

Strength Properties of Medium Density Fiberboards (MDF) Manufactured with *Pinus Elliottii* Wood and Polyurethane Resin Derived from Castor Oil

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Abstract The Objective of this work was to evaluate the mechanical properties: modulus of rupture (MOR), tensile strength in perpendicular direction (TP) and tensile strength in surface direction (TS) of Medium Density Fiberboards (MDF) manufactured with polyurethane resin prepared with castor oil (PU Castor Oil) and fibers of *Pinus elliottii* wood. To the essay characterization was used the European Standard EMB/IS-2:1995, and was prepared fiberboards with 500×500 mm and two thickness (8mm and 15 mm), one proportion of resin (6%), hot pressing (50 bar and 160°C), nominal density of 0,75 g/cm³ and fiber with 12% of moisture content. The results of the mechanical properties obtained shows that the Medium Density Fiberboards can be manufactured with 6% of the PU Castor Oil.

Keywords Medium Density Fiberboard, Mechanical Properties, Polyurethane Resin Derived From Castor Oil

1. Introduction

According to the Brazilian Association of Wood Industry of Panels – ABIPA[1], Brazil is one of the most advanced countries in the world in the production of particleboard (PB) and Medium Density Fiberboard (MDF), having industrial factories with the latest generation with annual production estimated at 1.8 million cubic meters.

In the literature on production of wood panels there are several studies to improve the quality of these products with respect to moisture resistance, mechanical strength, dimensional stability and fitting and fixing, ease of machining to produce artifacts turned and details below and embossed, surface finishes with paint, varnish and lacquer.

An important aspect to be considered is the need for the identification and characterization of novel binders (resins, adhesives), which provide best quality to the products and to minimize problems caused by the emission of toxic gases from the use of phenolic resins.

Rozman et al.[2] evaluated the use of melamine-anhydride-modified (PP); polimetilenofenil (PMPPIC) and 3-trimethoxysilyl-polymethacrylate (TPM) combined with

EFB type of vegetable fibers and glass fibers. The tests performed showed the best results of static bending strength in specimens with PP and TPM.

Gouveia et al.[3] evaluated the density, bending strength, the internal adhesion and pullout strength of screws of OSB produced with fibers of *Pinus* and *Eucalyptus* wood and three levels of phenol-formaldehyde resin (4, 6 and 8%). The assays were performed according to ASTM D 1037-91 and the best results were obtained with 6 and 8% resin in panels with 50% of fibers of each species.

Comparative analyses conducted by Maciel et al.[4] between agglomerated particleboards of *Pinus* wood with 25 and 50% polystyrene (PS) and polyethylene terephthalate (PET) and commercial panels with phenolic resins and urea resins, it was observed that the panels with PS and PET had higher values for modulus of elasticity, bending strength, perpendicular strength and pullout strength of screws. Panels with Urea resins without toluene were those with the smallest screw pullout strength, and panels with phenolic resin not observed any increase in strength. It is noteworthy that the values of PS and PET were all above the minimum required by ANSI/A 208.1-1993.

O'Donel et al.[5] studied the influence of vacuum permeate and the infusion of epoxy resins based acrylic soybean oil (AESO) in flax fibers, cellulose pulp to recycled paper and fiberglass in the manufacture of panels. In the panels with flax fiber and moisture content ranging between

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10 and 50% was observed an increase in the bending strength from 1.5 to 6 GPa and 17 GPa to the panels with fiberglass; panels with cellulosic pulp fibers was five times higher than the values of panels with conventional resins.

Rozman *et al.*[6] evaluated the use of vegetable oil in EFB matrix-type polyurethane (PU) with isocyanates (MDI, HMDI, TDI and PEG) in the manufacture of panels with vegetable fibers of fruit stalk (EFB). Among the isocyanates the best results were obtained with HMDI.

Campos and Lahr[7] studied the strength properties of MDF panels with *Pinus* and *Eucalyptus* fibers with 8, 10 and 12% urea formaldehyde, polyurethane bi-component derived from castor oil and inorganic resin, found that the best internal adhesion (0.91 and 0.89 MPa) and bending strength (29.4 MPa and 28) were obtained in the panels made with *Pinus* and *Eucalyptus* fibers with 12% polyurethane adhesive.

Brady *et al.*[8] studied the influence of a mixture of vegetable oil (EFB), matrix polyurethane (PU) in proportions (by weight) of 25:75, 30:70 and 35:65 to verify the mechanical strength of wood fiber panels. The 35:65 ratio gave the best values of bending strength, and also observed that this ratio provided better coating the fibers and consequently greater compliance.

Silva[9] studied the characterization of the composite fiber long and short sisal and coconut with PU resin derived from castor oil, found in general that the tensile, bending strength, impact, fracture toughness and water absorption were lower in composites made from coconut fibers. The best results were obtained for composites with long fibers of sisal in tensile strength and fracture toughness. The composites made with short fibers coconut exhibited a percentage of water absorption equal to 17%.

Silva and Lahr[10] evaluated the production of particleboard with homogeneous particles of wood from the Amazon (*Erismia uncinatum*, *Nectranda lanceolata*, *Erismia sp.*). The boards were made with nominal thickness of 10 mm, nominal density of 0.75 g/cm³, using 10% bicomponent polyurethane resin derived from castor oil and particles having lengths of from 0.02 mm to 6 mm, under conditions of hot pressing at a temperature of 90°C, 40 MPa and a time of 10 min. In the assessments performed according to ABNT NBR14810 standard, panels of wood particles *Nectranda lanceolata* showed higher strength values, which are above the limit set by the normative standard.

Dias *et al.*[11] evaluated the mechanical properties of plywood panels made of polyurethane resin-based on castor oil. The results obtained for the bending modulus of elasticity not reached the minimum value of 18 MPa, is substantiated by the poor distribution of adhesive during the panel forming process.

Fiorelli *et al.*[12] developed particle boards bonded with bagasse and polyurethane resin derived from castor oil investigating the response variables: density, swelling, absorption and bending modulus and bending strength. The results indicated the material as being manufactured from high density, suitable for industrial use, demonstrating the

efficiency of the polyurethane resin-based adhesive such as castor oil.

Paes *et al.*[13] evaluated the effect of the combination of pressure (2.0, 3.0, 3.5 MPa) and temperature (50, 60, 90°C) in panels of wood waste particles with *Pinus elliottii* and polyurethane resin derived from castor oil in response variables: density, swelling and water absorption (0-2h, 2-24h; 0-24h) and bending strength, screw pullout and internal adhesion, concluding that combinations: 3.0 MPa and 90°C and 3.5 MPa and 60°C showed the best results, proving to be the pressing temperature as the most significant variable (finish) in the prepared panels.

Sartori *et al.*[14] evaluated the mechanical performance of wood panels and reforestation particles boards made with sugar cane bagasse and bicomponent polyurethane resin derived from castor oil as an alternative to the system of lateral closing of the trunk collective management center for beef cattle. The physical and mechanical properties obtained have proved the efficiency of the structural model proposed for use in management center.

Considering the positive aspects of the current production of particle boards in Brazil and the need for studies that enable the use of new adhesives, this study aims to evaluate, with the support of the European normative standard EMB/IS-2[15], the mechanical properties: modulus of rupture (MOR), tensile strength in perpendicular direction (TP) and tensile strength in surface directions (TS) in the panels made from fibers of *Pinus elliottii* wood and monocomponent polyurethane resin derived from castor oil (PU -Castor).

2. Materials and Methods

The studies for preparation and evaluation of MDF panels were performed at the Laboratory of Quality Control and Product Development of DURATEX Industry according to the experimental procedures proposed by EMB/IS-2[15] standard and according to the experimental design shown in Table 1.

Table 1. Experimental design

PU (%)	Thickness (mm)	Temperature (°C)	Pressure (bar)	Moisture (%)	Density (g/cm ³)
6	15	160	50	12	0,75
6	8	160			

The panels were prepared with fibers of *Pinus elliottii* wood, obtained by thermo-mechanical shredding, according to the following steps:

First step: Setting the fiber mass, of nominal density and addition of 12% water (dry weight basis) using hand sprayer. The addition of water was performed using a balance with infrared heating system for controlling the moisture content of the fibers.

Second step: Addition of PU-adhesive Castor to the fibers (6% dry weight basis) and fiber mat formation.

The addition and mixing of adhesive fibers were made using a mix fiber and resin (Figure 1), equipped with a central axis in the longitudinal direction with mixing blades in the radial direction and pneumatic guns for distribution of adhesive to the fibers. Then the fibers were deposited with adhesive forming the mattress to define the volume of fibers (Figure 2).



Figure 1. Cylinder to mix fiber and resin



Figure 2. Pattern to board formation

Third Step: Pre-cold pressing of the mattress and pressing fibers with controlled temperature and pressure for the production of MDF panels.

The mattress of fibers prepared above was subjected to cold pressing to the equipment of Figure 3, in order to adapt its dimensions to press with pressure and temperature control working (Figure 4). This has the press panels (upper and lower instead of inferred) provided with resistances which are heated and transfers instead of transfers heat to the mat of fibers. The heat reacts with the PU-Castor resin providing immediate cure.



Figure 3. Machine for pre-press the board



Figure 4. Machine to press the board with control of pressure and temperature

Fourth Step: Manufacture of the specimens.

Were made three panels with dimensions $500 \times 500 \times 8$ mm and three other with dimensions of $500 \times 500 \times 15$ mm, resulting in 6 panels. These panels remained for approximately 72 hours to achieve thermal equilibrium.

Were obtained six specimens of dimensions $500 \times 50 \times (8$ and $15)$ mm of each panel produced to determine the modulus of rupture (MOR). To determine the perpendicular tensile strength (TP) and surface tensile strength (TS), were prepared specimens with dimensions of $50 \times 50 \times (8$ and $15)$ mm, twelve specimens of each panel to TP and five specimens for TS.

Fifth Step: Essays on characterization of the panels.

The results (Table 2) of the strength tests were compared with the minimum values of the properties proposed by EMB/IS-2[15] standard.

Table 2. Properties of the MDF, Standards, minimum values proposed by EuroMDFBoard/1995 and average values obtained from tests

Standards and properties according to EMB/IS-2: 1995		Minimum values depending on the thickness according to EMB/IS-2: 1995 standard	
EN310[16]	MOR	23 MPa	20 MPa
EN319[17]	TP	0,55 MPa	0,55 MPa
EN311[18]	TS	1,20 MPa	1,20 MPa
EN318[19]	Density	0,5 a 0,8 g/cm ³	0,5 a 0,8 g/cm ³
-	Thickness	> 6 a 9 mm	> 12 a 19 mm

The equipment tests to characterize the MDF are illustrated in Figures 5, 6 and 7.



Figure 5. Static bending test



Figure 6. Perpendicular tensile test



Figure 7. Superficial tensile test

Sixth Step: To prove the significance of the test results, statistical analysis were performed with the "General Linear Model" proposed by Tukey, using the software Minitab® 13. The analysis allowed the generation of graphs in which it is possible to evaluate if the test results satisfy the experimental model, namely if there random distribution of variance and normality of the data.

3. Results and Discussions

Table 3 shows the mean of the MOR, TP and TS and their respective standard deviations (SD) and coefficients of variation (CV) as a function of the thickness (TK) of the panels.

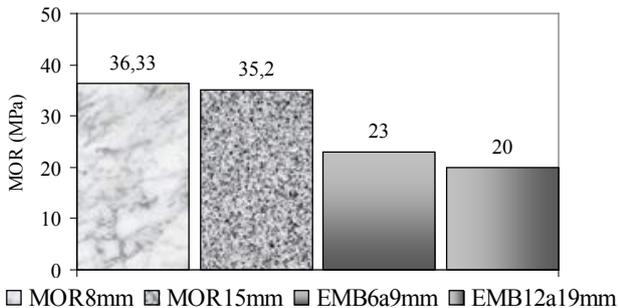


Figure 8. Average values of MOR

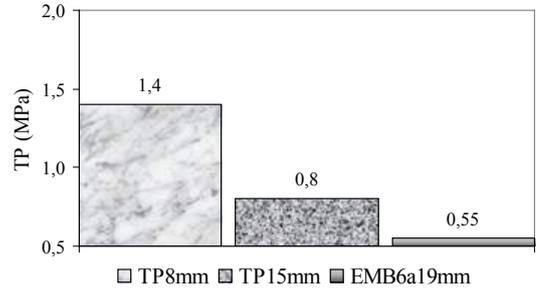


Figure 9. Average values of TP

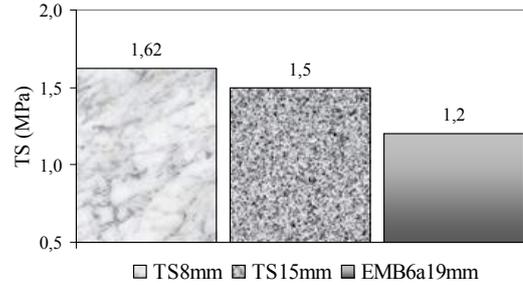


Figure 10. Average values of TS

Table 3. Average properties of strength and stiffness

Properties	TK (mm)	Mean	SD	CV
MOR	8	34,93	2,29	6,57
		36,66	4,86	13,25
		37,41	3,39	9,05
	15	32,25	3,25	12,71
		37,40	4,75	8,35
		33,59	2,80	8,35
TP	8	1,32	0,10	7,63
		1,50	0,10	6,55
		1,38	0,12	8,91
	15	0,79	0,60	7,52
		0,90	0,60	6,29
		0,72	0,60	8,70
TS	8	1,55	0,10	6,43
		1,60	0,22	13,56
		1,70	0,15	8,85
	15	1,43	0,04	2,90
		1,65	0,21	12,72
		1,30	0,08	5,94

Figures 8, 9 and 10 illustrate graphs of the strength properties obtained with the characterization tests of MDF panels with 8 and 15 mm thickness, compared with the minimum strength value proposed by EMB/IS-2[15]

standard.

As shown in Figures 8, 9 and 10, in all cases, considering the two thicknesses measured values obtained with the assays for the characterization of MDF were higher than the minimum values proposed by EMB/IS-2[15] standard.

Regarding the density, average values were determined equal to 0.75 and 0.80 g/cm³ respectively, within the range recommended by EMB/IS-2[15] standard, as presented previously in Table 2.

To verify the efficiency of the manufacture process and the homogeneity of the panels, statistical analyses were performed in the values of the MOR, TP and TS. The verification of the significance of these values was performed considering the simultaneous analysis of two thicknesses, 8 and 15 mm. Then relations were established between residues with calculated values and the scores of normal strength values determined for the MOR, TP and TS.

Figure 11 shows the verification of the random distribution of variance values of MOR, which shows the relation of the residual with the estimated values, it is possible to verify that there was random distribution of variance with two events highlighted, showing high values of residues. These events correspond to specimens with 8 and 15mm of thickness obtained by the edge regions of MDF, which showed MOR with values equal to 29.89 MPa and 28.14 MPa, above the minimal values (23 and 20 MPa) proposed by EMB/IS-2: 1995 standard. Figure 12 shows the verification of the hypothesis of normality between the values of MOR, that although the events highlighted with high amounts of residual, it is observed that the events are linearly distributed with a determination coefficient (R²) equal to 0.9286.

In checking the homogeneity of the MDF by comparing the MOR, Table 4 shows the multiple analysis of variance which evaluated the averages of these values between the MDF with same thickness (TK), ie, 8 mm (1 and 2); (1 and 3); (2 and 3) and with 15 mm (4 and 5); (4 and 6), (5 and 6), which verifies that the confidence intervals (CI) were determined with opposite signs values (- and +). These results, as the analysis model proposed indicate that panels are similar (equivalent) and are characterized by being identical repetitions.

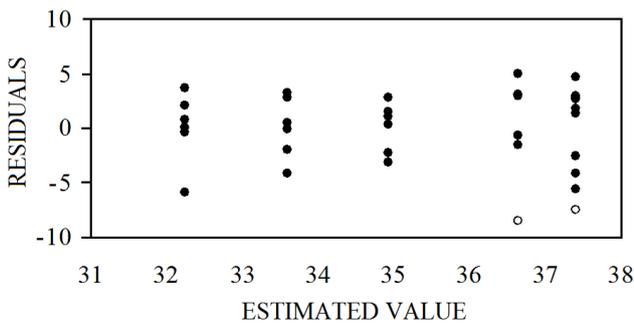


Figure 11. Residual distribution – MOR

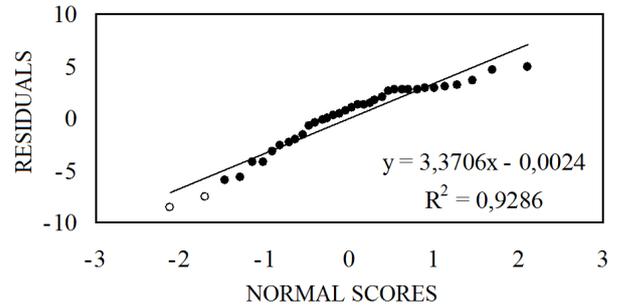


Figure 12. Residual Plot – MOR

Figure 13 shows the random distribution of variance values of TP, revealing that there were no events with high values of residual and are presented randomly. Figure 14 presents the hypothesis of normality between the values of TP, revealing that the events are distributed linearly, with determination coefficient equals to 0.9847.

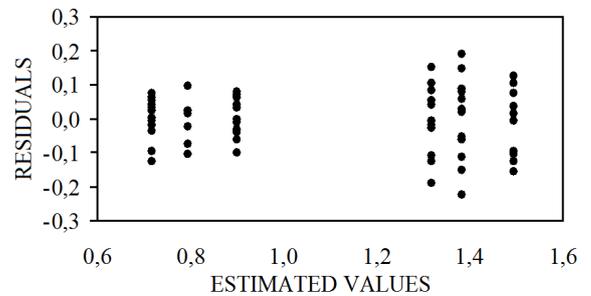


Figure 13. Residual distribution – TP

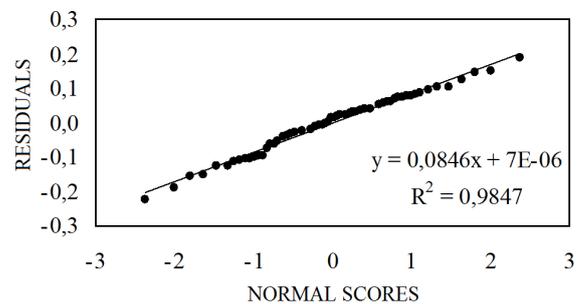


Figure 14. Residual Plot – TP

The verification of consistency between the MDF from the comparison of the values of TP can be observed in multiple analyses of variance shown in Table 5, where there is a comparison between MDF (1 and 3), (4 and 5) and (4 and 6) showed that ranges of values with different signs (+ and -), indicating that these panels are similar and allowing inferring that the process of manufacture of these panels was similar, however the MDF (1 and 2), (2 and 3) and (5 and 6) showed ranges of values with equal signs (+ and +) and (- e -), indicating that these panels are different, possibly due to process manual distribution of the fibers. However, it is noteworthy that there was no reduction in the average value of TP, which were higher than the minimum value (0.55 MPa) proposed by EMB/IS-2[15] standard.

Table 4. Comparison of MOR average values using multiple variance analysis

TK	Panels	Mean	Panels	Mean	DMA	DMS	CI		RM
8 mm	1	34,9	2	36,7	1,73	-6,46	-8,190	4,737	0,95
	1	34,9	3	37,4	2,49	-6,46	-8,949	3,979	0,93
	2	36,7	3	37,4	0,76	-6,46	-7,222	5,705	0,98
15 mm	4	32,2	5	37,4	5,16	-6,46	-11,620	1,310	0,86
	4	32,2	6	33,6	1,35	-6,46	-7,810	5,110	0,96
	5	37,4	6	33,6	3,81	1,15	-2,660	10,27	1,11

Table 5. Comparison of average TP values using Multiple Variance analysis

TK	Panels	Mean	Panels	Mean	DMA	DMS	CI		RM
8 mm	1	1,3	2	1,5	0,20	-0,08	-0,280	-0,10	0,87
	1	1,3	3	1,4	0,10	-0,07	-0,170	0,04	0,93
	2	1,5	3	1,4	0,10	0,11	0,008	0,21	1,07
15 mm	4	0,8	5	0,9	0,11	-0,10	-0,210	0,00	0,88
	4	0,8	6	0,7	0,07	0,04	-0,030	0,20	1,10
	5	0,9	6	0,7	0,20	0,28	0,080	0,30	1,29

In Figure 15 there is a random distribution of variance values of TS performed by using the relationship between residual and estimated values. In the graph are identified two events with high values of residues that correspond to the MDF with 8 and 15mm of thickness obtained in the region of the edges of the panels, with TS equal to 1.60 MPa and 1.43 MPa, which although having high residues are superior to minimum values (1.2 MPa) proposed by EMB/IS-2[15].

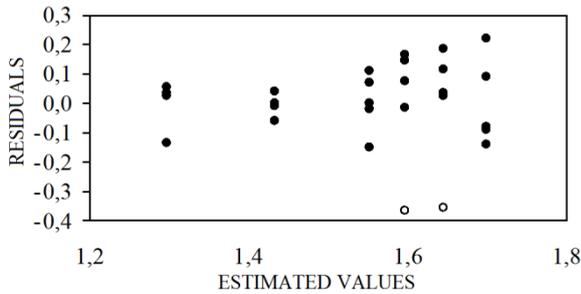


Figure 15. Residual distribution – TS

Figure 16 shows the hypothesis of normality values of TS by means of the ratio between residual and normal scores. This relationship determines a region on the graph with a

straight events distributed with determination coefficient $R^2 = 0.9067$. This graph also observe the events that showed high levels of residual.

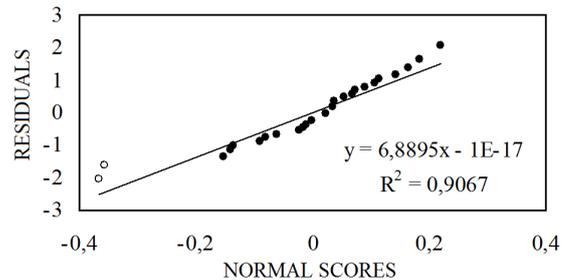


Figure 16. Residual Plot – TS

The verification of consistency between MDF from the values of TS can be seen in Table 6 (multiple ANOVA), where there is only a comparison between the MDF 5 and 6 presented value range with equal signs (+ and +), considering that the values of TS are determined above the minimum required value (1.2 MPa) by EMB/IS-2[15]. It is emphasized that the problems in the process of making the MDF did not influence the final TS.

Table 6. Comparison of average of T S values using multiple variance analysis

TK	Panels	Mean	Panels	Mean	DMA	DMS	CI		RM
8mm	1	1,55	2	1,59	0,04	-0,29	-0,33	0,24	0,97
	1	1,55	3	1,70	0,15	-0,28	-0,43	0,14	0,91
	2	1,59	3	1,70	0,11	-0,28	-0,39	0,18	0,94
15mm	4	1,43	5	1,64	0,21	-0,29	-0,50	0,05	0,87
	4	1,43	6	1,29	0,14	-0,01	-0,15	0,42	1,11
	5	1,64	6	1,29	0,35	0,41	0,06	0,63	1,27

4. Conclusions

According to the test results it can be concluded that the adhesive PU-Castor Oil in the ratio of 6% gave the MDF made with fiber of *Pinus elliottii* wood present mechanical properties compatible with the requirements of the standard EMB/IS-2: 1995 for both thicknesses.

Statistical analyzes showed that the homogeneity problems arising from the procedures of making the MDF in the laboratory were not significant.

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