Development of composites with plastic waste and used foundry sands

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ABSTRACT: The use of different residues for the production of new composite materials has gained strength in recent years, as it enables reuse of materials and creates value for the residue which would usually be insignificant. This work presents the results of the development of mixed plastic composites using plastic waste and used foundry sands from different origins as fillers. The materials were characterized by different methods and the composites formulated were evaluated for their mechanical properties. Results indicate that the incorporation of high contents (mass fraction) of sand in the polymer is possible. However, the increase in the sand content is limited by the effect on the mechanical properties of the composites, making them less usable in structural situations.

1 INTRODUCTION

The metal foundry activity generates a high volume of waste, among which, foundry sands are the largest. Although it is possible to use these sands in civil construction, namely in the production of concrete(Ellis 2001; Siddique, Schutter & Noumowe 2009; Khatib et al. 2010; Siddique & Singh 2011; Bhardwaj & Kumar 2017; Liu et al. 2020; Kavitha, Shyamala & Akshana 2021; Priyadarshini & Giri 2022) , this is not enough to satisfy the flow needs, and some decrease in mechanical properties makes it a less interesting recycling route. Foundry sand poses also some environmental problems, when they are disposed in landfills, because of leaching of metals and some organic compounds like phenol and furan. In this way, there is a strong need to develop new routes for the use of these sands in view of its recycling. Composite materials appeared to support needs that could not be met with other materials, or that were not economically viable(Ramakrishna et al. 2001; Hollaway 2003; Jose et al. 2012; McGrail, Sehirlioglu & Pentzer 2015; Friedrich 2018; Swolfs, Verpoest & Gorbatikh 2019). These materials are combinations of two or more components. The constituents of a composite are divided mainly in matrices and reinforcements(Hollaway 1994; Goodship 2009). The matrices of the composites can be metallic, ceramic or polymeric, being it´s function of structural character, as well as the distribution of the stresses, that the composite suffers, through the reinforcement. Up until 2015, approximately 4977 Mtons of plastic waste were accumulated in landfills or natural environments(Geyer, Jambeck & Law 2017). These wastes are made up of several types of plastics which makes the recycling process complex, as the separation processes are often not economically viable and/or efficient enough for all mixing situations. Currently, the main routes for the recycling of these materials is through processes such as incineration, for energy production, and mechanical recycling (crushing) for use as fillers(Franco-Urquiza et al. 2016). However, not every country has a proper system for solid waste management, which leads to little to no value for this plastic wastes, resulting in disposal in landfills or even losses in nature(Parveen 2018; Barnes 2019; Goli, Mohammad & Singh 2020). These routes are not able to keep up with the quantities of waste produced, therefore new forms of use are needed. The development of products based on materials discarded by different

industries may help the revalorization of wastes and is a step towards the concept of circular economy. With this perspective in mind, an experimental work was performed to develop and characterize polymer-based composites, made from plastics and foundry sands waste materials.

2 MATERIALS AND METHODS

The materials used during this work were Cast iron foundry sand (CIFS), Brass foundry sand (BFS), Aluminum alloy foundry sand (AAFS), Steel foundry sand (SFS) and mixed polymer wastes. These sands present higher density than plastics, a fine aggregated aspect and black or brown color. Regarding the plastic waste, matrix A is composed of purges from extrusion process, mixed with plastic injection purges, in approximately equal proportions. In the case of matrix B, this formulation contains part of matrix A, with the addition of other mixed plastics rejected from sorting operations, in proportions of 70 % of matrix A the rest being the mixed plastics. As matrix A has market value and the rejected plastics should be sent to landfill or energy valorization, with a negative value, this makes it possible to reduce matrix A consumption, hence lowering the overall material cost. All the used foundry sands employed as well as the polymer matrices were characterized by different methods.

3 SAMPLES PREPARATION AND TESTING

The sample preparation process was divided into two main steps: extrusion and compression molding, all made at laboratory scale. The extruder is of a single screw type with an L/D of 25. In the process, a speed of 60 rpm, with a flow of 3 kg/h and a temperature in the extrusion head of 180°C were used. The melt is then transferred to the mold with the aid of a spatula. The procedure is done quickly, in order to minimize temperature losses that might occur. After this transfer process, the compression phase begins. Compression was carried out with a load of 1.5 tons ± 0.2. This compression step allows the reorganization of the melt in the structure of the mold, over which it is immediately immersed in cold water. The composites were molded into the shape of parallelepipedal blocks with 160 x 40 x 40 mm and contain up to 70% incorporation of foundry sand. The composites were subject to mechanical testing. The bending test was conducted in accordance with EN 1015-11:2019, using a 50 N/s load across the test. The compression test also follows EN 1015-11:2019, with a 150 N/s load across the test. The tensile test follows the ISO 527 standard, with the tests carried out at room temperature and a speed of 5 mm/min.

4 RESULTS AND DISCUSSION

4.1 *Characterization of materials*

4.1.1 *Fillers*

X-ray fluorescence spectrometry, complemented by the elemental analysis of carbon and sulfur results are indicated in table 1. From the scanning electron microscopy observation, it is possible to determine that the sand granulometry lies between 100 and 500 micrometers.

Table 1. Chemical composition of the sands.

Component (weight %)	Cast iron foundry sand (CIFS)	Brass foundry sand (BFS)	Aluminum alloy foundry sand (AAFS)	Steel foundry sand (SFS)
C	16,60	20,70	38,20	4,06
S	0,28	0,35	-	1,24
SiO_2	80,60	58,50	60,10	71,80
ZrO_2	1,00	-	-	-
Fe	1,00	5,00	0,45	-
Al_2O_3	0,50	2,70	0,37	7,21
K_2O	-	0,56	0,31	0,76
TiO_2	-	0,39	0,16	0,14

Fe_2O_3	-	-	-	4,96
CaO	-	-	-	0,25
ZnO	-	-	-	0,05
MgO	-	-	-	0,16
Cr_2O_3	-	-	-	0,11
ZrO_2	-	-	-	4,11
MnO	-	-	-	0,17
Cu	-	6,90	-	-
Zn	-	3,90	-	-
Pb	-	0,61	-	-

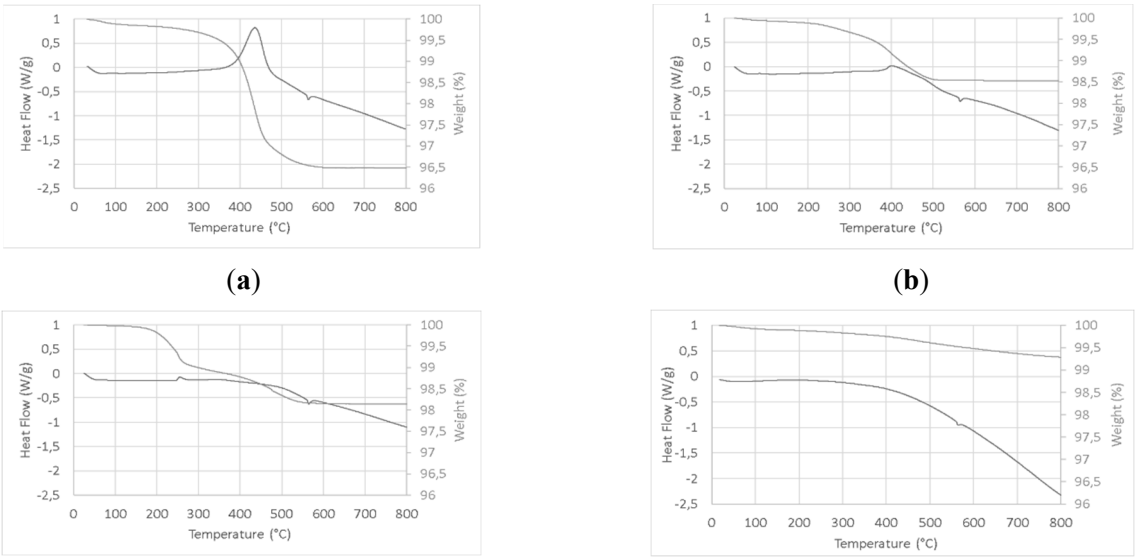

Figure 1. Differential thermal analysis (DTA) and Thermogravimetric analysis (TGA) for: (a) Cast iron foundry sand (CIFS); (b) Brass foundry sand (BFS); (c) Aluminum alloy foundry sand (AAFS); (d) Steel foundry sand.

The DTA and TGA of the sands, presented in figure 1, show that the resins present in the sands decompose above 250 °C and that the resin content is always lower than 3.5%. It is observed a correlation between the DTA peaks and the TGA mass decrease related to the decomposition of the resin in the sand. Interactions derived from the decomposition of these resins in the production process doesn´t affect the molten of the polymeric fraction since the processing window used is outside of the decomposition temperatures (higher than 400 ºC).

4.1.2 *Matrices*

The analysis of the FTIR spectra together with the results of the differential thermal analysis tests help in the identification of the polymers that constitute the matrices. The main peaks identified, in both matrix, are at 2914 and 2847 cm-1 associated to the CH2 asymmetric and symmetric stretching, at 1470 cm-1 associated with CH2 bending deformation and in between 710 to 730 is associated with rocking deformation of CH2(Gulmine et al. 2002; Bhargava, Wang & Koenig 2003; Coates 2006). The results of the DTA-TGA, figure 2, are similar showing an endothermic peak in the region of 130°C, and a strong mass loss of 93% and 98%, both in the region between 400°C and the 480°C. These data combined with the FTIR spectra indicate that both matrices are composed mainly of high-density polyethylene (HDPE), contaminated by other polymers or eventual degradations of the original main polymer(Gulmine et al. 2002).

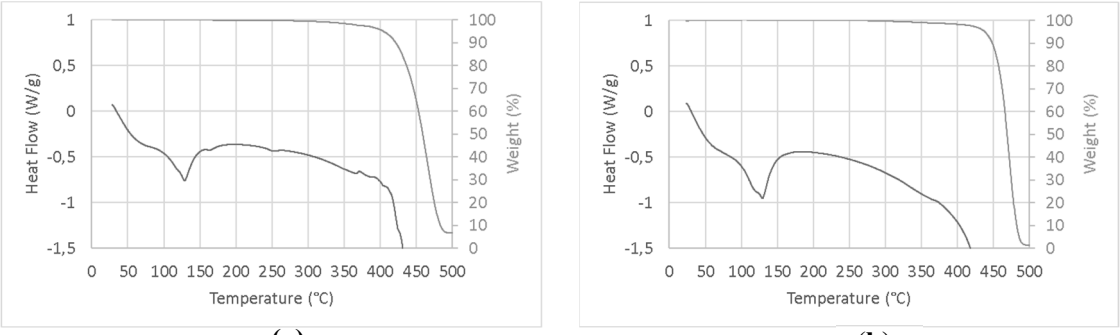

Figure 2. Thermal analysis: (a) DTA-TGA “Matrix A”; (b) DTA-TGA “Matrix B”.

4.2 *Mechanical Characterization*

4.2.1 *Flexural and Compression Strength*

Table 2 present the results for the flexural and compression strength of the composite samples (average of 4 samples). Through the analysis of these results, different behaviors are observed. A better flexural resistance is observed with the increase of the AAFS in “Matrix B” composites compared to “Matrix A” composites. By the other hand, the increase in the % of CIFS, presents better resistance in “Matrix A” composites than in “Matrix B” composites. These results show some dispersion than can be explained by the heterogeneity of the matrix and the presence of small voids. Regarding the compression tests, the “Matrix B” composites show usually better behavior regardless of the filler but also dispersed results.

Table 2. Flexural and compression strength results.

Composition	Flexural Strength (MPa)	st. dev.	Compression Strength (MPa)	st. dev.
100% Matrix A	16,1	4,7	10,9	1,9
100% Matrix B	12,8	4,2	14,1	1,6
50% Matrix A + 50% AAFS	9,1	0,5	12,7	1,5
70% Matrix A + 30% AAFS	9,9	1,4	12,3	2,4
85% Matrix A + 15% AAFS	11,9	1,1	12,3	0,7
50% Matrix B + 50% AAFS	11,2	1,1	16,6	1,5
70% Matrix B + 30% AAFS	9,4	0,6	14,7	0,4
85% Matrix B + 15% AAFS	9,7	1,9	14,0	1,7
30% Matrix A + 70% CIFS	9,0	4,2	9,2	4,2
50% Matrix A + 50% CIFS	9,1	1,9	10,5	1,8
70% Matrix A + 30% CIFS	9,2	2,2	10,3	1,9
30% Matrix B + 70% CIFS	8,5	3,6	12,3	4,6
50% Matrix B + 50% CIFS	7,7	2,3	9,1	5,7
70% Matrix B + 30% CIFS	10,5	3,0	13,2	1,3
50% Matrix A + 50% BFS	4,1	0,1	5,0	0,2
50% Matrix B + 50% BFS	6,5	0,3	4,1	0,4
30% Matrix B + 70% SFS	19,9	2,6	13,6	1,9
50% Matrix B + 50% SFS	18,0	1,6	11,4	1,9
70% Matrix B + 30% SFS	15,7	1,9	11,0	1,2

4.2.2 *Tensile strength*

Upon analysis of the stress-strain curves for the "pure" plastic materials, figure 3 (a) and ((b), it was observed that both materials exhibit a brittle behavior, "Matrix B" being more brittle. As for the composites, figures 3 (c) and (d), an increase in the amount of foundry sand results always in an enhancement of the brittle behavior. This change is substantiated by the observation that the

average value of the elastic modulus increases with the inclusion of residue, indicating a stiffening of materials in the presence of sand. Additionally, a decrease in the yield strength is noticeable.

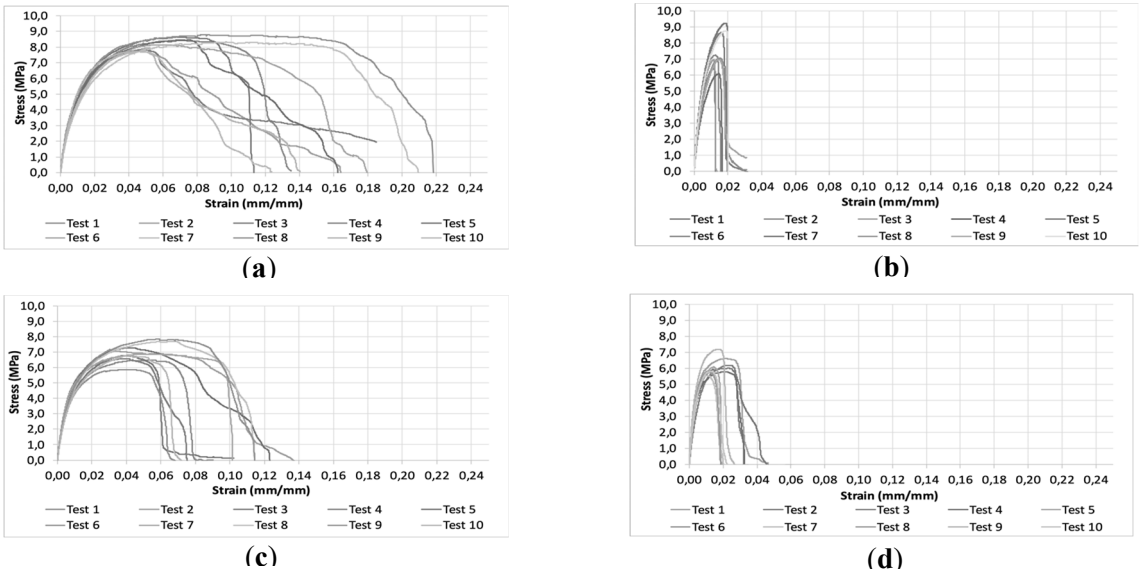

Figure 3. Stress vs Strain Curves composites: (a) 100% “Matrix A”; (b) 100% “Matrix B”; (c) 90% “Matrix A” + 10% AAFS; (d) 50% “Matrix A” + 50% SFS.

5 CONCLUSIONS

The results obtained demonstrated that it is possible to incorporate used foundry sands in polymeric composites, even at high sand contents, with some, but acceptable, decrease in the mechanical resistance, rendering this methodology a reasonable technical and environmental solution for the management of the tested waste materials. Allowing to the replacement of virgin materials and hence contributing for circular economy and sustainability.

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