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Evaluation of the Mechanical Properties of Particleboards Manufactured with Waste of *Pinuselliottii* Tree Pruning

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Abstract This work aimed to evaluate the bending strength (MOR) and the bending modulus of elasticity (MOE) of particle boards manufactured with *Pinuselliottii* and *Eucalyptusgrandis* species and the addition of waste of *Pinuselliottii* tree pruning, using a bicomponent polyurethane resin-based castor oil as an adhesive. We prepared nine different experimental conditions, six of the composition of particles of wood (*Pinus* and *Eucalyptus*) with pruning residue(30%, 50% and 70% waste) and other three made with 100% of each one of the three types of particle used, evaluated by the analysis of variance (ANOVA). The panels were prepared by adding 12% of polyurethane resin on the mass particle with a moisture content of 11%, using compaction pressure of 4.5 MPa and hot pressing of 90°C. The results showed that the inclusion of pruning residues reduced significantly the strength and stiffness properties of the panels when compared with the materials manufacture dintegrally with *Pinus*or *Eucalyptus* particles. The MOR of the materials in all conditions test ed was less than the 18 MPa, limit value set by the Brazilian standard, shown to be necessary to adjust the parameters process used for the achievement of the regulatory requirements.

Keywords Particleboards, Polyurethane Resin-based Castor, Waste Tree Pruning

1. Introduction

Several researches have been developed in the preparation of particleboards, aiming to verify the feasibility of preparing materials upon certain factors and experimental levels stipulated, and the adhesives of urea-formaldehyde used the most[1].

Widsten et al.[2] studied the influence of high temperature shredding in the physical and mechanical properties of MDF made with hardwood fibers. The authors concluded that the fibers showed better reactivity during bonding by shredding at high temperature, providing progressive breakdown of the lignin polymer contained in the fibers, facilitating the accession process and generally improving the physical and mechanical properties of the panels.

Nemli et al.[3] evaluated the emission of formaldehyde, bending modulus, bending strength, adhesion, thickness swelling and internal adhesion in panels manufactured with mimosa wood particles and with the addition of bark residues. The panels prepared with the inclusion of the residues of bark investigated reduced the mechanical properties when compared to panels manufactured without waste, significantly reducing the emission of formaldehyde and thickness swelling in the manufactured material.

Jun Li et al.[4] evaluated the feasibility of using two exotic species of wood larch (Larixgmelinii and Larix sibirica) as raw material for the manufacture of panels, the variables investigated were bending modulus of elasticity (MOE), modulus of rupture (MOR) and internal adhesion (AI). The results obtained for the three variables indicate the possible use of both species of wood in the manufacture of the panels.

AkgülaandÇamlibelb[5] evaluated the strength and stiffness of particleboards made from Rhododendron wood, foundin abundance in the Black Sea region(Turkey), and 14% of moisture content and adhesive based on urea formaldehyde. The results indicate the use of Rhododendro n wood to produce the panels of medium density.

Tibor et al.[6] evaluated the properties MOE, MOR and internal adhesion (AI) in wood panel of conifer class, originating from the town of Mohács-UNGARY, not getting satisfactory results only for internal adhesion, justified by the manual mixing of adhesive and urea-formaldehyde wood particles, and other results can be

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achieved by using mechanical mixers.

Saffian et al.[7] studied the feasibility of production of medium density panels in RRIM 2020 rubber tree clones with four years of age, were evaluated the modulus of elasticity (MOE) and rupture (MOR). The results indicated that it is possible to manufacture the panels with clones of the rubber used.

One aspectto consider because of the industrialization of particle boards is to us eproducts that pollute the environment, mainly through the emission of gases. Accordingly it is necessary to develop new products, such as the proposed study by Bradietal.[8], having considered the influence of mixing vegetable oil into the polyure than ematrix of fiberboard. The analysis shows that it is possible to use mixtures of vegetable oil in the polyure than ematrixratio35:65(by weight)for making panels of wood fibers.

Joseph andBeraldo[9] evaluated the performance of physical and mechanical particle boards with bamboo and polyurethane resin-based castor. The results demonstrated thep otential of engineered materials for industrial use.

Dias et al.[10] evaluated the mechanical properties of plywoodpanels made of polyure thane resin-based castor. The results obtained for the MOE not reached the minimum value of 18Mpais substantiated by thepoor distribution of adhesive during the panel forming process.

Fiorellietal.[11] developed particle boards bonded with bag asse and polyurethane resin-based castor, investigating the properties: density, swelling, absorption and modulus of elasticity and bending strength. The results indicated the materialas being manufactured from high density,suitable for industrial use, demonstrating the efficiency of the polyurethane resin castor oil based.

Paes et al.[12] evaluated the effect of the combination of pressure (2.0; 3.0; 3.5MPa) and temperature (50; 60; 90^{o}C) in panels with particulate of Pinus elliottiiwood waste and polyurethane resin-based castor in response variables: density, swelling and water absorption (0–2h, 2–24h, and 0–24h) and elastic modulus of rupture, screw pull-out and internal adhesion, concluding that combinations: 3.0MPa and 90ºC and 3.5MPa and 60°C showed the best results, proving to be the hot pressing temperature as the most significant variable quality (finish) of the panels prepared.

Sartori et al.[13] evaluated the mechanical performance of wood panels and reforestation panels particle

Scrushed can esugar with polyurethane resin-based castoras an alternative to the system of lateral closing 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.

According to the Brazilian Association of the Industry of Wood Panels[14], Brazil is one of the most advanced countries in the world in the manufacture of particle boards, medium density, with the largest number of factories of last generation, whose annual production amounts currently 612000m^3, accounting for worldwide production a very low percentage considering the timber potential of the country and the technology installed.

Considering the aspects of the potential production of particle boards from Braziland the need for studies that enable the use of new adhesives as well as the use of tree pruning waste, material unexplored in research involving particle boards, this study aimed to develop and evaluate mechanical properties of materials made from waste tree pruning, allowing to evaluate the potential of compounds developed.

2. Materials and Methods

For this work, we used pruning of trees(bark) of *Pinuselliottii* and wood particles of *Eucalyptusgrandis* and *Pinuselliottii* species, being prepared and investigated nine experimental conditions(EC), presented in Table 1.

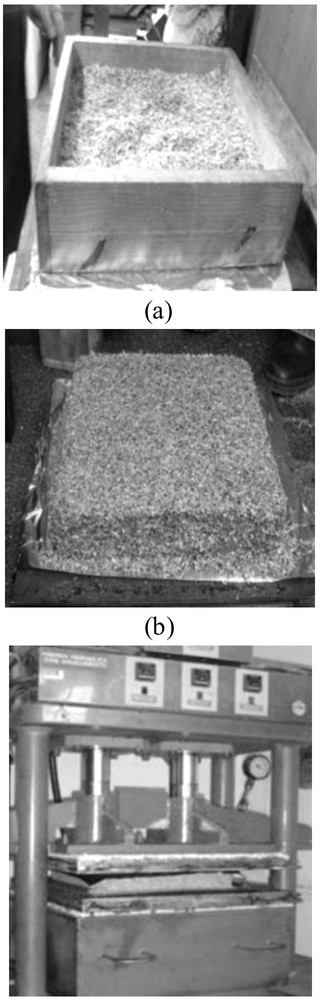
Table 1. Experimental conditions investigated

CE	Materials
C1	100% *Eucalyptus grandis*
C2	30% *Pinus elliottii* (bark) and 70% de *Eucalyptus grandis*
C3	50% *Pinus elliottii* (bark) and 50% de *Eucalyptus grandis*
C4	70% *Pinus elliottii* (bark) and 30% de *Eucalyptus grandis*
C5	100% *Pinus elliottii*
C6	30% *Pinus elliottii* (bark) and 70% de *Pinus elliottii*
C7	50% *Pinus elliottii* (bark) and 50% de *Pinus elliottii*
C8	70% *Pinus elliottii* (bark) and 30% de *Pinus elliottii*
C9	100% of*Pinus* barkresidue

The bicomponent polyurethane resin (PU) derived fromcastor (adhesive) is employed as the compounds manufactured, with low formaldehyde emissionand no extender having 66% solids, pH of 8 to 9 and an average bulk density of 1.29g/cm^3.For the curing process it is necessary touse acatalyst based on commercial sodiumchloride, with solids content of 20% at a dosage of 2.5% solids as catalyst for the solids content of the PU, classified as non-toxic[15].

After separate sheets of bark of *Pinuselliottii* wood, these along with the two wood species were taken into mill to bechopped. After this process, the particles were screened on sieves with mesh of 2.8mm, dried to amoisture content of 11% and subsequently mixed with the polyurethane resin. At this stage, the materials still remain without adhesion with a flour-like appearance. These are placed in a mould(Figure 1a) followed by application of apre-press toob tain cohesive(Figure 1b), and subsequently placed in a hydraulic press(Fig. 1c) and pressing temperature of 90°C. The compounds of the pressing process consisted in the use of a pressure of 4.5Mpa for 3 minutes, followed by pressure relief of the pressfor a period of30 seconds and subsequent employment pressure of 4.5Mpa for 7 minutes, for a total time of 10 minutes and 30 seconds with pressing for release of gases. This procedure was used for fabrication of all the panels and it was noted that there were no formation of blisters and ruptures in the material.

For the feasibility of production of the panels from the inputs mentioned, mechanical tests were performed based on standard ABNTNBR14810[16] (parts 2 and 3),being obtained mechanical properties: bending modulus of elasticity(MOE) and bending strength modulus (MOR).



(a)

(b)

(c)

Figure 1. Forming mattress (a), Mattress particles (b) and hydraulic press (c)

Five particle panels were manufactured for each one of the nine experimental conditions investigated (45 panels), with dimensions 400×400×10mm, each consisting of 1500g of particles with 180g of adhesive, amounting to 12% of the mass of particles[10]. After 72hours,the panels wer squared in dimensions 350×350×10mm.Each one panel were extracted seven specimens for bending tests, with dimension 50×250×10mm, leading to 315trials.

The analysis of variance(ANOVA) were used to evaluate the efficiency in the mechanical properties of compounds produced with the inclusion of the pruningresidues. For this purpose,three independent groups were evaluated, relating to the materials of the conditions C1 to C4 (Group 1), C5 to C8 (Group 2) and C1,C5 andC9 (Group 3).

3. Results and Discussions

Table 2 shows the mean value (X_m), coefficient of variation(CV) and P-value of Anderson-Darling normality test referring to the 35 specimens investigated by experimental condition.

Table 2. Results of the mechanical properties

CE	MOE (MPa)		
	X_m	CV(%)	P-value
C1	1304	12	0,729
C2	1332	9	0,116
C3	1306	15	0,817
C4	1363	13	0,676
C5	1482	16	0,133
C6	1139	21	0,209
C7	1314	19	0,321
C8	1524	17	0,503
C9	891	17	0,617
CE	**MOR (MPa)**		
	X_m	CV(%)	P-value
C1	12,91	12	0,527
C2	12,44	11	0,216
C3	11,64	11	0,983
C4	12,24	13	0,434
C5	16,41	14	0,389
C6	9,28	20	0,873
C7	11,35	19	0,671
C8	14,70	18	0,159
C9	7,49	19	0,180

The coefficients of variation were obtained in accordance with those presented in the work of Fiorellietal.[11], which gives consistency to there liability of the production process of the panels developed.

The Brazilian standard ABNTNBR14810[16]requires MOR minimum of 18 Mpa for thickness between 8mm and 13mm, but it is not indicating minimum value of MOE instatic bending. The results presented in Table 2 show that materials prepared were unable to reach the threshold value,the largest being obtained from materials manufactured C5 condition, 18.33% below the reference value.

For analysis of variance (ANOVA) assumptions are made that both samples are extracted from independent populations, which can be described by a normal distribution[17]. The distributions are considered normal when the P-value of the response exceeds 0.05[17].

Table 3 presents the results of the ANOVA for the mean response variables investigated, lying under scores the P-values less than or equal to 0.05 (5%), were considered significantat a confidence level of 95%[17].

Table 3. P-values of the main factors

Groups	P-value	
	MOR	MOE
Group1	0,005	0,415
Group2	0,000	0,000
Group3	0,000	0,000

From Table3, Group1 except for the response bending modulus, all other groups showed significant in the mechanical properties MOE and MOR, indicating that the inclusion of particles from the waste pruning affected the strength and stiffness properties of the particle boards manufactured.

Figures 2, 3 and 4 shows the main effect plots of experimental conditions by group on the mechanical properties investigated.

Group1, the inclusion of mass fractions of 30% and 50% bark residues when compared to those of the compounds made with 100% of wood particles of *Eucalyptus grandis* gave reductions of 3.87% and 6.21% respectively in MOR, an increase of 5.15% from 50% to70% of the fraction particles of bark.

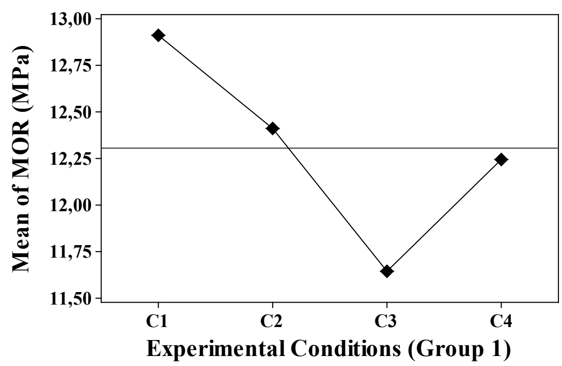


Figure 2. Main effects plot of the experimental condition (Group 1) on MOR

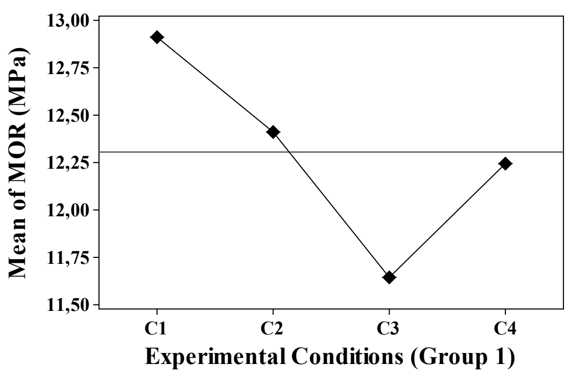
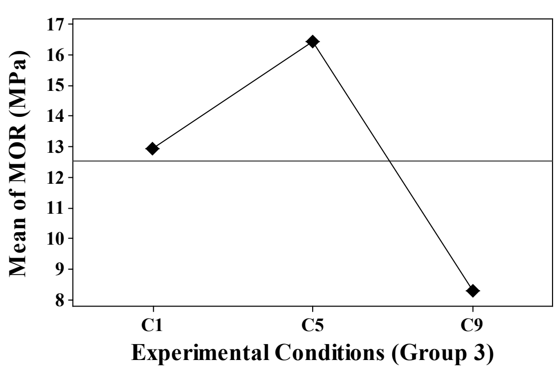
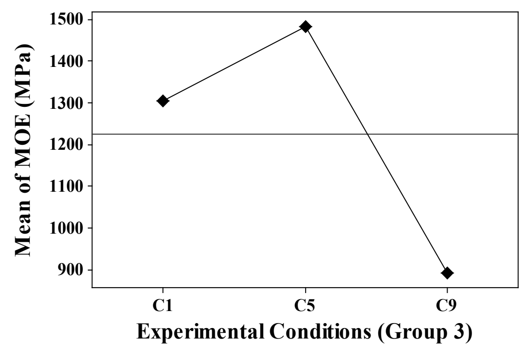


Figure 3. Main effects plot of the experimental condition (Group 1) on MOR



(a)



(b)

Figure 4. Main effects plot of the experimental conditions (Group 3) on MOR (a) and MOE (b)

Group2, the progressive inclusion of residues of bark in the compounds gave reductions in the mechanical properties in all compositions when compared with the results of the materials made with 100% of *Pinuselliottii* wood particles, and the results obtained under the C8 condition presenting MOR 43.44% less than the compounds produced in reference condition. The inclusion of 30% of particles of bark showed 2.81% increase in bending modulusin the compounds when compared to the results from reference condition(C5),andsuccessive reductions of 11.36% and 23.77% with increases of 50% and 70% of particles of waste.

Group 3, those made of the C5 condition(100% of particles of *Pinuselliottii*) showed the best results for the mechanical properties investigated, with the lowest coming from the C9 condition (100% of particles of bark). With regard to MOR, the materials of C5 conditionshown to be 27.11% and 98.46% higher when compared with materials manufactured of C1 conditions(100% of particles of*Eucalyptus grandis*)and C9 respectively.As in the MOR, the MOE of the materials of C5 condition be presented 13.70% and 66.34% higher when compared to the materials made of the C1 and C9 conditions respectively.

4. Conclusions

The inclusion of waste particle spruning of *Pinuselliottii* speciesin materials made from wood particles of *Pinuselliottii* and *Eucalyptusgrandis* species conferred significant reductions in both mechanical properties investigated, except for MOE materials manufactured from particles of *Eucalyptus*(Group1).

The results of bending strength in all experimental conditions investigated were below the limit of 18 MPa stipulated by Brazilian ABNTNBR14810[16] standard, the highest value being obtained from the composition with 100% of particles of *Pinuselliottii* species.

In future work will be necessary to adjust the process parameters used here as the inclusion of other factors such as the treatment of the particles, so that the regulatory requirements are met and allow for proposing the use of panelsthus produced.

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