m ²)
T1	4	A (R:100, E:20, C:1,5, W:20)	45,94	220
T2	4	A (R:100, E:20, C:1,5, W:20)	45,94	260
T3	4	B (R:100, E:40, C:1,7, W:40)	35,77	220
T4	4	B (R:100, E:40, C:1,7, W:40)	35,77	260
T5	4	C (R:100, E:60, C:1,9, W:60)	29,29	220
T6	4	C (R:100, E:60, C:1,9, W:60)	29,29	260

R: resin; E: extender-wheat flour; C: catalyst; W: water; SC: solids content

After pressing, the panels were squared and packed in a climatic chamber with a temperature of 20 ± 2 °C and relative humidity of 65 ± 5% until stabilization.

Physical and mechanical testing of panels

The specific mass of the panels was determined according to the recommendations of NTP-ISO 9427 (2014). Similarly, for static bending tests, six specimens were prepared with the direction of the fibers of the slides parallel to the length of the samples and six in the perpendicular direction, performing the tests based on the EN 310 (1994) standard.

For shear resistance tests of the glue line, 20 samples were taken from each panel, 10 for dry testing and 10 for wet testing, performed according to the EN 314-1 (2004) and EN 314-2 (1993) standards.

Statistical analysis

For the specific mass, the analysis of variance (ANOVA) and Tukey test were performed. For the results of static bending tests in the directions parallel and perpendicular to the grain and shear resistance in the glue line, a completely random statistical design was used, with a 3 x 2 factorial arrangement, taking as factors three glue formulations and two grammages. The statistical analysis was based on the ANOVA and Tukey test, depending on the significant factors, with a 95% confidence level, using the statistical program R Core Team v.3.5.0. In no case was there non-compliance with the premises observed in the residual analysis.

RESULTS

Anatomical characteristics of wood

The results obtained indicate that the wood of *Maquira coriacea* presents diffuse porosity, solitary oval pores and multiple radials of 2 and aliform vasicentric paratracheal axial parenchyma and aliform confluent with non-stratified rays, there are no differences between sapwood and heartwood; with an average frequency of 3 pores per mm², with a minimum value of 1 and a maximum of 5 and with average tangential diameter of the pores of 214 µm, with a minimum value of 139 µm and a maximum of 266 µm. Likewise, it shows a relative pore area of 11.16% (Figure 1).

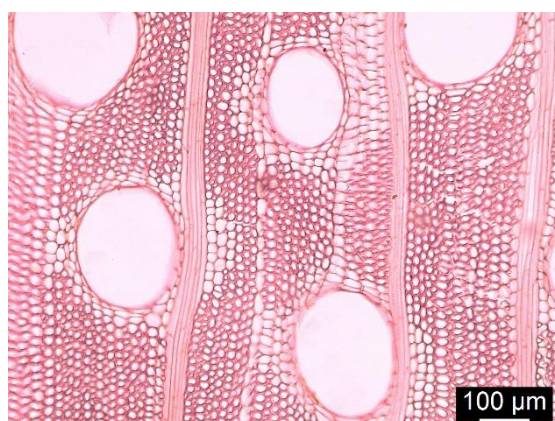


Figura 1. Fotografia da seção transversal da madeira de *Maquira coriacea*, onde são observados o parênquima axial paratraqueal e poros solitários.

Figure 1. Photograph of the cross section of the wood of *Maquira coriacea*, where the paratracheal axial parenchyma and solitary pores are observed.

Basic density and chemical properties of wood

Table 2 shows the average values and the coefficient of variation of the basic density, percentage of total extractives and pH of the wood of *Maquira coriacea*.

Tabela 2. Resultados médios e coeficientes de variação da massa específica básica e das propriedades químicas da madeira de *Maquira coriacea*.

Table 2. Average results and coefficients of variation of basic density and chemical properties of wood *Maquira coriacea*.

Property	Average value	Coefficient of variation (%)
Basic density (g/cm ³)	0,380	3,38
Total extractives (%)	3,15	6,08
pH	6,55	1,24

Physical and mechanical properties of plywood

Density

The results of density of the plywood panels are shown in Table 3. Using the Tukey test with 95% confidence, it was found that the highest average densities corresponds to treatment T2 (formulation A and grammage 260 g/m²), followed by treatments T1, T6, T3 and T4; however, treatments T3 and T4 also belong to the group with the lowest average densities, together with T5 (Formulation C and grammage 220 g/m²).

Tabela 3. Resultados médios e coeficiente de variação da densidade dos painéis compensados.

Table 3. Average results and coefficient of variation of the density of the plywood panels.

Treatment	Panels density	
	Average value (g/cm ³)	CV (%)
T1 (A/220)	0.524b	2,60
T2 (A/260)	0.533c	2,36
T3 (B/220)	0.516ab	1,48
T4 (B/260)	0.518ab	3,24
T5 (C/220)	0.512a	2,13
T6 (C/260)	0.523b	4,86

CV: Coefficient of variation (%) The averages followed by the same letter in the same column are statistically equal, by the Tukey test at 95% probability.

Static bending

Table 4 shows the average values of modulus of rupture (MOR) and elasticity (MOE) in the parallel direction of the panels. Regarding the MOR, the ANOVA test shows that only the effect of the formulation is significant ($F=9.32$, $p=0.00$ value), while for the MOE, the effects of the formulation were significant ($F=6,85$, $p=0.00$ value) and interaction ($F=5.47$, $p=0.01$ value). Therefore, for the MOR, the Tukey test was performed in relation to the effect of the formulation and, for the MOE, in relation to the effect of the interaction.

Tabela 4. Valores médios do módulo de ruptura e de elasticidade em flexão estática paralela.
Table 4. Average values of the modules of rupture and elasticity in parallel static bending.

Variable	MOR (MPa)	MOE (MPa)
Formulation		
A	43.10a (9.28)	4480,89 (6,56)
B	38.52b (10.70)	4239,71 (6,00)
C	42.30a (8.18)	4479,32 (6,24)
Grammage		
220	41,10 (10,04)	4366,92 (5,55)
260	41,51 (10,95)	4433,01 (7,69)
a x b:		
Formulation x Grammage		
1: (A-220)	42,70 (9,10)	4386.10ab (7.04)
2 (A-260)	43,51 (9,74)	4575.72b (5.61)
3 (B-220)	38,85 (10,89)	4349.48ab (4.60)
4 (B-260)	38,18 (10,92)	4130.01a (6.35)
5 (C-220)	41,76 (8,41)	4365.29ab (5.15)
6 (C-260)	42,84 (8,10)	4593.38b (6.33)

MOR: modulus of rupture; MOE: modulus of elasticity. The averages followed by the same letter in the same column are statistically equal, by the Tukey test at 95% probability. Values in parentheses are coefficients of variation.

Table 5 shows the average values of MOR and MOE in the perpendicular direction of the panels. For this property, both for the MOR and for the MOE, the ANOVA test showed that the grammage effects (MOR: $F=13.07$, $p=0.00$ value; MOE: $F=76.46$, $p\text{-value}=0.00$) and formulation (MOR: $F=4.77$, $p=0.01$; MOE: $F=26.47$, $p=0.00$) value is significant. Therefore, the Tukey test was performed, for MOR and MOE, in relation to the main effects - grammage and formulation.

Tabela 5. Valores médios do módulo de ruptura e elasticidade na flexão estática perpendicular.
Table 5. Average values of the modules of rupture and elasticity in perpendicular static bending.

Variable	MOR (MPa)	MOE (MPa)
Formulation		
A	21.07a (13.06)	1990.39a (8.44)
B	19.10b (10.93)	1783.21c (6.54)
C	19.91ab (11.15)	1867.90b (7.68)
Grammage		
220	19.08b (11.55)	1778.22b (5.49)
260	20.97a (11.41)	1982.70a (8.04)
a x b: Formulation x Grammage		
1: (A-220)	20,25 (12,35)	1852,27 (4,65)
2 (A-260)	21,88 (13,02)	2128,51 (5,10)
3 (B-220)	18,11 (10,29)	1709,48 (4,65)
4 (B-260)	20,10 (9,31)	1856,80 (5,45)
5 (C-220)	18,89 (9,46)	1772,92 (4,14)
6 (C-260)	20,93 (10,53)	1962,89 (6,82)

MOR: modulus of rupture; MOE: modulus of elasticity. The averages followed by the same letter in the same column are statistically equal, by the Tukey test at 95% probability. Values in parentheses are coefficients of variation.

Resistance of the glue line shear test

Table 6 shows the average values and the percentage of wood failures for the resistance of the glue line shear test of the plywood panels for dry and wet treatments. For both pretreatments, the ANOVA test showed that effects of grammage (dry: $F=10.95$, p value =0.00; wet: $F=12.79$, $p=0.00$) and formulation (dry: $F=8.40$, $p=0.00$; wet: $F=17.14$, $p=0.00$) value are significant. Therefore, the Tukey test was performed on the effects - formulation and grammage, for both pretreatments.

Tabela 6. Valores médios de resistência ao cisalhamento e porcentagem de falhas na madeira.

Table 6. Average values of shear strength and wood failure percentage.

Shear Resistance Variable	Dry		Moist (24 hours of immersion in water)	
	SR (MPa)	Failure (%)	SR (MPa)	Failure (%)
Formulation				
A	2.35A (13.64)	92	1.82a (12.66)	77
B	2.14b (15.02)	84	1.61b (12.52)	71
C	2.09b (13.03)	82	1.57b (13.66)	65
Grammage				
220	2.14b (15.02)	83	1.60b (13.44)	67
260	2.28a (14.23)	88	1.73a (14.32)	75
a x b: Formulation x Grammage				
1: (A-220)	2,27 (12,37)	89	1,74 (13,17)	74
2 (A-260)	2,42 (14,33)	95	1,90 (10,93)	80
3 (B-220)	2,09 (15,63)	82	1,57 (11,59)	68
4 (B-260)	2,19 (14,49)	86	1,64 (13,22)	74
5 (C-220)	1,95 (9,09)	80	1,48 (9,90)	59
6 (C-260)	2,24 (12,32)	85	1,66 (14,41)	70

SR: Shear Resistance The averages followed by the same letter in the same column are statistically equal, by the Tukey test at 95% probability. Values in parentheses are coefficients of variation.

DISCUSSION

Anatomical characteristics of wood

The *Maquira coriacea* wood does not present pore obstruction, has diffuse porosity and the average pore frequency is classified as very few; the tangential diameter is classified as large (IAWA, 1989). In this case, Burger and Richter (1991) point out that the greater the frequency and the diameter of the pores and the less obstructions, the greater the penetration of the adhesive into the wood, as was observed in the studied species. Albino et al. (2012), in a study carried out with *Eucalyptus grandis* W. Hill ex Maiden, from an 18-year-old plantation, to assess the influence of the anatomical characteristics of the wood on the quality of the bonding, found that the tangential diameter of the pores, that in the average of its radial section were 168 μm and classified as medium (IAWA, 1989), positively influenced the shear strength of the glue line; that is, the greater the value of the tangential diameter, the greater the resistance of the glue line to shear, which corroborates with the observed for *Maquira coriacea*. In this sense, Frihart and Hunt (2010) state that wood with small pore diameters and thick cell walls make it difficult for the adhesive to penetrate into the wood, limiting mechanical anchorage to less than two cells deep.

Basic density and chemical properties of wood

The average value of the basic density obtained for *Maquira coriacea* (0.380 g / cm^3) is less than that indicated by Chavesta (2018), which can be attributed to the fact that this species is extracted from a tropical forest

not managed, suffering the influence of the edaphoclimatic conditions of the place, age of the tree, physiography, among other factors. Likewise, as it is a wood with low density (AROSTEGUI, 1982), it facilitates the penetration of the adhesive in the woody structure and presents minor dimensional changes with changes in the ambient humidity. Low contraction and swelling of the wood generates less stress on the glue line, however, the high porosity of the wood induces greater penetration of the adhesive, resulting in low resistance of the glue line (IWAKIRI, 2005). In this regard, Iwakiri et al. (2012) state that the density of wood is an important factor in the quality of the bond, due to the interactions that occur between the porosity and the absorption of the adhesive in the formation of the adhesive bond. Iwakiri et al. (2011) and Iwakiri et al. (2012), in studies with plywood panels of *Schizolobium amazonicum* and *Sequoia sempervirens*, mentioned that the density of wood used in the manufacture of plywood panels has a strong influence on the properties of MOR and MOE in static bending, the low specific gravity of the wood contributed to the reduction in the values of MOE and MOR.

The average content of total extracts obtained for the *Maquira coriacea* wood is in the range of 1% to 10% mentioned by Gonzáles (2013). Therefore, the percentage found should not cause interaction problems between the adhesive and the wood, since, as reported by Frihart and Hunt (2010), when the wood has a high content of extracts and is subjected to high drying temperatures, these compounds migrate to the surface, where they concentrate and physically block the contact of the adhesive with the wood. The average pH value obtained for *Maquira coriacea* is slightly above the range of 3 to 6, as mentioned by Iwakiri (2005); However, this result did not influence the results of gluing the slides of the studied species. Iwakiri et al. (2012) also state that the extreme pH values can inhibit the chemical curing reactions of the adhesive, which may delay the polymerization process of urea-formaldehyde resin, while, at very low pH, it can accelerate the curing of the resin, causing pre-curing of the glue line with reduced bond strength.

Physical and mechanical properties of plywood panels

Density

The values presented in Table 3 indicate that the density of the panels varied from 0.512 to 0.533 g/cm³. The treatments T1 and T2, referring to formulation A, presented the highest average values of density, and the panels of these treatments also presented better results of dry and wet shear, as well as perpendicular MOR and MOE and parallel MOR. Likewise, treatments T3 and T4, referring to formulation B, showed lower average densities, reflecting lower results for this formulation, both for static bending (perpendicular MOR and MOE and parallel MOR) and for dry shear and wet. It is also observed that in formulations A and C, the treatments that used a grammage of 260 g/m² showed, statistically, average densities higher than those found with a grammage of 220 g/m². This trend coincides with that observed in shear tests (dry and wet) and perpendicular MOR and MOE, where the values found for the grammage of 260 g/m² would be greater than those of 220 g/m². These results show a correlation between density and static bending, as well as density and shear. In this regard, Iwakiri et al. (2011) and Iwakiri et al. (2012), state that the greater density of the plywood panels contributes to obtaining higher values of MOR and MOE in static bending.

Static bending

To assess the results of static bending tests, the standard EN 310 (1994) does not establish minimum values for MOR and MOE; therefore, comparisons were made with the available data from other species of coniferous and hardwood for this product.

The values presented in Table 4 indicate that the static bending in the parallel direction presented average values of MOR between 38.18 and 43.51 MPa and average MOE between 4130 and 4593 MPa; while in Table 5, the results obtained in the perpendicular direction report average MOR values between 18.11 and 21.88 MPa and average MOE between 1709 and 2128 MPa. The grammage was significant only in the results of static bending in the perpendicular direction; while the formulation, which would be directly related to the solids content, was significant in the results of static bending in the perpendicular and parallel direction. In addition, in parallel and perpendicular MOR, there was no significant difference between formulations A and C; however, these values were higher than the average MOR value obtained for formulation B. The same findings were not observed for the MOE.

The significant interaction between the formulation and grammage variables was found only for the parallel MOE. On the other hand, when analyzing the behavior of simple effects, it can be said that the highest values were found for formulations A and C; In the perpendicular, the highest average values of MOE were obtained for formulation A, followed by Formulation C. That is, formulations A and C showed very similar results, in both parallel and perpendicular directions. In economic terms, this result is important, since formulation C could be used instead of formulation A, generating a lower cost. Regarding the grammage, the increase in the amount of

glue from 220 to 260 g/m², resulted in higher average values of MOR and MOE, as a consequence of the better adhesion between the adjacent sheets.

The results of parallel MOR and MOE obtained for the *Maquira coriacea* panels were superior to those found by Iwakiri et al. (2012) for panels of *Sequoia sempervirens*, bonded with urea formaldehyde, with a grammage of 280 g/m² and a solids content of 35.8%, whose average values were 23 MPa and 3241 MPa; For perpendicular MOR and MOE, the values obtained were 13 MPa and 1051 MPa, respectively. Iwakiri et al. (2011), when evaluating the quality of plywood panels of *Schizolobium amazonicum*, bonded with urea formaldehyde resin with a solids content of 35.8% and grammage of 280 g/m², obtained average values of parallel MOR and MOE of 33.2 MPa and 4254 MPa, and perpendicular MOR and MOE of 19.1 MPa and 1586 MPa, respectively. The differences observed in the results presented in the literature can be attributed to the different wood densities of the species used in the production of plywood panels, with the panels of *Sequoia sempervirens* having a density of 0.357 g / cm³ and those of *Schizolobium amazonicum* of 0.371 g / cm³, which are smaller compared to those obtained for *Maquira coriacea*, with values in the range of 0.512 to 0.533 g / cm³.

The results of parallel MOR and MOE obtained for the *Maquira coriacea* panels were inferior to those found by Iwakiri et al. (2012) for panels of *Melia azederach*, bonded with urea formaldehyde, with a grammage of 320 g/m² and a solids content of 58%, whose average values were 71.1 MPa and 7632 MPa; For perpendicular MOR and MOE, the values obtained were 30.6 MPa and 2267 MPa, respectively. Iwakiri et al. (2012) found for plywood panels of *Pinus taeda* glued with urea formaldehyde resin, with a grammage of 360 g/m², average values of parallel MOR and MOE of 72.96 MPa and 8541 MPa and perpendicular MOR and MOE of 32.44 MPa and 2655 MPa, respectively. The differences observed for both *Melia azederach* and *Pinus taeda*, in relation to *Maquira coriacea*, can be attributed to the greater density of the veneers of the first two species (0.488 g/cm³ and 0.571 g/cm³) in relation to the veneers of the species studied in this research whose value was 0.380 g/cm³. Higher grammages used for the production of panels of *Melia azederach* (320 g/m²) and *Pinus taeda* (360 g/m²), may also have contributed to better results of MOR and MOE in relation to the panels of *Maquira coriacea*.

The results corroborate the concepts presented by Iwakiri (2005), which states that woods with low density have high porosity and offer better conditions of adhesive penetration, however, it can result in "hungry" glue line and low adhesion between the blades.

Resistance to shear on the glue line

In the results presented in Table 6, it is observed that both grammage and formulation have a significant influence on the shear of the glue line in dry and wet pretreatments. For the grammage of 220 g/m², there was a reduction in the average shear values of formulations A, B and C, both for dry and wet pretreatment, probably due to the reduction in the solids content of the three formulations evaluated. As for the grammage of 260 g/m², there is a reduction in the average shear strength values of formulations A and B, but there is a slight increase for formulation C; however, no significant differences were found between the three formulations evaluated. The best shear strength results were obtained for formulation A, with a average value of 2.35 MPa for the dry test and 1.82 MPa for the wet test. These results corroborate the concepts presented by Sellers (1993) and Iwakiri (2005), who state that the formulation and grammage of the adhesive directly influence the quality of plywood bonding and the final cost of the panel.

The average values of resistance in the glue line obtained for both dry and wet pretreatment were higher than the minimum value established in EN 314-2 (1993) for internal use panels, whose value is 1.0 MPa, without considering the percentage of wood failure. The shear resistance results obtained for all treatments were higher than the values found by Iwakiri et al. (2002) for plywood panels of *Pinus taeda*, produced with urea-formaldehyde resin, with values in the range of 1.06 to 1.57 MPa; and, Iwakiri et al. (2011), for plywood panels of *Schizolobium amazonicum* produced with urea-formaldehyde resin, with grammage of 280 g/m² and solids content of 35.8%, whose value obtained for the dry test was 0.77 MPa. On the other hand, the results obtained in this study were lower than those found by Trianoski et al. (2015) for plywood panels of *Melia azederach*, glued with urea-formaldehyde resin, with grammage of 320 g/m² and solids content of 58%, whose average values were 2.23 MPa for dry treatment and 2.03 MPa for wet treatment. This difference can be attributed to the higher wood density of *Melia azederach* L. (0.488 g/cm³), compared to *Maquira coriacea* (0.380 g/cm³), in addition to the higher grammage used.

CONCLUSIONS

- The plywood panels of *Maquira coriacea* produced with formulation A (R: 100, E: 20, C: 1.5, W: 20) and grammage 260 g/m², showed higher values of resistance to parallel, perpendicular and shear bending of the glue line.

- The grammage positively influenced only the perpendicular MOR and MOE, while the glue formulation positively influenced the parallel and perpendicular MOR and MOE.
- The results of the glue line shear strength of the plywood panels met the requirements established in EN 314-2.
- The main effects of grammage and formulation have a significant influence on the shear results, both in dry and wet treatment, indicating that the interaction formulation and grammage is not statistically significant.
- To reduce production costs by maintaining panel quality, formulation C (R: 100, E: 60, C: 1.9, W: 60) and a grammage of 220 g/m² is the most suitable one.
- The species *Maquira coriacea* has great potential for the production of plywood panels for internal use.

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