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Blending of industrial waste from different sources as partial substitution of Portland cement in pastes and mortars

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HIGHLIGHTS

- Portland cement has been replaced different waste materials.
- Individual, binary and ternary combinations have been tested.
- The best mechanical results were provided by rice husk ash with sewage sludge ash.
- A reduction up to 50% of remaining alkaline reserve has been observed.

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ABSTRACT

Binary and ternary combinations of sewage sludge ash (SSA) with marble dust (MD), fly ash (FA) and rice husk ash (RHA) as replacement in Portland cement pastes, were assessed. Several tests were carried out at different curing ages: thermogravimetry, density, water absorption, ultrasonic pulse velocity and mechanical strengths. Pozzolanic effects of the mineral admixtures, densities similar to control sample and improved absorptions when combining waste materials were identified. In general, the compressive strength reaches or exceeds the cement strength class, and blending SSA, FA and RHA (30% cement replacement) increase of strength by 9%, compared to the control sample, was achieved.

1. Introduction

The construction industry is a great consumer of resources and materials, which makes it a sector with enormous potential for the use of waste materials generated by its own activities and those from other sectors. The reuse of such materials in cement based materials not only reduces pressure on landfill capacities but also reduces the need for raw material extraction [1].

Mineral admixtures, also known as supplementary cementitious materials, that can be added in blended Portland cements include limestone and certain pozzolanic materials such as coal fly ash and blast furnace slag [2]. This paper focuses on the study of the viability of using four different mineral additions generated in diverse industrial processes as cement substitutes in the dosage of cement pastes and mortars: (a) ash from wastewater sewage treatment (SSA); (b) fly ash from coal power plant (FA); (c) marble dust (MD) generated from the cutting of large pieces of marble rocks; (d) rice husk ash (RHA) from burning rice husk in a cogeneration power plant.

The use of mineral admixtures restarted in the 1950s, at that time focusing on their use in the manufacture of Portland cement or in the production of mortars and concrete. Since then, there has been an exponential increase in the use of mineral admixtures. Its real global production is difficult to find out. With FA, it has been reported that around 200 million tonnes are produced annually in India alone [3]. In the US and EU-15, the power plants that belong to the ACAA and ECOBA associations produce a total of at least 85 million tonnes. Another 35 million tonnes are supposed to be produced from the additional EU-12 countries. This is already a total of 320 million tonnes and that figure does not account for the by far world's largest coal burning country, China. An estimate for global annual FA production could be closer to 800 million tonnes. Global blast furnace slag production was estimated in 2002 to be around 150–180 million tonnes [4], and so it is likely to be

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significantly higher today. No reliable data for RHA and SF has been found.

According to a specific study from the European Commission in 2010, the amount of sewage sludge from wastewater treatments produced in Spain was approximately 1.06 million tons of dry material [5]. The destination of this waste is: use as fertilizer (65–80%), controlled landfill (8–20%) or incineration to reduce its volume (generating sewage sludge ash, SSA). About 4–10% of the total amount of sludge is incinerated, but the trend is to increase this amount to 20–25%, which is the average percentage of sewage sludge incinerated in Europe [5–7]. The problem with these residues after incineration, which justifies an intensive searching for alternatives to the landfill, is the presence of heavy metals in their composition, which turns it into a potential pollutant [8,9].

Although marble dust (MD) is not a contaminant residue (98% calcium carbonate), the 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 (Spain) produces and exports 70% of domestic marble, being Spain the 2nd European producer and the 7th worldwide, generating near 500,000 tons of sludge (suspension of marble dust in water) in the region where the industry is concentrated, as a result of the cutting and polishing of natural stones [10].

Nowadays it is well known the effect of these residues individually, or combined in some cases, as substitutes for conventional binder composites:

- Previous work has shown that mortars containing SSA have good mechanical properties, and mortars with 10% cement substitution show insignificant differences in terms of steel reinforcement corrosion as compared to the control mortars [11,12]. This can be attributed to the pozzolanic activity of the SSA [7,13], although recent research in reused materials has revealed that, compared with well-known pozzolanic materials, the pozzolanic activity of SSA is, at least, weak [14]. Furthermore, it must be noted a reduction in workability due to the irregular shape and roughness of the particles, which prevents its behavior as a solid lubricant, and the water absorption on the surface of the ash particles [15,16].
- FA has been used for several decades as mineral addition, and its most notable features are: presence of cenospheres of particles, high content of vitreous silica (SiO_2) and alumina (Al_2O_3) and pozzolanic activity at medium and long terms [17]. The incorporation of FA in Portland cement composites increases the workability and consistency of mortars and concrete [18].
- In cement/SSA/FA ternary systems for binder's manufacturing, the SSA provides an important pozzolanic activity, increasing the mechanical strength of mortars between 7 and 28 days. Likewise, SSA reduces the fluidity of mortars while the FA improves it [19,20].
- Several publications show that the addition of MD in cementitious composites is effective in improving the cohesion of mixtures. It can replace up to 10% of sand without affecting the compressive strength, with a better mechanical performance as compared to the same limestone filler content, and providing lower water permeability [21,22]. In self-compacting concrete, where the plastic viscosity of the concrete increase with the addition of MD sludge, and is corrected by adding specific superplasticizers, the concretes obtained are consistent with the standard requirements and their mechanical properties have improved, as a consequence of the increase of packaging, due to the incorporation of fine particles [23].
- In studies where RHA was used as a partial replacement of cement in mortar and concrete, the results for substitutions of 25% showed the same or better results as compared to conventional concrete [24]. Even with substitutions up to 30%, improvements occurred in durability and consistency, not increasing the compressive strength at early ages, but improving it at older ages [25].

This paper gathers the effect on properties of standard pastes and mortars, replacing Portland cement by the mentioned waste materials, either individually, binary or ternary combinations, with special attention to SSA, expanding the knowledge about the exploitation of synergies generated in fresh and hardened mixtures.

2. Experimental

2.1. Materials

Mineral admixtures used in this work have the following origins: (a) SSA has been supplied in bulk by the incinerator of the wastewater treatment plant of Pinedo in Valencia (Spain), where it was obtained from the discharge electrostatic precipitator of a fluidized bed incinerator working with a maximum temperature applied of 800 °C, (b) FA (class F) comes from the coal power plant of Andorra-Teruel (Spain) and it has been provided also in bulk; (c) MD was obtained from a landfill located in the town of Novelda in the province of Alicante-Spain that collects the waste produced by numerous companies; (d) RHA was collected in DACSA (Valencia, Spain) from an energy recovery plant which uses rice husks as fuel.

The Portland cement used was CEM II/B-L-32.5R type according to EN 197-1 [2] supplied by Cementval in bags of 25 kg. The aggregate of mortar is CEN EN 196-1 (Normensand GMBH Beckum/Germany), supplied in bags with the required quantity (1350 g).

2.2. Dosage

Table 1 shows the dosage used in the different mixes. It can be seen that the mortar used as control is the one indicated in the Spanish Standard UNE-EN 196-1 [26]: mortars consisted of 3 parts sand, 1 part cement and 0.5 parts water. The water/binder ratio was kept constant for pastes and mortars. This means a water/(cement + addition) ratio of 0.5. Three series of each mixture were prepared: (a) series S1, with a substitution of 10% of Portland cement by each of the mineral residues used in this research. That is, in 1-S10 a 10% of cement has been replaced by SSA, in 1-R10 by RHA, in 1-M10 by MD, and in 1-F10 by FA; (b) series S2, with a substitution of 20% of cement by binary combination of the previous mineral additions. That is, in 2-S20 a 20% of cement has been replaced by SSA, in 2-S10F10 with 10% SSA and 10% FA, etc.; (c) series S3, with a substitution of 30% of cement by ternary combination.

This work intends to extend the possibilities for apprising a number of industrial wastes, paying greater attention to the SSA, so this residue appears as a component in all mixtures of series S2 and S3, except for the one identified as "2-M10F10". On the other hand, besides realizing comparisons with the control samples "C" (no additions), the series composed by the mixtures identified as "1-S10", "2-S20" and "3-S30", whose only addition is SSA, will be used also as references for comparisons.

2.3. Procedure on mineral additions: X-ray fluorescence analysis

In order to provide information about the chemical composition of the four residues used in this work as mineral additions, the X-ray fluorescence technique (XRF) was applied. The equipment used to carry out the technique was a sequential X-ray spectrometer (Philips Magix Pro) equipped with rhodium tube and beryllium window.

2.4. Procedure on pastes – thermogravimetry

Thermogravimetry (TG) tests were carried out in order to study the hydration of pastes. For this purpose, 3 paste samples of each mixture were made, one for each curing age (7, 28 and 90 days). PVC moulds with circular section, diameter of 3 cm and thickness of 1 cm were used. The components were dry mixed as a previous step to manual mixing. Each set of samples was held in the mould over a porcelain surface, covered with plastic wrap to prevent carbonation (which could invalidate future measurements of CH by TGA since $CH + CO_2 \rightarrow CC$), and stored in a humidity chamber (20 °C and 90% RH) until the TG tests were carried out.

After reaching the curing age required for each case, half of the sample was separated and conditioned following the next procedure: (1) grinding in agate mortar, (2) acetone washing with suction by a vacuum pump to remove all liquids, (3) sieving in a normalized 100 μm mesh, (4) drying in oven at 50 °C for 20 min. To carry out the TG test, a Netzsch-TG-209F3 thermobalance with an open ceramic (alumina) crucible of 85 μL was used. The test was conducted in a dry nitrogen atmosphere at 75 mL/min gas flow, with a heating rate of 10 K/min in the temperature range between 35 and 600 °C.