

Effect of battens edge bonding in the properties of blockboards produced with *Pinus* sp. recycled from construction sites.

ABSTRACT

The construction is an activity that generates large amounts of waste, demanding alternative reuse. Wood-based waste can be processed and used for the production of forest products, such as blockboards type plywood. This study evaluated the physical and mechanical properties of blockboards produced with wood from construction wastes, comparing the core bonded and without bonding the strips, in order to determine which production method shows better results as well as observe the phenol-formaldehyde adhesive properties in the panels. The production of blockboard as well as testing was made at the Forest Products Laboratory-LPF, Brazilian Forest Service - SFB. The wood wastes used were obtained in construction sites at the University of Brasilia-UnB, and the species used was *Pinus* sp. for the battens and Curupixá (*Micropholis venulosa*) for the face veneers. The adhesive used was phenol-formaldehyde (Cascophen HL-7090 HS). The panels were produced with dimensions 560 x 340mm x 15mm. The physical properties of the panels were assessed: moisture content (MC); apparent density (MEA); water absorption (AA); and recovery in thickness (RE) and swelling plus recovery in thickness (IR). The mechanical properties of the panels were evaluated: static bending (MOR and MOE); and shear strength in the glue line (RLC). In view of the source of the material used, the results were satisfactory for both treatments.

Keywords: construction, wood waste, blockboard.

1. INTRODUCTION

In construction sites, virtually all activities generates wastes, also called debris or construction and demolition wastes (CDW), or, as has currently been named, civil construction waste (CCW). According to [1], the CDW may correspond to more than 50% of the mass of municipal solid wastes. The generation of wastes in construction can occur at different stages of the life cycle structure - construction, maintenance and renovation and demolition and the main wastes generated in these **stages** are sand, gravel, mortar, concrete, plastic, metal, glass, paper and pieces of wood. Such a building model had no problems until recently, due to the abundance of natural resources [1].

According to [1], the intensification of the industrial activity, as well as the development of new technologies, population growth, increase in people in urban areas and diversification of consumer goods and services, the waste is a serious urban problem, in addition to being complex and costly to management, considering its volume and the very large amount. Also the resources become scarcer, so reducing their demand or using wastes materials has become of great importance.

From these problems it was found that there was great need to implement adequate solid waste management systems. For the preservation of natural resources, wastes can be recycled, extending the life of natural reserves and reducing the destruction of the landscape, flora and fauna [1].

Regarding wood in the Brazilian civil construction, it is used in the construction in a temporary way, for example, forms for concrete, scaffolding, supporting and also

definitively as roof structures, window frames, ceilings and floors. The scarcity of studies on recycling timber coming from civil construction wastes points to the importance of research like that developed by Silva [2].

As well as the construction industry, the timber industry is a major generator of wastes from the wood processing. The wood processing to adapt to market demands generates wastes such as sawdust, battens, shavings, shorts, etc. [3]. Currently, much of this waste and the construction remaining are used for energy, with little reuse for the production of higher value added products. Furthermore, according to [3], the supply of residues exceeds the demand, and the material often has no specific purpose.

The material from products like wood or solid wood, when collected, constitutes a source of fibers that after appropriately processed can be the basis for production of forest products, such as bonded panels and laminates, furniture components, finishing panels and plywood [4]. Teixeira and Silva [5] reported the use of wood waste from various species in the production and properties of blockboard.

The blockboard can be used for the manufacture of furniture, partition panels, among others carpentry services [6]. However, the production in Brazil is still reduced, reaching only 25% to 35% of the plywood production and consumption is 0.25-0.35m³ per cubic meter of laminated plywood [7]. Figure 1 shows a representation of the blockboard.

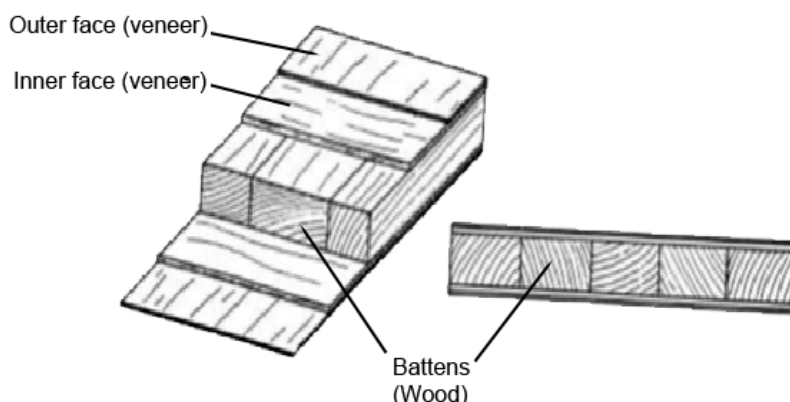


Figure 1. construction principle of blockboard.

Source: Mendes et al. [7]

According to [2], the production of blockboard type plywood from wood wastes is a good option for smaller parts, usually discarded, but when reused as part of the material gain value and have functionality for other purposes. The literature on the utilization of wood wastes from CCW for plywood production is limited.

The objective of this study is to determine the physical and mechanical properties of a blockboards made from construction waste using a phenol-formaldehyde adhesive, with and without bonding the core battens.

2. METHODOLOGY

This work was carried out at the Forest Products Laboratory-LPF of the Brazilian Forest Service-SFB.

2.1 Obtaining wood wastes

The residues were collected in construction sites carried out at the University of Brasilia-UNB Campus Darcy Ribeiro. The pieces collected were lumber of *Pinus* sp. after using as concrete forming.

2.2 Waste Processing

The residues were then processed according to established by the technical standards for adjustment and finishing of measures and subsequent bonding procedure. For processing the material it was used a circular saw, a thicknesser and a planner.

The processed material was then stored in an air conditioning room of the LPF under controlled conditions of temperature (20 ± 3) °C and relative humidity (65 ± 5)%, to constant mass and approximate humidity of 12%, considered ideal for bonding .

2.3 Production of blockboards

Two types of blockboards were produced: one with edge gluing the core battens and the other without gluing. Both were made with strips of *Pinus* sp. and double face layers (front and back) of veneers of curupixá wood (*Micropholis venulosa*), on each side of the blockboard, with medium density of 0.805 g/cm³ and thickness of 0.65 mm.

For each treatment (with and without edge gluing) three panels were produced, adding a total of 114 battens on the manufacturing. Each individual batten measured 35x3x1.5 cm (length x width x thickness).

In the treatment NG (no edge gluing the battens), the core battens were edge joined by simply clamping, in preparing to receive the face veneers. The clamps were removed after pressing. First the back veneers were glued, with grain direction perpendicular to the battens grain and then the outer veneer with the fibers in the parallel direction. In the WG (with battens edge gluing) treatment, the core battens were edge glued with PVA (polyvinyl acetate) using a gramature of 100 g/m² prior to bonding the face veneers. Figure 2 illustrates the pressing procedure with the clamps.



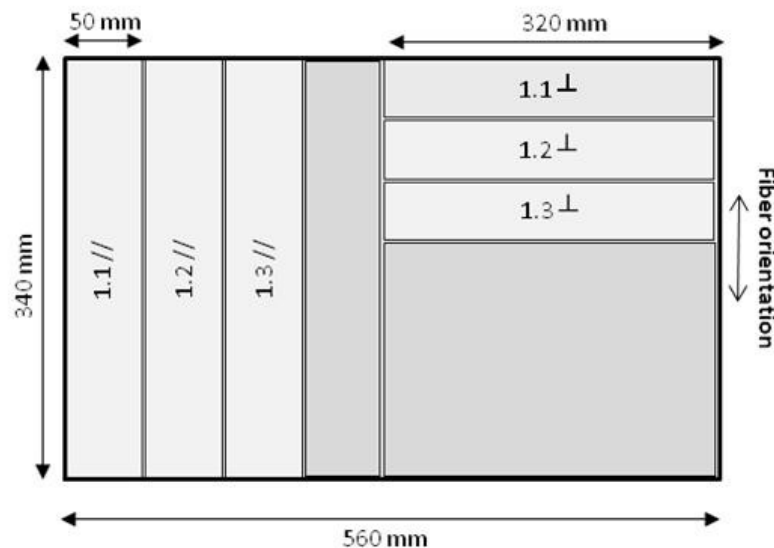
Figure 2. Pressing procedure of the core battens.

The process of gluing the core panels to the front and back face veneers was made by using the adhesive phenol formaldehyde Cascophen HL - 7090 HS in a gramature of 200 g/m². It is a liquid resin based in aqueous solution, developed especially for the bonding of wood of all kinds, where the primary demands are high quality and fully waterproof bonding. The hot pressing was made in a hydraulic press Indumec with 3.5 minutes pressing time, a constant temperature of 130 °C and pressure of 1.0 MPa.

2.4 Obtaining the specimens for testing

After making the panels and air conditioning, the specimens were cut from each board for testing. Three specimens were cut from each panel with direction parallel and three

110 with direction perpendicular to the core battens. The scheme described can be seen in
 111 Figure 3.
 112



113
 114 **Figure 3 - Sketch representing the cut panel for removal of specimens.**
 115

116 2.5 Evaluation of physical properties of panels

117 2.5.1 Moisture Content (MC)

118 The standard for plywood used for determining the moisture content was ABNT NBR
 119 9484 [8]. For each treatment 27 specimens were used, obtained from specimens after
 120 the bending test.

121 The initial mass was determined from the samples conditioned using a digital scale Bel
 122 with resolution of 0,01g. To obtain the dry mass, the samples were placed in an oven at
 123 (103±2)°C and monitored to reach constant mass. The moisture content was obtained
 124 using Equation 1.

$$125 \quad MC = \frac{M_i - M_d}{M_d} \times 100 \quad (1)$$

126 **Where:**

127 MC = Moisture content, %;
 128 M_i = Initial mass conditioned, g;
 129 M_d = Bone dried mass, g.
 130

131 2.5.2 Apparent density

132 To calculate the apparent density, the tests were conducted in accordance with the NBR
 133 9485 [9] standard for plywood using the specimens of the bending test, nine from each
 134 direction of fibers. The specimens were conditioned at (20±3)°C and (65±5)%, to reach
 135 equilibrium moisture content of 12%. Measures of mass, using a scale Bel with
 136 resolution of 0,01g, length, width and depth, using a digital caliper Mitutoyo with
 137 resolution of 0,01mm, of each sample was taken and apparent specific density
 138 calculated using Equation 2.

$$139 \quad MEA = \frac{M_i}{L \times W \times D} \quad (2)$$

140 **Where:**
 141 MEA = apparent specific density, g/cm³;
 142 M_i = Initial mass conditioned, g;
 143 L, W, D = length, width and depth, respectively, mm.
 144

145 **2.5.3 Water Absorption**

146 For this test, 36 specimens per treatment were used, according to the ABNT NBR 9486
 147 [10] standard for plywood, following the procedures and calculated as Equation 3:

- 148 I. Oven drying at (50±2) °C for 24 hours;
- 149 II. Cooling in desiccator;
- 150 III. Weighing, 0.01 g precision scale (M_i);
- 151 IV. Immersion in distilled water at constant temperature of (25±2) °C for 24 hours;
- 152 V. Fast drying on paper towels; and
- 153 VI. Weighing again, 0.01 g precision scale (M_f).
 154

$$155 \quad WA = \frac{M_f - M_i}{M_i} \times 100 \quad (3)$$

156 **2.5.4 Recovery in thickness (RE) and swelling plus recovery in thickness (IR)**

158 According to ABNT NBR 9535 [11] standard for plywood, swelling is the increase in
 159 thickness of the plywood when subjected to water absorption. Still according to the
 160 standard thickness recovery is the ability to regain the initial plywood thickness after
 161 immersion in water and subsequent drying.

162 For each treatment 72 specimens were used, being 36 for the control sample and 36 for
 163 the immersion test. Specimens were conditioned to reach constant mass. For the control
 164 specimens, a thickness measurement using a digital caliper Mitutoyo with resolution of
 165 0,01mm was made in the central part of the sample after conditioning and another after
 166 drying in an oven at (103±2) °C for 24 hours.

167 The test specimens were measured after conditioning and then immersed in distilled
 168 water at (20±2) °C for 24 hours. The measurement was made with saturated specimens
 169 and subsequent drying in an oven at the same temperature mentioned above for 24
 170 hours, taken as the final measurement of the dry specimen. The recovery in thickness
 171 (RE) was calculated according to Equation 4.

$$172 \quad RE = \left(\frac{e1.e5}{e2.e3} - 1 \right) . 100 \quad (4)$$

173 **Where:**

- 174 RE = recovery in thickness, %;
- 175 e1 = sum of thicknesses of specimens used as a control, conditioned, mm;
- 176 e2 = sum of thicknesses of specimens used as a control, oven dried, mm;
- 177 e3 = sum of thicknesses of specimens before immersion in water, mm;
- 178 e5 = sum of thicknesses of specimens after immersion in water, mm.
 179

180 The thickness swelling plus recovery in thickness (IR) was calculated according to
 181 Equation 5.

$$182 \quad IR = \left(\frac{e1.e4}{e2.e3} - 1 \right) . 100 \quad (5)$$

183 **Where:**

- 184 IR = thickness swelling more recovery in thickness, %;
- 185 e4 = sum of thicknesses of specimens after immersion in water, and after oven drying,
 186 mm.
 187

188 **2.6 Evaluation of Mechanical Properties of Blockboards**

189 **2.6.1 Resistance to Static bending**

190 The standard EN 310 [12] was used to calculate the modulus of elasticity (MOE),
191 modulus of rupture (MOR) and stress at Proportional Limit (SPL) of specimens using a
192 Universal testing machine Instron with capacity of 300kN. The SPL was determined
193 using the load and deformation at proportional limit at testing span of 290 mm and
194 average testing speed of 9.0 mm/min.

195 **2.6.2 Resistance to shear in bonding test**

196 As the Brazilian standard does not provide the shear test in the glue line to blockboards,
197 the tests were based on the European standard EN 314-1 [13] and EN 314-2 [14] using
198 a Universal testing machine Emic with capacity of 300kN. Fifteen specimens were used
199 for each treatment, with 25 mm of width and distance between the grooves of 25 mm.
200 For the shear boiling test, specimens were immersed for 24 hours in water at (20±3) °C,
201 boiled for 6 hours and again immersed in water for one hour. They were then subjected
202 to load at a constant speed of 6.0 mm/min, according to ABNT NBR 9434 [15].

203 Equation 6 was used to determine the resistance to shear strength.

$$204 \quad Tr = \left(\frac{F_{max}}{a \cdot b} \right) \quad (6)$$

205 Where:

206 Tr = maximum tension in shear, MPa;

207 F_{max} = tensile strength, MPa;

208 a = distance between grooves, cm;

209 b = width of specimen, cm.

210

211 **2.6.3 Dynamic Modulus of Elasticity Analysis - Stress Wave**

212 Stress Wave Timer method is a non-destructive test used to measure the dynamic
213 elastic modulus of a specimen. The method is based on the speed of propagation of
214 stress waves in the material, which is directly related to the material density. For this
215 calculation, Equation 7 was used.

216

$$217 \quad MOE_d = V^2 \times MEA \times \frac{1}{g} \quad (7)$$

218 Where:

219 MOE_d = dynamic modulus of elasticity, kgf/cm²;

220 V = speed of propagation of the tension wave, cm/s;

221 MEA = apparent specific density, g/cm³;

222 g = gravitational acceleration, 9.8 m/s².

223

224 **2.7 Analysis of results**

225 Test data for analysis, were tabulated and the statistical analysis conducted using
226 Microsoft Excel 2013. The software averages t test at 5% significance was used to
227 analyze the results.

228

229 **3. RESULTS AND DISCUSSION**

230 **3.1 Evaluation of Physical properties of panels**

231 **3.1.1 Moisture Content**

The moisture content of the test specimens after air conditioning are presented in Table 1.

Table 1. Results of moisture content for the blockboards.

Treatment	Factor	Mean	Standard deviation	Coefficient of variation (%)	$P(T \leq t)^*$ bi-caudal
NG	MC (%)	13.60	0.35	2.59	0.11
WG	MC (%)	13.05	2.28	17.47	

* $P = .05$, the difference is significant at the 5% significance level.

It is observed that the value of P is greater than 0.05, so the average of the difference of moisture content was not significant. The coefficient of variation shows that the WG treatment values had higher variability. The moisture values were close to expected.

Silva [2] found very similar values while doing the experiment with blockboards also produced from wastes and [18] obtained moisture content values close to 12% in plywood of *Pinus taeda*.

The National Program of Wood Quality (PNQM) determines the maximum moisture content of 18%, so the results were satisfactory.

3.1.2 Determination of the apparent specific density (MEA)

The results for the apparent specific density of the test treatments are shown in Table 2.

Table 2. Results of the apparent specific density for the blockboards.

Treatment	Factor	Mean	Standard deviation	Coefficient of variation (%)	$P(T \leq t)^*$ bi-caudal
NG	MEA (g/cm ³)	0.54	0.026	4.770	ns 0.780
WG	MEA (g/cm ³)	0.53	0.029	5.531	

* $P = .05$, the difference is significant at the 5% significance level.

It is observed that there is no significant difference of MEA between the treatments according to the t test.

3.1.3 Determination of Water Absorption (WA)

The values of WA obtained for the treatments, after immersion for 24 hours in water, are shown in Table 3.

Table 3. Results of water absorption for the blockboards.

Treatment	Factor	Mean	Standard deviation	Coefficient of variation (%)	$P(T \leq t)^*$ bi-caudal
NG	WA (%)	60.72	16.94	27.9	*0.027
WG	WA (%)	53.01	11.71	22.1	

* $P = .05$, the difference is significant at the 5% significance level.

Results show a significant difference between treatments according to the t test. The treatment NG, without edge gluing the battens, showed a greater susceptibility to water absorption. This can be explained by the smaller amount of glue on this material, conversely, in the WG treatment there is the edge gluing the battens with PVA adhesive, which provides less free spaces for water intake in the material.

3.1.4 Recovery in thickness (RE) and thickness swelling more recovery in thickness (IR)

Tables 4 and 5 show the values obtained for RE and IR, as well as the statistical analyzes and the results observed.

Table 4. Results of RE and IR for the blockboards.

Treatment	Factor	Mean	Standard deviation	Coefficient of variation (%)
NG	RE (%)	8.78	1.30	14.80
	IR (%)	1.82	0.81	44.60
WG	RE (%)	8.57	1.81	21.13
	IR (%)	2.41	1.70	70.55

Table 5. P values obtained by relating the two treatments.

Teste T	RE	IR
$P(T \leq t)_{bi-caudal}$	0.51	*0.05

* $P = .05$, the difference is significant at the 5% significance level.

From the table, one can observe that the average IR treatments presented significant difference at 5% significance level, with the WG treatment presenting higher mean and higher variability, as seen by the coefficient of variation. This can be explained by a possible inhomogeneous distribution of the adhesive during bonding in the material, which influences the swelling characteristics. Silva [2], using blockboards from construction waste obtained IR values close to 2%, i.e., comparable to values obtained in this work. Cabral [16], using multilaminar panels of *Pinus taeda* found IR values greater than 6%, however the adhesive used was Urea-formaldehyde.

For the average recovery in thickness (RE), the values do not differ significantly for the treatments at 5% significance level and again the variability (coefficient of variation) in relation to the WG treatment average was higher.

The thickness swelling of plywood panel is a result of water uptake as well as release of pressing tensions. Swelling can affect the pressing time, pressing temperature and type, proportion and formulation of the adhesive used [16].

3.2 - Evaluation of mechanical properties of blockboards

3.2.1 - Static bending

To define the feasibility of wood panels for structural use, it is important to determine the elasticity (MOE) and strength (MOR) of the material. Furthermore, it is also important to calculate the SPL, as this value indicates the stress at proportional limit, which is the tension when deformation changes from the elastic to the plastic regime, meaning that

the material may suffer rupture at any time beyond this point. In Table 6 we can see these average values of MOR, MOE, and SPL obtained for the treatments studied.

Table 6. Average values obtained in static bending for the blockboards.

Treatment	Factor	Mean (MPa)	Standard deviation	Coefficient of variation (%)
NG //	MOE	9,324	2,818	30.2
	MOR	58.21	13.32	22.8
	SPL	28.71	7.12	24.8
NG [⊥]	MOE	2,625	398	15.1
	MOR	22.6	2.07	9.2
	SPL	10.43	1.36	13.1
WG //	MOE	7,947	1,836	23.1
	MOR	54.95	16.27	30.0
	SPL	28.36	6.85	24.2
WG [⊥]	MOE	2,443	485	19.8
	MOR	19.00	3.7	19.6
	SPL	9.84	1.9	19.6

NG // - no edge gluing the battens, parallel to the fibers; NG[⊥] - no edge gluing the battens, perpendicular to the fibers; WG // - with battens edge gluing, parallel to the fibers; WG[⊥] - with battens edge gluing, perpendicular to the fibers.

The elasticity module is an intrinsic property of materials, which is dependent on the chemical composition, microstructure and defects such as pores and fissures. Module or tension of rupture is the maximum load supported by a beam until breakage. In this experiment, the comparison was made with respect to the direction of the fibers, i.e., comparing the treatments for parallel and perpendicular to the fibers test specimens separately.

The parallel specimens achieved much higher values and treatment NG presented higher MOE and MOR when compared to WG treatment, both in parallel and in the perpendicular directions. To conclude whether the differences are significant or not, the t test was performed comparing direction wise (parallel with parallel and perpendicular with perpendicular), as shown in Table 7.

Table 7. Values of t test comparing the specimens parallel, perpendicular, and all together.

<i>P</i> (<i>T</i> ≤ <i>t</i>) bi-caudal	MOE	MOR	SPL
NG // and WG //	0.23	0.95	0.89
NG [⊥] and WG [⊥]	0.39	0.02*	0.46
NG and WG	0.31	0.48	0.99

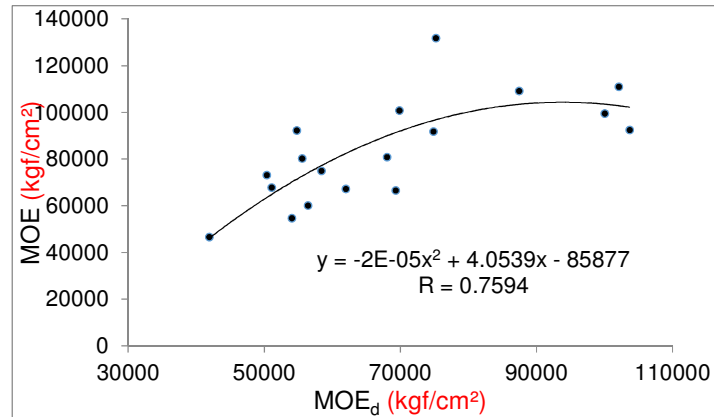
**P* = .05, the difference is significant at the 5% significance level.

A comparison between MOE and SPL does not result in significant differences. Only MOR of panels in the perpendicular direction showed significant difference (*P*=.05), which means that treatment NG had significantly higher MOR value than WG. Cabral [16] found mean values of 47.40 MPa for MOR and 5,765.30 MPa for MOE of parallel and 18.56 and 957.69 MPa for MOR and MOE, respectively, for perpendicular to the fibers direction. These results were obtained for a multilaminated panel of *Pinus Taeda*. It can be inferred from these results that the blockboard panel studied achieved better values of strength and stiffness.

3.2.2 Dynamic Analysis of elasticity module - Stress Wave Timer

334 It is important to compare the dynamic (MOE_d) with the static MOE, comparing values
 335 obtained in the non-destructive testing (Stress Wave) with the destructive, to observe the
 336 possibility estimating MOE without destructing of the material. It can be seen in Figures 4
 337 and 5, the relationship between the MOE_d and MOE for parallel and perpendicular
 338 specimens.

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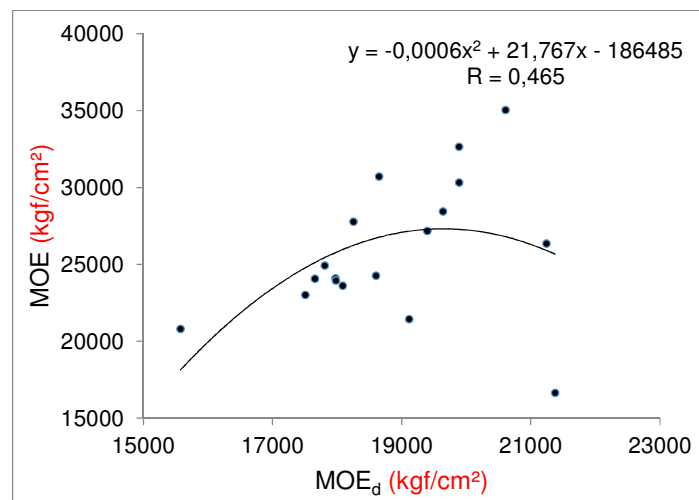
341

342 **Figure 4 – Regression between the MOE_d and MOE parallel to the fibers.**

343

344

345 It can be observed in this figure, the relationship between the two variables was
 346 reasonable, that is, the equation to determine the MOE from the MOE_d in this case, will
 347 estimate values similar to real.



348

349

350 **Figure 5 – Regression between the MOE_d and MOE perpendicular to the fibers.**

351

352 In the case of perpendicular direction, the correlation between MOE_d and MOE was low,
 353 but still acceptable for estimating non-destructively MOE.

354 **3.2.3 Resistance to shear in the glueline**

355 This experiment aims to evaluate the glueline quality and determine the more
 356 appropriate use for the blockboard, that is, suitable as indoor use, which is evaluated in

the dry test, intermediate, evaluated in the wet test, or outdoors, evaluated in the boiling test [2]. Considering that the phenol formaldehyde adhesive used is suitable for outdoors use, it was conducted the boiling test. The standard EN 314-2 [14], specifies the minimum tension resistance required in bonding and wood failure in the glue line, according to the test performed. Values are shown in Table 8.

Table 8. Bonding requirements (average values) for plywood panels.

Shear strength in the glue line	
Shear strength (TR) - kgf/cm ² e (MPa)	Wood failure (%)
2.0 (0.2) ≤ TR < 4.1 (0.4)	≥ 80
4.1 (0.4) ≤ TR < 6.1 (0.6)	≥ 60
6.1 (0.6) ≤ TR < 10.2 (1.0)	≥ 40
10.2 (1.0) ≤ TR	No requirements

Source: EN 314-2 [16] standard.

The mean shear strength (TR) and the average percent of wood failure are shown in Table 9.

Table 9. Results of shear strength and wood failure for the blockboards.

Treatment	Factor	Mean	Standard deviation	Coefficient of variation (%)
NG	TRC (MPa)	3.3	0.6	17.6
	Failure (%)	47.7	36.6	76.8
WG	TRC (MPa)	3.9	0.6	16.3
	Failure (%)	34.3	36.9	107.6

Comparing the results obtained and the values required by the standard, both treatments NG and WG are within the specified standard values either for the shear strength or wood failure. Silva [2], cited by [16], found an average shear strength of 1.73 MPa for plywood of *Pinus* sp. bonded with phenol formaldehyde adhesive. Using plywood produced from construction wastes, [2] found shear strength of 0.20 and 0.19 for PU and PVA adhesives, respectively. Working with plywood of *Pinus* sp. bonded with phenol-formaldehyde adhesive, [16] reported average values of 0.4 MPa.

To verify the statistical differences, the t test was performed on the samples, the result is shown in Table 10.

Table 10. t Test for the shear strength and wood failure.

t Test	P (T≤t)* bi-caudal
Shear strength	*0.002
Wood failure	0.287

*P = .05, the difference is significant at the 5% significance level.

Only shear strength was significant according to the P value, even though the results were very close. The WG treatment achieved higher shear strength than the NG

389 treatment. It is explained by the bonding of edge battens with PVA glue, as this
390 procedure can give more strength to the panel.

391

392 4. CONCLUSIONS

393 According to results of this study it can be concluded that:

394 • Physical properties of moisture content, density and recovery in thickness of the
395 blockboards were not affected by the treatments (with or without edge gluing the
396 battens) and are within the standard requirements. As for water absorption, the WG
397 treatment showed better results. Treatment WG had higher thickness swelling and
398 more recovery in thickness than NG;

399 • Mechanical properties of MOE and SPL, either in parallel and perpendicular to fiber
400 directions and MOR in parallel, were also not affected by the treatments (NG or
401 WG) and are within the standard requirements. Only MOR in the perpendicular
402 direction, even though not far apart, showed significant difference and treatment NG
403 was higher than WG. Pertaining to shear strength the higher value was obtained for
404 treatment WG, but also very close. Stress Wave Timer test may be a potential tool
405 for estimating the MOE of both treatments;

406 • The results obtained were satisfactory for both treatments and used material from
407 construction waste, therefore, of low cost.

408 • It is important to observe that bonding or not the battens in the core panel produced
409 no effect altogether, meaning that one less processing results in cut of costs in
410 production;

411 • It is recommended an analysis of the economic viability of producing panels with the
412 waste wood.

413

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