EFFECTS OF PLY GRADING AND ASSEMBLY ON THE PROPERTIES OF PLYWOOD PANELS FROM *Pinus merkusii*

Geraldo Bortoletto Júnior[1]

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ABSTRACT: This study aims to manufacture plywood panels with both graded plies (by visual and acoustic wave methods) and ungraded plies (randomly selected), bonded together in different arrangements, and also to verify the effect of these techniques on the specific mass, strength and stiffness against static bending and binding strength of finished panels. Plywood panels manufactured exclusively with superior quality plies, as graded by the acoustic wave method, and plywood panels manufactured exclusively with randomly selected plies had better performance, with no significant differences being noted between them, except for specific mass.

Key words: Ply grading, nondestructive testing, acoustic wave method.

EFEITOS DA CLASSIFICAÇÃO E MONTAGEM DE LÂMINAS SOBRE AS PROPRIEDADES DE COMPENSADOS DE *Pinus merkusii*

RESUMO: *Objetivou-se no presente estudo, produzir compensados com lâminas classificadas (métodos visual e de aplicação de ondas acústicas) e não classificadas (selecionadas aleatoriamente), dispostas de diferentes formas na fase de montagem, e verificar o efeito do uso dessas técnicas sobre a massa específica, a resistência e a rigidez à flexão estática e a resistência da colagem dos painéis obtidos. O compensado produzido integralmente com lâminas de maior qualidade, classificadas pelo método de aplicação de ondas acústicas, e o compensado produzido integralmente com lâminas selecionadas aleatoriamente, foram os que apresentaram a melhor performance, sem diferenças significativas entre si, exceto para a massa específica.*

Palavras-chave: Classificação de lâminas, ensaio não destrutivo, aplicação de ondas acústicas.

1 INTRODUCTION

Different types and grades of plywood are available, depending on the glue used and the quality of member plies (TSOUMIS 1991).

Most ply grading methods commercially used for making plywood panels rely on visual appearance (TAMMELA 1998).

In Brazil, two basic types of pine plywood are considered: indoor plywood (IR), whose plies are bonded by indoor resin (usually urea-formaldehyde) and intended for use in areas not exposed to water or to high relative humidity; and outdoor plywood (EX), whose plies are bonded together by outdoor resin (usually phenol-formaldehyde) and intended to withstand weather conditions, high humidity and direct contact with water (ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DE MADEIRA PROCESSADA MECANICAMENTE – ABIMCI 2002).

Pine plies are graded on the basis of the quality of face and back plies. Grading criteria take into account type, quantity and extent of defects present in the ply, which are identified by visual inspection (visual method). According to this inspection, plies can be attributed five (05) grades, in decreasing order of quality: A, B, C^+, C and D (ABIMCI 2002).

Despite some correlation between visual appearance and mechanical strength properties, this correlation is low. The use of nondestructive methods to grade plies according to their strength class, e.g. applying acoustic waves, can be an efficient way to assess raw materials (TAMMELA 1998).

Bortoletto Júnior (2008) conducted a study to evaluate the quality of *Pinus merkusii* wood for ply production, in an attempt to gather information to help broaden the scope of raw materials available for industrial processing. The author concluded that the *Pinus merkusii* wood is suitable for production of plies intended to manufacture multilayer products, for structural and nonstructural use.

This study aims to manufacture plywood panels with both graded plies (by visual and acoustic wave methods) and ungraded plies (randomly selected), bonded together in different assembly arrangements,

[1]Forest Engineer, Professor, Dr. in Forest Engineering – Departamento de Ciências Florestais – Escola Superior de Agricultura Luiz de Queiroz/ESALQ – Universidade de São Paulo/USP – Cx. P. 09 – Piracicaba, SP – 13418-900 – gbortoll@esalq.usp.br

and also to verify the effect of these techniques on the properties of finished plywood panels.

2 MATERIAL AND METHODS

2.1 Manufacture of plywood

To manufacture the plywood panels, wood plies of *Pinus merkusii* were used, with a nominal thickness of 2.00 mm and pregraded by two distinct methods: a) visual method – presence of defects in decreasing order of quality (A, B, C+, C and D), as set by the National Program for Wood Quality/Pine Plywood—PNQM/CP (ABIMCI 2002); and b) acoustic wave method (nondestructive) – based on their Dynamic Modulus of Elasticity (dMOE), using a Metriguard 239A Model Stress Wave Timer (SWT), according to Matos (1997), Metriguard (1997) and Pio (2002).

Data used in this study about manufacture of plies from *Pinus merkusii* wood, as well as details of the grading methodology used, can be obtained under Bortoletto Júnior (2008).

2.1.1 Gluing process - ingredients, preparation and quantity

The glue was formulated as follows, in parts per weight: phenol-formaldehyde resin (Cascophen HL-7550) = 100; powdered coconut husk = 5; wheat flour = 10; water = 10. It was made simply by mixing resin and other constituent elements in a stand mixer available at the Veneer and Plywood Laboratory–LLAPAM/ESALQ/USP.

Glue was applied at a rate of 380 g/m² in the form of double lines and daubed using plastic spatulas. According to Borden Química (2002), Cascophen HL-7550 resin was developed especially for short-press bonding of wood, allowing quick curing and exceptional binding quality, which makes it suitable for production of multilayer panels intended for naval use as well as for other uses where water-resistant properties are required.

2.1.2 Panel assembly, preliminary cold pressing and hot pressing cycle

After applying glue to plies, panels were assembled each with 07 layers and nominal size of 1.00 x 0.98 m by 14 mm of thickness. Different assembly strategies were adopted for panel assembly, resulting in 06 treatments (described in 2.1.3) each with three replicates, to a total of 18 finished panels.

Once assembled, panels were first subjected to cold pressing for fifteen (15) minutes, between wood slabs kept pressed by concrete weights, and then subjected to hot pressing at a temperature of 150ºC, specific pressure of 11 kgf/cm², for 8 minutes.

Once pressed, panels were kept in an upright position to restore room temperature. Next they were stacked and kept apart by separators, and protected from bad weather conditions until samples were removed to perform physical and mechanical tests.

2.1.3 Treatments adopted in the assembly phase

Panel assembly consisted of 06 treatments, each panel containing 07 layers, as described in Table 1.

Table 1 – Description of treatments.

Tabela 1 – *Descrição dos tratamentos.*

Treatment	Assembly and Grading								
	01 Face Ply			05 Core Ply			01 Back Ply		
	Random	dMOE (kgf/cm²)	Visual	Random	dMOE (kgf/cm²)	Visual	Random	dMOE (kgf/cm²)	Visual
PR	X			X			X		
PHM		140,000 to 180,000			140,000 to 180,000			140,000 to 180,000	
PLMC		140,000 to 180,000			80,000 to 100,000			140,000 to 180,000	
PLM		80,000 to 100,000			80,000 to 100,000			80,000 to 100,000	
PBF			B			C+			B
PCF			C+			C+			C+

PR = All Plies at Random; PHM = All Plies with Higher dMOE; PLMC = Plies with Lower dMOE in the Core; PLM = All Plies with Lower dMOE; PBF = Plies with B Grade on Faces (front and back); PCF = Plies with C+ Grade on Faces (front and back).

The methodology used for random selection of plies in treatment PR consisted of numbering plies from 1 to 224, then drawing 21 numbers, each number being put back. Where a number was repeated, the next immediate higher number would be considered. Following this procedure, 21 plies corresponding to the 21 randomly drawn numbers were therefore selected to compose three plywood panels for treatment PR.

Subsequently, and similarly to the random treatment, plies were selected for the remaining treatments, based on dMOE grade or the visual method.

2.2 Tests and data analysis

With the panels ready, samples were removed for physical and mechanical tests to determine properties, following procedures in Table 2.

All samples once taken were stored in a test room at the Laboratory for Mechanical Testing of Wood and Derivates–LEMMAD/ESALQ/USP at a temperature of 20 ± 2°C and relative humidity of 65 ± 5%. To check the effect of treatments on physical and mechanical properties of plywood panels, analyses of variance were performed at the 5% error probability level, and the Tukey test was used to compare means.

3 RESULTS AND DISCUSSION

3.1 Specific mass of plywood panels from *Pinus merkusii*

In analyzing Table 3, significant differences were noted among treatments, in such way as to divide them into 5 groups (A, B, C, D and E).

An analysis of treatments according to the ply grading methodology enabled the following comparisons and conclusions about specific mass:

Table 2 – Tests, properties and standards.

Tabela 2 – *Ensaios, propriedades e normas.*

Tests		Properties	Standards
Specific Mass		Apparent Specific Mass	NBR 9485/86
Moisture Content		------	NBR 9484/86
Static Bending	Parallel*	Strength and Stiffness against Bending	NBR 9533/86
	Perpendicular	Strength and Stiffness against Bending	
Shear Stress in Glue Line		Strength against Shear Stress (Dry Condition)	NBR 9534/86
		Strength Against Shear Stress (Wet Condition)	
		Strength Against Shear Stress (After-Boil Condition)	

* Grain orientation in face and back plies is parallel to span or sample length
Standards: Brazilian Association of Technical Standards—ABNT (1986a,b,c,d).

Table 3 – Specific mass means of plywood from *Pinus merkusii*, per treatment.

Tabela 3 – *Valores médios de massa específica do compensado de Pinus merkusii, por tratamento.*

Treatments	Specific Mass ** (g/cm³)	*
PR	$_{30}\,0.603^{7}$	B
PHM	$_{29}\,0.635^{4}$	A
PLMC	$_{30}\,0.544^{5}$	DE
PLM	$_{30}\,0.528^{5}$	E
PBF	$_{30}\,0.568^{4}$	C
PCF	$_{30}\,0.558^{6}$	CD
Mean	$_{179}\,0.572^{8}$	

The middle number is the mean value, to its lower left is the number of replicates, and to its upper right is the coefficient of variation. *Means with at least one similar letter do not differ statistically at the 5% probability level. **Mass and volume at an average 9% moisture content.

1) Visual (PBF) x Visual (PCF): no significant difference in specific mass was observed between these treatments. This indicates that the technique of placing two plies of superior quality (B) on the face and back of panels in treatment PBF did not help increase this property in relation to treatment PCF which used similar quality plies (C+) only.

2) Visual (PBF and PCF) x Random (PR): as mentioned before, treatments PBF and PCF were similar, and both differed statistically from treatment PR which showed a higher mean value of specific mass. This result demonstrates that random selection of plies to manufacture panels in treatment PR succeeded in preventing low specific mass values.

3) dMOE (PHM, PLMC and PLM) x dMOE (PHM, PLMC and PLM): treatments PLMC and PLM showed similarity but differed statistically from treatment PHM which showed a higher mean value of specific mass. This demonstrates that the use of superior quality plies (high dMOE value) contributed positively to increase specific mass in treatment PHM panels. It also demonstrates that the use of two superior quality plies (high dMOE value) on the face and back of treatment PLMC panels did not help increase specific mass in comparison to treatment PLM panels which used inferior quality plies only – similarly to results in treatments PBF and PCF. These results were expected to a degree because of the positive relationship between dMOE and specific mass. Calculation of dMOE involves the product of individual specific mass and acoustic wave velocity. The greater specific mass is, the higher the dMOE value. The intensity of a specific mass x dMOE relationship can be decreased by presence of knots, splits, distorted grain and other defects affecting acoustic wave velocity.

4) dMOE (PHM, PLMC and PLM) x Random (PR): all three treatments using plies graded by dMOE value had a specific mass value that differed statistically from treatment PR panels. Treatment PHM had a higher mean while treatments PLMC and PLM had lower means of specific mass than treatment PR. These results confirm what was discussed earlier. Use of randomly selected plies prevents low specific mass values in plywood panels. Superior quality plies (high dMOE value) result in panels with higher specific mass and, likewise, inferior quality plies result in panels with lower specific mass.

5) dMOE (PHM, PLMC and PLM) x Visual (PBF and PCF): all treatments that used plies graded by dMOE value statistically differed from treatments using plies graded by visual appearance, except treatments PLMC and PCF which had similar mean values of specific mass.

Treatment PHM panels had on the whole the highest mean value of specific mass, followed by treatment PR. Panels in treatments PBF and PCF showed intermediate mean values while panels in treatments PLMC and PLM showed the lowest mean values of specific mass.

Overall, mean values of specific mass of plywood panels from *Pinus merkusii* were found to be compatible with values found in the publication *Catálogo Técnico no.1* of the National Program for Wood Quality/Pine Plywood— PNQM/CP (ABIMCI 2002). Values provided in the above catalogue refer to tests on more than 20,000 samples of phenolic plywood panels from *Pinus* spp wood, manufactured with C^+ plies on the face and back and C plies in the core, with 5 to 9 layers and nominal thickness of 9 to 20mm, provided by 18 Program participating companies.

3.2 Mechanical properties of plywood panels from *Pinus merkusii*

3.2.1 Strength and stiffness against static bending

Tables 4 and 5 provide mean values of strength and stiffness against static bending, parallel and perpendicular, in *Pinus merkusii* panels, per treatment.

In analyzing constant results in Tables 4 and 5, a significant difference can be noted among treatments, which means they do not constitute a single cohesive group only. Instead, they can be divided into 3 groups (A, B and C) according to strength parallel, strength perpendicular and stiffness parallel. As for stiffness perpendicular, they can be divided into 4 groups (A, B, C and D).

An analysis of treatments according to the ply grading methodology enabled the following comparisons and conclusions about static bending:

1) Visual (PBF) x Visual (PCF): comparison of these treatments reveals statistical similarity for strength parallel, strength perpendicular and stiffness perpendicular. A statistical difference is noted however for stiffness parallel, with a higher mean in treatment PBF. This indicates better performance in this treatment, as when using the visual method, the use of 01 superior quality ply (B) on both the face and back resulted in significant improvement in stiffness parallel in comparison to the panel composed of similar quality plies (C^+). However, the technique used in treatment PBF failed to show significant strength gains in either direction or in stiffness perpendicular.

2) Visual (PBF and PCF) x Random (PR): a comparison of these treatments reveals that strength and

Table 4 – Mean values of strength and stiffness against static bending parallel to the *Pinus merkusii* panel, per treatment.

Tabela 4 – *Valores médios de resistência e rigidez à flexão estática paralela do compensado de Pinus merkusii, por tratamento.*

Treatments	Static Bending Parallel kgf/cm²			
	Strength	*	Stiffness	*
PR	$_{15}857^{12}$	AB	$_{15}114{,}010^{9}$	A
PHM	$_{15}881^{12}$	A	$_{15}117{,}623^{15}$	A
PLMC	$_{15}865^{10}$	AB	$_{15}117{,}847^{9}$	A
PLM	$_{15}676^{13}$	C	$_{15}82{,}099^{20}$	C
PBF	$_{15}871^{9}$	AB	$_{15}126{,}119^{11}$	A
PCF	$_{15}765^{19}$	BC	$_{15}97{,}953^{18}$	B
General Mean	$_{90}819^{15}$		$_{90}109{,}275^{19}$	

The middle number is the mean value, to its lower left is the number of replicates, and to its upper right is the coefficient of variation. *Means with at least one similar letter do not differ statistically at the 5% probability level.

Table 5 – Mean values of strength and stiffness against static bending perpendicular to the *Pinus merkusii* panel, per treatment.

Tabela 5 – *Valores médios de resistência e rigidez à flexão estática perpendicular do compensado de Pinus merkusii, por tratamento.*

Treatments	Static Bending Perpendicular kgf/cm²			
	Strength	*	Stiffness	*
PR	$_{15}535^{12}$	AB	$_{15}51{,}709^{14}$	A
PHM	$_{15}596^{8}$	A	$_{15}56{,}417^{8}$	A
PLMC	$_{15}430^{10}$	C	$_{15}37{,}567^{10}$	CD
PLM	$_{15}427^{13}$	C	$_{15}34{,}477^{30}$	D
PBF	$_{15}438^{10}$	C	$_{15}41{,}805^{9}$	BC
PCF	$_{15}478^{16}$	BC	$_{15}44{,}534^{11}$	B
General Mean	$_{90}484^{17}$		$_{90}44{,}418^{22}$	

The middle number is the mean value, to its lower left is the number of replications, and to its upper right is the coefficient of variation. *Means with at least one similar letter do not differ statistically at the 5% probability level.

stiffness parallel in treatment PBF were statistically similar to treatment PR, which in turn was statistically higher than PCF in stiffness parallel only. As for perpendicular direction, treatment PR showed higher mean values, differing statistically from treatment PBF in both strength and stiffness, and from treatment PCF in stiffness only. Results obtained in both directions, parallel and perpendicular, point to PR as the treatment with best performance, and reveal that plywood manufactured with visually graded plies did not bring significant gains in relation to plywood manufactured with randomly selected plies. Additionally, the technique used in treatment PBF being more expensive than in treatment PR, the latter offers considerable advantage.

3) dMOE (PHM, PLMC and PLM) x dMOE (PHM, PLMC and PLM): a comparison of these treatments regarding strength and stiffness parallel reveals statistical similarity between treatments PHM and PLMC and statistical difference between them and treatment PLM, with lower mean values – an expected result due to the use of inferior quality plies (low dMOE value). Statistical similarity between PHM and PLMC is a valuable piece of information in that it demonstrates that the use of only one superior ply (high dMOE value) on the face and another on the back with the core being composed of inferior quality plies help maintain strength and stiffness parallel properties in relation to panels manufactured with superior quality

plies only. Therefore, the technique used in treatment PLMC is rational and prevents rejection of inferior plies in superior quality products, unattainable, for instance, when the methodology of treatment PLM is used.

As for perpendicular direction, panels in treatment PHM had significantly higher mean values of strength and stiffness than treatment PLMC, which in turn was statistically similar to treatment PLM. Therefore, it can be said that the technique used in treatment PLMC is inefficient in perpendicular direction but efficient in parallel direction – similarly to treatment PBF in relation to PCF and PR. This inefficiency is due to the fact that strength and stiffness of wood plies against tension perpendicular to grain are both very low in comparison to tension parallel to grain. Thus, when in static bending testing the outermost ply of a panel is subjected to tension perpendicular, it presents lower strength and stiffness values, which is independent of its dMOE value longitudinal or parallel to grain, whether low or high. In this case, the adjacent ply being subjected to tension parallel will play a key role in the mechanical behavior of the panel. As in treatment PHM the adjacent ply is of superior quality, in other words, with a high longitudinal dMOE value, and in treatment PLMC the adjacent sheet is of inferior quality, inefficiency of the technique in treatment PLMC is explained when the panel is tested in perpendicular direction. Based on previous findings and considering results of properties in parallel and perpendicular directions, it can be inferred that treatment PHM had the best performance among those where grading was based on the acoustic wave method.

4) dMOE (PHM, PLMC and PLM) x Random (PR): regarding parallel direction, both strength and stiffness, treatments PHM, PLMC and PR were statistically similar but differed from treatment PLM for the reason already explained. Regarding perpendicular direction, both strength and stiffness, treatments PHM and PR were statistically similar but differed from treatments PLMC and PLM, which showed statistical similarity and lower mean values than other treatments. Based on these findings, in analyzing results of parallel and perpendicular directions, it can be inferred that treatments PHM and PR had the best performance. However, it should be noted that the use of superior quality plies (high dMOE value) in treatment PHM did not bring significant gains in relation to treatment PR where plies were randomly selected. The technique used in treatment PHM being more expensive than that used in treatment PR, using randomly selected plies obviously can offer advantages.

5) dMOE (PHM, PLMC and PLM) x Visual (PBF and PCF): treatments PHM, PLMC and PBF were found statistically similar in strength and stiffness in parallel direction, the latter having differed form treatment PLM, with a lower mean value. Treatment PHM had a higher mean value of strength parallel, differing statistically from treatment PCF which in turn was statistically similar to treatments PLMC and PLM, regarding the same property. Treatments PHM and PLMC had a statistically higher mean value of stiffness parallel than treatment PCF which in turn differed statistically from treatment PLM, with a lower mean value.

Based on earlier results, it should be again said that the use of superior quality plies (as defined by the visual method or by the acoustic wave method) on the face and back of panels and inferior quality plies in the core, as done in treatments PLMC and PBF, help maintain values of strength and stiffness in parallel direction of the same magnitude as in treatment PHM, which used only superior quality plies to manufacture panels.

As regards perpendicular direction, due to reasons already explained in item 3 –addressing dMOE x dMOE relationship, the technique used in treatments PLMC and PBF had a different performance than that in parallel direction, as strength and stiffness values in these treatments were significantly lower than those obtained in treatment PHM, being also lower in treatments PLM and PCF in relation to treatment PHM. Therefore, with both directions being considered, treatment PHM had the best performance.

Table 6 provides strength parallel/perpendicular and stiffness parallel/perpendicular relationships which reveal higher values in treatments PLMC and PBF, showing that the selection technique chosen for these treatments contributes positively for the mechanical response of the panel only when tested in parallel direction and increases the heterogeneity of properties between these two directions. Heterogeneity was more intensified for property stiffness.

Mean values of strength and stiffness against static bending parallel and perpendicular to the grain in *Pinus merkusii* panels were higher than values found in *Catálogo Técnico no.1* of the National Program for Wood Quality/Pine Plywood—PNQM/CP (ABIMCI 2002). This finding demonstrates that *Pinus merkusii* wood has great potential for use in the manufacture of plywood panels.

3.2.2 Glue line shear strength

Analysis of glue line strength results in *Pinus merkusii* panels (Table 7) point to a significant difference

Table 6 – Strength parallel/strength perpendicular and stiffness parallel/stiffness perpendicular against static bending of *Pinus merkusii* panels, per treatment.

Tabela 6 – *Valores das relações resistência paralela/resistência perpendicular e rigidez paralela/rigidez perpendicular à flexão estática do compensado de Pinus merkusii, por tratamento.*

Treatments	Strength	Stiffness
	Parallel / Perpendicular	Parallel / Perpendicular
PR	1.6	2.2
PHM	1.5	2.1
PLMC	2.0	3.1
PLM	1.6	2.4
PBF	2.0	3.0
PCF	1.6	2.2

Table 7 – Mean values of glue line shear strength of *Pinus merkusii* panels, per treatment.

Tabela 7 – *Valores médios de resistência da linha de colagem ao esforço de cisalhamento do compensado de Pinus merkusii, por tratamento.*

Treatments	Glue line strength against shear stress (kgf/cm²)								
	Dry Conditions	*	Wood Failure (%)	Wet Conditions	*	Wood Failure (%)	After-Boil Conditions	*	Wood Failure (%)
PR	$_{15}37^{16}$	AB	70	$_{15}27^{11}$	A	63	$_{15}22^{9}$	A	33
PHM	$_{15}39^{15}$	A	88	$_{15}27^{15}$	A	67	$_{15}24^{13}$	A	48
PLMC	$_{15}26^{27}$	D	94	$_{15}25^{12}$	AB	61	$_{15}18^{22}$	BC	32
PLM	$_{15}28^{21}$	CD	88	$_{15}22^{18}$	B	71	$_{15}17^{24}$	C	52
PBF	$_{15}31^{23}$	BCD	80	$_{15}25^{16}$	AB	63	$_{15}22^{14}$	AB	43
PCF	$_{15}33^{24}$	ABC	85	$_{15}25^{12}$	AB	71	$_{15}21^{14}$	AB	60
Mean	$_{90}32^{25}$		84	$_{90}25^{15}$		66	$_{90}21^{19}$		45

The middle number is the mean value, to its lower left is the number of replicates, and to its upper right is the coefficient of variation. *Means with at least one similar letter do not differ statistically at the 5% probability level.

among treatments, demonstrating that they do not constitute a single group only. According to glue line strength, treatments can be divided into 4 groups (A,B,C,D) under dry conditions, 2 groups (A and B) under wet conditions and 3 groups (A,B,C) under after-boil conditions.

An analysis of treatments according to the ply grading methodology enabled the following comparisons and conclusions about glue line strength:

1) Visual (PBF) x Visual (PCF): a comparison of these treatments reveals statistical similarity for glue line strength in all 3 testing conditions, dry, wet and after-boil. This demonstrates that face and back plies in treatment PBF panels, regardless of being superior to those in treatment PCF, did note influence glue line strength. This result is consistent since the glue line exposed to shear stress during testing was invariably the innermost and most critical of the panel, binding core plies which in both treatments have same quality (C^+).

2) Visual (PBF and PCF) x Random (PR): a comparison of these treatments also reveals statistical similarity for glue line strength in all 3 testing conditions. Therefore, all three treatments had equivalent performance regarding this property, while the B grade

plies on the face and back of panels in treatment PBF did not influence results.

3) dMOE (PHM, PLMC and PLM) x dMOE (PHM, PLMC and PLM): a comparison of these treatments reveals statistical similarity between treatment PLMC and treatment PLM in all 3 testing conditions, and statistical difference between them and treatment PHM which showed higher mean values of glue line strength.

The inferior glue strength performance of treatments PLMC and PLM in relation to treatment PHM may have resulted from the use of inferior quality plies (low dMOE value) in the core portion of panels. The low dMOE value in these plies could be related to presence of defects such as knots and splits which affect adhesive performance and/or to relatively lower specific mass. The lower the specific mass of a ply, the higher its porosity and consequently the deeper the glue penetrates, potentially causing excessive glue line absorption due to porosity and therefore less relative strength. The equivalent binding strength of treatments PLMC and PLM is nonetheless consistent as they were made of similar quality core plies (dMOE between 80,000 and 110,000 kgf/cm²).

Based on previous findings, and considering results of glue line strength in all 3 testing conditions, it can be inferred that treatment PHM had the best performance among treatments using the acoustic wave grading method.

4) dMOE (PHM, PLMC and PLM) x Random (PR): a comparison of these treatments reveals lower mean values of glue line strength in treatments PLMC and PLM, statistically differing from treatment PR which in turn was found similar to treatment PHM. Again, observations made in item 3 also apply here regarding core ply quality in treatments PLMC and PLM and how it affects glue line strength. It was also noted that the use of superior quality plies (high dMOE value) in treatment PHM did not bring statistically significant gains in relation to treatment PR, which used randomly selected plies. The technique used in treatment PHM being more expensive than that used in treatment PR, using randomly selected plies obviously can offer advantages.

5) dMOE (PHM, PLMC and PLM) x Visual (PBF and PCF): treatment PBF was statistically similar to treatment PLMC, in all 3 test conditions, differing from treatment PLM (only in after-boil conditions) in relation to which it had a higher mean value of glue line strength, and differing from treatment PHM (only in dry conditions) in relation to which it had a lower mean value.

In all 3 testing conditions, treatment PHM was statistically equivalent to treatment PCF which in turn differed from treatments PLMC (only in dry conditions) and PLM (only in after-boil conditions), both with lower mean values of adhesive strength.

In analyzing the 5 items above, treatments PR, PHM and PCF deserve special mention in that they showed similar adhesive strength behavior in all 3 testing conditions. These results suggest that using superior quality plies on the face and back of panels (treatments PLMC and PBF) did not improve the strength of the innermost glue line, and also that using inferior quality plies in the core portions of panels (treatments PLMC and PLM) results in relatively less resistant glue lines. Using superior quality plies in the core portions of panels (treatment PHM), on the other hand, helps improve glue line strength, yet equivalent to glue line strength in panels manufactured with randomly selected plies.

Mean values of glue line strength against shear stress in *Pinus merkusii* panels were higher than values found in the *Catálogo Técnico no.1* of the National Program for Wood Quality/Pine Plywood (ABIMCI 2002). This finding, added to what was discussed earlier about static bending test results, reinforces the great potential of *Pinus merkusii* for use in plywood panels.

4 CONCLUSIONS

Based on obtained results and considerations, the following conclusions can be drawn:

Panels manufactured with superior quality plies only (high dMOE value), as graded by the acoustic wave method, and panels manufactured with randomly selected plies had the best performance, with no significant differences between them in all properties being assessed, except for specific mass which was found slightly lower in panels assembled with randomly selected plies.

Panels assembled with superior quality plies on the face and back and inferior quality plies in the core portion, regardless of the grading method used (visual or acoustic wave), revealed that this ply arrangement is efficient to maintain strength and stiffness properties against static bending parallel in comparison to best performing panels, yet these properties provide relatively lower values in perpendicular direction.

Overall, it was noted that the use of superior quality plies on the face and back of panels did not improve the strength of the innermost glue line; the use of inferior quality plies in the core portion of panels resulted in relatively less resistant glue lines; the use of superior quality plies (high dMOE value) in the core portions helped improve glue line strength, yet equivalent to glue line strength in panels manufactured with randomly selected plies.

The acoustic wave method being more expensive due to special equipment and qualified people requirements, results obtained in this study suggest that the use of randomly selected plies to manufacture plywood panels can offer advantages.

Plywood panels from *Pinus merkusii* wood showed higher values of mechanical properties than those found in *Catálogo Técnico no.1* — Pine Plywood (ABIMCI 2002), indicating that the above species has great potential for use in the manufacture of plywood panels.

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