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Research paper

Microstructure and mechanical properties of cementless construction materials from thermal engineering wastes

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HIGHLIGHTS

- New construction material from three types of Porcelain industry wastes.
- Lime production waste was used as binder material.
- Uniaxial resistance strength at the age of one year reached 14 MPa.
- Structure formation processes were determined by XRD, SEM and EDS methods.
- Utilization of industrial wastes has high economical and environment efficiency.

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ABSTRACT

In order to solve environment problems of ceramics industry new compositions of materials were developed from three types of porcelain production tails – fired wastes (FW), unfired wastes (UW) and wastewater treatment plant sludge (WTPS) – as the main raw materials of new compositions of cementless building materials. The binder material used here was lime production waste (LPW), i.e., incompletely burned lime. The uniaxial compressive strength of the new materials containing 15 wt% of LPW at one year of age increased up to 14.2 MPa and the materials with 5% LPW content increased up to 8.6 MPa, exceeding the specifications of Brazilian standards for hollow concrete blocks. The water absorption (W_A) coefficient of different compositions at the age of 28 days ranged from 17.9 to 24.6%, but this does not affect the values of the water resistance coefficient (0.71–0.85). X-ray diffraction and scanning electron microscopy analyses indicated that the strength of the new materials increases due to the synthesis of amorphous and crystalline compounds. The feasibility of the new materials based on the use of four types of industrial wastes for the production of new building materials with high mechanical properties, which meet the requirements of national standards.

1. Introduction

The strategy of companies to improve their environmental performance is an essential part of their social function, since it not only satisfies their clients' wishes but also improves their relationships with environmental control agencies and with society in general. Mere compliance with the minimum standards established by environmental laws is not considered sufficient to maintain a competitive advantage, above all in export markets [1]. The need to recycle industrial wastes is increasing apace due to the rising cost of natural raw materials and effluent disposal, and the need for compliance with environmental legislation. It is estimated that 175 million tons of quarrying waste are produced each year [2]. The consumption of only natural decorative stone materials worldwide is growing annually by 7–9% and now stands at about 700 million m^2 [3]. ANEFA – National Association of Spanish Manufacturers Association of Aggregates–Aggregates Producers – informed [4] that the consumption of natural aggregates in Spain in 2007 reached the 479 million tons in the construction sector and 72

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million tons in industrial applications, such as cement, glass and ceramics production [4].

The world's scientific and technical literature contains a large number of experimental studies on the use of some industrial wastes, particularly ceramics wastes, as substitutes for these natural stone raw materials. John [20] described the panorama of industrial wastes utilization in the civil engineering and their influence on the quality of construction.

The solid wastes from the manufacture of ceramic materials are produced during the pressing and milling steps, the so-called "Unfired Wastes," and after the firing step, called "Fired Wastes", that present disqualifying faults. This material is very hard, which makes it difficult to introduce them directly into the process since doing so would significantly increase the costs of processing the material [5,6].

Especially numerous works were devoted to the problem of recycling of ceramics aggregates for concrete production [6–8]. Correia et al. [9] and Gomes and de Brito [10] studied the durability of structural concrete with incorporation of coarse recycled ceramic aggregates. Brito et al. [11] investigated mechanical behavior of non-structural concrete made with recycled ceramic aggregates. Rolón et al. [7] established a 6% reduction in strength of concrete after 28 days with 20% incorporation of porcelain aggregates. The contrary [12], did not observe any reduction of concrete strength even with a 30% content of ceramics. González and Martínez [13] established maximum contain of ceramics at 50% with increasing of water absorption coefficient and therefore the necessity to increase the water/cement ratio by approximately 6%.

Calcined clay waste was used [14] for development of blended cement. Binici [15] studied the influence of crushed ceramic in composites with basaltic pumice as fine aggregates on concrete mortars properties. Utilization of dust aggregates has been the focus of [16] studies. Obtaining of high eco-efficient concretes using recycled ceramic material from sanitary installations was studied by Refs. [17–20]. It was determined [21] the acceleration of concrete aging by incorporation of recycled electrical insulator porcelain in concrete structures. Ceramic wastes were used [22] as raw materials in Portland cement clinker fabrication and as a principal component of polishing [23] and buffing of metal art objects and artifacts.

Lime production wastes (LPW), used in this research as binder material, is poorly calcined limestone and therefore noncompliant with the specifications of Brazilian standards [24], characterizing it as being of low reactivity. With the exception of large companies that use modern techniques, most construction quicklime is produced in a highly impactful way that involves digging large pits and generating emissions of gases and particulate pollutants during the fabrication of these derivatives. The most important aspect in utilization of LPW may be the environmental aspect, in view of the real possibility of significantly reducing currently existing deposits of lime wastes, whose pH levels are extremely high [24,25].

Even such a brief review of the technical literature shows the interest of researchers to develop methods for ceramics waste utilization primarily as a raw material for the fabrication of building materials. Nevertheless, the amount of this type of waste is increasing and it makes a search for other more attractive methods for their disposal.

The objectives of this work were to study the use of three types of porcelain production – "Unfired and Fired Wastes" and wastewater treatment plant sludge (WTPS) – as principal raw materials in composites with LPW for the manufacture of environment efficient materials with improved characteristics for use in civil construction.

2. Experimental

Test samples (TSs) of developed materials were prepared from the wastes under study by mixing the initial components in different compositions (Table 1). FW is produced in the largest quantities; it has the highest hardness and therefore creates the most problems for the plant. Therefore, compositions A, B and C were tested to determine the possibilities of its priority utilization, till 95 wt%. The composition D, E and F were aimed at the complete utilization of all three industrial wastes of porcelain production plant.

3. Calculations

The coefficient of water resistance (C_{WR}) was determined based on the ratio [28]:

$$C_{WR} = R_{SAT}/R_D \tag{1}$$

where R_{SAT} – the uniaxial compressive strength of test specimens saturated after total immersion in water for 24 h, and R_D – the uniaxial compressive strength of the specimens oven-dried at 100 °C for 24 h.

The values of water absorption coefficient (C_{WA}) tests were carried out also on the 28th and 90th days of curing of the TSs, following the ASTM [29], which uses the following equation:

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

where M_{SAT} is the mass of the saturated specimen after 24 h of immersion in water and MD is the mass of the TSs oven-dried at 100 °C for 24 h.

4. Materials and methods

A ceramic tile manufacturer located in the region of Campo Largo, state of Paraná, Brazil, supplied three types of wastes: fired wastes (FW), unfired wastes (UW) and wastewater treatment plant sludge (WTPS). A quicklime plant located in the region of Colombo, state of Paraná, Brazil, supplied LPW – the incompletely burned lime, which was used in these experiments as binder in the mixtures.

The raw materials and final test specimens (TSs) were characterized by various complimentary methods. Chemical composition was studied by the X-ray fluorescence (XRF) method, using Philips/Panalytical, model PW 2400; mineral composition – by X-ray diffraction (XRD) Philips, model PW 1830; morphological structure – by scanning electron microscopy (SEM) FEI, model Quanta 200 LV; chemical micro analyses – by method of energy dispersive spectroscopy (EDS) of Oxford (Penta FET-Precision) and by micro-mass analyses through laser micro-mass analyzer LAMMA-1000, model X-ACT; solubility and lixiviation of metals from liquid extracts – by the method of analyses of atomic absorption (AAA) on

Table 1
Composition of TSs studied.

Compositions	Components, wt.%			
	FW	UW	WTPC	LPW
A	85	–	–	15
B	90	–	–	10
C	95	–	–	5
D	25	30	30	15
E	30	30	30	10
F	35	30	30	5