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By-Products of the Timber Industries as Raw-Material for the Production of MDP (Medium Density Particleboard)

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Abstract

This study aimed to verify technical potential of using waste from wood veneers and plywood as a raw material for the production of MDP. The variance analysis of the panels density was carried out. Physical-mechanical properties were evaluated by comparing them with the international standards and by analysis of variance. The averages were subjected to the analysis of covariance, at the level of 5% probability. Finally, Pearson's correlation analysis between properties was performed. The panels produced with "log core" and "veneer clippings" residues showed equivalent averages for physical properties and higher for mechanical properties of internal bond and surface screw withdrawal, when compared the averages of panels produced with commercial particles. Panels produced with "plywood cutting" showed unsatisfactory mechanical properties. It's concluded that the "log core" and "veneer clippings" residues show potential for use as a raw material in the composition of MDP.

Keywords: Residues, Chipboard panels, Reuse, Plywood, Physical-mechanical properties.

1. INTRODUCTION AND OBJECTIVES

Forest products from forest-based industries are numerous, produced from the planted tree sector and also from sustainable forest management. Wood for civil construction, furniture manufacturing, paper for the book production, notebooks, packaging, toilet paper, napkins, as well as products such as medicines and cosmetics, charcoal, firewood, pellets, cellulose, laminate floors, panels wood, biomass are some of the products from the trees (IBÁ, 2017).

In order to obtain these products, from harvesting to wood processing, the forestry sector generates a significant amount of waste that, although they are often used in some specific way, can cause environmental problems when not disposed of correctly.

This material, however, can be used in an alternative way to increase the revenues of some industrial sectors, such as furniture, handicrafts and panels, for example (FRANCESCHINI, 2004; NOLASCO et al., 2013).

Due to the high amount (66.6%) of wood residues generated in forestry and industrial activities, there is a need to find alternative uses in order to add value and minimize the environmental impact associated with them, such as improper disposal and incineration (WEBER, 2011).

The production of MDP (Medium Density Particleboard) panels can be an option for reusing these residues, which thus start to be considered as by-products. The MDP panel is produced from reconstituted wood, according to NBR 14810-2 with density between 551 and 750 kg/m^3 (ABNT, 2018). Generally, they consist of three layers of sliver-type particles, two of small and fine particles on the faces and one of thick particles on the panel core, being widely used in the furniture industry (MESQUITA et al., 2015).

The reconstituted wood panels are produced through processes of wood reduction in particulate or fibrous materials; they are classified and agglomerated by means of resins and additives which, under the action of heat and pressure, acquire the desired properties and shapes (CAMPOS, 2016).

In Brazil, the main source of raw material comes from planted forests, especially the species of *Eucalyptus spp*. and *Pinus spp*. (BNDES, 2018). *Pinus spp*. it is the most used genus due to its low basic density and other characteristics that make this wood suitable for production processes, followed in lesser quantities by *Eucalyptus spp* (FIORELLI et al., 2014; CABRAL et al., 2007; BALDIN et al., 2016).

The main variables that interfere in panel's quality are the wood density, the panel density, the particles geometry and it moisture content, the resin type and proportion used, the particle mattress forming and the pressing parameters of the panels, which are: compression ratio between 1.3 - 1.6, pressing pressure between 2.45 - 4.00 MPa, panel density between 400 and 800 kg/m^3, particle mattress humidity between 8 and 18.5 % and temperature between 120 - 170º C for urea-formaldehyde (MOSLEMI, 1974; MALONEY, 1993; BRITO et al., 2005).

The ratio of panel density and the wood density determines the compaction rate (CR). In general, the higher compaction rate results in highest strength and stiffness of the panel (TRIANOSKI et al., 2013; SOZIM et al., 2019).

Thus, it is verified that the panel's properties are dependent on the wood properties and that these interact with each other and with the production parameters to determine the panel's quality (PROTÁSIO et al., 2012).

This study aimed to verify the technical viability of using wood waste from the veneer and plywood obtained in the industry as the main raw material for the MDP production.

2. MATERIALS AND METHODS

2.1. Material

A diagnosis of waste generation was carried out in the veneers and plywood industries, established in the municipalities of Irati-PR and Guarapuava-PR. By means from visits to the industries and survey questionnaire, the wood waste generation was verified.

The greatest amount generated of wood residues in the veneer and plywood production process were those of the type "log core", "veneer clippings" and "plywood cutting", selected as raw material for panels production. Thus, those residues were collected a company located in the municipality of Irati-Paraná (Figure 1).

After the gathering, the material pre-characterization was carried out through a survey of the process that gave rise to it, collecting information such as: approximate volume, physical state, main constituents and wood species. For the characterization, the apparent density, dry density and the moisture content of each type of waste collected were determined.

The materials were processed in a chipper, to obtain chips, and stored in plastic bags. Using a hammer mill, the chips were chopped again to obtain *sliver* type particles for the production of MDP panels. The particles were sieved and was used that were retained in 10 mesh sieve, or 2.00 mm aperture (Figure 1). After, were subjected to drying in an oven at 65º C until reaching ideal moisture content for panel production, established between 3 and 6% (IWAKIRI, 2005).

Figure 1. Types of waste collected and particles obtained after classification in sieves. A) Log core; B) Veneer clippings; C) Plywood cutting.

2.2. MDP panels production

The panels were produced with each type of pure by-product and in different mixtures, as well as a panel type of commercial particles obtained in an industry (Table 1), with two repetitions each panel. The nominal dimensions were 500x500x10mm and the density was established at 650 kg/m^3, Urea-formaldehyde resin of 10%, ammonium sulfate catalyst of 2%, and paraffin emulsion of 1%, was used.

The particle mattress was manually formed in a 500x500 mm forming box, evenly distributed. Afterwards, the panels were subjected to a cold pre-pressing in order to reduce the mattress height, which was subsequently driven to the hydraulic press, along with 10 mm thick limiting bars. Pressing temperature of 140 ° C, pressure of 3.14 Mpa and pressing time of 10 min were used. After panel's manufacture, they were conditioned at 20 ± 2 ºC temperature and a 65 ± 5 % air relative humidity.

Table 1. Experimental design for the production of MDP panels.

Panel type	Proportion of each type of particle (%)			
	Log core	Veneer clippings	Plywood cutting	Commercial particles
P1	100	0	0	0
P2	0	100	0	0
P3	0	0	100	0
P4	50	50	0	0
P5	0	50	50	0
P6	50	0	50	0
P7	33,33	33,33	33,33	0
P8	0	0	0	100

2.3. MDP panels properties

The panels were squared by cutting 5 cm on each side. The specimens were cut according to the European standards of the EN 300 series.

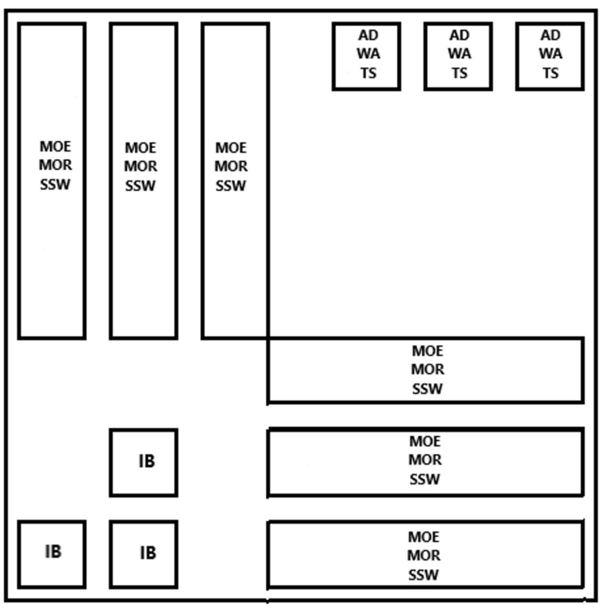

Figure 2. Sketch of the panels' specimens, where: AD = apparent density; MC= moisture content; WA= water absorption; IB= Internal bonding; TS= Thickness swelling; MOR = Modulus of rupture in static bending; MOE= Modulus of elasticity in static bending; SSW= Surface screw withdrawal.

Physical tests of apparent density, moisture content, water absorption and thickness swelling after 24 hours of immersion in water were performed and mechanical tests of static bending, internal bonding and surface screw withdrawal, which were performed in a universal testing machine of the EMIC brand, model DL 30000, electromechanical, capacity 300 KN. The tests performed, the properties obtained and the standards used are shown in Table 2.

The experiment was performed in a completely randomized design, composed of eight type of panels and two replications. For the data analysis, was used the statistic software. First, the variables of interest were submitted to the Bartlett test (α = 1%) to verify the homogeneity of the data variances. Analysis of variance (ANOVA) of density was carried out between the different types of panels. Once a difference was found, apparent density covariance analysis was used for the other analyzes to exclude the effect of panel density on other properties.

The covariance statistical analysis and Tukey's test was carried out between mean properties of each panel type, at the 5% probability. Also, the averages obtained were compared with the international normative requirements. Finally, Pearson's correlation analysis and significance test were performed between the different properties analyzed in order to verify the degree of correlation between them.

Table 2. Tests of the physical and mechanical properties of MDP panels.

Test / Properties	Symbol	Standard
Apparent density (Kg/m^3)	AD	EN 323 (1993)
Moisture content (%)	MC	EN 323 (1993)
Water absorption after 24h of immersion (%)	WA	EN 326-1 (1994)
Thickness swelling after 24h of immersion (%)	TS	EN 317 (1993)
Static bending (MPa)	MOR/MOE	EN 310 (1994)
Internal bonding (MPa)	IB	EN 319 (1993)
Surface screw withdrawal (N)	SSW	EN 320 (2011)

3. RESULTS AND DISCUSSION

3.1. Wood residues characterization

A statistical difference was found for the properties evaluated in the characterization of the wood residues. The apparent density: 395 Kg/m^3 for log core; 542 Kg/m^3 for veneer clippings and 523 kg/m^3 for plywood cutting was in accordance with the *Pinus* sp. wood density used. The log core is the central part of the log, which is composed of juvenile wood, where the density is lower.

The formation of juvenile wood is associated with the influence of the apical meristem. Regarding the properties, it has lower density, which will be related to the length of the cells, mechanical strength and thickness of the cell wall.

The moisture content was 6.35% for log core; 10.63% for veneer clippings and 5.44% for plywood cutting, being an important parameter for the MDP production, since the particles must have a value between 3 and 6%, recommended by the adhesive industries. The average values showed that the by-products of the log core and plywood cutting had a moisture content closer to the desired, which can contribute to lower drying costs.

For Weber (2011), low moisture content considered can cause poor wood/adhesive interlinking, thus reducing the MDP mechanical properties. On the other hand, high moisture content can cause excess steam at the pressing time and, consequently, panel bubbling or delamination.

3.2. Panel's physical properties

For apparent density and moisture content, a statistical difference was found between the panels produced (Table 3). The variation in the apparent density between the panels was due to variations along the manual production process in the laboratory, such as in the particles distribution for the mattress formation or in the resin application (sprinkling) where part of the glue is lost on the walls of the rotation drum. Also, the increase of panel volume which is inversely proportional, after the pressing process (HILLIG, 2000; DACOSTA, 2004).

In other studies, this variation in density in relation to the panel nominal density was also found and was attributed the loss of inputs (adhesive, paraffin and particles) during the panel manual production, as well the volume increase of the panels after hot pressing and packaging (BRITO et al., 2021; BAZZETTO et al., 2019; GUIMARÃES JÚNIOR et al., 2016).

Table 3. Average values for the physical properties of MDP panels.

Panel type	Proportion of each type of particle (%)				Physical properties				
	LC	VC	PC	CP	D (kg.m^{-3})	CR	MC (%)	WA24h (%)	TS24h (%)
P1	100	0	0	0	551.34 a	1.50	8.24 a	17.85 c	19.34 a
P2	0	100	0	0	551.23 a	1.50	8.78 abc	15.80 b	20.29 a
P3	0	0	100	0	468.70 c	1.28	9.31 bc	16.06 b	44.38 b
P4	50	50	0	0	557.64 a	1.52	8.80 abc	16.05 b	22.72 a
P5	0	50	50	0	513.39 abc	1.40	8.49 ab	18.51 c	25.34 a
P6	50	0	50	0	532.63 ab	1.45	9.52 c	20.35 d	25.47 a
P7	33.33	33.33	33.33	0	498.80 bc	1.36	9.05 abc	18.28 c	19.72 a
P8	0	0	0	100	553.41 a	1.51	9.76 c	13.61 a	17.99 a

For the averages, the Tukey test was applied at 5% probability; Where: LC = log core; VC = veneer clippings; PC = plywood cutting; CP = commercial particles; D= apparent density; CR= compaction rate; MC = moisture content; WA = water absorption after 24h of immersion; TS = thickness swelling after 24h of immersion.

There was a difference in the thickness of the panels caused by a return in relation to the nominal thickness of the limiting bars. This fact can be attributed to the operational conditions during the process of forming the mattress (IWAKIRI et al., 2008). The panels were manufactured with 10 mm limiting bars, however, there was an average thickness of 12.4 mm. This fact can be attributed to the release of tensions caused by pressing and which may have been aggravated by the resin loss on the walls of the rotating drum and consequent poor bonding particles. As a consequence of these variations, the density values of the panels were found to be lower than the pre-established ones, of 650 kg/m³.

Despite the average apparent density of the panels being lower at the nominal, it's was proximate to the minimum established for MDP by the standard NBR 14810-2 (ABNT, 2018), of 551 kg / m³. In addition, this fact was taken into account in the discussion of the results and did not interfere with the conclusions.

The compaction rate (CR) determines the degree of particles densification in the panel structure and affects they properties and they superficial quality (MALONEY, 1993; MOSLEMI, 1974; TSOUMIS, 1991). The adequate compaction rate for the production of MDP panels must be in the range of 1.3 to 1.6 (MOSLEMI, 1974). Thus, it appears that the materials used in this study provided an adequate CR, even the panels showing a lower apparent density than the nominal.

The variation in moisture content (MC) of the panels, between 8.24% and 9.76%, is within the range provided by the NBR 14810-2 standard, which is between 5 and 11%. These values, lower than the MC of wood equilibrium (*Pinus sp*.), can be explained by the fact that the particles has submitted to high temperatures in the pressing, causing loss of constitution water and loss of reactivity of wood to adsorb water from the air (WEBER, 2011).

There are no normative values for water absorption of MDP panels, however, the WA values are similar to the study by Melo et al. (2009), for panels produced with *Eucalyptus grandis* wood, at a nominal density of 600 and 700 kg/m³.

For TS, only the panel P3, produced with plywood cutting showed the highest thickness swelling value. This panel (P3) showed the lowest numerical density value and, consequently, the highest thickness swelling value. The density was not a determining factor for this test, since the panel with the highest density did not present the lowest value for thickness swelling.

The average values of TS were above this by the standards EN 312/2003 and NBR 14810-2 / 2018, of 15% and 18%, respectively (EUROPEAN..., 2003; ABNT, 2013). However, the panels produced with particles obtained from log core and veneer clippings, pure or in mixtures, presented close values (up to 22%). The marketing standard ANSI 208.1 (ANSI, 1987), considers acceptable up to 35% of TS, which in this case was achieved by all panels, except for panel P3.

The results found in the present study are closed to the range verified by Trianoski et al. (2011a), for 3-layer particleboard produced with wood of Angiospermae, whose average values of WA and TS varied from 7.56 to 36.36% and from 11.02 to 22.16%, respectively.

3.3. Panel's mechanical properties

Statistical differences were found between the panels type for the four mechanical properties evaluated (Table 4). The values of internal bonding (IB) for the P3 panel, produced with plywood cutting, was not presented due to the fact that it was not possible to perform the test for this panel type.

Table 4. Average values for the mechanical properties of MDP panels.

Panel type	Proportion of each type of particle (%)				Mechanical properties			
	LC	VC	PC	CP	MOE (MPa)	MOR (MPa)	IB (MPa)	SSW (N)
P1	100	0	0	0	825.9 b	5.98 b	0.383 b	789.74 a
P2	0	100	0	0	771.3 b	4.69 c	0.460 a	731.96 ab
P3	0	0	100	0	131.7 d	0.74 e	-	76.24 c
P4	50	50	0	0	822.1 b	5.57 b	0.463 a	804.9 a
P5	0	50	50	0	489.5 c	2.35 d	0.156 e	577.77 b
P6	50	0	50	0	440.8 c	1.93 d	0.215 d	623.94 ab
P7	33.33	33.33	33.33	0	685.3 b	4.45 c	0.153 e	636.32 ab
P8	0	0	0	100	1375.2 a	7.36 a	0.368 c	720.11 ab

For the averages. the Tukey test was applied at the level of 5% probability; Where: LC = log core; VC = veneer clippings; PC= plywood cutting; CP = commercial particles; MOR = modulus of rupture (MPa); MOE = modulus of elasticity (MPa); IB = internal bonding (MPa); SSW = surface screw withdrawal.

The plywood cutting particles used in panel P3 showed in their composition a remnant of the phenol-formaldehyde resin. This, combined with its particle geometry (Figure 1), may have been a determining factor for the poor efficiency in bonding these panels. Thus, the specimens submitted to the perpendicular tensile (internal bond) test did not demand force that could be registered for their rupture.

Low values of MOE, MOR and SSW were observed for the P3 panel, a fact attributed to the influence of the cured adhesive (phenol-formaldehyde) impregnated in the refill of the plywood, which acted as impurity and did not allow adhesion between particles and the urea-formaldehyde adhesive used in the panels production.

Araújo et al. (2019) found MOE values between 1387 to 1875 MPa and MOR average values of 8.43 MPa, higher than the present study for particleboard produced with residues from the mechanical processing of Eucalyptus wood. The factors that may have contributed to the low values found for the mechanical properties of panels were the return in thickness and consequent decreased in density, as well as a possible loss of resin at the application time through adhesion on the drum walls.

ANSI A 208.1 (1993) standards establish values for MOE from 1025 to 1725 MPa and MOR from 5 to 11 MPa, thus only commercial particleboards met the requirement for both properties and the P1 panel met the requirement for MOR. The standard EN 312 (2003), which establishes minimum values of 1600 MPa for MOE and 13 MPa for MOR, was not met by any of the types of panels produced.

The "log core" type waste panels and their mixture with "veneer clippings" proved to be more strength and stiffness in bending strength. A factor that may have contributed to this was the higher compaction rate, since their particles density particles was lower.

MOE and MOR of panel produced with commercial particles was higher the panels produced with residues. The particles produced in the laboratory (Figure 2) had a lower slenderness ratio (length / thickness) than commercial particles. According to Souza et al. (2019), higher slenderness ratio contributed to greater strength and stiffness of MDP panels.

For internal bonding it was possible to verify that the panels P1, P2, P4 and P8 met the requirements of the EN 312 standard (EN, 2003), of 0.24 MPa. The results are also close to those found by Araújo et al. (2019), between 0.38 to 0.48 MPa. ANSI A

208.1 (1993) establishes internal bond values varying of 0.15 to 0.40 MPa, values reached or exceeded in all panels type.

The panel P2 (100% veneer clippings) and P4 (50% log core; 50% veneer clippings) showed the best internal bonding values, followed by P1 (100% log core). This fact is also related to the shape of the particles, which being more rounded favored a better bonding (Figure 2). On the other hand, the panels produced with "plywood cutting", pure or in mixtures, did not obtain a good bonding due to the presence of phenol-formaldehyde resin cured in their particles, which has already been mentioned previously.

For the surface screw withdrawal test, statistical differences were found. Panels P1 (100% log core) and P4 (50% log core; 50% veneer clippings) showed the highest averages, differing statistically only from panel P3 (100% plywood cutting).

Trianoski et al. (2015) for *Pinus taeda* MDP panels with the incorporation of *Grevillea robusta*, with a nominal density of 800 Kg/m^3, found average values of strength to screw withdrawal between 990 and 1137 N.

The ANSI A 208.1 (1993) standard, for particleboard of low and medium density, admits values between 550 to 1000 N for surface screw withdrawal strength, values that were not reached only in panel P3 (plywood cutting).

3.4. Correlation between the properties of the panels

The results of Pearson's correlation analysis between the physical and mechanical properties of the panels are shown in Table 5.

Table 5. Correlations between the physical and mechanical properties of MDP panels.

	MC	WA	TS	MOE	MOR	IB	SSW
MC	1						
WA24h	-0.267^{ns}	1					
TS24h	0.206^{ns}	0.034^{ns}	1				
MOE	0.104^{ns}	-0.544^{ns}	-0.814*	1			
MOR	-0.089^{ns}	-0.525^{ns}	-0.813*	0.955**	1		
IB	-0.251^{ns}	-0.373^{ns}	-0.723*	0.749*	0.806*	1	
SP	-0.309^{ns}	-0.007^{ns}	-0.984**	0.762*	0.796*	0.851*	1

Where: AD = apparent density; MC= moisture content; WA= water absorption; TS= Thickness swelling; MOE = modulus of elasticity; MOR = modulus of rupture; SSW= surface screw withdrawal; ^{ns} = not significant at 5% probability; *= significant correlation at the 5% probability; **= significant correlation at the 1% probability.

The moisture content and 24h water absorption of the panels did not correlate with any of the other properties studied. For thickness swelling 24h there was a negative correlation with all mechanical properties that correlated with each other positively.

There was no correlation between thickness swelling and water absorption in 24h of immersion. In general, greater water absorption may contribute to greater thickness swelling, but this was not the case in this study.

The thickness swelling correlated with the internal bonding, with the strength and hardness of the panels. This factor was attributed to the internal bonding, since a worse bonding favors the action of water inside the panels, as well as explaining less strength and hardness in bending strength and easier removal of screws. The relation with thickness swelling and internal bonding was also observed by Carvalho et al. (2014), that got lower values of internal bonding and higher thickness swelling values for panels made of wood from *Pinus caribaea*.

The significant correlation between the mechanical properties of the panels and also with thickness swelling, it showed that the factors of panel's production, such as particle shape, bonding and pressure, contributed in an analogous way to most of the properties. The higher coefficients between MOE and MOR (0.955), also reinforce this fact, because in some studies the correlation coefficient found between these two properties it was below 0.87 and 0.95 (PROTÁSIO et al., 2012; MODES et al., 2012; MORAIS et al., 2015).

4. CONCLUSIONS

From the results, it can be seen that the particles of "log core" and "veneer clippings" show potential for use in MDP panels, both pure and mixed between them. The particles of "plywood cutting" have no potential to be used as raw material for MDP, since it not present good bonding, making a panel fragile and brittle, resulting in low properties values.

Commercial particles show better performance in the MDP production for physical properties and static bending (MOE and MOR), however, particles of "log core" and "veneer clippings" show better performance for internal bonding and surface screw withdrawal.

The panels produced with particles of the "log core" and "veneer clippings" present values close, although lower, to those specified by the standards. It was considered that the laboratory production process can be improved and the apparent density of the panels increased, thus, there is the technical potential of using these residues as raw material for the production of MDP.

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