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Portland cement systems with addition of sewage sludge ash. Application in concretes for the manufacture of blocks

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ABSTRACT

This study analyzes the viability of using sewage sludge ash (SSA) as a raw material in the composition of concrete, with a similar dosage to when it is used to manufacture blocks, therefore, with dry consistency given the type of the industrial process of these precast. These ashes are a serious problem, so their valorization in a sector like construction, with a high demand of resources, would be a great advantage from an economic and environmental perspective. A scale with the percentages of addition of ash in relation to cement (5, 10, 15 and 20%) was designed and the replacement of sand by this material, as well as the addition of an inert material such as marble dust. For a better understanding about how these mixtures behave in other cementitious systems, thermogravimetric analysis were performed on pastes with curing ages of 7, 28 and 90 d, and physical and mechanical tests on mortars cured for 28 and 90 d. It was proved that the addition of *SSA* in concrete used for manufacturing blocks cured for 28 d provided densities and resistances similar to the control sample (without SSA) and significantly reduces the water absorption. The replacement of sand by the mineral addition significantly improves the parameters mentioned above.

1. Introduction

The construction industry is a great consumer of resources and materials, which makes it a sector with an enormous potential for the use of waste materials generated by its own activities and those from other sectors. The use of such waste materials allows decrease the energy consumption, to preserve non-renewable natural resources, and to reduce the high amount of material that goes to landfills (CEDEX, 2014). However, in the cement industry, which has always been among the largest CO2 emission sources, technical, economic and legal challenges still play as remarkable obstacles against the widespread implementation of procedures to help mitigate this situation (Benhelal et al., 2013).

Although industrial wastes can be incorporated in cementitious materials by various traditional methods, the substitution ratio of industrial wastes in cementitious materials is relatively low to avoid unacceptable performance loss. Novel methods, such as improving hydraulic activities of metallurgical slags by adding composition adjusting material at high temperature, improving surface cementitious properties of fly ashes by dehydration and rehydration treatment, and arranging cement clinker and industrial wastes in the particle size and distribution of blended cements according to their hydraulic activities, are reviewed. These methods provide more effective approach to prepare high performance blended cements with larger amount of industrial wastes, leading to a very significant role in CO_2 emissions reducing, resources and energy conservation of the cement industry (Tidåker et al., 2006).

Mineral additions are defined as inorganic materials, pozzolanic materials or latent hydraulic materials that finely divided can be added to concrete and/or to Portland cement based mortars, in order to improve some of their properties or confer special characteristics (Hewlett, 1998). This paper focuses on the study of the viability of using sewage sludge ash (*SSA*), a mineral addition, as an additive to Portland cement in the dosage of concretes for the manufacture of concrete blocks. It was also used to lesser extent another mineral addition such as marble dust (*MD*), generated from the cut of large pieces of marble rocks by numerous companies within the province of Alicante, Spain.

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The amount of sewage sludge produced in Spain was approximately 1.06 Mt of dry material (European Commission, 2010). According to the source consulted, there is wide variation in the destination of the percentage distribution of this residue, but the figures allow an approach to the current situation: 65% as fertilizer, 20% in controlled landfill and 10% is incinerated to reduce its volume, but the trend is to increase this amount to 20–25%, which is the average percentage of sewage sludge incinerated in Europe (European Commission, 2010); or 80% as fertilizer, 8% in controlled landfill and 4% is incinerated (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2014). Approximately, 1.7 Mt of such incinerated waste are being produced worldwide (Donatello and Cheeseman, 2013). The problem with these residues after incineration, which justifies an intensive search for alternatives to its landfill, is the presence of heavy metals in its composition, which turns it into a potential pollutant. In the last two decades, different recycling and recovery options have been developed (Donatello and Cheeseman, 2013): manufacturing of ceramic tiles and bricks, synthesis of lightweight materials, production cementitious inorganic binders and phosphate recovery. Also, the use of sewage sludge as an alternative fuel was proposed in the clinkerization process in Portland cement industry (Husillos-Rodriguez et al., 2013).

The leaching behavior of systems containing SSA is also an important topic and has been analyzed by several authors: It was shown that the leaching behavior of mortars containing SSA was of the same order of magnitude as the reference mortar without residue (Cyr et al., 2007). Results obtained from the leaching of ashes in their powdery form revealed that among the potential contaminants followed, only Mo and Se were leached at concentrations above the threshold limits considered. The leaching tests conducted on concrete monoliths showed, however, that none of the contaminants monitored, including Mo and Se, were leached above the threshold limits, according to the Building Materials Decree of Netherlands (Maozhe et al., 2013). Another study evaluated alternatives to render inert waste in cement-based materials by combining the reduction of waste content with the immobilization properties of metakaolin. In particular, the use of metakaolin led to a significant decrease of soluble fractions and heavy metals released from the binder matrix, especially in the case of crushed mortars (Cyr et al., 2012). Also, ash from incineration of sewage sludge has been compacted and fired at different temperatures to produce a range of sintered ceramics, reducing the leaching of metals for all metals analyzed (Cheeseman et al., 2003).

Although *MD* is not a contaminant residue (98% calcium carbonate), its uncontrolled dumping represents a problem in local scale, as it can cause environmental damages, primarily for visual impact and water pollution. Currently, the province of Alicante produces and exports 70% of domestic marble, being Spain the 2nd European producer and the 7th worldwide, which generates near 500,000 t of sludge in the region where the industry is concentrated, as a result of the cutting and polishing of natural stones (Marble Association of Alicante, 2014).

It is known the effect of these wastes as cement substitutes in matrices with conventional binders. For example, previous work has shown that mortars fabricated with 10% of replacement by SSA meet the mechanical requirements of the European standard in terms of early age compressive strength and nominal compressive strength (Garcés et al., 2008), and mixtures containing 30% of SSA as cement replacement showed a higher compressive strength at the age of 7d compared to the reference mixture, and a similar strength at 28d (Fontes et al., 2004). On the other hand, the compressive strength of SSA mortar increased with the increase of SSA fineness: 15% replacement of portland cement by SSA with particle sizes of 80, 40 and 20 μm (Monzó et al., 1996), or 20% replacement with Blaine fineness of 500–1000 m^2/kg (Pan et al., 2003). The improvement is due to the pozzolanic activity of the SSA (Donatello et al., 2010), although SSA presented a limited content of SiO2 and Al2O3, which are the two oxides responsible for the pozzolanic activity in cement-based materials. Moreover, a fraction of these oxides were in a crystallized form, thus limiting the pozzolanic activity of SSA compared to other classical mineral admixtures (Cyr et al., 2007). Furthermore, it must be noted also a reduction in workability due to the irregular shape of the particles, which prevents its behavior as a solid lubricant, and the water absorption on the surface of the ash particles (Monzó et al., 2003), however, the use of FA as a second replacement material in mortars containing water demanding pozzolans is an appropriate procedure for enhancing the workability of the mixtures. The contribution to strength development due to the presence of FA in association with other pozzolanic such as SSA becomes important, especially for long curing times (28–90 d) (Payá et al., 2002).

Several researches show that the addition of *MD* in cementitious composites is effective to improve the cohesion of mixtures. It can replace up to 10% of sand without affecting the compressive strength, with a better mechanical performance compared to the same limestone filler content (Corinaldesi et al., 2010). In concrete with a 15% replacement of sand, a good workability is obtained; the abrasion resistance is comparable to that of conventional concrete; and provides a lower water permeability (Binici et al., 2007). In self-compacting concrete, where although the plastic viscosity of the concrete increased with the addition of sludge, and was corrected by adding specific superplasticizers, the concretes obtained are consistent with the stated requirements and their mechanical properties have improved, as a consequence of the increase of packaging, due to the incorporation of fine particles (Valdez et al., 2010). Additionally, waste marble dust was used for preparing Portland cement by intergrinding of Portland cement clinker and 10% of waste (Aruntaş et al., 2010).

No research was found about the application of the wastes proposed as concrete components for the manufacture of concrete blocks, however, previous studies have proposed to use construction and demolition waste in the manufacture of blocks (Sabai et al., 2013), and the results showed that the blocks produced with 100% of recycled aggregates were weaker than those made with natural aggregates. Nevertheless, the results also showed that there is a possibility for recycling these wastes because the 85% of the samples tested achieved compression strengths equals to or greater than the minimums required by the standards.

This study aims to determine the effect of the addition of *SSA* to Portland cement regarding the properties of concretes for the manufacture of precast blocks, therefore with particular characteristics due to the manufacturing process. To a lesser extent, it will also be considered the addition of an inert residue, as it is the *MD*. Previously, and in a complementary manner, the behavior of these additions on two completely different cementitious matrices, such as pastes and standardized mortars, will be studied to expand the knowledge about the use of these mineral wastes.

Although the results obtained in this study with cubic concrete specimens would not be directly comparable to the results obtained with precast concrete blocks, as they differ in size, configuration, and in the manufacturing process, as it will be seen in the experimental procedure. However, since the same dosage was used, this work could be a previous step to the pilot manufacturing of precast blocks with those additions, showing a better technical answer in the laboratory. It is known that the European Conformity mark on building materials is an essential requirement to commercialize a product, and does not imply the compliance of some specific and minimal requirements, but the manufacturers must establish and guarantee the features of their products. This means that although some of the additions studied provide