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Particleboards with waste wood from reforestation

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ABSTRACT. This paper examined the potential of manufacturing bonded particleboards using timber industry waste of *Pinus* spp. Panels were evaluated with 0.6 and 0.8 g cm^{-3} of density and produced with urea-formaldehyde resin and bi-component polyurethane resin based on castor oil. Panels were made of particles with nominal dimensions 40 x 40 cm and a thickness of 1 cm. As process parameters was adopted 2 - 5% moisture content, temperature ranging from 90 to 130°C, average pressure of 5.0 MPa and resin content from 10 to 15% of the weight particles. This study determined physical-mechanical properties of the panels, following the recommendations of ABNT (2006) NBR 14810. The results indicated statistically significant difference ($p < 0.05$) in physical and mechanical properties of the panels studied. Panels were classified by ANSI (1993) A208.1 – Mat-formed wood particleboard: Specification, as of low and medium density. Scanning electron microscopy images (SEM) illustrated the agglomeration of particles for the different resins. The polyurethane resin based on castor oil stood out as a viable alternative in the production of particleboards with timber waste.

Keywords: adhesive, castor oil, density, composite.

Painéis de partículas com resíduos de madeira de reflorestamento

RESUMO. Este trabalho apresenta um estudo do potencial da fabricação de painéis de partículas com resíduo de madeira da espécie *Pinus* spp. Foram avaliados painéis com densidade 0,6 e 0,8 g cm^{-3} produzidos com resina poliuretana bicomponente à base de óleo de mamona e resina de ureia-formaldeído. Os painéis confeccionados tinham dimensões nominais 40 x 40 cm e espessura de 1,0 cm. Como parâmetros de processo foram adotados: umidade de partícula de 2 - 5%, temperatura variando de 90 a 130ºC, pressão média de 5,0 MPa e teor de resina de 10 - 15% da quantidade de partículas. Foram determinadas propriedades físico-mecânicas dos painéis, seguindo as recomendações do documento normativo ABNT (2006) NBR 14810. Os resultados obtidos indicam diferença estatística significativa ($p < 0,05$) entre as propriedades físico-mecânicas dos painéis em estudo. Os painéis foram classificados, segundo a Norma ANSI (1993) A208.1 – Mat-formed wood particleboard: Specification, como sendo de baixa densidade e média densidade. As imagens por microscopia eletrônica de varredura ilustram a aglomeração das partículas para as diferentes resinas. A resina poliuretana à base de óleo de mamona destaca-se como alternativa viável na produção de painéis de partículas com resíduo da indústria madeireira.

Palavras-chave: resina, mamona, densidade, compósito.

Introduction

The contemporary trend of relationships between nations has been characterized by the generalization in the concept of global economy. There is an experience of association of countries with common interests in ensuring the maintenance of markets and seek to expand in a strongly scenario marked by competitiveness and the need to achieve innovative solutions for various problems. Brazil has sought options to increase economic activity and stimulate the development of policies in the forestry sector, for example, in the production of particle panels (CALIL et al., 2003).

This type of product can replace solid wood in different uses, such as in the manufacture of furniture and flooring. Particle board may be intended for industrial use (packaging, container, furniture and vehicle parts), structural use in construction (ceilings, partitions, formwork and concrete boxes, internal and external walls and others) and even for making toys, shelves and household utensils.

In countries with agricultural profile, like Brazil, the use of agro-industrial waste should be encouraged.

In recent years, several studies have been developed given the use of natural fibers and agro-industrial wastes for the manufacture of particleboards. These studies stand out due to the shortage of wood supply. Furthermore, has intensified the study on the best use of these fibers and wastes for the production of particleboards destined to the production of furniture, car covering and linings. The production of particleboards using fibers and waste from different sources can contribute to meet demands, provide an appropriate final disposal of this product and also generate materials that preserve the earth's natural resources.

Based on the information, there is interest and vast scope for agro-industrial wastes, such as wastes of wood processing industries in order to add value to the material. One option for this purpose consists in manufacturing particleboards.

The technology for production of bonded particleboards has been developed mainly after the Second World War, due to the shortage of raw material, and also due to the reduction of losses in both the timber industry and in forestry. In Brazil, the production of bonded wood panels began in 1966 (MENDES et al., 2003).

These panels are typically manufactured from wood particles bonded by adhesive or other synthetic binder, and then this mixture is pressed under high temperature for time sufficient for curing the resin (IWAKIRI et al., 2004).

According to Kelly (1977), who developed a study on the relationship between process parameters and physical-mechanical properties of particleboards, the type and amount of adhesive, temperature and pressure conditions, are the main factors that must be considered during the manufacture process to ensure the efficiency of the respective panels.

The author stated that the most frequently used adhesives are based on urea-formaldehyde and phenol-formaldehyde.

The resin of urea-formaldehyde has two drawbacks: loss of strength when acting under the action of moisture in a relatively short time and in the pressing process, when occurs elimination of formaldehyde. Its use has become problematic in countries where environmental control is rigorous (SAMLAIC, 1983).

With the global trend towards the use of biodegradable products from clean and renewable inputs, those researches led to the discovery of the polyurethane resin based on castor oil.

Many studies were developed to evaluate the use of wood particles in the production of panels (BARROS FILHO et al., 2011; NASCIMENTO; LAHR, 2002; NOCE et al., 2008; SANTOS et al., 2011; SILVA et al., 2005). Within this context, the present study aimed to verify the feasibility of producing particleboards with wood waste and bi-component polyurethane resin based on castor oil and urea-formaldehyde resin.

Material and methods

Wood flakes were obtained from *Pinus spp* furniture industry, located in the city Macatuba, São Paulo State, Brazil. According to Gonçalves (2000) these particles are classified as flakes or shavings. For the manufacture of panels were used polyurethane resin based on castor oil and urea-formaldehyde resin.

Manufacture of particleboards

The process of manufacturing particleboards from wood waste and urea-formaldehyde resin or bi-component polyurethane based on castor oil follows the steps briefly discussed and detailed below by Maloney (1996).

The process began with the collection of material.

Then, wood flakes were oven dried and subsequently separated with 6 mm-sieves for removal of small particles, because particles as small as powder affect the characteristic distribution of resin and therefore the agglomeration of particles, decreasing mechanical properties of the panel. Larger particles (6-20 mm) retained on the sieve were introduced into a planetary mixer and added of resin (bi-component polyurethane based on castor oil and / or urea formaldehyde resin) in a proportion of 10 - 15% of the dry weight of raw material.

After homogenization, the mass containing particle + resin was introduced into a mold and then placed in the thermo-hydraulic press. As for pressing parameters were used: mean temperature up to 130°C, resin content of 10 - 15% of the quantity of particles and an average pressure of 5 MPa for approximately 10 minutes. Particleboards were made with nominal dimensions of 40 x 40 cm and 1.0 cm thickness. In addition, those panels were produced with densities of 0.60 and 0.80 g cm^{-3} (Table 1). After the pressing process, panels were stacked for 72 hours to cure the resin (Figure 1).

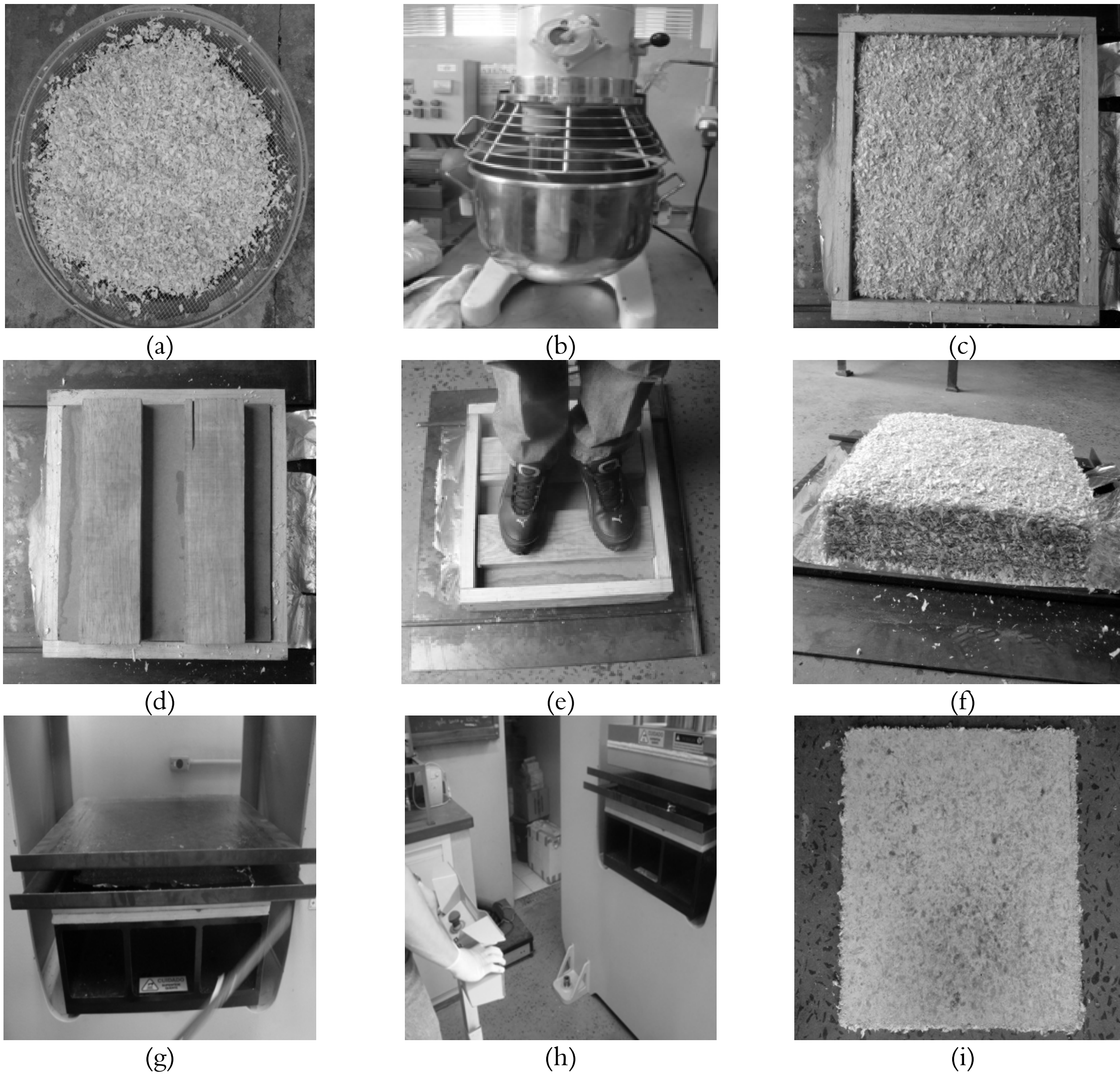

Figure 1. Wastes being sieved (a), planetary mixer (b), mold (c), preparing the pre-press (d), pre-press (e), particle mattress (f), positioning the plate on the press (g), pressing (h), particle board after pressing.

Particle properties characterization

Particles used in fabrication of panels were characterized. The density of the particles was determined in Helium Multipicnometro (Quantachrome Instruments, model MVP 5DC with specimens volume 56.56 cm^3) and the dimensions was determined in a Digimatic Micrometer.

Physical-mechanical characterization

After manufacturing the panels, test specimens were removed from the particleboard for testing physical-mechanical properties: density, thickness swelling (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending and internal bond (IB). Dimensions of test specimens, quantity and test procedures were established according to ABNT (2006) NBR 14.810-3 (Chapas de Madeira aglomerada).

Statistical analysis

Two experiments were performed; the first examined the influence of density (0.6 and 0.8 g cm^{-3}) on physical-mechanical properties using polyurethane resin-based castor oil. The second experiment investigated the influence of resin (polyurethane castor oil and urea-formaldehyde) on physical-mechanical and micro structural properties of panels with a density of 0.8 g cm^{-3}.

Experiments were arranged in a completely randomized design (CRD) in which the factor studied in the first experiment was the density with two levels (0.6 and 0.8 g cm^{-3}), while in the second experiment the factor studied was the resin with two levels (castor oil polyurethane and urea formaldehyde). In both experiments, we adopted the F test to check a 5% difference between treatments. Results were evaluated and interpreted using the free software R.

Micro-structural characterization

Images were taken by scanning electron microscopy (SEM) in order to identify differences in the micro-structure of panels manufactured with and castor oil-based polyurethane resin and urea-formaldehyde resin.

Results and discussion

This section presents the results of particle properties (Table 1) and physical-mechanical and micro-structural properties of particleboards manufactured with polyurethane resin based on castor oil and urea-formaldehyde resin from the experimental program showed in Table 2. In treatment (A), specimens were produced with density of 0.6 g cm^{-3} and castor oil-based polyurethane resin. In treatment (B), specimens were produced with density of 0.8 g cm^{-3} and castor oil-based polyurethane resin. In treatment (C), specimens were produced with density of 0.8 g cm^{-3} and urea-formaldehyde resin.

Table 1. Particle properties.

Particle	Density (g cm^{-3})	Average Particle Dimension (mm)
Pinus spp.	1.24	17.48

Table 2. Experimental program.

Treatment	Nominal Density (g cm^{-3})	Number of test samples	Type of Resin
A	0.6	10	Castor Oil
B	0.8	10	Castor Oil
C	0.8	10	Urea-Formaldehyde

The average values of density, thickness swelling (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending and internal bond (IB) of these panels are listed in Tables 4 and 6. Table 4 presents the mean values and statistical analysis related to panels with different densities (0.60 and 0.80 g cm^{-3}), in treatments A and B. Table 6 shows mean values and statistical analysis concerning the boards containing two-component: polyurethane resin based on castor oil and urea-formaldehyde resin, B and C. Table 3 and 5 present results of the P-Values for ANOVA.

Table 3. Results of P-Values for ANOVA – different density.

ANOVA - Different density	
Variables	P-value
MOR	1.818e-05*
MOE	5.011e-07*
TS 24h	1.76e-08*

*Significant at $p < 0.05$

Table 4. Mean values of physical-mechanical properties– different density.

	0.6 (g cm^{-3})	0.8 (g cm^{-3})
MOR	8.15 A	14.56 B
MOE	700 A	1543 B
TS 24h	124.78 A	29.31 B

Uppercase and different letters in the row are significantly different by F-Test at $p < 0.05$

Table 5. Results of P-Values for ANOVA – different resin.

ANOVA - different resin	
Variables	P-value
MOR	0.0001646*
MOE	0.1449NS
IB	0.9959NS
TS 24h	0.3695NS

*Significant at $p < 0.05$.

Table 6. Physical-mechanical properties average values – different resin.

	Castor Oil	Uréia
MOR	14.56 A	8.69 B
MOE	1543 A	1813 A
IB	0.54 A	0.54 A
TS 24h	29.31 A	26.99 A

Uppercase and different letters in the row are significantly different by F-Test at $p < 0.05$.

Physical Properties

Density

Average density values were used to classify the panels under study, according to the recommendations of ANSI (1993) A208.1 – Mat-formed wood particleboard: Specification, as low density (A) and medium density (B and C). Density values are important because the MOR, MOE and IB have a close relationship with the density factor proven by statistical analysis, which identified a significant difference ($p < 0.05$) between these physical and mechanical properties of wood particleboards made with polyurethane resin based on castor oil with different densities: 0.6 and 0.8 g cm^{-3} (Table 2).

Thickness Swelling (24 h)

TS tests (24h) provide indications about the conditions of accession and the strength of particles that form the panel when subjected to water immersion. Average values of TS (24h) are shown in Tables 4 and 6 for different treatments. All panels had higher values than recommended by the ABNT (2006) NBR 14.810-3. Statistical analysis identified significant differences ($p < 0.05$) between the values of TS for A and B. This result demonstrated the influence of the density of the panel on this physical property. Panels with wood waste and castor oil-based polyurethane resin had lower mean values of TS (24h) compared with panels made of urea-formaldehyde resin, proving the positive efficiency of polyurethane resin based on castor oil for the production of particleboards.

The results obtained for TS (24h), higher than recommended by the ABNT (2006) NBR 14810-3 corroborate with those reported by Iwakiri et al. (1999) who evaluated the TS (24h) of particleboards made of particles of pine and eucalyptus, with density 0.70 g cm^{-3}, and obtained values of TS equal to 32.24% (pine) and 34.95% (eucalyptus).

Mechanical properties

Modulus of rupture - MOR

Based on the results of Table 4, it is possible to observe an upward trend in MOR as increased the panel density. This result can be ascribed to the amount of wood particles and resin incorporated during the production process.

Considering the Table 6, panels made of wood particles and polyurethane resin based on castor oil showed higher mean values significantly different ($p < 0.05$) from panels manufactured with urea-formaldehyde resin. Panels A, B and C met the recommendations of strength established by ANSI (1993) A208.1 for using in applications with low structural request, for example in door filling (A and C) and for applications with medium structural request, such as for commercial use (B).

Modulus of elasticity – MOE

The mean values of MOE (A, B, and C) in Tables 4 and 6 are close to the minimum value established by ANSI (1993) A208.1, 550 MPa and 1725 MPa, for low and medium density panels. It was possible to verify a significant difference ($p < 0.05$) between treatments A and B, for this property, proving the relationship of the panels density with their mechanical properties.

Internal Bond - IB

IB results in Table 6 indicated that the production process and the amount of resin (B and C) are suitable, since have met the minimum recommendation established by ABNT (2006) NBR 14.810-3, 0.4 MPa. Moreover, no significant difference ($p < 0.05$) was detected between B and C.

Scanning electron microscopy

The Figure 2 shows images by scanning electron microscope (SEM). There was a homogeneous dispersion of resin particles, factor responsible for load distribution between fibers and composite matrix material (CALLISTER, 2002). Images in figure 2 (a) - (d) showed that panels with polyurethane resin based on castor oil had a better agglomeration of particles when compared to panels made with urea-formaldehyde resin, factor that accounts for the best physical-mechanical properties in these panels.

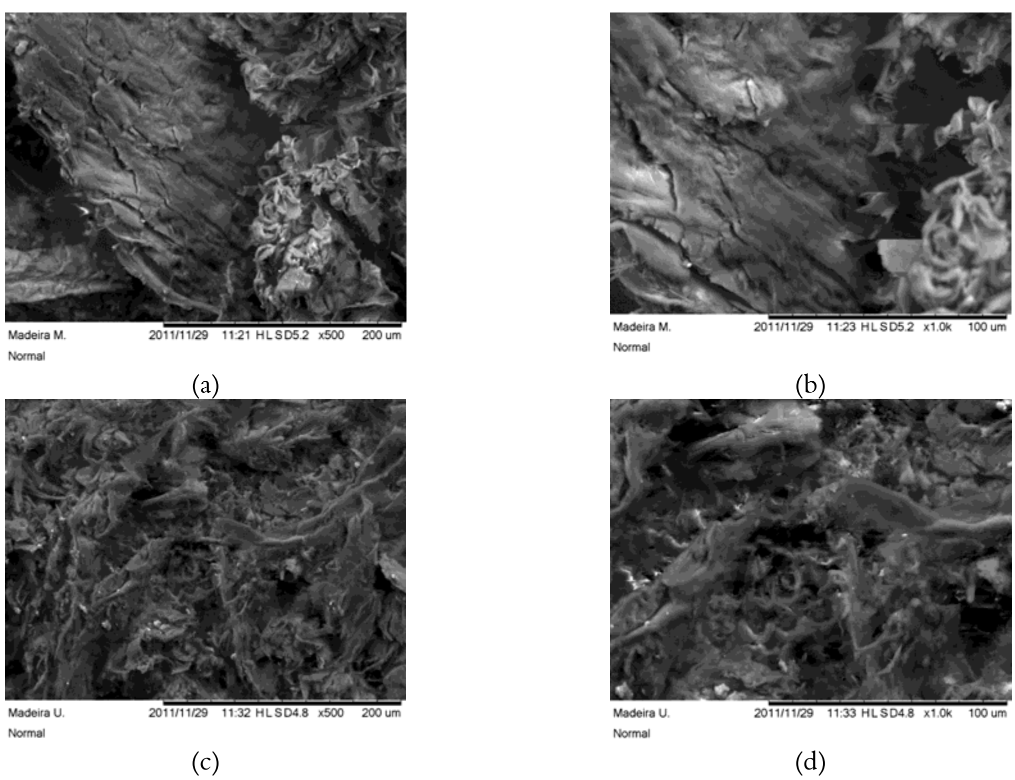

Figure 2. SEM image - Panel with wood particles: castor oil resin (a) - (b) and urea-formaldehyde resin (c)-(d). Magnifications of 500x and 1000x, respectively.

Conclusion

Based on the information presented in this study, it can be concluded that it is possible to produce in laboratory, particleboards with wood waste (flakes) adding value to this material; A bi-component castor oil-based polyurethane resin is a viable option for producing panels with wood particles (flakes), replacing thus the urea-formaldehyde resin. Panels with density of 0.6 g cm^{-3} reached the minimum values of MOR and MOE, recommended by ANSI (1993) A208.1, being thus classified as low density and recommended for use as door filling.

Panels with density of 0.8 g cm^{-3} met the specifications of ANSI (1993) A208.1 and ABNT (2006) NBR 14.810-3 for minimum values of MOR, MOE and IB, being classified as medium density panels and recommended for commercial use. SEM images indicated that panels with polyurethane resin based on castor oil showed a better agglomeration of particles compared with panels manufactured with urea-formaldehyde resin, a factor that accounts for the better physical-mechanical properties in these panels.

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