SCIENTIA
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Use of hybrid *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* and *Pinus taeda* L. in the production of OSB panels

Utilização do híbrido *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* e *Pinus taeda* L. na produção de painéis OSB

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Resumo

O objetivo do trabalho foi avaliar o potencial de utilização da madeira do híbrido *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* para a produção de painéis OSB. Para a realização do estudo foram utilizadas árvores de *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* (PECH) e árvores de *Pinus taeda* L. (PT). O delineamento experimental constituiu-se de 8 tratamentos, arranjados em esquema fatorial, com a avaliação dos efeitos de 2 ciclos de prensagem (ciclo convencional de laboratório e ciclo modificado com alívio da pressão em patamares) e de 4 proporções de mistura de partículas de madeira de PECH e de PT (sem mistura; 75% PECH e 25% PT; 50% PECH e 50% PT). Mediante a análise dos resultados concluiu-se que: O aumento da proporção de partículas da madeira de PECH na manufatura do OSB resultou em tendência de redução dos valores da massa específica e das propriedades mecânicas MOR paralelo e MOE paralelo e perpendicular dos painéis. A estabilidade dimensional foi influenciada negativamente pelo ciclo de prensagem modificado e a utilização de PECH em diferentes proporções, resultando em tendência de aumento dos valores de absorção de água e inchamento em espessura. Apesar dessas tendências, os painéis OSB manufaturados com as partículas de madeira de PECH na proporção 50%, apresentaram o maior potencial de uso da madeira do híbrido.

Palavras-chave: Painéis de partículas orientadas, ciclo de prensagem, mistura de partículas, propriedades físico-mecânicas.

Abstract

The aim of this study was to evaluate the potential use of the wood of the hybrid *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* for the production of OSB panels. For the study we used trees of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* (PECH) and *Pinus taeda* L. (PT). The experiment consisted of 8 treatments arranged in a factorial design, with the assessment of the effects of two pressing cycles (conventional laboratory cycle and modified cycle with pressure relief in steps) and four PECH and PT wood particle mixture proportions (unmixed; 75% PECH and 25% PT, 50% PECH and 50% PT). Increasing the PECH wood particle proportion in the manufacture of OSB resulted in a tendency to reduce the values of apparent density and the mechanical properties of the panels MOR parallel and MOE parallel and perpendicular. Dimensional stability was negatively influenced with modified pressing cycle and the use of PECH in different proportions, resulting in a tendency towards increase of the water absorption and thickness swelling values. Despite these trends, OSB manufactured from PECH wood particles in the 50% proportion, showed the highest potential for use of the hybrid wood.

Keywords: Oriented strand board, pressing cycle, particle mixture, physical and mechanical properties.

INTRODUCTION

OSB panels are used for structural applications such as ceilings, floors and beam structural components, among others, in view of their mechanical strength characteristics. The great advantage in

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their production, compared to competing products, is the degree of utilization of the wood logs; in that the losses are minimal and occur in the generation and drying phases of the particles in the form of fines (IWAKIRI, 1999).

Wood apparent density is one of the basic requirements in the choice of species for the OSB production, as it directly influences the OSB compression ratio, as well as interacts with other variables in the process (MALONEY, 1993).

Studies on properties as well as production and the influence of processing variables of OSB from *Pinus* species have been conducted by authors such as Del Menezzi (2004); Iwakiri et al. (2009); Mendes et al. (2012); Pecho et al. (2004); Saldanha e Iwakiri (2009).

Considering the growing need to supply raw material for the wood industry, an increase in the number of species with potential use is desirable and may be possible through research.

In 2000, Brazil began the implantation of experimental plots with the *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* hybrid. Studies conducted to date on the development of the hybrid revealed that its genetic material would be suitable for cultivation in the South, Southeast and Midwest regions of the country. In addition, it showed high relative precocity compared to other pure plantations of *Pinus elliottii* and *Pinus taeda*, since at 5.6 years of age the hybrid showed an average annual increase (AAI) of 44.8m^3/ha/year; compared to *Pinus elliottii* 18.8 m^3/ha/year and *Pinus taeda* 28.5 m^3/ha/year (PINUS BRASIL, 2010).

Although there are few references in the literature about the quality of the wood of the hybrid in question and its potential for technological application for generating specific wood products, especially in Brazil, studies on physical and mechanical properties, production of veneer and manufacture of plywood (ALMEIDA, 2012) with the wood of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* have been conducted in the Escola Superior de Agricultura "Luiz de Queiroz".

Accordingly, we conducted this study to evaluate the potential use of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* hybrid wood for the production of OSB panels.

MATERIAL AND METHODS

In the present study five trees were used of the *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* (PECH) hybrid at 7 years and 10 months of age, planted in the municipality of Buri, São Paulo - Brazil, and four trees of *Pinus taeda* L. (PT), at 35 years of age, planted in the municipality of Jaguariaíva, Parana - Brazil. The *Pinus taeda* wood, used commercially for the production of OSB, was placed in mixture proportions with the hybrid wood to improve the compression ratio of the panels.

Experimental design

The experimental design consisted of eight treatments in a 4 x 2 factorial arrangement, in which the factors were the proportion of particles of different woods (PECH and PT) and pressing cycles (conventional and modified), respectively, as described in Table 1. For each of the treatments three OSB panels were produced, with a nominal density of 0.65 g/cm^3 and dimensions of 560 x 560 x 15.7 mm. The strand-like particles were produced in the dimensions of 0.65 x 25 x 90 mm (thickness, width and length, respectively).

Table 1. Experimental design for the OSB panel production.
Tabela 1. Delineamento experimental para a produção dos painéis OSB.

Treatments	Proportion of PECH particles (%)	Proportion of PT particles (%)	Pressing cycle
T1	0	100	Conventional
T2	100	0	
T3	75	25	
T4	50	50	
T5	0	100	Modified
T6	100	0	
T7	75	25	
T8	50	50	

Sci. For., Piracicaba, v. 43, n. 108, p. 763-772, dez. 2015
DOI: dx.doi.org/10.18671/scifor.v43n108.2

Manufacture of panels and property evaluations

The application of the adhesive and the wax was carried out by spraying in a rotary blender. The adhesive was phenol-formaldehyde (PF), with a solids content of 53.2%, a pH of 11.74, gel time at 121° C of 8.33 minutes and viscosity of 620 cP at 25°C. The amount of adhesive used was 6% solids (based on particle dry mass). The wax was added at 1% of solids (based on particle dry mass).

All OSB panels were produced with three layers composed of face, core and face at the respective proportions of 30:40:30, based on the mass of particles, the faces being arranged perpendicular to the core.

After the particle mat had undergone a cold pre-pressing in a manual hydraulic press, it was placed in a motorized hydraulic press. Besides the mix proportion ratio between the woods, the other factor tested in the manufacture of the panels was the pressing cycle, aiming at the improvement of dimensional stability. Figure 1 illustrates the two pressing cycles (conventional and modified) adopted. In both pressing cycles the maximum pressure was 35 kgf/cm², at a 180°C of temperature and a total time of 10 minutes, using separators with a 15.7 mm of thickness.

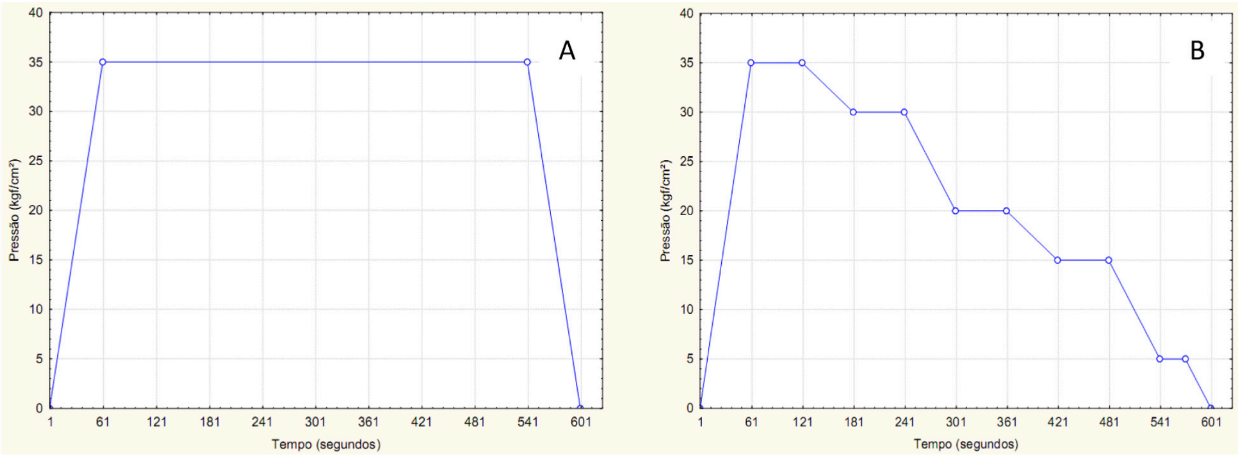

Figure 1. Pressing cycles: A) Conventional pressing cycle; B) Modified pressing cycle.
Figura 1. Ciclos de prensagem: A) Ciclo de prensagem convencional; B) Ciclo de prensagem modificado.

After pressing, the consolidated OSB panels were removed from the press and conditioned at 22 ± 2°C temperature and 65 ± 5% relative humidity. A sliding table saw was used to obtain the OSB test-samples.

The dimensions of the test-samples and the procedures used to evaluate the properties and/or parameters, panel moisture content, water absorption (WA) after two and twenty-four hours of immersion, thickness swelling (TS) after two and twenty-four hours of immersion, irreversible thickness swelling rate (ITS) and internal bond (IB); were defined based on the American Norm ASTM D 1037 (2006). To evaluate the properties of MOR and MOE in bending in parallel and perpendicular directions, the DIN 52362 (1982) norm was used. The apparent density of the panel was determined by averaging the densities of the test-samples used in all the tests mentioned above, totalizing 16 per panel.

Statistical analyses were carried out in a completely randomized design with treatments arranged in a 4 x 2 factorial design (four levels of species association and two types of pressing cycle). To verify the effect of the factors, analyses of variance were conducted and subsequently Tukey tests at a 95% level of probability were carried out.

RESULTS AND DISCUSSION

Moisture content, apparent density and thickness of OSB panels

The average basic apparent density determined for the wood of *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* was 0.34 g/cm³ and 0.50 g/cm³ for *Pinus taeda* wood.

The average values for moisture content, apparent density and thickness of OSB panels for each treatment, are shown in Table 2.

Table 2. Mean values of apparent density, moisture content and thickness of OSB panels.
Tabela 2. Valores médios de massa específica, teor de umidade e espessura dos painéis OSB.

Treatments	**Moisture Content** (%)	**Apparent Density** (g/cm³)	**Thickness** (mm)
100% PT/CC	9.8 (0.3) a	0.70 (0.03) b	15.78 (0.81) a
100% PECH/CC	10.3 (0.1) a	0.61 (0.01) a	17.48 (0.54) b
75% PECH + 25% PT/CC	10.1 (0.3) a	0.67 (0.02) ab	15.95 (0.39) a
50% PECH + 50% PT/CC	10.2 (0.5) a	0.67 (0.01) ab	15.96 (0.24) a
100% PT/MC	9.4 (0.2) a	0.70 (0.03) b	15.86 (0.44) a
100% PECH/MC	9.4 (0.2) a	0.66 (0.03) ab	16.45 (0.48) ab
75% PECH + 25% PT/MC	10.1 (0.3) a	0.67 (0.02) ab	16.32 (0.14) ab
50% PECH + 50% PT/MC	9.7 (0.5) a	0.68 (0.02) b	15.87 (0.51) a
Overall Average	9.9 (0.5)	0.67 (0.03)	16.21 (0.67)
CVe (%)	3.46	3.47	2.98

Means followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Values in parenthesis represent the standard deviation; PT: *Pinus taeda*; PECH: *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*; CC: Conventional Cycle; MC: Modified Cycle; CVe: experimental coefficient of variation

According to Table 2, there was no significant difference between the moisture content of the panels. The average moisture content of the panels ranged from 9.4 to 10.3% and the overall average was 9.9%. Information from LP Building Products, manufacturer of OSB in the United States, Canada, Chile and Brazil, indicates that the average moisture content of these panels is in the range of 8 ± 3% (LP BRASIL, 2012).

In the analysis of the average apparent density of the panels (Table 2) a significant difference was observed among treatments. The panels produced with unmixed PECH particles and at different mix ratios, except for the 50% PECH proportion of the modified pressing cycle, were statistically equal and show a tendency to reduce their average apparent density values in relation to the others. This trend had a more pronounced effect for the panels produced with PECH without mixture in the conventional cycle, causing a statistically significant difference to be observed between that treatment in relation to the panels produced with PT without mixing in the conventional and modified cycles.

According to Iwakiri (2005), particle boards with apparent density between 0.59 and 0.80 g/cm³ are classified as medium apparent density panels. Accordingly, all panels produced in the present study, with apparent density ranging from 0.61 to 0.70 g/cm³, fall into the class specified by the author.

Furthermore, upon examination of Table 2 there is also a significant difference between the average thicknesses of the panels. The lowest and highest average thickness numerical value of the panels corresponds, respectively, to treatments consisting of 100% PT/CC (15.78 mm) and 100% PECH/CC (17.48 mm). On the other hand, it was found that the opposite was verified for the average apparent density of the panels of these two treatments, as it was those that showed the highest (0.70 g/cm ³) and lowest (0.61 g/cm³) numeric value for this property.

According to Maloney (1993), an increase or expansion in the thickness occurs for most of the particle boards following the opening of the hot press, at the end of pressing, following the pressing pressure relaxation. Taking into account that the increase of the thickness results in an increase in the volume of the panel and the panel apparent density is given by the ratio between mass and volume, it can be inferred that the tendency to reduce the apparent density of the panels composed of PECH is explained, in part, by to the increase in their thickness.

The lower apparent density of the PECH wood (0.34 g/cm³) means that there is an increase in the height of the mat for the same mass of particles and consequently, there is an increase of specific surface area, which in turn can change the availability of the adhesive. Furthermore, woods with lower densities cause the panels to have a higher nominal compression ratio and they release the compressive stress generated during the pressing process to a greater extent, resulting in increased panel thickness after this process, and as previously discussed, in decreased panel apparent density.

Sci. For., Piracicaba, v. 43, n. 108, p. 763-772, dez. 2015
DOI: dx.doi.org/10.18671/scifor.v43n108.2

Water absorption, thickness swelling and irreversible thickness swelling rate

The average water absorption values for the OSB panels after two and twenty-four hours of immersion (WA2h and WA24h), regarding the particle proportion and pressing cycle factors are shown in Tables 3 and 4, respectively. According to analysis of variance, there was no significant interaction between the two factors analyzed.

Table 3. Water absorption (WA) after two and twenty-four hours of immersion related to wood type.
Tabela 3. Absorção de água após duas e vinte e quatro horas de imersão em função do tipo de madeira.

Proportion of particles	WA 2h	WA 24h
	%	
100% PT	39.52 (6.18) a	64.21 (4.83) a
100% PECH	37.67 (9.42) a	89.05 (12.51) b
75% PECH + 25% PT	37.45 (6.16) a	84.70 (7.28) b
50% PECH + 50% PT	39.97 (6.20) a	80.60 (9.60) b

Means followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Values in parenthesis represent the standard deviation; PT: *Pinus taeda*; PECH: *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*

According to Table 3, it can be seen that there was no significant influence of the type of wood on the WA2h. For WA24h the proportion composed of 100% PT particles differed significantly from the others, presenting the lowest average value. We also observe that the panels with an increased proportion of PECH particles tended towards higher WA24h values.

Considering that the PECH wood had low apparent density, and this fact led to an increase in the particle volume used in the panel manufacture, one can deduce that the number of hygroscopic sites available for water binding also increased, a fact also associated with the lowest apparent density of the panels produced with highest proportions of PECH wood particles and also the highest thickness swelling after two hours of immersion in water of the panels produced with PECH wood (Table 5), which contributed to the WA24h increase.

Table 4. Water absorption (WA) after two and twenty-four hours of immersion related to pressing cycles.
Tabela 4. Absorção de água após duas e vinte e quatro horas de imersão em função dos ciclos de prensagem.

Pressing cycle	WA 2h	WA 24h
	%	
Conventional	36.35 (7.27) a	75.57 (10.70) a
Modified	40.96 (5.54) a	83.71 (13.77) b

Means followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Values in parenthesis represent the standard deviation

According to the data in Table 4, a significant difference can be observed between cycles only for the WA24h property. The modified cycle caused a negative effect on the panel, resulting in higher water absorption after twenty-four hours of immersion. It is assumed that the consolidation of the panel was less effective for the modified cycle, facilitating water penetration.

Iwakiri et al. (2003) produced OSB panels from *Pinus taeda* with nominal density of 0.70 g/cm ^{3} and found water absorption values after 2 and 24 hours, of 38% and 55%, respectively, with only the value for immersion in 2 hours being consistent with that obtained in the present work.

Gouveia et al. (2003) produced OSB panels of *Eucalyptus grandis* and *Pinus elliottii* with the mix proportion set at 50% and adhesive content equal to 6% and found water absorption values after 2 and 24 hours of 6.92% and 37.53%, respectively; lower than the results obtained in the present study.

Regarding the analyses of variance performed for the properties thickness swelling of OSB panels after two and twenty-four hours immersion (TS2h and TS24h) irreversible thickness swelling rate (ITS), it was found that there was significant interaction among treatments for the particle proportion and pressing cycle factors. The average values for the TS2h, TS24h and ITS, of the interactions between particle proportion and pressing cycle factors are shown in Table 5.

Table 5. Thickness swelling (TS) after two and twenty-four hours of immersion and irreversible thickness swelling rate (ITS) of the interactions between the particle proportion and pressing cycle factors.
Tabela 5. Inchamento em espessura após duas e vinte e quatro horas de imersão e taxa de não-retorno em espessura das interações entre os fatores proporção de partículas e ciclo de prensagem.

	TS 2h	
Proportion of particles	Pressing cycle	
	Conventional	Modified
	%	
100% PT	16.50 (1.85) aA	17.37 (0.75) aA
100% PECH	23.94 (3.32) bA	30.63 (1.18) bcB
75% PECH + 25% PT	22.38 (1.18) bA	28.04 (1.08) bB
50% PECH + 50% PT	21.80 (1.06) bA	33.63 (2.89) cB
	TS 24h	
Proportion of particles	Pressing cycle	
	Conventional	Modified
	%	
100% PT	22.63 (2.77) aA	27.80 (1.34) aB
100% PECH	41.20 (0.81) cA	49.75 (1.32) cB
75% PECH + 25% PT	38.18 (1.17) bcA	43.99 (1.68) bB
50% PECH + 50% PT	33.71 (2.15) bA	46.45 (3.42) bcB
ITS		
Proportion of particles	Pressing cycle	
	Conventional	Modified
	%	
100% PT	15.48 (2.56) aA	19.95 (0.96) aB
100% PECH	37.45 (0.92) cA	42.48 (1.75) cB
75% PECH + 25% PT	30.90 (1.13) bA	36.25 (1.64) bB
50% PECH + 50% PT	27.44 (1.85) bA	38.25 (2.63) bB

Means followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Lowercase letters refer to values in columns and uppercase values on the lines. Values in parenthesis represent the standard deviation; PT: *Pinus taeda*; PECH: *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*

According to the data in Table 5, analyzing the particle proportion factor within each pressing cycle, it is observed that the panels produced with 100% PT presented a significant difference from the others in both pressing cycles, with lower values in all properties.

Through the analysis of interactions (Table 5), we can see that the modification of the pressing cycle on the various proportions of particles in the manufacture of the OSB panels provided a statistically significant effect on those properties, considerably affecting the dimensional stability of the panels. It was found that there were significant differences between the TS2h, TS24h and ITS values in almost all treatments, except for the panels produced with 100% PT for the TS2h property.

It was found that the use of PECH wood at a proportion of 50% and 75% mixture was statistically equivalent for all properties within the conventional cycle. In the modified cycle, these same proportions were equivalent only for the TS24 and ITS.

It was also observed that increasing the proportion of PECH particles causes increase in physical property values, which can be associated with the release of compressive stress, allied to the low PECH wood density and, therefore, greater compression ratio, which facilitated and enhanced the entry of water into the layers of the panel.

Pecho et al. (2004) evaluated the influence of juvenile wood of *Pinus radiata* on the physical and mechanical properties of OSB and found a significant difference in the thickness swelling values after immersion for 24 hours. Panels made of 100% juvenile wood differed significantly from the others, presenting an average value of 32.5%. Thus it can be said that the gain in thickness of the panels of the treatments with higher PECH is partly explained by the presence of juvenile wood.

Okino et al. (2009) evaluated the physical and mechanical properties of oriented strand board from *Pinus taeda* with strands of 200 mm in length and 5% phenol-formaldehyde adhesive and found values of 48.5% and 60.5% for TS2h and TS24h properties, respectively; higher than those found in our study for the properties in question.

Sci. For., Piracicaba, v. 43, n. 108, p. 763-772, dez. 2015
DOI: dx.doi.org/10.18671/scifor.v43n108.2

Note that the CSA Norm 0437 (1993) provides values only for the property thickness swelling after twenty-four hours of immersion, with the stipulated maximum value of 10% for panels with thickness greater than 12.7 mm. According to the above, the panels of all treatments exhibited average values above those stipulated by the reference standard and as such, could not meet it.

Mechanical properties

The average values for internal bond, modulus of rupture parallel (MOR) and modulus of elasticity (MOE) in parallel and perpendicular static bending, of the proportion of particles and pressing cycle factors, are shown in Tables 6 and 7, respectively. According to the analysis of variance, there was an interaction between factors only for the MOR perpendicular variable. The results are shown in Table 8.

Table 6. Mean values of internal bond, modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending in function of the type of wood.
Tabela 6. Valores médios de ligação interna e de módulo de ruptura (MOR) e módulo de elasticidade (MOE) à flexão estática em função do tipo de madeira.

Proportion of particles	MOR Parallel	MOE Parallel	MOE Perpendicular	Internal Bond
	MPa			
100% PT	49.57 (5.15) c	7600.24 (650.49) c	1353.00 (94.91) b	0.50 (0.10) a
100% PECH	37.02 (3.33) a	3788.92 (355.30) a	1078.39 (148.48) a	0.55 (0.15) a
75% PECH + 25% PT	42.68 (3.95) ab	4812.42 (621.46) b	1233.43 (98.96) ab	0.64 (0.05) a
50% PECH + 50% PT	45.75 (4.36) bc	5477.87 (515.38) b	1327.87 (238.56) ab	0.49 (0.08) a

Averages followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Values in parenthesis represent the standard deviation; PT: *Pinus taeda*; PECH: *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*

According to the data in Table 6, the average values of MOR parallel for the panels made of 100% and 75% of PECH wood, were equivalent and differ significantly from the proportion of panels which were composed of 100% PT particles. This result may be an indication that there was an influence of the apparent density of the panels on the results of MOR parallel, that is; by reducing the apparent density, there was a subsequent reduction of the values for this property.

In analyzing the MOE parallel, we found that the proportions composed of 75% and 50% PECH were statistically equivalent and different from the other proportions. The panels consisting of 100% PECH also differed significantly from the other proportions, presenting the lowest value of MOE parallel. The proportion of 100% PT showed the highest average MOE parallel.

With regard to the MOE perpendicular, it appears that the proportions made up of PECH were statistically equivalent, but only the 100% PECH proportion differed significantly from the 100% PT particle proportion, thus presenting the lowest average value for this property.

Also according to Table 6, analyzing the internal bonding property, it is observed that there was no significant difference among treatments for the particle proportion factor. However, it was noted that there was a tendency of increased internal bond with the increase in the PECH proportion.

Table 7. Mean values of internal bond and modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending in function of pressing cycles.
Tabela 7. Valores médios de ligação interna e de módulo de ruptura (MOR) e módulo de elasticidade (MOE) à flexão estática em função dos ciclos de prensagem.

Pressing cycle	MOR Parallel	MOE Parallel	MOE Perpendicular	Internal Bond
	MPa			
Conventional	43.77 (6.78) a	5399.31 (1477.72) a	1250.00 (195.06) a	0.58 (0.11) a
Modified	43.74 (5.73) a	5440.41 (1615.09) a	1246.35 (177.99) a	0.51 (0.10) a

Means followed by the same letter do not differ statistically by the Tukey test ($\alpha = 0.05$). Values in parenthesis represent the standard deviation

According to Table 7, it can be seen that there was no significant difference among treatments for the properties MOR parallel, MOE parallel and MOE perpendicular and internal bond, for the pressing cycle factor.

Table 8. Mean values of modulus of rupture (MOR) perpendicular to static bending of the interaction between the particle proportions x pressing cycle factors.
Tabela 8. Valores médios de módulo de ruptura perpendicular à flexão estática da interação entre os fatores proporção de partículas x ciclo de prensagem.

Proportion of particles	Pressing cycle	
	Conventional	Modified
	MPa	
100% PT	16.52 (1.01) aA	19.18 (1.86) aA
100% PECH	15.35 (0.74) aA	19.84 (1.05) aB
75% PECH + 25% PT	19.15 (2.01) abA	17.80 (0.73) aA
50% PECH + 50% PT	21.19 (2.51) bA	19.26 (2.79) aA

Means followed by the same letter do not differ statistically by the Tukey test (α = 0.05). Lowercase letters refer to values in columns and uppercase values on the lines. Values in parenthesis represent the standard deviation; PT: *Pinus taeda*; PECH: *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*

According to this interaction analysis (Table 8), it is emphasized that the combination of changing the pressing cycle with the use of a 100% of PECH particle (T6) proportion in the manufacture of OSB provided a statistically significant increase for the MOR perpendicular variable. It was also observed that within the conventional cycle, the treatment with a mixture of wood differed significantly from the others, showing the highest average values, which can be explained by the higher compression ratio of the particle mat. According to Kelly (1977), panels of the same nominal density produced with low density wood, present a higher compression ratio and consequent increase in the mechanical properties of the panels.

Bortoletto Júnior and Garcia (2004) determined the bending properties of commercial OSB panels of 15 mm thickness and found average values for the parallel and MOR perpendicular of 25 and 16 MPa, respectively. For MOE parallel and MOE perpendicular, the authors found values of 3987 MPa and 1756 MPa, respectively

Mendes et al. (2012) evaluated the effect of thermal treatment of oriented strand board and obtained values of 8061 MPa for MOE parallel and 2022 MPa for MOE perpendicular for panels composed of *Pinus taeda* and 6% phenol-formaldehyde adhesive. For MOR parallel and perpendicular the authors found average values of 57.5 and 20.8 MPa, respectively. For the internal bond property the authors obtained an average value of 0.60 MPa.

Saldanha and Iwakiri (2009), evaluating OSB produced with the wood of *Pinus taeda* L., nominal density of 0.65 g/cm³ and 6% phenol-formaldehyde adhesive, obtained an average value of 0.39 MPa for the internal bond property.

In general, the values obtained for the mechanical properties were consistent with those found in the literature, with the exception only of the values of MOE perpendicular, which were lower.

The CSA Norm 0437 (1993) stipulates MOR parallel 28.4 and 22.9 MPa as minimum values for ratings O1 and O2, respectively. For the MOR perpendicular the values are 12.2 and 9.4 MPa, respectively. Based on the above, all the results of modulus of rupture in bending were above those stipulated to classify as O2, the most demanding of that reference norm.

For the MOE parallel, the norm stipulates 5500 and 4500 MPa as minimum for ratings O1 and O2, respectively. The MOE perpendicular values are 1500 and 1300 MPa for ratings O1 and O2, respectively. It is observed that the treatments composed of 100% PT were above the values stipulated for the O2 classification by the reference norm; the treatments made up of 50% and 75% PECH particles were above the values stipulated for classification O1, and the treatments with 100% PECH did not meet the norm. For MOE perpendicular in the treatments consisting of 50% and 100% PT were above the values stipulated for the O1 classification, but the others did not meet the norm.

For the internal bond property, the norm stipulates a minimum value of 0.34 MPa for both O1 and O2 classifications. It was verified that the OSB of all treatments exhibited an average internal bond above the minimum required.

CONCLUSIONS

Increasing the *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* wood particle proportion in the experimental manufacture OSB trial resulted in downward trend in the values of apparent density and mechanical properties of MOR parallel and MOE parallel and perpendicular.

Sci. For., Piracicaba, v. 43, n. 108, p. 763-772, dez. 2015
DOI: dx.doi.org/10.18671/scifor.v43n108.2

The increase in the proportion of PECH wood particles in the experimental manufacture of OSB, combined with the modified pressing cycle, resulted in a trend towards increased values of WA24h, TS2h, TS24h and ITS of the panels.

Despite those tendencies, the OSB panels manufactured with the PECH wood particles in the 50% mixture proportion with PT wood particles, were those with the greatest potential for use of the hybrid wood, because they met the minimum requirements specified by the CSA Norm 0437 (1993) for all mechanical properties evaluated.

REFERENCES

ALMEIDA, N. F.; BORTOLETTO JR., G.; MENDES, R. F.; SURDI, P. G. Avaliação da madeira de *Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis* para produção de compensados. **Scientia Forestalis**, Piracicaba, v. 40, n. 96, p. 435-443, dez. 2012.

ASTM - AMERICAN SOCIETY FOR TESTING AND MATERIALS. D-1037: standard methods of evaluating properties of wood-base fiber and particles materials. In: ______. **Annual book of ASTM standard.** Philadelphia, 2006. p. 1-30.

BORTOLETTO JR., G.; GARCIA, J. N. Propriedades de resistência e rigidez à flexão estática de painéis OSB e compensados. **Revista Árvore**, Viçosa, v. 28, n. 4, p. 563-570, 2004.

CSA - CANADIAN STANDARDS ASSOCIATION. **0437.0–93**: OSB and Waferboard. Ontario, 1993. 18 p.

DEL MENEZZI, C. H. S. **Estabilização dimensional por meio do tratamento térmico e seus efeitos sobre as propriedades de painéis de partículas orientadas (OSB).** 2004. 226 p. Tese (Doutorado em Ciências Florestais) – Universidade Federal do Paraná, Curitiba, 2004.

DIN – NORMEN FÜR HOLZFASERPLATEN SPANPLATTEN SPERRHOLZ. **52362**: Testing of wood chipboards bending test, determination of bending strength. Berlin, 1982. 40 p.

GOUVEIA, F. N.; VITAL, B. R.; SANTANA, M. A. E. Avaliação de três tipos de estrutura de colchão e três níveis de resina fenólica na produção de chapas de partículas orientadas - OSB. **Revista Árvore**, Viçosa, v. 27, n. 3, p. 365-370, jun. 2003.

IWAKIRI, S. **Painéis de madeira reconstituída**. Curitiba: FUPEF, 2005. 245 p.

IWAKIRI, S.; MONTEFUSCO, A. R. G.; ZABLONSKY, K. M.; SIQUEIRA, K. P.; SALDANHA, L. K.; SOUZA, M. A. M. Produção de chapas de partículas "strand" com inclusão laminar – "Com-Ply". **Floresta e Ambiente**, Rio de Janeiro, v. 10, n. 2, p. 30-35, 2003.

IWAKIRI, S.; SALDANHA, L. K.; ALBUQUERQUE, C. E. C.; MENDES, L. M. Influência da espessura de partículas e reforço laminar nas propriedades dos painéis de partículas orientadas OSB de *Pinus taeda* L. **Cerne**, Lavras, v. 15, n. 1, p. 116-122, jan./mar. 2009.

KELLY, M. W. **A critical literature review of relationships between processing parameters and physical properties of particleboards.** Madison: USDA Forest service, 1977. 66 p. (FPL General Technical Report, 10).

LP BRASIL. **LP Building Products**. Disponível em: < http://www.lpbrasil.com.br/produtos/lp-osb-home-plus-estrutural.html >. Acesso em: 20 jan. 2012.

MALONEY, T. M. **Modern particleboard and dry-process fiberboard manufacturing**. 2.ed. São Francisco: Miller Freeman Publication, 1993. 689 p.

MENDES, R. F.; BORTOLETTO JR., G.; ALMEIDA, N. F.; SURDI, P. G.; BARBEIRO, I. N. Effect of thermal treatment on properties of OSB panels. **Wood Science and Technology**, Berlin, v. 47, n. 2, p. 243-256, 2012.

OKINO, E. Y. A.; TEIXEIRA, D. E.; SOUZA, M. R.; SANTANA, M. A. E.; SILVA, C B. G.; TOMAZ, R. B.; SOUSA, M. E. Uso das madeiras de seringueira, pinus e cipreste na fabricação de chapas OSB. **Floresta**, Curitiba, v. 39, n. 2, p. 457-468, abr./jun. 2009.

PECHO, R.; ANANIAS, R. A.; BALLERINI, A.; CLOUTIER, A. Influencia de la madera juvenil de *Pinus radiata* D. Don sobre las propiedades físicas y mecánicas de tableros Oriented Strand Board (OSB). **Maderas, Ciencia y Tecnología**, Concepción, v. 6, n. 1, p. 87-87, 2004.

PINUS BRASIL. **Pinus Brasil Agro Florestal LTDA**. Disponível em: < www.pinusbrasil.com.br >. Acesso em: 18 out. 2010.

SALDANHA, L. K.; IWAKIRI, S. Influência da densidade e do tipo de resina nas propriedades tecnológicas de painéis OSB de *Pinus taeda* L. **Floresta**, Curitiba, v. 39, n. 3, p. 571-576, jul./set.2009.

Recebido em 16/09/2014
Aceito para publicação em 09/04/2015