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Mechanical and toxicological evaluation of concrete artifacts containing waste foundry sand

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ABSTRACT

The creation of metal parts via casting uses molds that are generally made from sand and phenolic resin. The waste generated after the casting process is called waste foundry sand (WFS). Depending on the mold composition and the casting process, WFS can contain substances that prevent its direct emission to the environment. In Brazil, this waste is classified according to the Standard ABNT NBR 10004:2004 as a waste Class II (Non-Inert). The recycling of this waste is limited because its characteristics change significantly after use. Although the use (or reuse) of this byproduct in civil construction is a technically feasible alternative, its effects must be evaluated, especially from mechanical and environmental points of view. Thus, the objective of this study is to investigate the effect of the use of WFS in the manufacture of cement artifacts, such as masonry blocks for walls, structural masonry blocks, and paving blocks. Blocks containing different concentrations of WFS (up to 75% by weight) were produced and evaluated using compressive strength tests (35 MPa at 28 days) and toxicity tests on *Daphnia magna*, *Allium cepa* (onion root), and *Eisenia foetida* (earthworm). The results showed that there was not a considerable reduction in the compressive strength, with values of 35 ± 2 MPa at 28 days. The toxicity study with the material obtained from leaching did not significantly interfere with the development of *D. magna* and *E. foetida*, but the growth of the *A. cepa* species was reduced. The study showed that the use of this waste in the production of concrete blocks is feasible from both mechanical and environmental points of view.

1. Introduction

In the casting manufacturing process, a metal or a metallic alloy in the liquid state is poured into a mold that contains a cavity with the shape and measurements corresponding to the piece to be produced. One of the inherent problems of this process is that, after a specific number of repetitions, the mixture made from sand and usually phenolic resin loses the properties necessary for the fabrication of other molds, thus generating a significant amount of waste. According to McIntyre et al. (1992), the production of a ton of cast metal generates approximately one ton of waste. Data from the Brazilian Casting Association (Associação Brasileira de Fundição, ABIFA) indicate that 3.3 million tons of cast metal was produced in Brazil in 2011. Thus, in 2012 alone, the Brazilian casting industry generated approximately 3 million tons of waste foundry sand (WFS).

In Brazil, this waste is classified as a Class II (Non-Inert) waste according to the Standard ABNT NBR 10004:2004. The Brazilian environmental legislation determines that these wastes must be deposited in controlled industrial landfills or incinerated. This requirement poses a serious environmental problem due to not only the elevated volume produced but also the toxic substances found within the WFS, as the sand is contaminated by several dangerous chemical elements such as heavy metals (arsenic, cadmium,

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lead, and mercury) and organic compounds such as phenols (Klinsky, 2008).

Among the various existing possibilities for reuse, rendering this waste inert in a cement matrix, such as in the production of concrete, is highlighted because not only is it more economical, but it also helps to reduce the disposal problems (Siddique and Singh, 2011). However, it is important to evaluate the toxicological activity of the manufactured products as well as their mechanical properties to prevent their impact on the environment.

Thus, the objective of this study is to investigate the effect of the addition of WFS on the manufacture of cement artifacts.

2. Materials and methods

The WFS used in this study was obtained from the Coopermetal foundry (Criciúma, SC, Brazil) and was used as received. The granulometric characteristics of this waste (Fig. 1) were concentrated predominantly in the range from 212 to 300 μm (d_{50} = 226 μm, determined by sieving), which may be considered appropriate for the manufacture of cement artifacts (Silva et al., 2011; Rocha et al., 2011). The chemical analysis of the waste was performed using two methods: X-ray fluorescence (XRF, Philips PW 2400, Eindhoven, The Netherlands) and the continuous solvent extraction method in order to identify the presence of residual phenolic compounds from the phenolic resin existing in the WFS. The concern about phenolic compounds is related to their solubility in water. Possible leaching of phenolic compounds from the cimenticious artifacts studied in this work could lead to a significant environmental impact. So, the continuous extraction technique was used to identify the organic components present in the waste, based on the use of solvents with different polarities in the extraction process. The intention was to make possible the extraction of different organic compounds fractions present in waste. In this study, different organic solvents were used: dichloromethane (CH_2Cl_2), ethyl acetate ($CH_3COOCH_2CH_3$), hexane (C_6H_6), and ethanol (C_2H_5OH). For this method, 600 g of the waste were dried at 85 °C for 24 h in a laboratory dryer in order to guarantee enough material for possible repetition of experiments. Next, each of the three chosen solvents was tested with a 20 g-sample of waste. The extractions were performed using a *Soxhlet* apparatus. The soxhlet extractor enables solids to be extracted with fresh warm solvent that does not contain the extract. This can dramatically increase the extraction rate, as the sample is contacting fresh warm solvent. A detailed description of this method may be found in Vogel and Tatchell, 1996. After the extraction, three trials of the extract from each solvent were combined and placed in a 1 L beaker to concentrate the extract on a hot plate. The respective solvent used in the extraction was added to each of the beakers to resolubilize the extracted contents, which were then transferred to small glass receptacles. The lids were left slightly open to allow the remainder of the solvent present in each sample to evaporate. The samples extracted by the different types of solvents were then analyzed using Fourier Transform Infrared Spectroscopy FTIR (Shimadzu IR Prestige – 21, Tokyo, Japan). Weight loss of the waste was analyzed by thermogravimetric analysis (TGA Q500, TA Instruments, USA; 10 °C min^{-1} in nitrogen). The crystalline faces of the waste were determined by X-ray diffraction (XRD, Shimadzu, model LABX XRD-6000, Tokyo, Japan; $2\theta = 5$ to 85°, 2° min^{-1}, Cu Kα1 radiation, 30 kV, 30 mA). The experimental plan used in this study is shown in Table 1 and was based on a 2^3 factorial plan with three central points using the following variables: concentration of cement (3 levels and 3 replicates), concentration of green sand and concentration of foundry waste (3 levels and 3 replicates), and curing time (3 levels and 3 replicates). The observed responses were the compressive strength and toxicity. The objective was to obtain a minimum compressive strength of 35 MPa to meet the lower limit established by the Standard ABNT NBR 9781:2013, in addition to meeting the environmental control parameters (Standard ABNT NBR 10004:2004, Standard ABNT NBR 10005:2004, and Standard ABNT NBR 10006:2004). Five test samples of each composition were prepared and properly stored for curing for 28, 56, and 91 days. The axial compressive strength of the test samples at the ages of 28, 56, and 91 days was determined according to the Standard ABNT NBR 9781:2013 in a universal machine of mechanical tests (EMIC PC200CS, São José dos Pinhais, PR, Brazil). Graphical and statistical analyses are both important in the analysis of data (Dean and Voss, 1999). Statistical analysis quantifies the relative responses of the factors, thus clarifying conclusions. In this sense, linear models to model the response and the method of least squares may be used for obtaining estimates of the parameters in the model. So, tests of statistical significance were used to identify which obtained results of the study contained enough information to be considered important in the analysis. Among others, *p*-value takes an important role. The *p*-value of a test is the probability (the smallest choice) of a significance level that would allow the null hypothesis to be rejected (Dean and Voss, 1999) and was used to evaluate the effect of WFS content on compressive strength. The toxicity of the test samples was evaluated using different techniques for composition C1 at 91 days (curing time). According to Brazilian Standard ABNT NBR 10004:2004, toxicity is the *potential property that the toxic agent is capable to cause, a greater or lesser degree, an adverse effect as a consequence of its interaction with the organism.* The acute toxicity was evaluated according to the Standard ABNT NBR 12713:2009 using *Daphnia magna*. The acute lethality test was performed with earthworms (*Eisenia foetida*). Prior to the test, the earthworms were kept on filter paper moistened with distilled water for a period of 24 h to purge their intes-

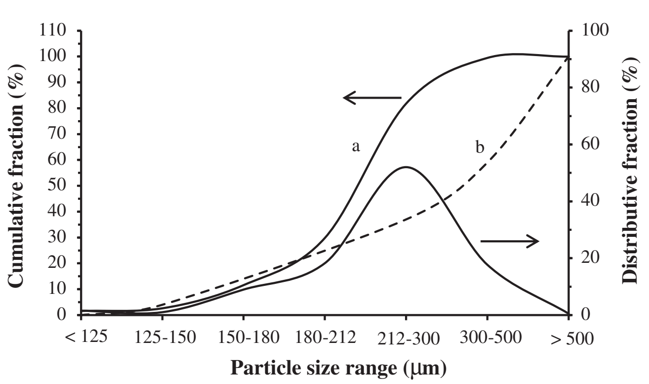

Fig. 1. Particle size distribution of: (a) WFS and (b) representative sand used in Brazilian concretes.

Table 1
Compositions of the tested mixtures: C – cement; An – green sand; Af – WFS; P – gravel.

Mixtures	Composition (wt%)			
	C	An	Af	P
M1—C1[a]	22	68	0	10
M2—C1	22	51	17	10
M3—C1	22	34	34	10
M5—C2	17	73	0	10
M6—C2	17	55	18	10
M7—C2	17	36.5	36.5	10
M9—C3	13	77	0	10
M10—C3	13	58	19	10
M11—C3	13	38.5	38.5	10

[a] Standard composition.