LAB TESTING FOR P3 MOISTURE RESISTANT OVERLAID PARTICLEBOARDS MADE FROM WOOD RESIDUES

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In Chile the amounts of wood sawdust, shavings, and chips available is around of 2.72 million, 340 thousand, and 4.25 million m^3/year, respectively, and about 30% of this material is employed in the manufacture of particleboards. Two types of particleboards were made from wood residues as moisture-resistant particleboards, and the main goal was to meet the requirements for P3 moisture resistance according to the European Standard EN 312. Five mats of each type were pressed without stops in a 30 cm diameter electrically heated hot press at 180°C for 3.5 min. Target board density was 680 kg/m^3 (T1) and 720 kg/m^3 (T2), mat moisture was 10%, resin dosage applied was 6%, and board thickness was 15 mm for both boards (0.5 x 0.5 m). Samples were designated as T1 and T2, on which both physical and mechanical tests were conducted. Density, moisture content, thickness swelling, and water absorption were measured. Mechanical tests included internal bond before and after cyclic test, as well as fire retardancy. The analysis of the high resolution images allowed us to ensure that there was no gap between the veneer and the particleboard; therefore it can be concluded that there was no adherence loss. Results for all tests showed that both boards met all the P3 standards for moisture resistant non-structural board for use in humid conditions.

Keywords: Particleboard; Radiata pine; Wood residues; Moisture resistant particleboards; PMDI adhesive

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INTRODUCTION

In Chile, as throughout the world, the panel industry has grown continuously in recent years, using mainly wood produced on plantations. The most important Chilean company producing particleboards (over 90% of the national production) has adopted the ISO 14001 certification to produce boards only from industrial byproducts, such as radiata pine sawdust, shavings, and chips, instead of logged trees. As a result, this industry currently uses byproducts derived from other industrial processes, and it competes to an increasing degree to access these resources at competitive prices. Such practices allow them to achieve higher profitability in their business (Garay *et al.* 2009 a, b).

The incorporation and characteristics of crop residues have been studied in particleboard panels (Garay *et al.* 2009 a, b) in a mixture with wood from *Pinus radiata* D. Don. Four crop residue stubble types were used: wheat, corn, rice plants, and rice husk. Their densities were compared. A wide array of mixtures, ranging from a ratio of

9:1 to 1:9 wood: agrifibres, were used to make the boards, from which the fundamental physical and mechanical properties were determined in order to select the one with the best properties and potential uses. It was found that all the agrofibres (AG) were suited to board panels, although wheat and corn stubble gave better results, and their low fiber content was easily incorporated in low proportions without major modifications of processes and products.

Some critical properties are more affected by decreasing the quality of raw materials, and they are mainly related to moisture resistance and density uniformity (Gatchell 1996; Guler 2006, 2008). It is also possible to improve the adhesive properties by incorporating isocyanates for better resistance to moisture.

P3 moisture-resistant particleboards are meant to be used for non-structural purposes in humid conditions. Their moisture content varies between 5% and 11%, according to European Standard EN 312 (Garay *et al*. 2009b).

Lab tests of 15 mm particle boards for interior use typically show a swelling in thickness of 14% after 2 h and 16.5% after 24 h, water absorption 62.5% after 2 h, and 96.2% after 24 h of immersion (Particleboards laboratory, Wood Department, Forestry and Conservation Faculty, University of Chile). According to Table 1, in swelling in thickness, the minimum requirements for P3 particleboard for use in humid conditions are 14%. Then, particleboard for interior use does not meet this requirement.

According to test results from Garay and Henríquez (2010), particleboards with no fire retardant properties had a loss of weight of 16.89% and a char index of 8.00%. For particleboards with fire retardant properties, the results were 10.96% and 4.96%, respectively.

The European Standard EN 312 (2004) classifies composite boards for structural or non-structural applications and whether they are for use in dry or humid conditions. P3 designates a non-structural board for use in humid conditions. The same standard defines humid conditions as the service class 2 of ENV 1/1/1995, which is characterized by a moisture content of the material corresponding to a temperature of 20 ºC and a relative humidity that exceeds 65% only several weeks a year. The minimum requirements of P3 Particleboards for use in humid conditions are shown in Table 1 below.

Table 1. Minimum Requirements of P3 Particleboard for Use in Humid Conditions

Mechanical and Swelling Properties	Unit	Requirement
Thickness	mm	13-20
Bending strength (EN 310)	N/mm^2	14
Internal bond (EN 319)	N/mm^2	0.45
Swelling in thickness, 24 h (EN 317)	%	14
Moisture resistance properties (EN 312)	N/mm^2	0.13
Swelling in thickness after cyclic test (EN 312)	%	13

This study presents the test results of physical properties (density, moisture content, swelling in thickness, and moisture absorption), mechanical properties (internal bond before and after cyclic test), and fire resistance carried out according to European and American standards. Additionally, a detection of loss of adherence by a method of image analysis was conducted on the glue line particleboard (PB) core-overlay material.

EXPERIMENTAL

Materials

Particleboard was made from a radiata pine mix of sawdust (33%), shavings (33%), and chips (33%), which came from a sawmill located in the 8th region of the country. From this raw material, two classes of particle were prepared: fines and coarser particles. The fines were in the range 1 to 3 mm long, 0.5 to 1 mm width, and thickness from 0.1 to 0.3 mm. The coarser particles had lengths 10 to 20 mm, widths of 3 to 5 mm, and a thickness of 0.3 to 0.5 mm. Five specimens (0.5 x 0.5 m) were made from each particleboard type, and both were covered with overlay of thickness 1 mm after manufacturing. One was covered with veneer sheets on both faces (T1) and the other with melamine foil on both faces (T2). The resin used for the manufacture of boards was polymeric methylene diphenyl diisocyanate - PMDI (100% solid content, from ICI Resins).

Methods

After screening, the chips were dried to 6.5% to 7% moisture content (MC). The amount of resin used was based on the oven-dry weight of wood. Pre-weighed raw material was placed into a resinating chamber. While being agitated by rotary arms inside the chamber, isocyanate resin was sprayed at a rate of 5.8 g/sec through a swirl air, solid cone spray nozzle with an air feed of 3 litres/sec at 25 psi. Following resin application, the furnish continued to be agitated to give a total mixing time of 5 minutes. Mats were pressed without stops in a 30 cm diameter electrically heated hot press at 180°C for 3.5 min and pressing at 20 Kg/cm^2 as specific pressure. Target board density was 680 kg/m^3 (T1) and 720 kg/m^3 (T2), mat moisture was 10%, resin dosage applied was 6%, and board thickness was 15 mm for both boards, including overlay (1 mm). The overlay was glued to the board after its manufacture with polyurethane adhesive, followed by cold-curing and pressing at 5 to 6 Kg/cm^2 for 4 hours. Statistical analysis was carried out using Tukeys studentized range test to determine significance at 5% level. Boards were conditioned at 20°C and 65% relative humidity prior to testing physical and mechanical properties, and 10 samples were taken for each test.

Internal bond after cyclic test – EN 319 (1993)

Specimens of 50 ± 1 mm square (EN 326 1993) obtained from the boards were subjected to the cyclic test according to standard EN 319 1993. Cycles consisted of periods of immersion in cold water, freezer, and oven for 21 days, after which they were tested to measure their internal bond according to standard EN 321, Option 1 (2002), consisting of an accelerated aging test known as a cyclic test in humid environment. There were three cycles, each comprising (70 ± 1) h water immersion at (20 ± 1)°C; (24 ± 1) h in a freezer at (-12 to -25)°C, and (70 ± 1) h in an oven at (70 ± 2)°C.

Density – EN 323 (1993)

Specimens of 50 ±1 mm square (EN 323, 1993) were oven-dried until constant weight (mass) was reached. The thickness was taken at the centre point where the two diagonals intersected. Two measures of the sides were also taken.

Moisture content - EN 322 (1993)

Moisture Content Specimens were oven-dried at 103ºC until constant mass was reached. In this case they were oven-dried for 24 h.

Swelling in thickness – EN 317 (1993)

Thickness of the specimens was measured at the point where the two diagonals intersect using a dial with 0.01 mm precision. Specimens were submerged in clean water (pH of 7 ± 1 and a temperature of 20 ± 1 ºC, 2 and 24 hours) in an upright position, at rest.

Once the immersion test was finalized, the excess of water was drained, and the thickness at the intersection of the diagonals was re-measured.

Water absorption – EN 317 (1993)

Specimens were submerged in water for 2 and 24 h. Mass was measured prior to the test, after 2 h, and after 24 h of immersion.

Loss of Adherence in the Glue Line PB Core with Veneer and Melamine Foil Overlay

The glue line between the particleboard core and the overlaid veneer was tested to check for loss of adherence.

According to EN 314 Part 2 (1993), the standard is related to plywood (Plywood – Bonding quality – Part 2: Requirements). Although this standard is related to plywood, it was used as well to evaluate adherence of foil and veneer sheets in this set of experiments, despite the fact that the manufactured woodboard was a particleboard. According to the specification, bonding should be maintained after specimens have been boiled in water for 4 h. Ten specimens were used, size 25 x 100 mm for each types board.

Additionally, digital pictures of the glue line taken with a Canon EOS 7D camera were magnified to look for evidence of loss of adherence, based on detecting its characteristic in the image. Using Photoshop CS4, the color curve of images was also adjusted to enhance the vision of the glue line.

Fire Retardancy

ASTM D1360-90a Standard Test Method for Fire Retardancy of Paints Cabinet Method (1994) was used. The substrate was exposed to the direct flame of an alcohol burner, and the damage by fire was measured by loss of weight and charring flame rate. In this case, the overlay material was considered a coat of paint.

Ten replicates (size 300 x 135 x 15 mm) were considered for each substrate for both the face and the back of the board overlaid with wood veneer and foil melamine. Weight and thickness were measured for each specimen prior to the test. Thickness was measured 10 cm from the bottom center. Specimens were laid at a 45º angle in the combustion chamber and were exposed to a flame by burning 5 mL of absolute ethyl alcohol of a 78.5 ºC boiling point. A precision weight scale was used to calculate the loss of weight according to the following formula, $P_p = P_I - P_F$, where P_p is the loss of weight, P_I is the weight prior to testing, and P_F is the weight after the test.

The char index (INC %) was calculated according to the formula below. The specimen was cut both across and alongside with a circular saw. Using a caliper, the thickness after burning and both the maximum width and length of carbonization were measured.

$$INC\ (\%) = [l_{\max} * a_{\max} * e_{c}] / V_{\text{initial}}, \quad (1)$$

where l_{max} is the maximum length of carbonization, a_{max} is the maximum width of carbonization, e_c is the burned thickness (difference between thickness prior and after the test), and V_{initial} is the volume of the specimen prior to the test.

According to ASTM D1360-90a (1994), both average and standard deviation were calculated for the loss of weight and char index.

RESULTS AND DISCUSSION

Density and Moisture Content

Test results were within the normal range for these boards, as seen in Table 2. The difference in density between T1 and T2 was attributed to the difference in thickness for the two boards due to the overlay (veneer or melamine). T2 is thinner than T1, which factors for both densities up for T2. Nevertheless, the difference in density is not relevant and does not affect the physical and mechanical performance of the board.

Table 2. Means Value and (Standard Deviation) of Actual, Oven-Dry Density, and Moisture Content of Each Board

Type of boards	Actual Density(kg/m³)	MC (%)	Oven-dry density(kg/m³)
T1	681.3 (24.7)	8.14 (0.2)	652.5 (26.5)
T2	721.8 (45.3)	8.53 (0.3)	690.5 (46.1)

*Means value of 12 specimens.

Thickness Swelling

The thickness swelling values shown in Table 3 are key in the moisture resistance analysis of the particleboards in study. That's because they show significantly lower averages compared with regular particleboards.

Table 3. Means Value and (Standard Deviation) of Thickness Swelling after 2 and 24 h Immersion in Water

Type of boards	Percentage of thickness swelling*	
	2 h	24 h
T1	1.48 (0.41)	3.19 (0.42)
T2	0.94 (0.36)	2.68 (0.30)

*Means value of 12 specimens.

Water Absorption

Table 4 shows the test results for water absorption as a percentage of the specimen mass prior to immersion.

Table 4. Water Absorption after 2 and 24 h Immersion

	2 h	24 h
T1	5.06	13.95
T2	4.11	10.21

Thickness swelling and water absorption test results were as expected. On standard urea formaldehyde particleboards, the thickness swelling test results were above 25% (EN 317). As shown above, the thickness swelling behavior is far superior on P3 boards.

A statistical analysis showed that the differences between the two boards tested were significant. Table 5 provides a summary of the statistical comparison of the averages for MC, density, thickness swelling, and water absorption for the two tested boards.

Table 5. The ANOVA Procedure Summary for Physicals Properties Evaluated

	Source	Sum of Squares	DF	Mean Square	F-ratio	P-Value
MC	Between groups	0.9126	1	0.9126	14.08	0.0011
	Intra groups	1.42633	22	0.0648333		
	Total (Corr)	2.33893	23			
Density	Between groups	12077.2	1	12077.2	12.31	0.0020
	Intra groups	21579.6	22	980.89		
	Total (Corr)	33656.8	23			
Thickness swelling (24 h)	Between groups	654.379	1	654.379	0.81	0.3767
	Intra groups	17683.0	22	803.773		
	Total (Corr)	18337.4	23			
Moisture absorption (24 h)	Between groups	90.0938	1	90.0938	304.19	0.0000
	Intra groups	6.51583	22	0.296174		
	Total (Corr)	96.6096	23			

There were significant differences for thickness in swelling with 95% confidence and a correlation index of 4.48. Both boards met the EN 312 requirements for P3 boards of 13% maximum swelling.

Considering both assays, *i.e.* thickness swelling and water uptake, it was possible to verify a good performance of tested boards against moisture due to the fact that mixtures of wood residues and MDI adhesives met the standard EN 312 for P3 boards. This last standard was not met in previous works (Garay *et al.* 2009 a, b) because of the use of a mixture composed by agricultural residues, radiata pine wood, and urea formaldehyde as adhesive. Urea formaldehyde does not seem to be enough to offset the utilization of raw materials exhibiting lower quality.

The porosity of the sheet (T1) allows for greater moisture absorption and thickness swelling compared with melamine foil overlay (T2).

Internal Bond After Cyclic Test

The internal bond (Table 6) was considered as an indicator of internal cohesion between the particles and as an indicator of the boards' resistance to humidity.

Table 6. Internal Bond of the Overlaid Particleboards

Type of boards	Internal bond (N/mm^2)	
	Control	Cycled
T1	0.457 (0.043)	0.153 (0.022)
T2	0.577 (0.028)	0.176 (0.233)
EN*	0.45	0.13

*Minimum requirements according to EN 319 and EN 321 respectively. Means value of 10 specimens.

The EN 312 internal bond requirement for P3 boards is 0.13 N/mm^2, therefore both boards met the standard requirements.

Table 7. ANOVA Results for IB

	Source	Sum of Squares	DF	Mean Square	F-ratio	P-Value
IB	Between groups	1.31756	3	0.439187	498.92	0.0000
	Intra groups	0.0316897	36	0.00088027		
	Total (Corr)	1.34925	39			

There was a statistically significant difference between the average internal bond in boards level for a confidence level of 95.0%.

Loss of Adherence in Glue Line PB Core with Veneer and Melamine Foil Overlay

According to EN 314, Part 2, bonding should be retained after specimens are boiled in water for 4 h. Specimens showed glue lines with adequate adherence after 4 h in boiling water, and the veneer did not come apart after the test. The PB core did not disaggregate and wood chips kept adherence. Therefore, the boards met the standard. As shown in Fig. 1 and 2, the particle board specimens showed no evidence of adherence loss after the test.

Additionally, by using Photoshop CS4, the color curve of the images was adjusted to enhance the difference between the glue line and the rest of the material, as shown in Fig. 2. The analysis of the high resolution images allowed us to ensure that there was no gap between the veneer and the particleboard; therefore it can be concluded that there was no adherence loss. Images for T1 and T2 were alike; therefore only one curve is presented in Fig. 3.

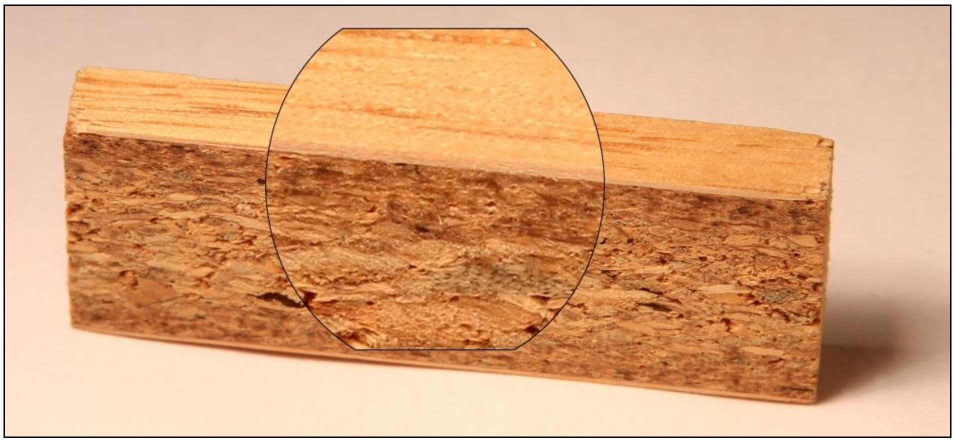

Fig. 1. T1 Glue line on veneer PB-overlay. The PB core shows adequate adherence

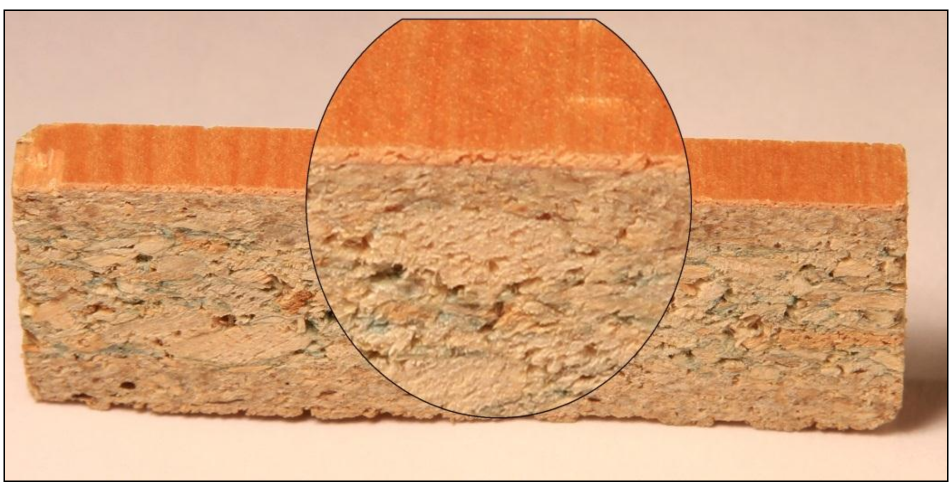

Fig. 2. T2 Glue line on melamine PB-overlay. The PB core shows adequate adherence

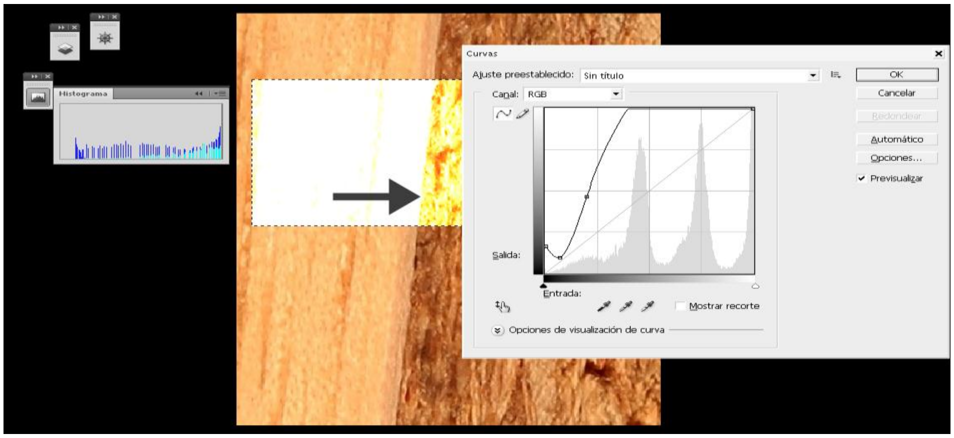

Fig. 3. Adjusted color curve of the glue line of humidity resistant PB

Fire Retardancy

Specimens were tested according to ASTM D1360-90a (1994). Figures 4 and 5 provide images of T1 and T2 tested on both face and back surfaces.

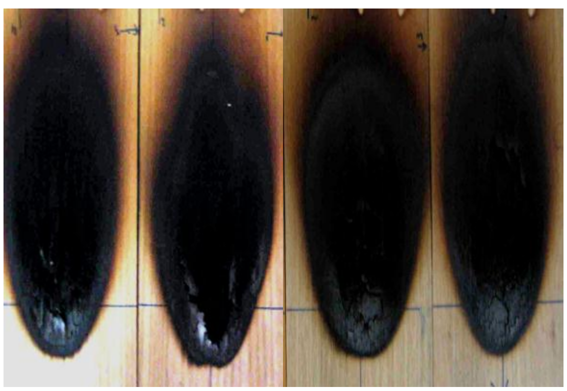

Fig. 4. T1 Fire retardance test

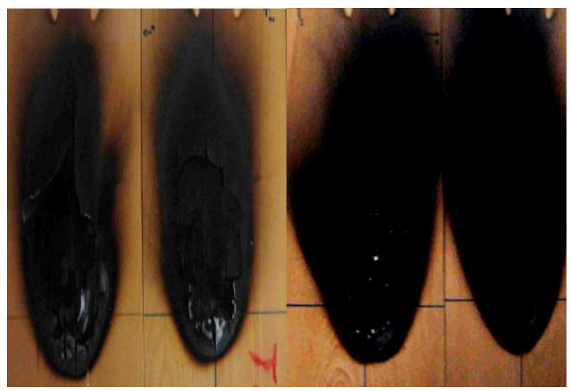

Fig. 5. T2 Fire retardance test

Table 8 provides the fire retardance test results for loss of weight and char index. The two PB tested showed better fire retardance results than standard PB and standard MDF when compared to data reported by Garay and Henríquez (2010). In this paper, the best results for both loss of weight and char index were obtained on PB with a fire retardant coat of paint. In this case, T1 (with veener) showed higher values than T2 (with melamine foil). The ANOVA results compare veneer and melamine foil of the boards and revealed no difference between both boards (Table 9). The weight loss in T1 was higher than T2, because the sheet thickness is greater than melamine foil and has more influence on the weight of each board, but both boards burned similarly, which is expressed by the fact that analysis of variance for char index did not give significant differences.

Table 8. Fire Retardance Test Results of Overlaid Particleboards

Type of boards	Loss of weight (%)		Char Index (%)	
	Face	Back	Face	Back
T1	3.17[a] (0.25) [b]	2.40 (0.09)	4.22 (0.24)	6.25 (1.48)
T2	1.78 (0.1)	1.95 (0.24)	3.89 (0.74)	7.05 (2.23)
Standard PB [c]	3.04 (0.2)		8 (1.0)	
Standard MDF [c]	5.16 (0.3)		19.46 (5.4)	

[a] Means value of 16 specimens. [b] Values in parentheses are standard deviations.
[c] Reported in Garay and Henríquez (2010).

Table 9. ANOVA Char Index (IC) for T1 and T2

	Source	Sum of Squares	DF	Mean Square	F-ratio	P-Value
Char Index (IC)	Between groups	4.82129	1	4.82129	1.37	0.2518
	Intra groups	105.943	30	3.53145		
	Total (Corr)	110.765	31			

CONCLUSIONS

1. Particleboards made from wood residues were used to test moisture resistant requirements, and the test results showed adequate properties.
2. The two tested boards met thickness swelling and internal bond standards for P3 moisture resistant particleboards for use in humid conditions.
3. T1 and T2 were similar in resisted fire, veneer, or melamine foil and did not exhibit differences in fire retardancy. However, T2 showed better results than T1 for water absorption and swelling in thickness, and both T1 and T2 results were above the minimum requirements for P3, including internal bond, which was considered an indicator of behavior of resistance to humidity of boards.

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