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USE OF RESIDUES OF FORESTRY EXPLORATION OF *Pinus taeda* FOR PARTICLEBOARD MANUFACTURE¹

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ABSTRACT – This study aimed to evaluate the quality of particleboards manufactured with forest exploitation waste from *Pinus taeda*. The material in the form of branches, tree tops, stumps and roots, was obtained from a forest plantation located in the Municipality of Mafra - SC. All the material was processed into wood chips for biomass and transported to the place of studies. The *Pinus* industrial particles were used as control and mixed with the waste in different proportions. The experimental plan consisted of the panels manufacture with 100% of each type of material and mixture of these com proportions of 75/25%, 50/50% and 25/75% with *Pinus* industrial particles, in addition to the mixture in equal parts, of the three types of materials. Experimental panels were manufactured with nominal density of 0.75 g/cm³, using the urea-formaldehyde resin, in the proportion of 8% of solids - dry weight basis of the particles. The panels were pressed with specific pressure of 4.0 MPa, temperature of 160°C and pressing time of 8 minutes. The results of the internal bond tests met the requirements of the standard EN 312, is indicative that there has been a proper bonding of these particles originating forest exploitation wastes. General evaluations of the physical and mechanical properties results of the experimental panels indicate the possibility of use of particles obtained from branches, tree tops, stumps and roots, mixed com the industrial *Pinus* particles, in proportion of, up to, 50%, for particleboard manufacture.

Keywords: *Pinus particles; Panels pressing; urea-formaldehyde resin.*

UTILIZAÇÃO DE RESÍDUOS DE EXPLORAÇÃO FLORESTAL DE *Pinus taeda* PARA PRODUÇÃO DE PAINÉIS AGLOMERADOS

RESUMO – Esta pesquisa teve como objetivo avaliar a qualidade de painéis aglomerados produzidos com resíduos de exploração florestal de *Pinus taeda*. O material na forma de galhos e ponteiros e de tocos e raízes, foram obtidas de um plantio florestal localizado no Município de Mafra – SC. Todo o material foi transformado em cavacos para biomassa e transportados até o local de estudos. As partículas industriais de *Pinus* foram utilizadas como testemunha e em mistura com os resíduos em diferentes proporções. O plano experimental consistiu na produção de painéis com 100% de cada tipo de material e em mistura destes com proporções de 75/25%, 50/50% e 25/75% com partículas industriais de pinus, além da mistura em partes iguais dos três tipos de materiais. Foram produzidos painéis experimentais com densidade nominal de 0,75 g/cm³, utilizando a resina uréia-formaldeído na proporção de 8% de sólidos - base peso seco das partículas. Os painéis foram prensados com pressão específica de 4,0 MPa, temperatura de 160 °C e tempo de prensagem de 8 minutos. Os resultados dos ensaios de tração perpendicular atenderam aos requisitos da norma E 312, sendo indicativo de que houve uma colagem adequada destas partículas provenientes de resíduos de exploração

florestal. Avaliações gerais dos resultados das propriedades físicas e mecânicas dos painéis experimentais indicam a possibilidade de uso de partículas obtidas a partir de galhos e ponteiros e de tocos e raízes em mistura com as partículas industriais de pinus na proporção de até 50% para produção de painéis aglomerados.

Palavras-Chave: Partículas de pinus; Prensagem de painéis; Resina uréia-formaldeído.

1. INTRODUCTION

The species of the genus *Pinus* and *Eucalyptus*, originating from forest plantations, are the basis of raw material for the particleboards manufacture in Brazil. Wood particles used in the panels composition are obtained from logs extracted within the commercial trees height. All the remaining material such as stumps, roots, tree tops and tree branches are considered wastes of exploitation and are left in the forests without a destination to take advantage of this woody material as industrial raw material.

Studies on potential of use of various types of waste wood, and products derived from wood, in particleboard manufacture have been objects of researchers in Brazil and other countries. Weber and Iwakiri (2015) assessed the feasibility of waste use from plywood panels processing, particle board and MDF in particleboard manufacture; Azambuja (2015) carried out studies on the potential use of civil construction and demolition waste as a raw material in the production of particleboards; Iwakiri et al. (2012) have evaluated the quality of particleboards manufactured with waste from sawmills in the Amazon region. The researchers found satisfactory results for the use of these residues in particleboard manufacture, indicating the possibility of its incorporation into the matrix of raw material for these industries.

There are wide sources of raw material with the possibility of use in particleboard manufacture, such as the various types of waste studied by these researchers. However, there are not in the literature, references about the use of exploitations wastes, such as stumps, roots, tree tops and tree branches for particleboards manufacture.

The wood's anatomical, physical and chemical properties are different among species and vary, also, among the trees and different parts of the same tree, which have a strong influence on the wood bonding process (Marra, 1992). Therefore, the woody material from stumps, roots, branches and tree tops, may present variations in physical and chemical properties resulting from the growing process.

Moslemi (1974) affirms that the choice of wood species for particleboard manufacture must be based on some important parameters such as density, pH and extractives. The wood

density is one of the basic requirements on the choice of species for production of particleboards, due to its influence on the compression ratio, which is the relationship between the panel density and the wood density. According to the author, the compression ratio must be at least 1.3 to ensure a proper contact area among the particles and to enough densification of the panel. Maloney (1993) states that, for panels of same density, which are manufactured with low density wood, they will present superior mechanical properties, however, their dimensional stability will be lower. Moslemi (1974) reports that the species with a density of, until, 0.55 g/cm^3 , are the most suitable for production of particleboards, due to reaching a compression ratio between 1.3 and 1.6.

Regarding the pH and woods extractives, Moslemi (1974) asserts that the same can directly influence the cure of the resin and, consequently, in quality of manufactured panels. The wood pH may vary from 3.0 to 5.5 and, according to Maloney (1993), wood with very acid pH may cause the pre-cure of the urea-formaldehyde resin in the phase of press closure, hindering the adhesion among the particles and reducing the properties of the panels. On the other hand, woods that have a slightly acidic pH require a little more of a catalyst to accelerate the cure of the urea-formaldehyde resin. As for the influence of extractives in the polymerization and adhesive cure, Maloney (1993) argues that, the wood with high content of extractives present difficulties for bonding, resulting in low resistance of the adhesive connection among the particles.

In view of the lack of information on the use of residues of forestry exploitation of *Pinus taeda*, like branches, tree tops and stumps with roots as a raw material in the production of particleboard, the objective of this work was to evaluate the quality of the panels manufactured with such wastes, in pure form and in mixtures with *Pinus* industrial particles.

2. MATERIAL AND METHODS

2.1 Material

Woods originating forestry exploitation wastes from a plantation of *Pinus taeda*, located in the

Municipality of Mafra - SC were used in this study. The materials in the form of stumps with roots, trees tops and branches, were removed from the area of harvest and processed in a chipper in the form of chips for biomass. *Pinus taeda* Industrial particles were obtained from the panelboards manufacture line and used as a control and in mixture with wastes particles from forest exploitation.

For the panels manufacture, urea-formaldehyde resin with solids content of 65%, pH of 7.8 and a viscosity Brookfield 740 cP was used. The ammonium sulfate was used as a catalyst to resin cure and paraffin emulsion as a moisture repellent.

2.2 Preparation of particles and evaluation of their physical and chemical properties

The material was received in the form of chips for biomass, being initially dried in the open air and, next they were sent for pre-drying in an oven and later for processing at the hammer mill for particulate generation. The particles were classified into sieves of meshes in 8 and 30 mesh and dried to the final moisture content of 3%.

The specific bulk mass of particles derived from wastes and industrial particles, was determined by the weighing method of the material corresponding to the volume of a beaker of 1,000 ml. The pH and the content of total extractives were determined according to the procedures of the standards TAPPI, 2002 and NBR, 2002 respectively.

2.3 Panels Manufacture and laboratory tests

The panels were manufactured with a nominal density of 0.75 g/cm³ and dimensions of 50 x 38 x 1.25 cm, with different proportions of *Pinus* industrial particles, stumps and roots and tree tops and branches, according to experimental design presented in Table 1.

The urea-formaldehyde resin, catalyzed with 2% of sulphate of ammonia, was applied on the particles in an amount of 8% solids in relation to its dry mass. It was applied, also, 1% of emulsion of paraffin. For the formation of the particles mat a forming open box was used with dimensions of 50 cm x 38 cm. The panels were pressed at a temperature of 160°C, specific pressure of 4.0 MPa and pressing time of 10 minutes. Three panels per treatment were manufactured, for a total of 30 panels.

After pressing, the panels were squared and packaged in climatic chamber with a temperature of 20 ± 2°C and a relative humidity of 65 ± 5%, until their stabilization to the average moisture content of 12%.

For evaluation of the physical and mechanical properties, five specimens were removed from each panel for testing the apparent density, five for water absorption and thickness swelling, after 2 and 24 hours of immersion in water, five for static bending and five for internal bond. The tests were based on the procedures described in the standards EN 323 (2003), EN 317 (2003), EN 319 (2003) and EN 310 (2003), respectively.

The statistical analysis was performed according to a completely randomized experimental design and the results were evaluated by means of the Bartlett test, analysis of variance and the Tukey test at the level of probability of 95%.

3.RESULTS

3.1 Physical and chemical properties of wood particles

Table 2 shows the mean values of specific bulk density, pH and total extractives of industrial *Pinus* particles of and wastes particles.

The particles obtained from tree tops and branches had higher mean of specific bulk density and the industrial particles the lowest average among the three types of materials. These values should serve as references on the compression of the particles in the panel and may influence in their physical and mechanical properties.

Regarding the materials chemical analysis, the pH varied in the range from 4.27 to 4.56 being the lowest value obtained for stumps and roots and the highest values for the industrial particles of *pinus*. These values were very close to the average value of 4.52 obtained by Trianoski (2010) for *Pinus taeda* wood. As for the total extractives, the average values ranged from 3.14% to 5.14%, being that the particles of stumps and roots showed a value well superior relative to the industrial particles and tree tops and branches.

3.2 Physical Properties of the panels

Table 3 presents the average values of densities of panels manufactured with different types of materials and their combinations.

The average values of panels densities ranged from 0.706 g/cm³ for the panels manufactured with a

Table 1 – Experimental chart.
Tabela 1 – Delineamento experimental.

Treatment	Type of materials and mixtures	Proportion (%)
T1 - Pip	Pinus industrial particles	100
T2 - ST	Stumps and roots	100
T3 - TB	Tree tops and branches	100
T4 - Pip/ST	Pinus Industrial particles + stumps and roots	75/25
T5 - Pip/ST	Pinus Industrial particles + stumps and roots	50/50
T6 - Pip/ST	Pinus Industrial particles + stumps and roots	25/75
T7 - Pip/TB	Pinus Industrial particles + tree tops and branches	75/25
T8 - Pip/TB	Pinus Industrial particles + tree tops and branches	50/50
T9 - Pip/TB	Pinus Industrial particles + tree tops and branches	25/75
T10-Pip/SR/TB	Pinus Industrial particles + stumps and roots + tree tops and branches	33/33/33

Table 2 – Average values of physical and chemical properties of the particles.
Tabela 2 – Valores médios das propriedades físicas e químicas das partículas.

Material	BDWP(g/cm ³)	pH	Total extractives (%)
Pinus industrial particles - Pip	0.190	4.56	3.14
Stumps and roots - SR	0.215	4.27	5.14
Tree tops and branches - TB	0.259	4.54	3.78

Table 3 – Average values of the panels density.
Tabela 3 – Valores médios da densidade dos painéis.

Treatment	Density (g/cm ³)
T1 – Pip 100	0.718 _(5.49) ab
T2 – SR 100	0.721 _(5.26) ab
T3 – TB 100	0.715 _(5.43) ab
T4 – Pip/SR 75/25	0.724 _(4.26) ab
T5 – Pip/SR 50/50	0.715 _(6.81) ab
T6 – Pip/SR25/75	0.732 _(4.78) a
T7 – Pip/TB 75/25	0.710 _(4.83) ab
T8 – Pip/TB 50/50	0.744 _(5.34) a
T9 – Pip/TB25/75	0.707 _(6.44) ab
T10-Pip/SR/TB 33/33/33	0.706 _(4.60) b

mixture of three types of materials (T10) to 0.744 g/cm³ for the panels manufactured with mixture of industrial particles and tree tops and branches in the proportion of 50% each (T8), and the means were statistically different among themselves. There were no significant differences among the averages obtained for the other treatments.

There were small variations among the values of density, obtained for the panels and the calculated value of 0.75 g/cm³. The differences observed between the treatments may be attributed to the loss of material during the formation of the panels and return in thickness after hot pressing followed by conditioning.

Table 4 shows the mean values of water absorption and thickness swelling after 2 and 24 hours of immersion in water of the panels.

The average values of water absorption after 2 hours of immersion ranged from 5.06% for panels manufactured with 50% of industrial particles and 50% of stumps and roots (T5) to 7.91% for panels manufactured with 25% of industrial particles and 75% of stumps and roots (T6), being the means statistically different among themselves.

There were no significant differences between the panels manufactured entirely with different types of

Table 4 – Average values of the physical properties of panels.
Tabela 4 – Valores médios das propriedades físicas dos painéis.

Treatment	WA 2h (%)	WA 24h (%)	TS 2h (%)	TS 24h (%)
T1 – Pip 100	5.61 _(26.29) ab	23.89 _(18.37) bc	20.05 _(19.23) c	64.71 _(5.46) cd
T2 – SR 100	6.76 _(19.88) abc	26.98 _(11.17) c	17.85 _(13.90) abc	73.76 _(5.33) e
T3 – TB 100	5.70 _(39.46) ab	18.85 _(6.64) a	14.62 _(17.33) a	51.49 _(12.23) a
T4 – Pip/SR 75/25	5.77 _(17.37) ab	22.32 _(7.18) ab	18.32 _(11.26) abc	60.53 _(7.17) bcd
T5 – Pip/SR50/50	5.06 _(28.11) a	22.26 _(10.79) ab	17.03 _(17.38) abc	59.86 _(9.36) bc
T6 – Pip/SR 25/75	7.91 _(24.48) c	22.57 _(13.72) abc	18.01 _(10.96) bc	67.30 _(8.76) de
T7 – Pip/TB 75/25	6.89 _(21.79) abc	22.52 _(14.87) abc	18.82 _(17.86) abc	60.72 _(13.51) bcd
T8 – Pip/TB 50/50	6.70 _(18.58) abc	20.65 _(17.74) ab	15.71 _(23.50) ab	54.30 _(11.28) ab
T9 – Pip/TB 25/75	6.93 _(28.24) abc	20.40 _(20.17) ab	16.62 _(16.62) ab	56.48 _(15.82) ab
T10-Pip/SR/TB 33/33/33	7.40 _(20.27) bc	21.79 _(18.91) ab	16.69 _(17.94) abc	59.66 _(13.36) bc

materials (T1, T2, T3), with different proportions of mixture of industrial particles and tree tops and branches (T7, T8, T9), and also those manufactured with mixtures of three types of materials (T10). Concerning the mixture of industrial particles and trunks and roots, the panels manufactured with a proportion of 25 and 75%, respectively, had an average value of water absorption statistically superior in comparison to the panels manufactured with a proportion of 50 and 50%, 75 and 25%.

For water absorption after 24 hours of immersion, the mean values ranged from 18.85% to panels manufactured with tree tops and branches (T3) to 26.98% for panels manufactured with trunks and roots (T2).

The panels manufactured with tree tops and branches (T3) had mean statistically lower than the panels manufactured with industrial particles (T1) and trunks and roots (T2), and statistically equal to other treatments. All treatments manufactured with wastes showed means statistically equal to or less in comparison to the control panels.

The average values of thickness swelling after 2 hours of immersion ranged from 14.62% to panels manufactured with tree tops and branches (T3) to 20.05% for panels manufactured with industrial particles (T1)

The panels manufactured with tree tops and branches (T3) had mean statistically lower than the panels manufactured with industrial particles (T1) and with their mixture with trunks and roots (T6), at the proportions of 25% and 75% respectively. There were no significant differences compared to other treatments.

For thickness swelling after 24 hours of immersion, the mean values ranged from 51.49% to panels manufactured with tree tops and branches (T3) to 73.76% for panels manufactured with trunks and roots (T2).

The panels manufactured with particles of tree tops and branches (T3) showed an average statistically equal to the panels manufactured with mixture of industrial particles and tree tops and branches, at the proportions of 50/50% (T8) and 25/75% (T9), and inferior to the control panels (T1) and all other treatments.

3.3 Mechanical properties of the panels

The Table 5, shows the mean values of internal bond (IB), modulus of elasticity (MOE) and modulus of rupture (MOR) of the panels.

The average values of internal bond ranged from 0.51 MPa for panels manufactured with industrial particles (T1) to 0.70 MPa for panels manufactured with mixture of industrial particles and tree tops and branches in the proportions of 50/50% (T8).

The panels manufactured with a mixture of industrial particles and tree tops and branches in the proportions of 50/50% (T8) showed an average statistically equal to the panels manufactured with industrial particles and tree tops and branches in the proportion of 75/25% (T7) and a mixture of three types of materials (T10), and superior compared to all other treatments.

The average values of MOE ranged from 1.154 MPa for panels manufactured with tree tops and branches (T3) to 1.913 MPa for panels manufactured with industrial particles (T1).

The panels manufactured with industrial particles and stumps and roots in the proportions of 75/25% (T4) and 50/50% (T5) and panels manufactured with a mixture of particles industrial and tree tops and branches in the proportions of 75/25% (T7), showed average values of MOE statistically equal to the control panels.

Table 5 – Average values of the mechanical properties of panels.
Tabela 5 – Valores médios das propriedades mecânicas dos painéis.

Treatment	IB (MPa)	MOE (MPa)	MOR (MPa)
T1 – Pip 100	0.51 _(12.79) a	1.913 _(14.99) e	10.3 _(19.99) e
T2 – SR 100	0.59 _(12.71) ab	1.341 _(13.56) ab	8.3 _(15.37) abcd
T3 – TB 100	0.59 _(16.86) ab	1,154 _(21.82) a	6.9 _(24.68) ab
T4 – Pip/SR 75/25	0.54 _(15.25) a	1.739 _(11.60) de	8.8 _(19.95) cde
T5 – Pip/SR 50/50	0.58 _(9.81) ab	1.774 _(14.21) de	9.5 _(22.03) cde
T6 – Pip/SR 25/75	0.55 _(21.91) a	1.440 _(15.68) bc	9.1 _(19.05) cde
T7 – Pip/TB 75/25	0.60 _(17.08) abc	1.808 _(8.53) de	10.0 _(11.20) de
T8 – Pip/TB 50/50	0.70 _(8.37) c	1.589 _(11.06) cd	8.5 _(15.81) bcde
T9 – Pip/TB 25/75	0.59 _(12.60) ab	1,286 _(13.11) ab	6.6 _(20.91) a
T10-Pip/SR/TB 33/33/33	0.69 _(17.77) bc	1,367 _(9.34) abc	7.8 _(24.80) abc

The other treatments exhibited averages statistically lower in comparison to the control panels.

The average values of MOR ranged from 6.65 MPa for panels manufactured with mixture of industrial particles and tree tops and branches at the proportions of 25/75% (T9) to 10.27 MPa for panels manufactured with industrial particles (T1).

The panels manufactured with industrial particles and stumps and roots in the proportions of (T4, T5 and T6), besides panels manufactured with a mixture of industrial particles and tree tops and branches in the proportions of 75/25% (T7), and 50/50% (T8) showed average values of MOR statistically equal to the control panels. The other treatments exhibited averages statistically lower in comparison to the control panels.

4.DISCUSSIONS

The lowest density of pinus industrial particles and consequent increase in the compression ratio of the panels did not influence the results of water absorption, thickness swelling and internal bond, but there was an increase in the values of MOE and MOR of the panels manufactured with such particles. Moslemi (1974) states that the larger the compression ratio, the greater the mechanical properties and thickness swelling of the panel will be. However, this relationship is valid considering that the density of solid wood, whose compression ratio should vary in the range of 1.3 to 1.6 for species listed as suitable for the production of wood particulate panels.

The pH and the concentrations of total extractives of different types of materials did not affect significantly the results of physical and mechanical properties of

the panels. The only exception was for the panels produced with particles of stumps and roots, whose content of extractives was the highest (5.14%) and probably could have influenced the increase of swelling in thickness after 24 hours of immersion. The values of total extractives obtained in this research are inferior to 10% as referenced by Sjöström (1981). Fengel and Wegener (1989) claim that the range of variation in total extractives for conifers wood is 5±3%.

The panels manufactured with particles of tree tops and branches showed better results of water absorption and thickness swelling, when compared to the control panels. The results also indicated the possibility of mixture of these materials with the industrial particles in particleboards manufacture.

The results of water absorption obtained in this study were satisfactory when compared to some of the references presented in the literature on experimental particleboards of species originating from forest plantations. Naumann et al. (2008) found, for particleboards of *Eucalyptus urophylla* and *Schizolobium amazonicum*, absorption values after 24 hours of 97.2% and 117.9%, respectively. Iwakiri et al. (1996) found, for particleboards of *Pinus taeda* and *Eucalyptus dunnii*, water absorption values 24 hours of 75.04% and 80.05%, respectively. Concerning the thickness swelling after 24 hours, the results obtained in this study were high when compared to values obtained by Naumann et al. (2008) for panels of *Eucalyptus urophylla* and *Schizolobium amazonicum*, of 30.50% and 35.09%, respectively. Iwakiri et al. (1996) found for panels of *Pinus taeda* and *Eucalyptus dunnii*, values of 30.50% and 35.09%.

All treatments met the requirement of standard EN 312 which specifies for internal bond a minimum value of

0.35 MP, indicating that there was a proper bonding of the particles deriving from these exploitation wastes and its viability for particleboard manufacture. When it comes to the tests of static bending, no treatment met the requirement of standard EN 312 for MOR, whose minimum value is 13 MPa. Whereas, for MOE, the mixtures of 25% to 50% of particles from trunks and roots and branches met the standard specifications of 1,600 Mpa.

Trianoski et al. (2011) found for particleboards manufactured with wood of *Acrocarpus fraxinifolius*, *Melia azedarach* and *Toona ciliata*, IB values of 1.50 MPa, 1.88 MPa and 1.64 MPa, respectively. Colli et al. (2010) found for particleboards manufactured with *Schizolobium amazonicum* average value of 0.22 MPa. Whereas, Vital et al. (1974) found for particleboards of *Virola spp.*, with compression ratio of 1.2:1.0 (low) and 1.6:1.0 (high), values of 0.48 MP and 0.65 MPa, respectively.

The results of MOR and MOE obtained in this study were satisfactory when compared to some of the results presented in the literature. Naumann et al. (2008) found for particleboards produced with wood of *Eucalyptus urophylla* and *Schizolobium amazonicum*, values of 4.26 MPa and 13.96 MPa for MOR and 696 MPa and 1.873 MPa for MOE, respectively. Whereas, Trianoski et al. (2011) found for particleboards produced with wood of *Acrocarpus fraxinifolius*, *Melia azedarach* and *Toona ciliata*, MOR average of 18.19 MPa, 18.56 MPa and 19.83 MPa, and MOE average of 2.134 MPa, 2.191 MPa and 2.427 MPa respectively for the three studied species.

The results of the mechanical properties indicate the possibility of mixture of particles from trunks and roots and tree tops and branches in the proportion of up to 50% in mixture with the pinus industrial particles for particleboards manufacture.

5.CONCLUSIONS

The density, pH and the content of total extractives of particles from tree tops and branches and from stumps and roots did not influence, significantly on the properties of the panels.

The panels manufactured with particles from tree tops and branches showed better results of water absorption and thickness swelling, when compared to the control panels. The results also indicated the possibility of mixture of these materials

with the pinus industrial particles in particleboards manufacture.

The results of internal bond, obtained for all treatments, complied with the minimum requirement of 0.35 MPa, as specified in standard EN 312, indicating that there was an adequate bonding of particles originating from these exploitation residues.

Based on the results, it is concluded that it is feasible the particleboard manufacture, with up to 50% of forestry exploitation wastes, in mixture with the industrial particles of pinus, bearing in mind that their properties meet the requirements from commercial standard EN 312. It is necessary, however, to evaluate the quantitative availability of these materials, operational and economic matters, so that the same can be incorporated into the raw material matrix of particleboards industries. The use of forest exploitation wastes, in the production chain of particleboards industries, will result in positive impacts in terms of optimization in the use of forest resources, generating social, environmental and economic benefits.

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