CERNE
ISSN: 0104-7760
cerne@dcf.ufla.br
Universidade Federal de Lavras
Brasil

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CERNE, vol. 19, núm. 2, abril-junio, 2013, pp. 263-269
Universidade Federal de Lavras
Lavras, Brasil

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EVALUATION OF THE USE POTENTIAL OF NINE SPECIES OF GENUS *Eucalyptus* FOR PRODUCTION OF VENEERS AND PLYWOOD PANELS

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(received: February 11, 2011; accepted: January 25, 2013)

ABSTRACT: The objective of this study was to evaluate the use potential of nine species of *Eucalyptus* for production of veneer sheets and multilaminated plywood panels. Veneers were cut using a pilot laminating lathe to a nominal thickness of 2.0 mm. Analysis included finding values of overall yield and yield according to three quality classes for the nine relevant species. Plywood panels were manufactured in a laboratory, consisting of five 2.0 mm veneer sheets which were bonded together with phenol-formaldehyde resin at a weight of 360 g/m² (double line). The panels were compressed using a specific pressure of 10 kgf/cm², a temperature of 140°C and a pressing time of 10 minutes. Results indicated that, with the exception of *E. phaeotricha* and *E. pellita*, all other *Eucalyptus* species had above 50% average veneer yield after lamination. Results of glue line shear testing and static bending parallel and perpendicular demonstrated that species *Eucalyptus grandis, Eucalyptus saligna, Eucalyptus dunnii, Eucalyptus globulus, Eucalyptus viminalis, Eucalyptus robust*a and *Eucalyptus pellita* have great potential within the parameters of this study for use in the production of veneer sheets and plywood panels intended for outdoor use.

Key words: Veneer sheets, plywood panels, Eucalyptus.

AVALIAÇÃO DO POTENCIAL DE USO DE NOVE ESPÉCIES DO GÊNERO *Eucalyptus* PARA PRODUÇÃO DE LÂMINAS E COMPENSADOS

RESUMO: *Conduziu-se esta pesquisa, com o objetivo de avaliar o potencial de uso de nove espécies de Eucalyptus na produção de lâminas e painéis compensados multilaminados. As lâminas foram obtidas num torno laminador piloto com espessura nominal de 2,0 mm. Foram obtidos os valores de rendimento total e em três classes de qualidade para as nove espécies estudadas. Os painéis compensados foram produzidos em laboratório, com cinco lâminas de 2,0 mm de espessura, utilizando a resina fenol-formaldeído, com gramatura de 360 g/m² (linha dupla). Os painéis foram prensados com pressão específica de 10 kgf/cm², temperatura de 140ºC e tempo de prensagem de 10 minutos. Os resultados de laminação indicaram que, com exceção de E. phaeotricha e E. pellita, todas as demais espécies de Eucalyptus apresentaram rendimento médio em laminação acima de 50%. Os resultados de ensaios de cisalhamento da linha de cola e flexão estática paralela e perpendicular, demonstraram que as espécies de Eucalyptus grandis, Eucalyptus saligna, Eucalyptus dunnii, Eucalyptus globulus, Eucalyptus viminalis, Eucalyptus robusta e Eucalyptus pellita, apresentam grande potencial dentro dos parâmetros estudados neste trabalho para produção de lâminas e compensados para uso exterior.*

Palavras-chave: Lâminas de madeira, compensados, Eucalyptus.

1 INTRODUCTION

In Brazil, the timber used for production of plywood panels is both sourced from nonnative forests, whose most common species are *Pinus taeda* and *Pinus elliottii*, and from native forests consisting of tropical Amazonian species.

The economic, social and environmental contribution made by the nonnative forest sector is very expressive in Brazil. According to 2008 data, Brazil boasts 6.5 million hectares of nonnative forests, out of which 4.26 million are *Eucalyptus* and 1.87 million are *Pinus* forests. This sector contributes around R$9 billion in tax collections and creates 2.2 million direct and indirect jobs. And environmentally speaking, that means seven to ten tons of CO_2 being sequestered per hectare/year (SOCIEDADE BRASILEIRA DE SILVICULTURA - SBS, 2008).

Figures provided by a study known as Estudo Setorial da Associação Brasileira de Madeira Processada Mecanicamente - ABIMCI (2009) demonstrated that Brazil produced around 2.6 million m³ of plywood in 2008, out

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of which 2.0 million m³ were produced with species from nonnative forests (*Pinus spp.*), against 0.60 million m³ produced with species from native forests (tropical woods). Figures demonstrated that around 70% of these plywood panels are produced with *Pinus* sourced from forest stands. Extensive exploitation of traditional *Pinus* species (*Pinus taeda* and *Pinus elliottii*) has created problems relating to supply of timber from large-diameter trees with which to derive good quality veneers for production of plywood panels.

Several studies have been conducted in search for alternative species, looking to increase the supply of quality timber for production of veneers and plywood panels. Some studies conducted by Brazilian researchers and involving *Eucalyptus* species for veneer and plywood production are reported below.

Jankowski (1979) was a pioneer in the study of veneer cutting and plywood production in Brazil. This author used wood from *Eucalyptus grandis, E. saligna* and *E. urophylla* and found good results with *E. grandis* for veneering and plywood production. Jankowski and Aguiar (1983) evaluated the species *Eucalyptus saligna, E. grandis, E. triantha, E. microcorys* and *E. pellita* at age 10 years for veneer cutting and plywood production, and concluded that only *E. triantha* and *E. saligna* offered acceptable quality veneers which were suitable for manufacture of plywood panels.

Keinert Júnior and Interanmense (1994) studied the behavior of six species of genus *Eucalyptus* in production of veneers and plywood panels and found good results in their qualitative material assessments. Similarly, Interanmense (1998) and Pio (1996) studied the behavior of four *Eucalyptus* species for production of plywood panels intended for exterior use and found positive results regarding their mechanical properties.

Bortoletto Júnior (2003) evaluated the behavior of 11 species of genus *Eucalyptus* for production of plywood panels and concluded that the following species are suitable for production of plywood for exterior use: *Eucalyptus pilularis, E. propingua, E. microcorys, E. maculata, E. pyrocarpa, E. tereticornis, E. urophylla, E. pellita, E. torelliana* and *E. saligna*.

Iwakiri et al. (2007) studied the properties of structural panels from *Eucalyptus grandis* and *Eucalyptus dunnii* as manufactured with different formulations and concluded that both species comply with minimum requirements set in standard EN 314 (EUROPEAN COMMITTEE FOR STANDARDIZATION - EN, 1993) concerning glue line strength in panels intended for exterior use. These authors also found that variations in the amount of glue being used did not significantly influence the mechanical properties of resulting plywood panels.

As far as plywood production is concerned, technological factors should be analyzed carefully, in particular those concerning the physicochemical process involved in bonding veneer sheets (MARRA, 1992). The choice of resin to be used in veneer bonding should consider suitability for the end environment, more specifically urea-formaldehyde should be used for interior applications while phenol-formaldehyde should be used for exterior applications. Parameters such as formulation and quantity of adhesive will directly influence not only the bonding quality but also the production cost of plywood panels (BALDWIN, 1993; SELLERS, 1993). These authors argue that wood density is a critical factor in defining these parameters, given the interactions that occur between wood porosity and glue absorption to finally form an adhesive bond between the veneer sheets. According to Marra (1992), low-density woods absorb larger quantities of adhesive, on account of their high porosity. In such cases, adhesive viscosity should be increased in order to avoid excessive glue line absorption due to porosity. Other factors such as pH and extractives content are also critical as they may affect adhesive curing during the hot-press process. Baldwin (1993) argues that some extractives present in veneers may obstruct the vaporization process and migration from one glue line to another, and then to the edges of the panel. This process being very slow will result in increased vapor pressure within, resulting in a burst at the time the press is opened and consequently in a delamination of the panel. Therefore, heterogeneity and variability in the anatomical, physical and chemical properties of wood, whether among species or among different parts of a single tree, indeed may affect the bonding conditions of veneer sheets during the manufacturing process of plywood.

This study aimed to evaluate the use potential of nine species of genus *Eucalyptus* for production of veneers and plywood panels intended for exterior use.

2 MATERIAL AND METHODS

The following species were used in this research: *Eucalyptus grandis, Eucalyptus saligna, Eucalyptus dunnii, Eucalyptus globulus, Eucalyptus viminalis, Eucalyptus robusta, Eucalyptus phaeotricha, Eucalyptus deanei* and *Eucalyptus pellita*. At the time of sample collection, the first two above species were 21 years and the other species were 18 to 19 years. Two trees of each species were sampled from forest stands located in the region of Piên – PR and Jaraguá do Sul – SC. For bonding the veneer sheets a phenol-formaldehyde resin (FF) was used with a solids content of 49%, a pH of 11.5 and Brookfield viscosity of 420 cP.

Each tree was bucked into three logs 0.60 m in length each, to a total of six logs per species prior to veneer cutting. Veneers were obtained using a pilot lathe to a thickness of 2.0 mm and divided using a pneumatic guillotine so as to obtain 600 mm x 600 mm pieces. Samples 20 mm x 300 mm in size were randomly taken from veneers of each species for determination of apparent specific mass, using a total of 20 test pieces per species.

Veneers were graded as A, B and C, according to requirements specified in standard ABNT 31:000.05-001/1 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT, 1986). Also determined were the proportions of veneers in each of the three quality classes contributing to the overall yield per species. Veneer yield per species was determined by the ratio of produced veneer volume to log volume without bark. Determinations were made of total yield and yield per quality class for each species being studied, as well as of veneer surface evenness after drying.

Prior to being assembled, the veneer sheets were oven-dried to an average moisture content of 8% and finally cut to a square shape 500 mm x 500 mm in size. Each panel was made with five veneers using phenol-formaldehyde resin with the following formulation, in parts by weight: resin = 100 p/w, wheat flour = 15 p/w and water = 15 p/w. Adhesive was applied manually at a rate of 360 g/m² (double line), using a spatula across the surface of the veneer. The panels were compressed using a specific pressure of 10 kgf/cm², a temperature of 140°C and a pressing time of 10 minutes. Two panels were produced per species, to a total of 18 experimental panels.

After keeping the panels in a temperature-controlled chamber set at a temperature of 20 $\pm$ 2ºC and relative humidity of 65 $\pm$ 5%, test pieces were taken and submitted to the following laboratory tests: glue line strength to shear stress (dry test, boil/dry cycle and 72-h boil) and static bending for determining the modulus of elasticity (MOE) and modulus of rupture (MOR) parallel and perpendicular to panel plane. Tests were performed according to procedures described in European Standards EN 314 and EN 320 respectively. Test results were examined using analysis of variance and Tukey test at the 95% probability level, outlining a completely randomized design.

3 RESULTS AND DISCUSSION

3.1 Apparent specific mass of veneers

Mean values of apparent specific mass for the veneers of each species are illustrated in Table 1.

Table 1 – Apparent specific mass of veneers.

Tabela 1 *– Massa específica aparente das lâminas.*

Species	Apparent specific mass (g/cm³)
Eucalyptus grandis	0.436
Eucalyptus saligna	0.687
Eucalyptus globulus	0.564
Eucalyptus viminalis	0.617
Eucalyptus dunnii	0.561
Eucalyptus robusta	0.577
Eucalyptus phaeotricha	0.584
Eucalyptus deanei	0.571
Eucalyptus pellita	0.597

As can be noted, mean values of apparent specific mass ranged from 0.436 g/cm³ for veneers of *Eucalyptus grandis* to 0.687 g/cm³ for *Eucalyptus saligna*. These values fall within the medium to low range of reference values reported in literature and thus can be considered suitable for manufacture of plywood.

In a study with 11 *Eucalyptus* species, Bortoletto Júnior (2003) found the following mean values of basic density: *E. pilulararis* – 0.67 g/cm³, *E. propinqua* – 0.77 g/cm³, *E. microcorys* – 0.63 g/cm³, *E. maculata* – 0.71 g/cm³, *E. pyrocarpa* – 0.64 g/cm³, *E. tereticornis* – 0.74 g/cm³, *E. urophylla* – 0.60 g/cm³, *E. pellita* – 0.65 g/cm³, *E. citriodoroa* – 0.76 g/cm³, *E. torelliana* – 0.61 g/cm³, *E. saligna* – 0.56 g/cm³. In a study with veneers of *Eucalyptus cloeziana, Eucalyptus punctata* and *Eucalyptus maculate*, Interanmense (1998) found mean values of basic density of 0.70, 0.76 and 0.78 g/cm³ respectively. And Pio (1996) found basic density values of 0.64 and 0.56 g/cm³ for veneers of *Eucalyptus scabra* and *Eucalyptus robusta* respectively.

3.2 Yields in the lamination process / veneer quality

Yield results in the lamination process, both overall and by quality class, are given in Table 2.

Table 2 – Lamination yield and veneer quality.

Tabela 2 – *Rendimento em laminação e qualidade das lâminas.*

Species	RT	A	B	C	QS
Eucalyptus grandis	50.31	0.88	9.90	39.53	SO
Eucalyptus saligna	67.22	0.00	1.39	65.83	SO
Eucalyptus globulus	58.39	0.00	25.28	33.10	MO
Eucalyptus viminalis	55.95	2.43	45.22	8.30	MO
Eucalyptus dunnii	55.52	0.71	7.52	47.29	PO
Eucalyptus robusta	54.53	0.00	40.34	14.19	PO
Eucalyptus phaeotricha	41.37	0.00	15.11	26.26	PO
Eucalyptus deanei	50.02	0.00	31.85	18.16	MO
Eucalyptus pellita	45.46	0.00	21.06	24.40	PO

RT: overall yield; QS: quality of veneer surface (after dry); SO: no undulation; PO: few undulations; MO: many undulations.

Mean values of overall lamination yield, for each of the nine *Eucalyptus* species, ranged from 41.37% for *E. phaeotricha* to 67.22% for *E. saligna*. With the exception of *E. phaeotricha* and *E. pellita*, all other species had mean lamination yields above 50%. As regards veneer quality, only three species, namely *E. grandis, E. viminalis* and *E. dunnii*, derived superior quality veneers (A), despite the percentages below 3%. Higher percentages of class B veneers were found for *E. viminalis* (45.22%) and *E. robusta* (40.34%). As for class C, higher percentages of class C veneers were found for *E. saligna* and *E. dunni*, with 65.83% and 47.29% respectively.

Results found in this study are satisfactory in comparison with values of lamination yield reported in literature for *Eucalyptus* species. While studying clones I and II of *Eucalyptus grandis x Eucalyptus urophylla*, Almeida et al. (2004) found mean yields of 51.74% and 56.81% respectively. Pio (1996) found mean yields of 36.47% and 44.00% for species *E. scabra* and *E. robusta* respectively. This author cites, as sources for comparison, mean yields for the following species: *Pinus elliottii* (42.40% and 55.50%), *Pinus strobus* (54.40%) and *E. robusta* (49.10%). Interanmense (1998) found mean yields of 50.00%, 50.43% and 44.86% for species *E. viminalis, E. cloeziana* and *E. maculata* respectively.

3.3 Glue line strength to shear stress testing

Results of glue line strength to shear testing on panels are illustrated in Table 3.

Table 3 – Glue line strength to shear stress testing.

Tabela 3 – *Cisalhamento da linha de cola.*

Species	Dry (MPa)		Cycle (MPa)		72-h Boil (MPa)	
	Mean (CV)	FM (%)	Mean (CV)	FM (%)	Mean (CV)	FM (%)
E. grandis	2.72 a (20.99)	82	1.41 bc (15.89)	27	1.73 a (28.47)	69
E. saligna	2.05 b (16.17)	23	1.82 a (19.50)	13	1.54 ab (32.83)	22
E. globulus	2.00 b (6.29)	22	1.38 bcd (16.84)	4	1.21 bc (25.10)	3
E. viminalis	2.78 a (10.47)	30	1.54 ab (11.01)	11	1.86 a (11.33)	19
E. dunnii	1.79 bc (16.07)	11	1.08 ef (20.63)	3	0.86 c (18.58)	1
E. robusta	2.29 ab (16.22)	9	0.81 f (19.37)	0	1.08 c (22.53)	3
E. phaotrica	2.13 b (22.56)	41	1.09 def (7.35)	7	1.00 c (36.97)	11
E. deanei	1.37 c (13.85)	23	1.32 bcde (9.79)	17	0.91 c (17.86)	5
E. pellita	1.99 b (14.46)	42	1.12 cde (22.98)	13	1.18 bc (11.90)	15

CV: coefficient of variation; FM: percentage of wood defects; Means followed by the same letter in a column are statistically similar at the 95% probability level.

In the dry test, the mean values of shear stress ranged from 1.37 MPa for *E. deanei* to 2.78 MPa for *E. viminalis*. The mean values found for panels made from *E. viminalis* were statistically similar to values found for panels made from *E. grandis* and *E. robusta* but higher in comparison with panels made from the remaining *Eucalyptus* species.

In the boil cycle test, the mean values of shear stress ranged from 0.81 MPa for *E. robusta* to 1.82 MPa for *E. saligna*. Panels made from *E. saligna* had statistically similar mean values to panels made from *E. viminalis* but higher values in comparison with the remaining *Eucalyptus* species.

As for the 72-hour boil test, the mean values of shear stress ranged from 0.86 MPa for *E. dunnii* to 1.86

MPa for *E. viminalis*. Panels made from *E. viminalis* had statistically similar mean values to panels made from *E. grandis* and *E. saligna* but higher values in comparison with panels made from the remaining *Eucalyptus* species.

Except for species *E. robusta, E. dunnii* and *E. deanei*, the mean values of shear stress found for panels from all other species, both in the boil cycle test and in the 72-hour boil test, were found to be above the minimum value of 1.0 MPa defined by standard EN 314-2 (EN, 1993) as being a requirement for panels intended for exterior use.

Results of glue line strength to shear stress found in this study for all nine *Eucalyptus* species can be considered satisfactory in relation to reference values reported in literature. Iwakiri et al. (2007) studied phenolic plywood panels produced with veneers from *E. grandis* and *E. dunnii* and found mean values of shear stress of 2.69 MPa and 2.43 MPa in the dry test, against 1.57 MPa and 1.20 MPa in the boil cycle test, respectively for each of the two species. Bortoletto Júnior (2003) studied 11 species of *Eucalyptus* and found mean values of shear stress in the range of 1.9 MPa to 2.4 MPa in the boil cycle test.

3.4 Static bending parallel

Test results of static bending in the parallel direction are illustrated in Table 4.

The range of variation in mean values of MOE parallel was 9,378 MPa for panels made from *E. deanei* and 18,494 MPa for panels made from *E. dunnii.* Regarding MOR parallel, variation ranged from 72.23 MPa for panels made from *E. deanei* and 115.68 MPa for *E. viminalis*.

The mean values of MOE parallel found for panels from *E. dunnii, E. viminalis* and *E. saligna* were statistically higher in comparison with panels made from other species of *Eucalyptus*. As for MOR parallel, the mean values found for panels from *E. viminalis* were statistically similar in relation to panels from *E. dunnii, E. saligna, E. phaeotricha* and *E. globules* but higher in relation to panels from other *Eucalyptus* species.

With reference to results reported in literature, Iwakiri et al. (2007) found 11,058 MPa and 12,699 MPa as mean values of MOE parallel, against 83.70 MPa and 77.50 MPa as mean values of MOR parallel, for plywood panels made from *E. grandis* and *E. dunnii* respectively. Bortoletto Júnior (2003), in a study with 11 species of *Eucalyptus*, found mean values of MOE parallel in the range of 12,336 MPa to 19,331 MPa, against mean values of MOR parallel in the range of 84 MPa to 130 MPa.

Table 4 – Static bending parallel.

***Tabela 4 –** Flexão estática paralela.*

Species	MOE (MPa)		MOR (MPa)	
	Mean	CV (%)	Mean	CV (%)
Eucalyptus grandis	12,251 b	10.09	91.29 bc	8.62
Eucalyptus saligna	17,379 a	10.49	106.61 ab	22.41
Eucalyptus globulus	12,987 b	7.78	96.38 ab	10.22
Eucalyptus viminalis	17,523 a	4.67	115.68 a	5.88
Eucalyptus dunnii	18,494 a	8.76	113.87 a	6.53
Eucalyptus robusta	13,285 b	9.01	91.15 bc	10.37
Eucalyptus phaotrica	13,754 b	7.42	106.28 ab	9.94
Eucalyptus deanei	9,378 c	4.83	72.23 c	13.17
Eucalyptus pellita	12,450 b	6.98	90.37 bc	9.52

MOE: modulus of elasticity; MOR: modulus of rupture; CV: coefficient of variation; Means followed by the same letter in a column are statistically similar at the 95% probability level.

Therefore, it can be said that results found in this study in static bending parallel testing for all nine species of *Eucalyptus* are considered satisfactory.

The mean values of MOE and MOR in the parallel direction found in this study for all nine *Eucalyptus* species fully comply with the minimum requirements established in standard DIN 68792 (DEUTSHE INSTITUT FÜR NORMUNG - DIN, 1979) for plywood panels intended for exterior use - concrete moulds, whose values are 5,000 MPa for MOE and 45 MPa for MOR.

3.5 Static bending perpendicular

Results of static bending tests in the perpendicular direction are illustrated in Table 5.

The range of variation in mean values of MOE perpendicular was 2,738 MPa for panels made from *E. deanei* and 4,627 MPa for panels from *E. viminalis*. For MOR perpendicular, variation ranged from 34.46 MPa for panels made from *E. deanei* to 53.43 MPa for *E. viminalis*. As was expected, values of MOE and MOR in the perpendicular direction were much lower in relation to values found for the parallel direction.

Table 5 – Static bending perpendicular.

Tabela 5 *– Flexão estática perpendicular.*

Species	MOE (MPa)		MOR (MPa)	
	Mean	CV (%)	Mean	CV (%)
Eucalyptus grandis	3,801 bc	18.46	46.14 ab	16.64
Eucalyptus saligna	4,305 ab	10.94	53.43 a	8.13
Eucalyptus globulus	3,383 cd	11.16	43.79 bc	8.32
Eucalyptus viminalis	4,627 a	1.38	46.67 ab	3.86
Eucalyptus dunnii	3,978 abc	9.25	41.98 bc	6.38
Eucalyptus robusta	3,935 abc	3.99	45.46 ab	1.85
Eucalyptus phaotrica	3,690 bc	14.03	45.67 ab	13.72
Eucalyptus deanei	2,738 d	6.33	34.46 c	16.52
Eucalyptus pellita	3,616 bc	14.23	39.44 bc	17.58

MOE: modulus of elasticity; MOR: modulus of rupture; CV: coefficient of variation; Means followed by the same letter in a column are statistically similar at the 95% probability level.

The mean values of MOE perpendicular found for panels from *E. viminalis* were statistically similar in relation to panels from *E. saligna, E. dunnii* and *E. robusta* but higher in relation to panels from other *Eucalyptus* species. As regards MOR perpendicular, the mean values found for panels from *E. saligna* were statistically similar in relation to panels from *E. viminalis, E. phaeotricha* and *E. robusta* but higher in relation to panels from other *Eucalyptus* species.

Results of MOE and MOR perpendicular are rarely reported in literature. Yet, if confronted with results reported by Bortoletto Júnior (2003) for 11 species of *Eucalyptus*, the values found in this study can be considered satisfactory. The mean values found by the above author for MOE perpendicular ranged from 3,419 MPa to 5,487 MPa, while for MOR perpendicular the values ranged from 46 MPa to 64 MPa.

The mean values of MOE and MOR in the perpendicular direction found in this study for all nine *Eucalyptus* species fully comply with the minimum requirements established in standard DIN 68792 (DIN, 1979) for plywood panels intended for exterior use - concrete moulds, whose values are 2,500 MPa for MOE and 30 MPa for MOR.

4 CONCLUSIONS

Results found in this study led to the following conclusions:

- The mean values of apparent specific mass found for all nine *Eucalyptus* species fell within the medium to low range, indicating suitability for production of veneers and plywood panels.

- With the exception of *E. phaeotricha* and *E. pellita*, all other *Eucalyptus* species had average lamination yields above 50%.

- With the exception of *E. robusta, E. dunnii* and *E. deanei*, panels made from all other *Eucalyptus* species had mean values of shear stress above the minimum of 1.0 MPa established by standard EN 314-2:1993 as being a requirement for panels intended for exterior use.

- The mean values of MOE and MOR, parallel and perpendicular, as found for all nine *Eucalyptus* species, comply with the minimum requirements established in standard DIN 68792 (DIN, 1979) for panels intended for exterior use.

- Based on results, it can be said that species *Eucalyptus grandis, Eucalyptus saligna, Eucalyptus dunnii, Eucalyptus globulus, Eucalyptus viminalis, Eucalyptus robusta* and *Eucalyptus pellitai* have great use potential for production of veneers and plywood panels intended for exterior use.

- Species *Eucalyptus viminalis* was found to provide the best results in all tests.

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