



Individual and combined effects of Portland cement-based hydrated mortar components on alkali-activated slag cement



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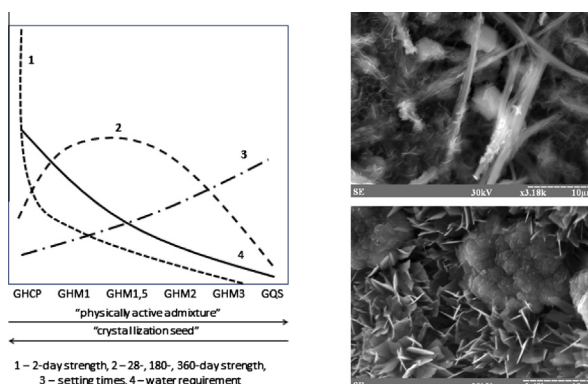
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HIGHLIGHTS

- GHM strengthens AASC and allows slag substitution of up to 50%.
- GHM consists of a 'nucleator seed' and a 'physically active' additive.
- Blending AASC with GHM increases its two-day strength to 9.9 MPa.
- A 1:1.5 cement:sand ratio yields the highest strength after 28–360 days.

GRAPHICAL ABSTRACT

Time-series analysis of the influence of ground hydrated cement paste, ground quartz sand and ground hydrated mortar with a cement:sand ratio of 1:1–3 on the properties of fresh and hardened alkali-activated slag pastes.



ARTICLE INFO

Article history:

Received 23 April 2014

Received in revised form 3 September 2014

Accepted 24 September 2014

Keywords:

Granulated Blast-Furnace Slag

Alkali Activated Cement

Cement paste

Mortar

Waste management

ABSTRACT

A comparative analysis was made of the individual and combined effects of the constituents of ground hydrated mortar (GHM) on the properties of fresh and hardened alkali-activated slag cement (AASC) pastes, which took into consideration properties such as the liquid/solid ratio, setting time, water absorption, density and compressive strength development. From the results obtained, it is evident that GHM is a multifunctional mineral additive that consists of a 'nucleator seed' and a 'physically active additive'. Moreover, these components function both jointly and separately to micro-reinforce and fill the AASC paste, thereby accelerating its curing and providing a prolonged strengthening effect.

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Abbreviations: HMW, hydrated mortar waste; AASC, alkali-activated slag cement; PC, Portland cement; GGBFS, ground granulated blast furnace slag; GQS, ground quartz sand; GHCP, ground hydrated cement paste; GHM, ground hydrated mortar; S_{sp} , specific surface area; l/s , liquid/solid ratio; C/S , cement:sand ratio.

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1. Introduction

One of the major challenges facing the cement industry in its bid to achieve a sustainable future is finding a means of producing binders based on a mix of different mineral supplements. This not only requires increased use of known supplementary cementitious

materials (SCMs), but also the development and application of entirely new SCMs [1]. Mineral wastes are amongst the most promising of the latter; however, further methodical study is still needed to develop an effective approach to their practical application. This is particularly true of multicomponent wastes, which are characterised by a variation in their chemical and mineralogical composition, and therefore require a component-wise approach based on assessing the individual and combined effect of each component on the properties of the binder. Such an approach should assist in determining the utility, feasibility and effectiveness of secondary resources, thereby leading to more effective and efficient recycling of mineral wastes.

1.1. Hydrated mortar waste

The highest volume wastes of mixed composition are concrete and demolition wastes, which are currently used as coarse and fine secondary aggregates in concrete production after they first mechanically crushed, sieved, and sorted [2–9]. This crushing of concrete wastes, however, leaves behind residual mortar, which is often referred to as waste concrete powder, concrete fines or hydrated mortar waste (HMW). This HMW typically makes up 25–30% of the crushed-material by volume [7,10], though its composition can vary depending on the composition of the parent concrete, the curing conditions, the time of exploitation and various other factors. The chemical compositions of a number of different concrete wastes are listed in Table 1.

As can be seen, HMW typically consists of quartz, calcite, ettringite, non-hydrated Portland cement (PC) minerals, hydrates of calcium silicate and calcium aluminate, feldspars and hydromica. The presence of non-hydrated PC particles makes HMW a particularly promising material for the recycling and production of cement clinker and blended cements. Indeed, with suitable mechanical, mechanochemical, thermal, or hydrothermal activation, HMW can be used as:

- a raw mixture to produce cement clinker or as an additive in the raw mixture [16–18],
- an additive to ensure a basic or thermally activated state in PC minerals [13,19,20], or
- an additive for clinker-free cements [11,14,21].

1.2. Hydrated mortar waste as an additive in alkali-activated slag cements

Alkali-activated slag cements (AASCs) are one of the most promising binders for use in alternative cements [22], producing a C–A–S–H gel on hardening due to the alkali activation of the calcium aluminosilicate that makes up the bulk of ground granulated blast furnace slag (GGBFS) [23–25]. The mineral matrix is therefore characterised by a high binding power, low basicity and solubility of the binder gel, lower porosity and smaller pores in the hardened AASC paste, high adhesive strength due to a high pH and concentration of alkali, and a dense and uniform interfacial transitional

zone between the aggregate and AASC paste [26–31]. Furthermore, alkali activation ensures effective interaction between the AASC paste and any fillers or modifiers, as well as ensuring compatibility with blended-mineral materials of various compositions and structures. Indeed, a much wider range of mineral materials can be successfully blended with AASCs than with ordinary Portland cements (OPCs) [32,33]. The use of mineral additives as means of manipulating the GGBFS content, physical properties and structural performance of AASC therefore appears to be quite a promising option for the sustainable development of mineral binders, as it should allow the range of useable mineral wastes to be greatly expanded.

The interaction between AASC pastes and mineral additives can, however, vary significantly in relation to differences in raw material composition, the structure formation process, and the composition and properties of the PC and AASC binder gel. These factors therefore determine the feasibility of replacement and modification, as well as the way in which such additives are classified. Taking into consideration the individual effects of the raw material and binder gel, as well as the structural and physical properties of AASC, a new classification system was proposed that defines supplementary materials for AASCs as either: (1) nucleator seeds, (2) chemically active, (3) physically active, or (4) physically active and reactive [32]. Chemically active supplementary materials have an amorphous structure that forms hydration products with cementitious properties and modifies the composition of the binder gel. Physically active supplementary materials, on the other hand, have a crystalline and/or chemically inert structure that does not modify the composition of the binder gel, but does affect the physical structure of the mixed binder. Physically active and reactive supplementary materials combine both of these effects.

The activity of HMW, as depicted in Fig. 1, is based on a ‘nucleator seed’ of hydrated and non-hydrated PC and a ‘physically active’ quartz sand (QS) additive. The influence of hydrated mortar on fresh and hardened AASC pastes will therefore depend greatly on its ratio of hardened PC paste to QS.

1.2.1. Hydrated mortar and its individual components as additives in AASC

Calcium silicate hydrate (C–S–H), Portland clinker/cement and concrete wastes have been the most widely studied in relation to their effect on the early strength of AASC pastes. Hubler et al. [34] reported that the addition of C–S–H seeds causes the hydration rate of AASC to peak earlier and higher, resulting in a compressive strength after one day of curing that is at least four-times greater than a control sample. This increase in strength was, however, strongly dependent on the curing method used, with sealed curing more favourable in this regard than underwater curing. The addition of a small percentage of Portland clinker (1–7%

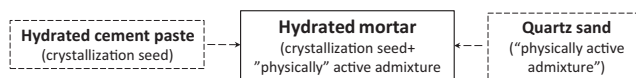


Fig. 1. Activity of hydrated mortar and its constituents.

Table 1
The chemical composition of concrete wastes.

Waste type	Chemical composition (wt.%)								Reference
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	LOI	
Waste concrete	41.15	7.80	12.57	20.64	1.50	2.07	1.98	13.07	[11]
Waste concrete powder	51.4	5.01	3.72	35.23	1.25	1.5	0.51	0.093	[12]
Hydrated mortar waste	27.98	3.87	2.10	36.01	1.48	1.29	0.26	26.3	[13]
Ground waste concrete	40.1	9.6	3.5	20.6	2.1	2.3	1.7	–	[14]
Construction and demolition waste materials	30.99–60.2	4.5–11.27	1.43–4.52	11.6–23.96	2.78–5.49	1.05–2.04	0.55–1.53	11.24–26.77	[15]

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