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Clay-based construction and demolition waste as a pozzolanic addition in blended cements. Effect on sulfate resistance

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HIGHLIGHTS

- The influence of sulfates in blended cements based on construction and demolition waste as pozzolanic addition.
- The influence of sulfate concentration in durability of cementitious matrices.
- Changes in microstructure and morphology of cementitious matrices due to the incorporation of C&DW as pozzolanic material.
- The influence that C&DW as pozzolanic addition has in corrosion indices.
- Changes in porous network and its influence on behavior in the face of sulfate solution.

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ABSTRACT

The significant structural implications of cement durability have given rise to substantial research on the subject. This study explores the performance of new blended cements bearing pozzolanic construction and demolition waste (C&DW) as an addition when exposed to sulfate attack. Durability is studied in cement pastes with and without C&DW, addressing the formation of new compounds, mechanical strength, outward appearance and porosity after soaking in two concentrations of sodium sulfate solution for exposure times ranging from 14 to 56 days. The findings confirm that the inclusion of clay-based C&DW improves blended cement durability.

1. Introduction

Governments worldwide are becoming increasingly sensitised to environmental issues and drafting policies accordingly.

One of the measures adopted is to encourage the recycling, reuse and valorisation of materials with a heavy environmental impact. Such measures also help reduce the amounts of raw materials extracted to generate new products and drive the replacement of fossil fuels with alternative sources of energy [1–4].

Recycling, reuse and valorisation are also avenues for reducing the environmental footprint of an industry such as construction, normally regarded as scantly sensitised to such concerns. Much research has been conducted to improve industry sustainability, including the use of alternative raw materials and renewable energies [1,2,5,6]. Another approach consists in reintroducing materials that have reached the end of their service life in other realms into the production cycle for future constructions. Similarly, industrial waste and by-products such as kaolin, metakaolin, blast furnace slag and fly ash can also be used as raw materials for cement manufacture [7–12].

In this vein, construction and demolition waste (C&DW) is also liable to reintroduction into the industry's production cycle.

Earlier studies describing the successful use of clay-based materials (tile, brick, sanitary ware) as pozzolanic additions in cement have inspired further research on the introduction of C&DW in cement manufacture [13–19]. At present, such waste is normally reused as an aggregate in recycled concrete, drainage material in roads or for aesthetic applications [20–30]. The successful partial replacement of cement clinker (at different ratios) with pozzolanic clay-based C&DW from Spanish recycle plants has given rise to two international patents [31,32].

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This durability study explores the performance of conventional and blended cement when exposed to 0.0, 0.5 or 1.0 M sodium sulfate for different periods of time, comparing the post-attack formation of compounds such as gypsum ($Ca_2SO_4·2H_2O$), ettringite ($3CaO·Al_2O_3·3CaSO_4·32H_2O$), thaumasite ($Ca_3Si(SO_4)·(CO_3)·(OH)_6·12H_2O$) and combinations of the three [33–41]. The expansive nature of such compounds renders their study particularly pertinent, given the cracking damage they may induce in cement paste [33,35,42]. After exposure over lengthy periods, such cracking may lead to severe deterioration of the structures built with such cements. Deterioration in specimens soaked in sodium sulfate solutions at different concentrations worsens with time. This study quantifies the fluctuations in specimen weight, which are then related to the formation of new products and changes in outward appearance.

Prior studies have shown that three factors affect the durability of blended cements containing pozzolanic additions: pore structure refinement, low alkalinity and the low portlandite content in the respective cement pastes [37,38,41,43,44]. This study focuses on the third factor. A number of instrumental techniques are used to compare the pastes in terms of their portlandite content and the compounds formed.

These new cements must be studied to determine the feasibility of their use and whether the replacement of clinker with C&DW materials enhances the properties of conventional cement.

Of particular importance in this regard are durability-related properties. This study compares durability between reference cement and cement in which 30% of the clinker is replaced by 100% clay-based C&DW.

A number of analytical techniques are deployed to establish cement composition and morphology and compare the differences between the pastes with and without C&DW. Paste flexural strength is also studied to determine sulfate-induced deterioration as per the Köch-Steinegger procedure [45].

2. Experimental

2.1. Materials

The CEM I 42.5 R ordinary Portland cement (OPC) used throughout had a clinker content of at least 95% and a minority component content of no >5%, as per European standard EN 197-1 [46]. Its chemical composition, determined by X-ray fluorescence (XRF), is given in Table 1.

Table 2
Information about mineralogical compounds of the C&DW and cement pastes.

Compound	Chemical formula	ICSD code
Illite	$K(Al_4\ Si_2O_9(OH)_3)$	090144
Quartz	SiO_2	067121
Orthoclase	KSi_3AlO_8	010270
Anorthite	$CaAl_2Si_2O_8$	202710
Calcite	$CaCO_3$	040112
Dolomite	$CaMg(CO_3)_2$	202162
Hematite	Fe_2O_3	082904
Ettringite	$Ca_6(Al(OH)_6)_2(SO_4)_3(H_2O)_{26}$	016045
Monocarboaluminate	$Ca_4Al_2(OH)_2(CO_3)(H_2O)_5$	059327
Portlandite	$Ca(OH)_2$	064951
Belite	Ca_2SiO_4	079551
Ferrite phase	Ca_2FeAlO_5	009197

Clay-based (tile and brick) construction and demolition waste (C&DW) was sourced from a Spanish recycle plant, where it was ground to a particle size of under 63 µm. In addition to the majority component, SiO_2, it contained other acidic oxides such as Al_2O_3 and Fe_2O_3 (Table 1) characteristic of pozzolanic materials [8,11,13–17,46–54]. The XRD pattern for the C&DW reproduced in Fig. 1 shows the mineralogical phases detected, where the majority compound is quartz [19]. Table 2 includes the chemical formula and the ICSD (Inorganic Crystal Structure Database) code of all the compounds.

The blended cement (C&DWC) used in this study was prepared with 30 wt.% C&DW and 70 wt.% OPC.

2.2. Instrumental techniques

The samples were chemically characterised via X-ray fluorescence (XRF) on a Philips PW1404 spectrometer fitted with a dual anode Sc/Mo X-ray tube.

Sample mineralogy was determined on a Bruker AXS D8 X-ray powder diffractometer fitted with a 3-kW (Cu Kα1.2) copper anode and a wolfram cathode X-ray generator. Scans were recorded between 2θ angles of 5–60° at a rate of 2°/min. The voltage generator tube operated at a standard 40 kV and 30 mA.

Table 1
Chemical composition of the starting materials (%) determined by XRF.

Oxides	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	SO_3	K_2O	TiO_2	P_2O_5	LOI[a]
OPC	20.00	6.03	2.57	0.03	1.75	59.63	0.56	3.90	1.49	0.15	0.15	3.26
C&DW	59.63	18.51	5.92	0.09	3.12	4.78	0.73	0.42	3.59	0.84	0.15	2.15

[a] LOI: Loss On Ignition.

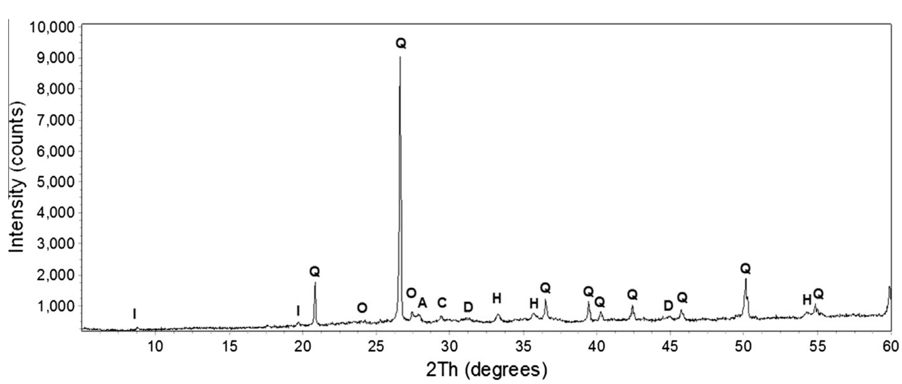

Fig. 1. XRD patterns for recycled C&DW (I: illite, Q: quartz, O: orthoclase, A: anorthite, C: calcite, D: dolomite, H: hematite).