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Red ceramics enhancement by hazardous laundry water cleaning sludge

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A B S T R A C T

Permanently increasing number of industrial and municipal wastes accumulated in the dumps, inevitably leads to contamination of soils, surface waters and subterranean waters, the atmosphere and is a perceptible factor of climate change on our planet.

This paper is one more proof that waste utilization, as a valuable source of components for new materials production, is environmentally and economically the best way for their management.

The purposes of the research were the next: to develop eco-friendly ceramics that include and immobilize hazardous laundry sludge after cleaning of extremely polluted industrial uniforms with high contents of As, Ba, Cd, Pb, Cr, Hg, Cu, Zn and grease, oil, resin, tar, paints, organic volatile compounds, etc.; to improve the mechanical properties of red ceramic, using laundry sludge; to demonstrate a possibility of natural raw materials extraction decrease, partially replacing them with laundry sludge. This sludge was introduced in the traditional clay-sand mix in the amount of 0, 3, 5, 7, 10, 15 and 20 wt. %. After sintering of these composites at temperatures 1000°, 1050°, 1100°, 1150 °C the maximum values of flexural strength resistance of the ceramics was 15.6 MPa, values of linear shrinkage ranged from 4.5 to 14.1%, water absorption values – from 13.0 to 20.3%, and density values ranged from 1.65 to 1.83 g/cm^3. All these characteristics of the mechanical properties of the developed materials significantly exceed the properties of ceramics from traditional clay-sand mixes without laundry sludge. The leaching and solubility values of the heavy metals immobilized within these ceramics are hundreds of times lower than threshold levels set by the national standards of Brazil. This study showed that industrial laundry sludge can be safely used as additive to ceramics in proportions of 10–20% wt. %, enhancing the mechanical properties of the materials and constituting an ecological way to manage these wastes.

1. Introduction

Some types of industrial and municipal wastes are extremely hazardous because of their high content of dangerous components, such as concentrated heavy metals. One example is laundry sludge (LS) from extremely polluted industrial uniforms, containing many heavy metals including As, Ba, Cd, Pb, Cr, Hg, Cu, and Zn. Their concentration far exceeds Brazilian toxicity thresholds, and therefore, this type of LS must be classified as hazardous waste. The most common practice is to discharge this waste directly into landfills (Richter, 2004).

There is extensive scientific and technical literature on finding environmentally safe and economical methods to use waste as a raw material (Mymrin, 2012; Pan et al., 2001) including sewage sludge from water cleaning. One of the more widespread methods is the use of waste sludge to produce ceramics (Ramirez et al., 2008; Teixeira et al., 2006; Oliveira et al., 2004). Herek et al. (2012) studied the use of different concentrations of textile laundry sludge for ceramic brick production, and Abdul et al. (2004) used sewage sludge as a raw material in red brick firing. Dondi et al. (1997) classified industrial sewage sludge as a valid material flux in ceramics fabrication, and Leite and Pawlowsky (2002) used it to plastify waste. Mahzuz et al. (2009) developed a method to use arsenic-contaminated sludge to produce ornamental bricks. Jordán

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(2005) reported that sewage sludge can decrease the bending strength of construction materials. However, other study (Ramirez et al., 2008) showed a positive influence of the sludge on the mechanical properties of concrete and mortar. Pietrobon et al. (2004) came to a neutral conclusion: they reported that the addition of 10%, 20% and 30% of sewage sludge negatively altered the structure of cement, but that the difference was not critical. Additionally, Castro (2010) examined the acoustic properties of ceramic blocks. John et al. (2001) successfully used WTPS as an additive to cement mortars. Kizinievič et al. (2013) analyzed the influence of WTPS (from 5 to 40 wt. %) on the physical and mechanical properties, structural parameters as well as mineralogical composition of the ceramics sintered at 1000 °C and 1050 °C. Anyakora (2013) used WTPS by adding 90% of natural clay to produce the brick. Alqam et al. (2011) investigated the use of WTPS (10–50 wt. %) used cement in the production of paving tiles.

The researchers of Federal Technological University (UTFPR), Brazil, in the area of civil engineering have fairly extensive experience in developing of new construction materials with extensive use of more than 80 types (Mymrin, 2012) of industrial and municipal wastes as valuable components, which are significantly improving mechanical and chemical properties of these materials. A significant fraction of these wastes are sludge, including the particularly dangerous waste of galvanic sludge.

The objectives of this study were as follows: to investigate experimentally the efficiency of using LS from extremely polluted industrial uniforms and possessing a high content of multiple heavy metals, oily wastes and other organic substances; to study the physicochemical process of forming red ceramic structures after composite sintering; and to develop new and environmentally friendly composites for ceramics production, with mechanical properties meeting or exceeding the criteria established by Brazilian technical standards, by using the wastewater sewage sludge from an industrial laundry.

As one of the green chemistry principles expresses, wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment (Anastas and Green, 1998). In this study, the aim was to include a toxic laundry waste in ceramics production, converting it in a useful material that in this new form does not pose any significant toxicity.

2. Research methods

2.1. Methods

The raw materials and ceramics were characterized using various methods. To determine the chemical composition, a Philips/Panalytical X-Ray Fluorescence Spectrometer model PW2400 was used. Studies of mineralogical composition using the powder method were performed with a Philips X-Ray Diffractometer, model PW1830, with a monochromatic wavelength λCu-Kα, at 2θ° range of 2–70°. Morphological structures were determined by scanning electron microscopy (SEM) using an FEI Quanta 200 LV. Chemical microanalyses were determined using energy dispersive spectroscopy (EDS) with an Oxford (Penta FET-125 Precision) X-ACT and by micro-mass analyses using a laser micro-mass analyzer (LAMMA-1000, model X-ACT). The samples of the ceramics with particles diameter <9 mm were washed in deionized water, agitated in solution with pH = 4.8 at 25 °C during 18 h and leached extract was separated on a glass fiber filter with a porosity of 0.6–0.8 μm. Leached metals were analyzed using atomic absorption spectrometry method with a Perkin Elmer 4100 spectrometer. Granulometric composition was determined using laser diffraction particle size distribution analysis with a Granulometer CILAS 1064 (Brazil). Mechanical resistance was tested using the three-point flexural resistance strength method on an EMIC universal testing machine. The water absorption coefficient by immersion was determined with an Instrutherm BD 200 under the Brazilian NBR 13818/1997 standard. Linear shrinkage of the TS was determined using a digital caliper (DIGIMESS).

2.2. Calculations

The flexural rupture strength of the tested specimens (TSs) was measured following standard NBR 15270-3/05 (2005) and using the following equation:

$$R_F = (3PL)/\left(bh^2\right) \quad (1)$$

where R_F is the flexural rupture strength (MPa), P is the maximum load supported by the specimen (kgf), L is the distance between the supports (mm), b is the width of the TS (mm), and h is the height of the TS (mm).

Water absorption (W_A) was measured according to the Brazilian standard NBR 15270-3/05, (2005), which uses the following equation:

$$W_A = [(M_{SAT} - M_D)/M_D] \times 100 \quad (2)$$

where M_{SAT} is the mass of the water-saturated specimen after 24 h of water immersion, and M_D is the mass of the dry specimen after sintering.

Apparent specific density D_A was calculated using the equation

$$D_A = Md/(Md - Mw) \quad (3)$$

where D_A – apparent specific density (g/cm^3); Md – the weight of the ceramics body in air (g); Mw – mass of the ceramics body immersed in water (g) equal to the volume of immersed specimen (cm^3). In accordance with Archimedes' law the weight of a body immersed in the liquid is reduced by the buoyant force acting on the body fluid side; it is equal to the weight of the displaced volume (cm^3) of body fluid.

3. Results and discussion

3.1. Raw materials under study

A sample of LS was obtained from the filters of washing machines of the industrial laundry in Curitiba, Brazil, that specializes in cleaning extremely polluted industrial uniforms. Its high calorific value (almost 5300 kcal/kg), density and black color similar to bitumen indicated that these clothes were worn by workers engaged in petroleum extraction and refining. The LS ash content was 28.2%, and the extracted ash mainly consisted (Table 1) of SiO_2 (71.5%), Al_2O_3 (12.74%) and Fe_2O_3 (8.34%). A very high C.L. (71.8%) was most likely caused by grease, oil and general emulsified oily components, resin, tar, paints, organic volatile compounds, carbonates, and water. A very high content of oily materials precluded

Table 1
Chemical composition of the raw materials characterized by XRF method.

Raw material	Concentration, wt.%							
	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	SO_3	MgO	C.L.
LS	71.57	12.74	8.34	1.47	1.23	0.87	1.41	71.83
TM	57.50	19.70	8.70	0.10	0.00	0.00	1.40	7.58

Note: C.L. – calcinations loss.