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Durability of new recycled granite quarry dust-bearing cements

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HIGHLIGHTS

- The granite sludge has been used as SCM in the design of the new blended cements.
- Granite quarry dust exhibits no alkali-silica reactivity.
- Binder bearing 20% granite quarry dust are low heat cements.
- The new cements are apt for aesthetically sensitive applications.
- The new blended cements have good durable behaviour.

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ABSTRACT

Cements prepared to new designs in which different types of waste are used as additions must be tested for mechanical strength and durability to ensure their performance will be satisfactory throughout their service life. This study explored the effect of adding 10% or 20% granite quarry dust to cement on properties such as transport (total and capillary water absorption and electrical resistivity), dimensional stability (drying shrinkage and expansion), the alkali-silica reaction, heat of hydration and colour. No alkali-silica reaction was observed in the new materials and expansion and contraction were less intense than in conventional cement. The water absorption and capillary absorption coefficients rose less in the additioned cements than the replacement ratio, whilst their higher resistivity values afforded greater corrosion protection than found in the reference. The inclusion of this waste also prompted a rise in lightness and a decline in peak heat of hydration. The multivariate analysis of variance (MANOVA) conducted showed that the factors time and replacement ratio affected the properties significantly, whereas the combined effect of the two was statistically significant or otherwise depending on the property analysed. The findings showed that the partial replacement of cement with quarry dust is not detrimental to product durability and the recycled material qualifies as a strength class 42.5, type II/A binder. The materials bearing 20% granite quarry dust, in turn, were found to meet the requirements to qualify as low heat cements (CEM II/A LH).

1. Introduction

World-wide cement output in 2016 came to 4.6 billion tonnes, 5.3% and 57.3% of which was produced in Europe and China and India, respectively. Nearly half (47%) of that amount was used in residential construction, while 32% went to commercial construction and 21% to civil works [1]. That scenario is indicative of the vast amounts of natural resources consumed by the industry and of its enormous potential to reduce that consumption by reusing waste, either generated in construction per se or in other industries.

In recent years the cement industry has made a huge effort to develop alternative inputs, known as supplementary cementitious materials (SCMs), in the design of new cements. Their use would lower energy consumption and the GHG emissions intrinsic to cement manufacture. Much research has been conducted the world over to analyse the viability of valorising waste, primarily from the fired clay, agroforestry, steelmaking and ornamental stone industries.

Granite quarrying is estimated to account for over 30% of the total volume of ornamental stone waste. The vast amounts

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(125 Mt in 2012) [2] involved are presently deposited in land fills, with the concomitant damage to the environment and risk to human health, both causes for concern in modern societies.

With a view to solving these problems, in recent years researchers have tested the viability of valorising (coarse, fine and dust) quarry waste as a raw material in new eco-efficient materials. The literature identifies three major applications for valorising industrial waste: i) fine or coarse aggregates for sustainable concretes [2–5] or mortars [6]; ii) partial cement replacements in the design of new concretes (up to 30%) [7,8] or cements (up to 10%) [9]; and iii) other uses, such as geopolymers [10] or roof tiles [11]. Much of the scant research conducted worldwide to date on the valorisation of such waste in cement has focused primarily on mechanical strength or chloride penetration-related durability.

That has left a large scientific-technical gap in the understanding of other properties associated with the durability of granite quarry dust-based SCMs. The issues requiring further research include: i) indirect indicators of transport intensity (water absorption, capillarity and electrical resistivity); ii) volume change resulting from drying shrinkage or early-age swelling that may induce micro- or macrocracking, compromising service life; iii) the alkali-silica reaction due to the simultaneous presence of moisture, reactive silica and cement-borne alkalis, forming silica gel and subsequently map-like cracking; and iv) the heat released during hydration, possibly generating steep thermal gradients that may prompt cracking, a major concern in structures requiring large volumes of concrete such as dams.

This study consequently sought to further knowledge of the effect of partially (10% or 20%) replacing cement with granite quarry dust on the physical and mechanical characteristics, durability and colour of type II/A cements. The variables studied included 28 days mortar mechanical performance and pore size distribution, along with transport (water absorption, capillarity and resistivity), drying shrinkage and swelling, the alkali-silica reactivity of the new pozzolan and the calorimetric properties and colour of these new binary cements. A multivariate analysis of variance (MANOVA) was conducted to determine the effect of age and replacement ratio on mortar performance and bivariate correlations between the variables studied were established.

2. Materials and experimental

2.1. Materials

The granite quarry dust (AF) analysed was furnished by an ornamental stone quarry at Quintana de la Serena in the Spanish province of Badajoz (region of Extremadura). The waste generated by the quarry is presently carried directly to uncontrolled spoil banks, a practice with obvious environmental implications illustrated in Fig. 1. The granite quarry dust visible in the photograph, generated by ornamental granite mining, has an obvious and adverse impact on the landscape. Representative samples collected by random selection from three heights on the on-site stockpile were subsequently homogenised in the laboratory. After selection, the waste was dried and characterised chemically, physically and mineralogically as described in an earlier paper [12].

The X-ray fluorescence analysis of this dust performed in an earlier study [12] showed that it was acidic ($SiO_2 + Al_2O_3 + Fe_2O_3$ > 85.0 wt%) with 1.5 wt% to 4.0 wt% of Na_2O and K_2O, as well as other minority oxides such as: CaO (2.36 wt%), MgO (1.60 wt%), TiO_2 (0.51 wt%) and P_2O_5 (0.17 wt%). Tectosilicates, phyllosilicates and hematites prevailed in Its mineralogical composition (see Fig. 2) [12]. Its BET specific surface was 1.35 m^2/g [12] and its Blaine fineness 0.23 m^2/g, whilst the fineness value for the cement was 0.34 m^2/g.

Fig. 1. Stockpiled granite quarry dust.

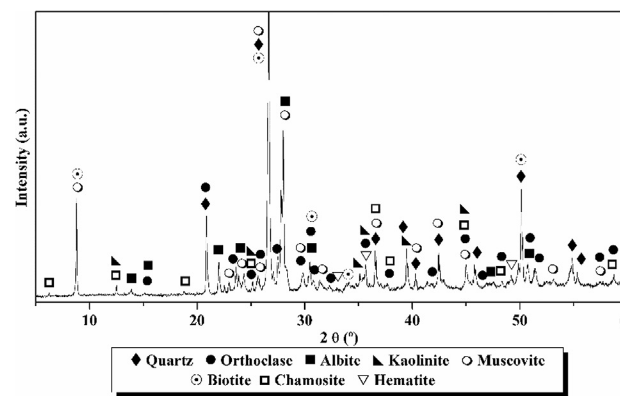

Fig. 2. X-ray diffractogram for granite industry waste [16] (courtesy of Elsevier).

CEN-standardised, European standard EN 196-1 [13]-compliant sand with a particle size ranging from 2.0 mm to 0.078 mm was used.

A non-reactive limestone (≈97% $CaCO_3$) sand with a particle size of 4.0 mm to 0.063 mm was used to analyse the alkali-silica reactivity of the granite quarry dust included as a pozzolan in the design of type II/A cements.

The EN 197-1 [14]-compliant CEM I 42.5 R ordinary Portland cement (OPC) used was furnished by Lafarge, a Spanish cement manufacturer sited in the province of Toledo.

2.2. Blends

The blended cements were prepared in a high-speed powder mixer to ensure homogeneity of the mix before preparing the mortars. Blend proportions were computed by weight, with OPC/AF ratios of 100/0 (OPC), 90/10 (OPC + 10%AF) and 80/20 (OPC + 20% AF). These replacement ratios were adopted on the grounds of the percentages allowed for type II/A (6%–20%) cements in European standard EN 197-1 [14].

The pore size distribution of the cements shown in Fig. 3 was obtained by measuring N_2 absorption isotherms on a Micrometrics ASAP 2000 analyser. All the cements were observed to have pore diameters ranging from 0.7 nm to 190 nm. The OPC had a small shoulder at 2.0 nm and cements OPC + 10%AF and OPC + 20%AF had two each, at 1.6 nm and 2.0 nm. The new shoulder at 1.6 nm would be attributed to the addition, as observed by Medina et al. [15].