Optimization of properties of *Eucalyptus* oriented strand boards by specific gravity of panels

Optimización de las propriedades de tableros de hojuela orientada de *eucaliptos* a través de la densidad específica de los tableros

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Abstract

This study aimed to determine the influence of specific gravity on properties of oriented strand boards produced with five *Eucalyptus* species and get linear models between the properties and the densification of the panels. The species studied were: *Eucalyptus benthamii*, *E. dunni*, *E. grandis*, *E. saligna*, *E. urograndis* and the mixture between them. The panels were produced with phenol formaldehyde resin and nominal densities of 0,65 g/cm³ and 0,75 g/cm³. The water absorption has an inverse relationship to the density of the panel. The relation between mechanical properties and specific gravity of the panel is directly proportional. The panels produced with the *Eucalyptus* species showed better properties than those produced with control species (*Pinus taeda*), except for tensile perpendicular. By means of linear models obtained in this study conditions for each species, it can estimate the specific gravity to produce oriented strand board panels that adequate the standard requirements.

Keywords: fast growing species, linear regression, normative requirements, oriented strandboard.

Resumen

El objetivo de este estudio fue determinar la influencia de la masa específica de tableros OSB producidos con cinco especies de *Eucalyptus* en sus propiedades y obtener modelos lineales entre las propiedades y la densificación de los tableros. Las especies estudiadas fueron: *Eucalyptus benthamii*, *E. dunni*, *E. grandis*, *E. saligna*, *E. urograndis* y una mezcla entre ellas. Los tableros fueron producidos con resina fenol-formaldehído y las densidades específicas nominales fueron de 0,65 g/cm³ y 0,75 g/cm³. La absorción de agua tiene una relación inversa a la densidad específica del tablero. La relación entre las propiedades mecánicas y la densidad específica del tablero es directamente proporcional. Los tableros producidos con las especies *Eucalyptus* presentaron mejores propiedades que los producidos con la especie testigo (*Pinus taeda*), excepto para la tracción perpendicular. La mezcla compenso los valores de cohesion interna en la elaboración del tablero. A través de modelos lineales obtenidos en las condiciones de este estudio para cada especie, se puede estimar la densidad específica para producir tableros de hojuela orientada que cumplen con los requisitos reglamentarios.

Palabras clave: especies de crecimiento rápido, regresión lineal, requisitos reglamentarios, tableros de hojuela orientada.

Introduction

In Brazil, the *Eucalyptus* is the genus with the largest area of planted forests, with about 5,56 million hectares. In all this area, 46,1% is destined for the coal industry and industrial wood, 42,1% for pulp and paper and just 4,3% for reconstituted panels sector (Associação Brasileira de Produtores de Florestas Plantadas [Abraf], 2013).

According to Indústria Brasileira de Árvores [IBÁ] (2014), 66,4% of total consumption of wood *in natura* of Brazilian industries panels are from the *Pinus* genus and only 31,7% of the *Eucalyptus* genus.

Most of the *Eucalyptus* wood volume of short rotation forests is directed to the energy sector, because it is wood from young trees, which are not commonly used in sectors of great economic value as lumber, due to insufficient diameter, or

present predominantly juvenile wood, thus resulting in high anisotropy coefficient and growth stresses disturb the drying timber.

On the other hand, these problems arising from juvenile wood that may interfere in any way in certain segments of the forestry industry, are simply eliminated in the particulate panel production process, since the solid wood is reduced to chips and then the particles smaller. Furthermore, authors as Iwakiri, Albuquerque, Prata and Costa (2008a); Mendes, Mendes, Mendonça, Guimarães Júnior and Mori (2014); Gorski, Cunha, Rios, Trianoski and Martarello (2015) concluded that panels produced with species of the genus *Eucalyptus* showed superior properties to the panels traditionally made of *Pinus*.

Among the factors that affect the properties of oriented strand board (OSB), the specific gravity panel is one that strongly influence the physical and mechanical properties. The increase in specific gravity results in a higher compression ratio and a consequent increase in the mechanical properties of the panels (Mendes *et al.*, 2008). On the other hand, according to Maloney (1993) and Moslemi (1974), this increase can impair the dimensional stability due to the higher thickness swelling. According to Kelly (1977), the largest amount of particles present on panels with higher densification results in an increased hygroscopic swelling of the wood, due to the release of compressive stress, which acted during the pressing process.

The specific gravity panel produces a large impact on the physical and mechanical properties, and the increased density of the panels results in better mechanical properties; on the other hand, the physical properties are not linearly improved with this increase (Istek and Siradag, 2013).

Studying different densities in particleboard of *Toona ciliata*, Trianoski, Iwakiri and Matos (2014) noted that the panels produced with lower density adequate the standard minimum requirements, thus reducing the amount of raw material used.

OBJECTIVES

This study aimed to determine the influence of specific gravity of OSB produced with five *Eucalyptus* species on their properties and get linear models between the properties and the densification of the panels.

MATERIALS AND METHODS

Raw material

For this study were used woods of *Eucalyptus benthamii*, *E. dunni*, *E. grandis*, *E. saligna* and *E. urograndis* from short rotation plantations with about seven years old, located in Rosario do Sul, Brazil. Were sampled five trees by species, which were cut in logs, after in blocks and then processed to generate *Strands*.

The particles were produced with nominal dimensions of 80 mm in lenght, 25 mm in width and 0,6 mm in thickness, using a rotating disk chipper with four knives. The particles were dried in a heater at 80°C of temperature to obtain a moisture content of approximately 3%, and then classified manually using a sifter with 9,52 mm of apertures for removal of "fines".

The resin used was phenol-formaldehyde, with solids content of 51,57% and a viscosity of 503 cP in a proportion of 6% solids based on dry weight of the particles. In order to reduce the hygroscopicity of the panels are also used, 1% wax emulsion.

Panels manufacturing

Three panels for each one of the 14 treatments were manufactured, totaling in 42 OSB panels. The panels were produced in the dimensions of 48 cm × 48 cm × 1,2 cm and two densification, 0,65 g/cm³ and 0,75 g/cm³. The percentage of outer and inner layer was of 20:60:20.

The bonding was done through of a compressor and the air spray gun with a dosing container in a rotary drum. After bonding, the particles were oriented to each layer of the mattress perpendicularly, using a guiding box coupled to the forming box with dimensions of 48 cm × 48 cm × 20 cm. After the formation of the mattress a pre-press was performed to remove air and accommodation of the particles.

The mattress was pressed in a hydraulic press at a temperature of 160 °C, specific pressure of 4 MPa and 10 minutes time pressing.

The produced panels were conditioned in a chamber with temperature of 20 °C ± 3 °C and a relative humidity of 65% ± 5% to reach moisture balance. After stabilization of the panels, the samples were prepared and taken back again to the chamber to get the temperature and constant humidity to perform the physical and mechanical tests.

Physical and mechanical tests

The physical and mechanical tests were performed following the procedures of European standards: Apparent specific gravity (EN 323:2002), water absorption (EN 317:2006), thickness swelling (EN 317:2006), static bending (EN 310:2006) and internal bond (EN 319:2006). The standard EN 300:2006 was used to compare the results.

All statistical analyzes were performed at 95% significance level, using the software Statgraphics Centurion XV, where models were estimated for each property using linear regression.

RESULTS

Physical properties

Table 1 and table 2 presents the linear equations with the determination coefficient and standard error of estimative obtained to water absorption after two and 24 hours of immersion of panels, by species.

It can be observed that both to WA 2h as to WA 24h were found high determination coefficient values, indicating that the equations obtained explain satisfactorily the linear relationship between the density of panels and water absorption.

To thickness swelling properties after two and 24 hours, not found linear proportionality relationships with the specific gravity of panels to the obtained data in this study.

Mechanical properties of panels

Table 3 and table 4 present the equations with the determination coefficient and the standard error of estimate obtained for the Modulus of Rupture obtained in the direction parallel and perpendicular to plane of panels for each species.

The coefficient of determination values for MOR in parallel and perpendicular direction ranging from 0,5186 to 0,7924 and 0,5452 to 0,6859, respectively. According to the tables, it can be observed that equations obtained from MOR and ASG showed determination coefficient values satisfactory; therefore, equations explain much of the linear interaction between the two properties, showing also the high correlation.

Table 5 and table 6 present the equations together with the determination coefficient and standard error of estimate obtained for the Modulus of Elasticity obtained in the direction parallel and perpendicular to plane of panels to each species.

It can be observed that the coefficient of determination values for MOE in parallel and perpendicular direction ranging from 0,5297 to 0,9203 and 0,4124 to 0,6590, respectively. As found in the MOR values; probably because they are deeply correlated, the values obtained to MOE showed directly proportional to specific gravity of panels.

Table 7 presents the equations with the coefficient of determination and the standard error of estimate obtained for Internal Bond for each species.

TABLE 1. Estimated equations for water absorption after 2 hours by species.

Species	Equations	F	R²	Syx
E. benthamii	WA 2h = - 35,6721ASG + 36,6351	495,45*	0,9501	0,77
E. dunnii	WA 2h = - 41,9789ASG + 43,6034	97,08*	0,8292	1,28
E. grandis	WA 2h = - 35,2343ASG + 35,6076	65,98*	0,7499	1,41
E. urograndis	WA 2h = - 38,2368ASG+ 39,1844	176,58*	0,8803	1,57
E. saligna	WA 2h = - 44,0301ASG + 42,9089	152,31*	0,8639	1,61
Mix	WA 2h = - 38,9708ASG + 39,6259	86,97*	0,7698	1,68
P. taeda	WA 2h = - 107,811ASG + 104,017	97,08*	0,7802	5,46

* Significant at 5% probability of error.

WA 2h = Water Absorption after 2 hours of immersion; ASG = Apparent Specific Gravity.

TABLE 2. Estimated equations to water absorption after 24 hours by species.

Species	Equations	F	R²	Syx
E. benthamii	WA 24h = - 90,3628ASG+ 101,351	606,39*	0,9604	1,74999
E. dunnii	WA 24h = - 103,901ASG + 117,544	123,38*	0,8205	4,61379
E. grandis	WA 24h = - 105,703ASG + 110,95	76,75*	0,7470	4,01577
E. urograndis	WA 24h = - 108,903ASG + 116,517	243,18*	0,8967	4,22347
E. saligna	WA 24h = - 117,640ASG + 118,594	285,76*	0,9108	4,06453
Mix	WA 24h = - 93,6589ASG + 102,314	126,25*	0,8238	3,35897
P. taeda	WA 24h = - 123,927ASG + 152,399	143,42*	0,8516	5,31435

* Significant at 5% probability of error.

WA 24h = Water Absorption after 24 hours of immersion; ASG = Apparent Specific Gravity.

TABLE 3. Estimated equations to MOR parallel by species.

Species	Equations	F	R²	Syx
E. benthamii	MOR = 75,5329ASG - 25,7039	88,15*	0,7655	3,69
E. dunnii	MOR = 96,1925ASG - 41,9166	140,13*	0,7924	4,94
E. grandis	MOR = 94,6051ASG - 32,6963	36,04*	0,6692	5,09
E. urograndis	MOR = 104,361ASG - 43,5444	104,47*	0,7844	5,89
E. saligna	MOR = 99,3502ASG - 34,5875	55,82*	0,6074	5,36
Mix	MOR = 69,2747ASG - 14,9858	51,82*	0,5186	5,65
P. taeda	MOR = 97,0801Asg - 32,4374	85,84*	0,7675	4,37

*Significant at 5% probability of error.

MOR = Modulus of Rupture; ASG = Apparent Specific Gravity.

TABLE 4. Estimated equations for MOR perpendicular by species.

Species	Equations	F	R²	Syx
E. benthamii	MOR = 65,6161ASG - 21,2101	17,54*	0,5743	5,38
E. dunnii	MOR = 66,2006ASG - 19,7609	5,99*	0,5452	4,04
E. grandis	MOR = 54,064ASG - 12,0822	17,03*	0,6301	3,46
E. urograndis	MOR = 71,8782ASG - 25,8767	27,22*	0,6447	4,41
E. saligna	MOR = 58,9796ASG - 9,22809	15,16*	0,5795	4,56
Mix	MOR = 115,408ASG - 59,3886	28,39*	0,6859	6,50
P. taeda	MOR = 55,1541ASG - 14,3944	22,36*	0,6507	2,88

*Significant at 5% probability of error.

MOR = Modulus of Rupture; ASG = Apparent Specific Gravity.

TABLE 5. Estimated equations to MOE parallel by species.

Species	Equations	F	R²	Syx
E. benthamii	MOE = 12502,5ASG - 3444,89	311,75*	0,9203	324,58
E. dunnii	MOE = 14686ASG - 4844,47	140,13*	0,8590	597,58
E. grandis	MOE = 10684,1ASG - 1780,79	36,04*	0,5297	770,97
E. urograndis	MOE = 17568,3ASG - 6431,66	104,47*	0,7946	969,51
E. saligna	MOE = 14473,3ASG - 3905,47	55,82*	0,6907	650,53
Mix	MOE = 11708,3ASG - 2051,31	51,82*	0,6835	674,26
P. taeda	MOE = 8942,08ASG - 1820,85	158,48*	0,8591	296,37

* Significant at 5% probability of error.
MOE = Modulus of Elasticity; ASG = Apparent Specific Gravity.

TABLE 6. Estimated equations for MOE perpendicular by species.

Species	Equations	F	R²	Syx
E. benthamii	MOE = 5947,23ASG - 1603,49	23,89*	0,6476	417,76
E. dunnii	MOE = 3785,62ASG + 408,23	9,30*	0,6503	185,69
E. grandis	MOE = 3484,69ASG + 286,295	10,74*	0,5179	281,05
E. urograndis	MOE = 6184,14ASG -1584,31	17,13*	0,5331	477,89
E. saligna	MOE = 3936,57ASG + 622,206	7,72*	0,4124	426,12
Mix	MOE = 9868,62ASG - 4432,3	16,56*	0,5602	727,34
P. taeda	MOE = 4499,4ASG - 902,16	23,19*	0,6590	230,55

*Significant at 5% probability of error.
MOE = Modulus of Elasticity; ASG = Apparent Specific Gravity.

TABLE 7. Estimated equations for Internal Bond by species.

Species	Equations	F	R²	Syx
E. benthamii	IB = 1,78893ASG - 0,791231	56,52*	0,7108	0,11
E. dunnii	IB = 1,17014ASG - 0,485519	33,51*	0,5827	0,09
E. grandis	IB = 1,34317ASG - 0,424055	36,61*	0,5847	0,09
E. urograndis	IB = 1,24017ASG - 0,494409	82,95*	0,7904	0,06
E. saligna	IB = 1,11112ASG - 0,322361	61,04*	0,7532	0,07
Mix	IB = 1,41473ASG - 0,454031	38,11*	0,6558	0,08
P. taeda	IB = 0,919355ASG + 0,0140927	19,26*	0,4075	0,16

*Significant at 5% probability of error.
IB = Internal Bond; ASG = Apparent Specific Gravity.

For Internal Bond, the determination coefficient values ranged from 0,4075 to 0,7904, to *P. taeda* and *E. urograndis*, respectively. With exception to *P. taeda,* the models explain more than 50% of results; thus, the trend of internal bond behavior to the *Eucalyptus* species was better represented with the equations. The low correlation found between specific gravity and internal bonding was also observed by Iwakiri *et al.* (2008b), indicating the impossibility of predicting the bond strength based on the specific gravity of the panels at 5% probability of error.

Through of graphs, it was found clearly that WA 2h and WA 24h to the studied species, showed an inversely proportional relationship the ASG of panels. Furthermore, observed that the panels composed of *Eucalyptus* species showed less propensity to absorption which the panels produced with control species (*Pinus taeda*).

According to figure 1, among the species the *E. saligna* was the that suffered the greatest influence of specific gravity in absorption, showing the highest absorption values in panels with lower density, however, the smaller values in panels with higher densification.

It can be observed in the graphics that the variables MOR and ASG are directly proportional between them, in other words, as higher the specific gravity of panels, a greater Modulus of Rupture tends to be obtained.

To MOE in parallel direction the species showed near, however, a higher data scattering was found to MOE in perpendicular direction; the species *E. saligna* highlighted with the highest values.

The association between the internal bond and specific gravity of panels according to the graph is of proportionality, thus the resistance accompanied the increase in densification of panels.

DISCUSSION

Physical properties

According to the results it can be affirmed that the specific gravity of panel exerts a significant influence on absorption properties; therefore, the higher the specific gravity of panels is, the smaller will be the water absorption. Some authors such, as Melo and Dell Menezzi (2010), believe that the higher water absorption in panels of lower density has occurred because there is a greater volume of voids that can be occupied by water.

Under the conditions of this study, and through of shown equations, it can obtain panels with water absorption values preestablished working with the variation of the nominal specific gravity according to the species used, but, generally, for obtaining panels with lower indexes of water absorption, the increasing of

density of panels is necessary, however, according to Chen, Du and Wellwood (2010), although, this propertie benefitted from higher panel density, and increasing density means increased manufacturing cost.

The European standard EN 300:2006 does not stipulate maximum values of water absorption to OSB, therefore, it can work with the specific gravity as function of other variables of greatest impact.

Mechanical properties

According with results, the MOR and ASG have a relationship directly proportional, in other words, as higher the specific gravity of panels, a greater Modulus of Rupture tends to be obtained.

The standard EN 300:2006 recommends minimum values of MOR parallel and perpendicular to OSB Class 1 and 2 of 20 MPa and 10 MPa, respectively. Thus, through the equations obtained and in conditions of this study, it can be worked with panels with specific gravity of 0,50 g/cm³ to 0,65 g/cm³ to adequate the parallel MOR requirement and from 0,53 g/cm³ to 0,60 g/cm³ to adequate the perpendicular MOR requirement, according to the species to be used. Therefore, good quality panels can be manufactured having a better utilization of raw materials available, and consequently reducing the amount of components used as the resin, because it is the element of greatest cost in panels production, as well as reducing the weight of the product which implies directly on transportation cost.

For MOE the Mix of species obtained a greater influence of specific gravity, with a significant increase in MOE values according with specific gravity of panels.

According to EN 300:2006, the minimum acceptable values for MOE are 3500 MPa for parallel and 1400 MPa for perpendicular. Based in obtained equations, it can be estimate a specific gravity range of 0,48 g/cm³ to 0,60 g/cm³, according to species to obtain MOE values that adequate the minimum standard requirements in parallel direction. For MOE in perpendicular direction, the estimated range of specific gravity to work is 0,27 g/cm³ to 0,60 g/cm³; however, the parallel MOE can be damaged if it is considered a specific gravity value only to adequate MOE values in perpendicular direction.
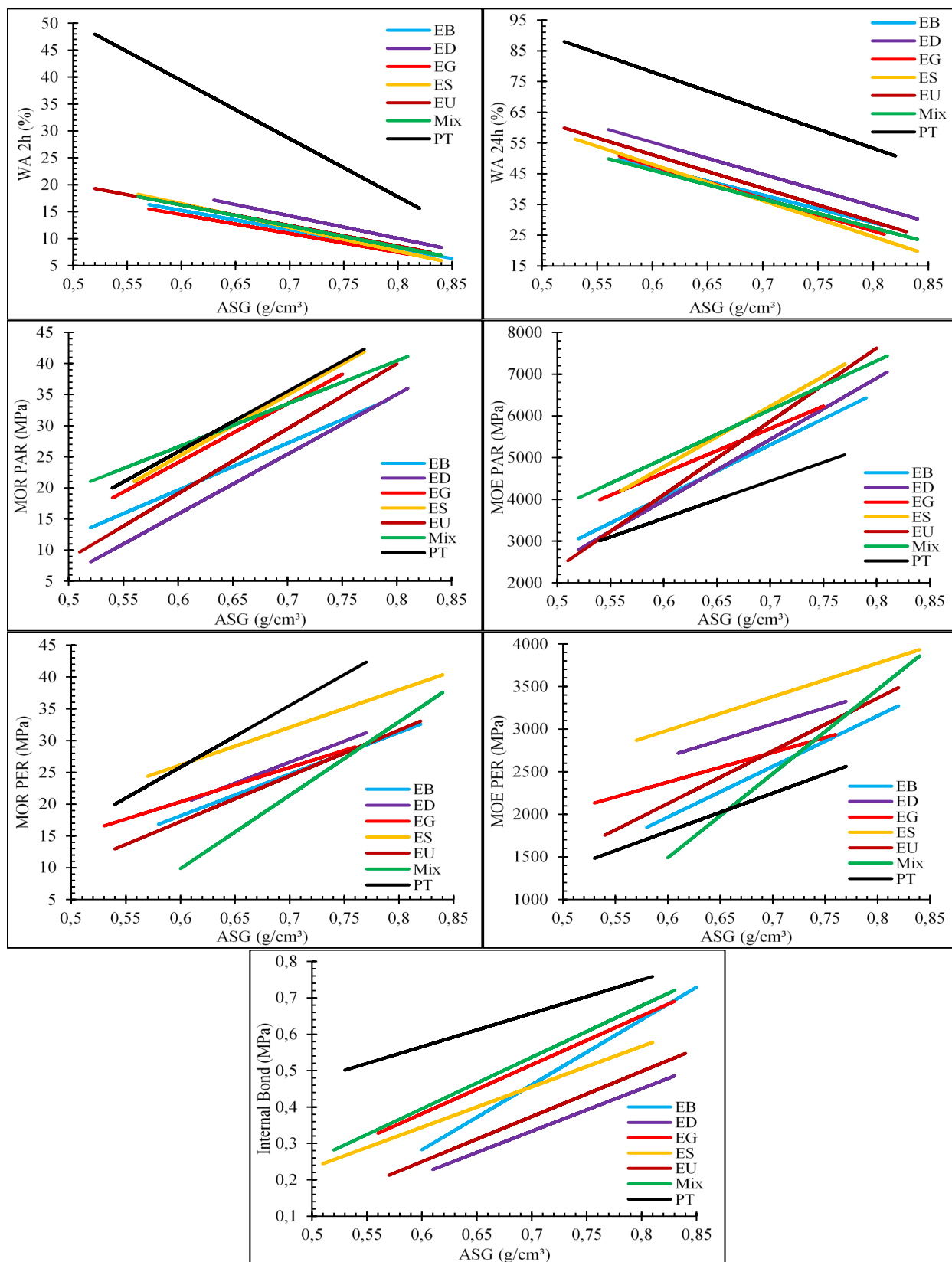
FIGURE 1. Graphs with estimated trend lines for physical and mechanical properties of panels as a function of ASG by species.

Note: WA = Water Absorption; MOR = Modulus of Rupture; MOE = Modulus of Elasticity; PAR = Paralel; PER = Perpendicular; EB = *Eucalyptus benthamii*; ED = *Eucalyptus dunnii*; EG = *Eucalyptus grandis*; ES = *Eucalyptus saligna*; EU = *Eucalyptus urograndis*; PT = *Pinus taeda*.

For internal bond, it is noted that the control species (*P. taeda*) was highlighted when compared with the other species, it may be linked to fact that *P. taeda* has a lower wood specific gravity, the main factor contributing to obtaining panels with high compression ratio, high compression ratio value ensures good contact between particles and good densification of panel. Maloney (1993) affirms that a higher compression between particles, the larger amount of resin used effectively between, resulting in good adhesion.

On the other hand, among the species of *Eucalyptus*, it was observed that the Mix resulted in good internal bond, exceeding the values obtained for each species separately. Thus, it can be affirmed that there was a positive interaction between species, obtaining good results for the property in question.

According to standard EN 300:2006, the minimum acceptable value for internal bond is 0,32 MPa. Through of equations obtained for each species, it is estimated that it can achieve the standard requirement, working under the conditions of this study with specific gravity of panels in the gap of 0,34 g/cm³ to 0,69 g/cm³.

Therefore, through of equations obtained for each species, it is possible to optimize the properties of OSB panels to be produced, making it to achieve pre-determined values by variation of specific gravity of panels.

Conclusions

Based on the results obtained in this study it can be concluded that:

The water absorption has an inverse proportional relationship with the specific gravity of panel.

The relationship between mechanical properties and specific gravity of panel is directly proportional.

Except internal bond, panels produced with the *Eucalyptus* species showed better properties than those produced with the control species (*Pinus taeda*).

For internal bond, the Mix balanced the values emphasizing among *Eucalyptus* species.

The equations obtained for each species showed a good representation of data with satisfactory determination coefficients.

Through of linear models obtained in conditions of this study for each species, it can be estimated the specific gravity to produce OSB panels that will adequate the European standard requirements.

References

Associação Brasileira de Produtores de Florestas Plantadas [Abraf]. (2013). *Anuário estatístico*. Brasília.

Chen, S., Du, C., & Wellwood, R. (2010). Effect of panel density on major properties of oriented strandboard. *Wood and Fiber Science*, *42*(2),177-184.

Gorski, L., Cunha, A. B., Rios, P. D., Trianoski, R., & Martarello, L. P. (2015). Produção de painéis de partículas orientadas (OSB) de *Eucalyptus benthamii* e *Pinus* spp. em diferentes combinações de camadas. *Scientia Forestalis*, *43*(106), 367-375. doi: 36280/26965

Indústria Brasileira de Árvores [IBÁ]. 2014. *Anuário estatístico*. Brasília.

Istek, A., & Siradag, H. (2013). The effect of density on particleboard properties. *International Caucasian Forestry Symposium*, 932-938.

Iwakiri, S., Albuquerque, C. E. C., Prata, J. G., & Costa, A. C. B. (2008a). Utilização de madeiras de *Eucalyptus grandis* e *Eucalyptus dunnii* para produção de painéis de partículas orientadas – OSB. *Ciência Florestal*, *18*(2), 265-270. doi: 10.5902/19805098463

Iwakiri, S., Stinghen, A. B. M., Silveira, E. L., Zamarian, E. H. C., Prata, J. G., & Bronoski, M. (2008b). Influência da massa específica sobre as propriedades mecânicas de painéis aglomerados. *Floresta*, *38*(3), 487-493. doi: 10.5380/rf.v38i3.12414

Kelly, M. W. (1977). *A critical literature review of relationships between processing parameters and physical properties of particleboards* (General Technical Report 10). Madison, United States: USDA, Forest Service, Forest Products Laboratory.

Maloney, T. M. (1993). *Modern particleboard & Dry-process fiberboard manufacturing*. São Francisco: Miller Freeman Inc.

Melo, R. R., & Del Menezzi, C. H. S. (2010). Influência da massa específica nas propriedades físico-mecânicas de painéis aglomerados. *Silva Lusitana*, *18*(1), 59-73.

Mendes, L. M., Mendes, S. A., Iwakiri, S., Chaves, M. D., Mori, F. A., & Mendes, R. F. (2008). Influência da densidade do painel e da composição em camadas nas propriedades físico-mecânicas de painéis "OSB" de clones de *Eucalyptus spp. Cerne*, *14*(4), 379-385.

Mendes, R. F., Mendes, L. M., Mendonça, L. L., Guimarães Júnior, J. B., & Mori, F. A. (2014). Qualidade de painéis aglomerados homogêneos produzidos com a madeira de clones de *Eucalyptus urophylla*. *Cerne*, *20*(2), 329-336. doi: 10.1590/01047760.201420021273.

Moslemi, A. A. (1974). *Particleboard: technology*. London, England: Southern Illinois University.

Trianoski, R., Iwakiri, S., & Matos, J. L. (2014). Avaliação de painéis aglomerados de *Toona ciliata* produzidos com diferentes densidades e teores de resina. *Madera y Bosques*, *20*(3), 49-58. doi: 10.21829/myb.2014.203151