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CHEMICAL CHARACTERIZATION OF RESIDUES FROM *EUCALYPTUS* SPP. AND MECHANICAL BEHAVIOR OF WOOD-PLASTIC COMPOSITES (WPC)

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Abstract. *Logging waste is generated in large volumes during the mechanical processing of wood, causing considerable environmental impacts, such as soil and water contamination. In this research, wastes collected in a typical sawmill for the manufacture of slats, boards and pallets were used. The objective of this work was to characterize chemically waste of Eucalyptus spp. for reinforcements in polypropylene composites, investigating the use of polypropylene compatibilizer with maleic anhydride and to evaluate the mechanical properties in tensile and flexural tests analyzing different formulated compounds. Initially, the residues were dried and separated in sieves for granulometric classification. The quantitative chemical composition of the wastes was determined according to the precepts of the technical standards. Composites with different concentrations of polypropylene, polypropylene with maleic anhydride and residues were produced in an interpenetrating, corotative twin screw extruder and injection molded in the form of tensile and flexural test specimens. The tensile tests results indicated that the addition of filler raises the Young's modulus and the compatibilizer provides increase in the tensile strength. The flexural tests results indicated that the addition of filler raises the flexural modulus and the compatibilizer provides increased flexural strength and maximum deflection.*

Keywords: *Wood-Plastic Composites, compatibilizer, eucalyptus, polypropylene.*

1. INTRODUCTION

Approximately 47.0 million tons of wood waste from the wood processing and forest harvesting industry were generated in 2015, of which 33.0 million (70.5%) were generated by forestry activities and 13.8 million tons (29.5%) by industrialists (IBÁ, 2016). Studies by Hillig et al. (2006) and Teixeira (2013) point out that the utilization of the wood used in sawmills is approximately 45% and the remainder is transformed into waste. In case of *Eucalyptus* spp, the formation of residues is between 40% and 50%.

Waste generation is a natural consequence of the wood processing and, if left untreated, can cause damage to the local and the regional ecosystems. The waste can be used for small farmers, for use in breeding sites, forage crops, or sold to briquette, pottery and fertilizer companies. Wood residues can also be used as reinforcements in the production of wood-plastic composites, referred to commercially as WPC.

It is currently common to manufacture WPC composites with polypropylene resin and wood, using a compatibilizer to improve adhesion between the matrix and the reinforcement. The compatibilizer PP-g-MA (polypropylene graphite with maleic anhydride) is one of the most used, because it presents an excellent adhesion between the matrix-filler interface (Keener et al., 2004).

The possibility of using the waste, besides improving the image of the industries before the society, generates jobs in the factories, by the simple transformation into new products. The inclusion of lignocellulosic residues in thermoplastic matrix provides consistent results for commercial use (Hillig et al., 2008). The automotive sector was the pioneer in the use of vegetable waste of the genus *Eucalyptus* in composites, to manufacture parts with a reduction of approximately 40% of the weight (Leão et al., 2009). One of the causes that prevent the increase of the production of the wood-plastic composites is the distance between the sawmills and the processing industries, besides the little knowledge of the qualities of the residues (Clemons, 2002).

Knowing the properties of waste and using them properly is important to produce environmentally friendly products at cost savings. These new materials can have advantages in the production of components with greater dimensional stability, lower weight and easy processing (Malkapuram et al., 2009; Leong et al., 2014). The characterization of wood as to density, moisture and chemical composition is fundamental for the correct use of this material (English and Falk, 2000; Stokke and Gardner, 2003).

In this context, the present work had the objective of the chemical characterization of the residues of *Eucalyptus* spp. for particulate reinforcement in the preparation of composites and evaluation of the mechanical properties of these compounds.

2. MATERIALS AND METHODS

Residues of *Eucalyptus* spp. were collected after the mechanical processing of the wood in a sawmill, dried at room temperature, and then in an oven at 105 ± 2 ºC for 48 hours and characterized as granulometry (ASTM D 1921, 2012), density (ABNT NBR 11941, 2003), moisture (ABNT NBR 14929, 2003) and the chemical constituents (ABNT NBR 13999, 2003; ABNT NBR 14853, 2010; ABNT NBR 7989, 2010).

Polypropylene (PP) blends, residues (10%, 20%, 30%, 40%) and compatibilizer PP-g-MA (1%, 5%, 10%) were prepared. An interpenetrating twin screw extruder, Werner-Pfleiderer, was used for homogenization of the components. Processing was carried out in the temperature range of 200 °C to 240 °C. An Arburg Allrounder model 270V / 300-120 was used for conformation of tensile and flexural test specimens. The injection temperature ranged from 210 °C to 235 °C.

The mechanical tests were performed in a universal testing machine, EMIC, model DL 10000/700. The tensile test was performed according to ASTM D 638 (2014) with type I test bodies, test speed of 5 mm min^{-1}, load cell of 1000 kgf and strain gauge of 25 mm. The flexural test was performed according to ASTM D 790 (2010) using test specimens with procedure A geometry. The load cell used was 200 kgf and deformation rate was 1.36 mm min^{-1}.

3. RESULTS AND DISCUSSION

The maximum granulometry adopted for the residues was 2.00 mm, because larger particles make difficult in the extrusion and injection process. The density of *Eucalyptus* spp. obtained was 0.11 ± 0.01 g cm^{-3}. The density of the residues in the WPC preparation was between 0.1 and 0.3 g cm^{-3}, because porosity may occur in the composite, resulting in non-homogeneous material (Clemons, 2002; Yamaji and Bonduelle, 2004).

The moisture content of the particulates of *Eucalyptus* spp. for processing was considered high, with a content of 9.9 ± 0.9% (should be less than or equal to 8%). The higher the moisture, the larger the volume of gases generated inside the extruder, with bubbles formation, surface staining and difficulty of matrix-filler adhesion during the process (Harper, 2004; Rodolfo and John, 2006).

The values of the residues components of *Eucalyptus* spp. are shown in Tab. 1.

Table 1 - Chemical constituents of *Eucalyptus* spp (in mass).

Constituent	**%**
Ashes	0.38 ± 0.08

Extracts in etanol:toluene (1:2, v/v)	1.76 ± 0.04
Total extracts	3.6 ± 0.5
Lignin	25.5 ± 0.5
Holocellulose (cellulose + hemicellulose)	70.8 ± 0.1

The properties of tensile strength, Young's modulus and flexural strength in composites can reach higher values with the correct selection of the type of plant as filler (Grison et al., 2015). Considering the fact that there are variations in the different regions in a tree, in the wood and by environmental conditions, the determination of the constituents of the wood is important, since they characterize the mechanical and thermal properties of the materials (Klyosov, 2007). The values of the constituents of each residue are in agreement with the results described by Klock et al. (2005), which demonstrates a quality control of the residues used in the preparation of composites.

In relation to the tensile tests, the addition of the residues reduces the deformation at the rupture of the composites and the incorporation of the compatibilizer showed no significant influence on the elongation. Regarding to the Young's modulus, there was an increase of approximately 30%, 60%, 95% and 115% for 10%, 20%, 30% and 40% in mass of *Eucalyptus* spp. residues, respectively, in compositions without compatibilizer. It was observed that there was influence in the Young's modulus of the composites with 20%, 30% and 40% in mass of residue containing 5% of compatibilizer.

The behavior of the stress-strain curves for PP and the different formulations PP/PP-g-MA/*Eucalyptus* spp., in which the rigid load reduces the stress in the matrix flow is observed in Fig. 1 ductile polypropylene homopolymer and increases the modulus of elasticity in non-compatibilized formulations. According to Correa, Razzino and Hage Junior (2007), it was already expected, due to the lack of adhesion between the wood flour and the polypropylene matrix, being verified in several studies (Caraschi and Leão, 2002, Correa et al., 2003; Qiu et al., 2003). According to Correa, Razzino and Hage Junior (2007), a possible explanation is the fact that the particulate load acts as a voltage concentrator and thus, even with the application of voltages below the matrix flow voltage, it is reached at points located in around the particles, values equivalent to the yield stress of PP. This because the reduced deformation ability, by the presence of the wood particles themselves, breaks without transferring tension to the reinforcement, due to the lack of adhesion at the interface.

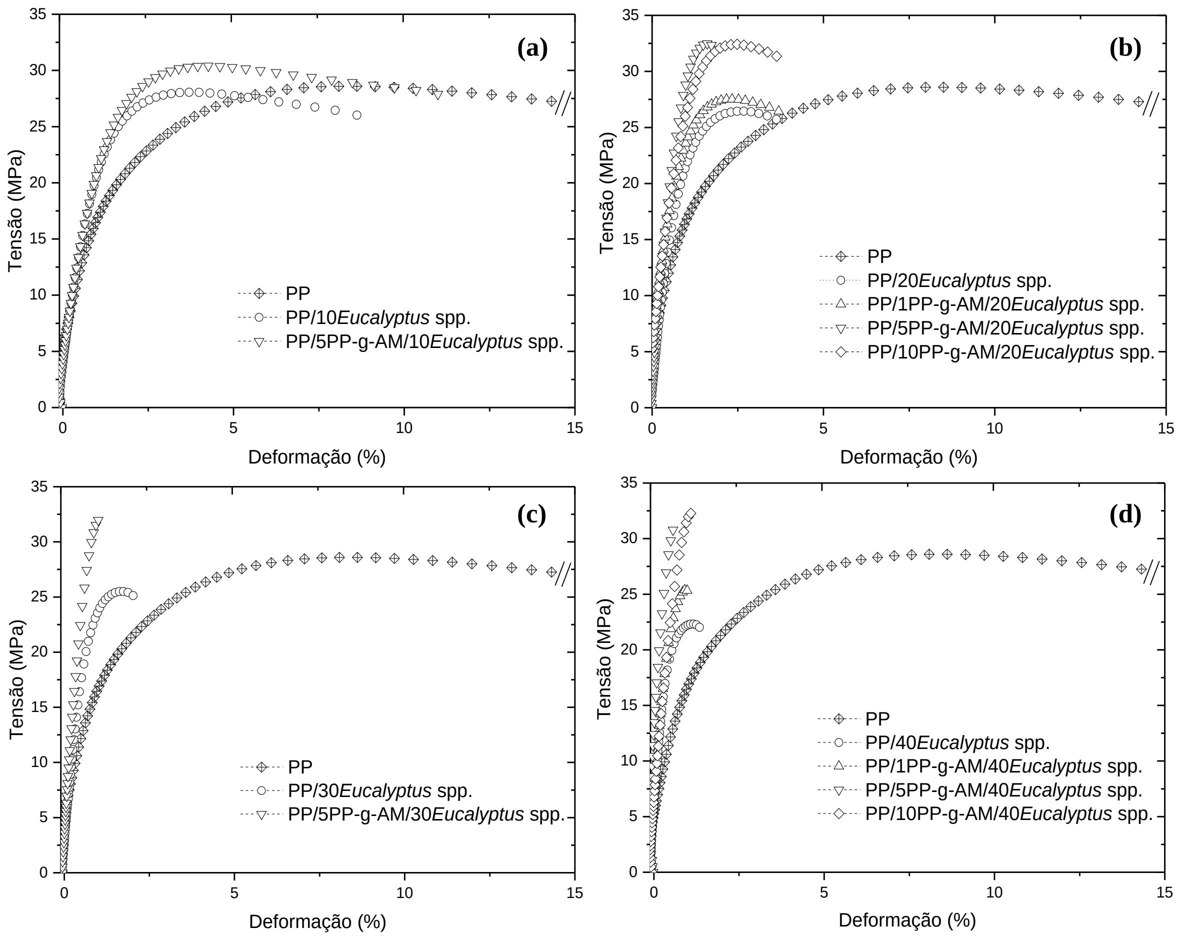

Figure 1 - Strain-strain curves for PP matrix and composites compatibilized or non-compatibilized containing 10% (a), 20% (b), 30% (c) and 40% (d) of *Eucalyptus* spp., under tensile tests.

In relation to the flexural tests, the values of flexural strength and flexural strain decrease as the amount of residue in the formulation increases. However, an increase in stiffness is observed with addition of the residue, with increases of the order of 20% at the flexural strength for the PP/10%Residue, 20% at the flexural strain for the PP/10%Residue and 75% in the flexural modulus for PP/40%Residue, without compatibilizer. With the addition of up to 5% of the compatibilizer it is possible to notice an improvement in some mechanical properties in the series of prepared composite materials, which indicates possible wetting and mechanical adhesion between the matrix-filler and/or probable chemical interactions between the cellulosic surface and the polypropylene grafted with maleic anhydride. In general, the compatibilizer presence was relevant in some properties of the composites, due to the better interfacial interaction.

Figure 2 shows the behavior of stress-strain curves for PP and the different formulations PP/PP-g-MA/Eucalyptus spp. It is observed that composites with concentrations greater than 30% by weight of load can rupture before the test reaches maximum deformation, regardless of the addition of compatibilizer.

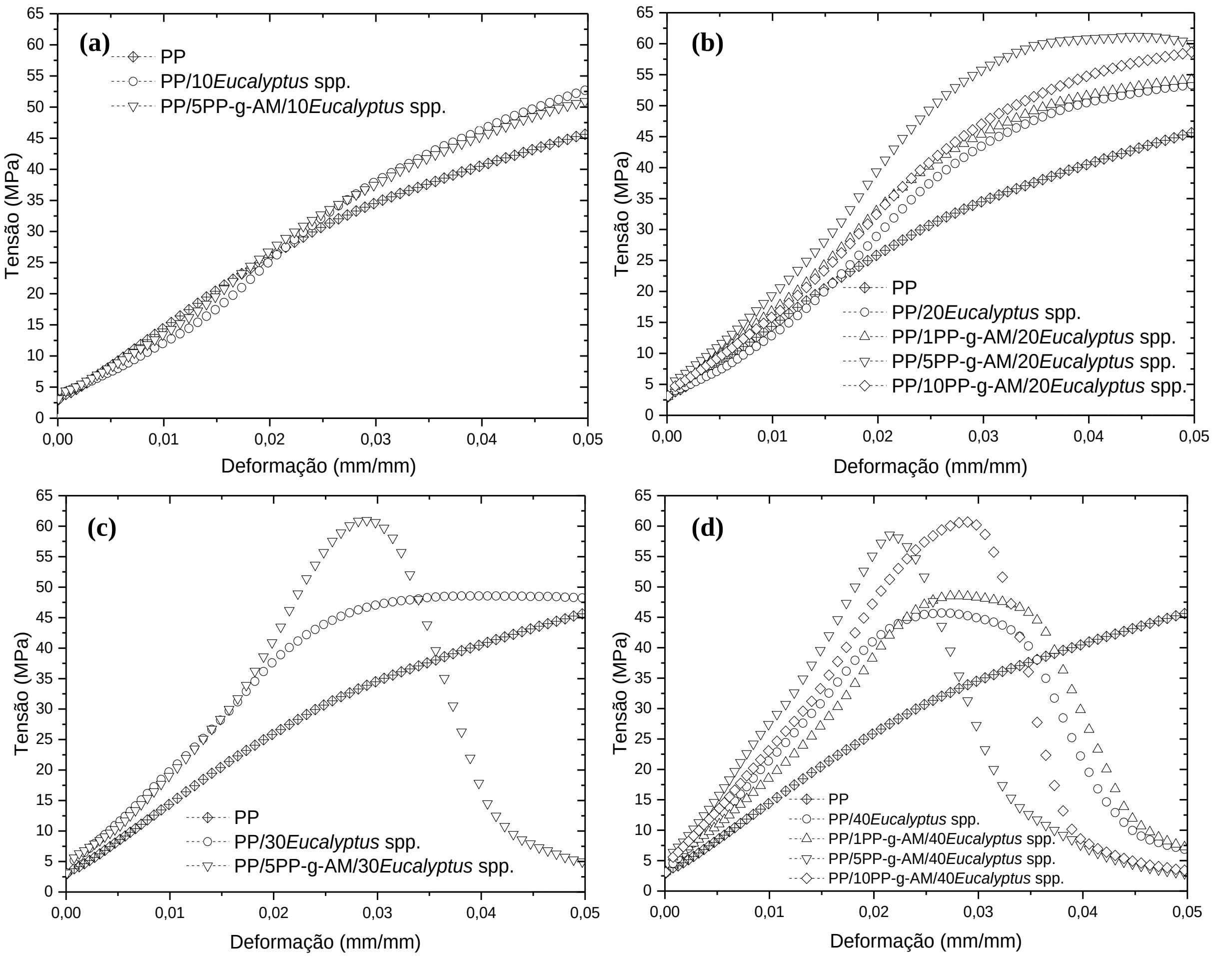

Figure 2 - Strain-strain curves for PP matrix and composites compatibilized or non-compatibilized containing 10% (a), 20% (b), 30% (c) and 40% (d) of *Eucalyptus* spp., under flexural tests.

4. CONCLUSION

The addition of particulates of *Eucalyptus* spp. to the polypropylene matrix gives a reinforcing character to the materials.

There is a high gain in the Young's modulus with the addition of residues of *Eucalyptus* spp. in PP matrix and the positive influence on the tensile strength with the use of PP-g-MA, which is shown as a factor of increase of the reinforcing action to the obtained composite materials. The improvement of the interfacial adhesion does not interfere in the elongation of the composites.

An increase in flexural modulus occurs with the addition of residues of *Eucalyptus* spp. in the polymer matrix and the positive influence on flexural strength and flexural strain with the use of compatibilizer.

In general, the use of PP-g-MA was efficient in increasing the mechanical strength of the developed composites, which proves a better matrix-filler interaction.

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