



Housing and Building National Research Center

HBRC Journal

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FULL LENGTH ARTICLE

Effect of demolition/construction wastes on the properties of alkali activated slag cement

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Received 4 November 2015; revised 30 November 2015; accepted 1 December 2015

KEYWORDS

Alkali activated slag;
Crystallinity degree;
Hydration products;
Nucleation sites;
Demolition and building
wastes

Abstract The key point of this investigation is to study the effect of demolition and building wastes on the physico-chemical and mechanical properties of alkali activated slag (AAS). In this study, ground granulated blast-furnace slag (GGBFS) was activated by mixture of 3:3 wt.% sodium hydroxide:liquid sodium silicate ($\text{NaOH}:\text{Na}_2\text{SiO}_3$) ratio by weight of GGBFS. AAS was individually replaced by 10 wt.% ceramic, red clay brick and concrete wastes (CW, RCBW and CoW). The results showed that, significant shorter setting times were observed when AAS was replaced by CW, RCBW or CoW. The AAS-CoW showed the shortest setting times compared to other all mixes. The chemically combined water and pH decreased in the direction of AAS-CoW > AAS > AAS-RCBW > AAS-CW. CoW has a positive effect on the compressive strength development at one day of curing, while, CW and RCBW have a negative effect at the same time (1 day). At later ages of curing, the AAS-RCBW showed the highest compressive strength values as compared with AAS-CW, AAS-CoW and AAS. The crystallinity degree of hydration products enhanced when AAS was replaced by these wastes. Also, the Fe_2O_3 present in waste played an important role on the development of compressive strength. The hydration products were investigated using X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM) and the results were compared with the development in compressive strength.

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Peer review under responsibility of Housing and Building National Research Center.



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Introduction

In recent years, much works has been carried out to investigate the possibility of utilizing industrial wastes as raw materials in the production of geopolymer cements. GGBFS was the first cementitious material to be activated by alkali due to its latent hydraulic properties. Alkali activated slag (AAS) has been

<http://dx.doi.org/10.1016/j.hbrcj.2015.12.001>

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Please cite this article in press as: S.R. Zedan et al., Effect of demolition/construction wastes on the properties of alkali activated slag cement, HBRC Journal (2015), <http://dx.doi.org/10.1016/j.hbrcj.2015.12.001>

commercially produced and used in construction projects. However, most of the commercial application of AAS has taken place in the former Soviet Union, China, and some Scandinavian countries. Due to environmental issues and the search for an alternative binder for concrete other than Portland cement, the research on AAS has aroused worldwide interest [1–8].

According to Glukhovskiy et al. [9] and Davidovits [10], the mechanism of alkali activation is composed of conjoined reactions of destruction–condensation, that include the destruction of the prime material into low stable structural units, their interaction with coagulation structures and the creation of condensation structures. The first step consists of a breakdown of the covalent bonds Si–O–Si and Al–O–Si, which happens when the pH of the alkaline solution raises; so those groups are transformed into a colloid phase. Then an accumulation of the destroyed products occurs, which interacts among them to form a coagulated structure, leading in a third phase to the generation of a condensed structure. Other authors also agree that the majority of the proposed mechanisms indicate an initial phase of silica dissolution, followed by the phases of transportation and polycondensation [11,12]. However, these phases occur almost simultaneously, preventing their analysis in an individual mode [13]. In Egypt, the amount of demolition and building wastes increases with time. These wastes negatively affect the environment. Construction industry can be the end user of all demolition and building wastes and in this way can contribute to solve this environmental problem. The nature of construction industry, especially the concrete industry, is such that ceramic wastes can be used safely with no need for dramatic change in production and application process. According to some authors the best way for the construction industry to be a more sustainable one is by using wastes as building materials [14,15]. Several authors studied the effect of demolition wastes on the properties of ordinary Portland cement was investigated [16–19]. A few researches were done to study the effect of demolition wastes on alkali activated slag cement [20].

In this work, the effect of different demolition and building wastes such as concrete (CoW), red clay brick (RCBW) and ceramic wastes (CW) on the physico-chemical and mechanical properties of AAS was investigated to elucidate which one of these wastes has better effect on the performance of AAS.

Materials and experimental methods

Materials

The materials used in this investigation are ground granulated blast-furnace slag (GGBFS), ceramic waste (CW), red clay brick waste (RCBW) and concrete waste (CoW). GGBFS was provided by Helwan Steel Company, Helwan, Egypt.

The activators used in this study were sodium hydroxide and liquid sodium silicate (NaOH and Na₂SiO₃). NaOH with purity 99.99% was purchased from Fisher Scientific Chemical Company, United Kingdom (UK). Na₂SiO₃ with 17% Na₂O, 32% SiO₂ and density of 1.46 was obtained from El Gomhourya Chemical Company, Egypt. The chemical compositions of GGBFS, CW, RCBW and CoW as determined by X-ray fluorescence (XRF) are listed in Table 1. The mix composition of GGBFS–CW, GGBFS–RCBW and GGBFS–CoW blends, is given in Table 2. The mineralogical compositions of these materials are shown in XRD patterns Fig. 1. The mineralogical analysis shows that, GGBFS is completely amorphous with a hump at 2θ of 20–40. CW exhibits different crystalline peaks related to quartz (Q) and traces of anorthite (A) minerals. RCBW consists mainly of Q, Anorthite (A), Andenite (An) and microcline (MC). The crystalline peaks observed in XRD pattern of CoW are characteristic for Q, calcite (C) and dolomite (D). The oxide molar ratios of all blends are listed in Table 3.

Preparation of alkali activated GGBFS, GGBFS–CW, GGBFS–RCBW and GGBFS–CoW blends

Firstly, GGBFS, CW, RCBW and CoW were crushed in automatic grinding machine to pass from 90 μm sieve. In order to prepare geopolymer cement, GGBFS, GGBFS–CW, GGBFS–RCBW and GGBFS–CoW were activated by 3:3 NaOH: Na₂SiO₃ weight ratio. The dry mixes were placed on smooth, nonabsorbent surface. The mixing water containing activator for all mixes was adjusted at 0.25 of water to solid ratio (W/S). The mixing operation was then completed by slow mixing for about 2 min then continuous and vigorous mixing by means of ordinary gauging trowel for about three min.; the fresh pastes were then casted in (25 × 25 × 25 mm) cubic molds in two layers and manually-vibrated to eliminate air voids. The samples were then covered to avoid moisture loss then cured in humidity chamber at 100% relative humidity (RH) and 37 ± 2 °C for 24 h. All samples were demolded then cured in tap water at 23 ± 2 °C until the time of investigation.

Methods of investigation

The initial and final setting times were measured using the Vicat test according to ASTM 191 specification [21]. The pH

Table 1 Chemical compositions CW, GGBFS and CoW, wt.%.

Oxides	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	SO ₃	TiO ₂	P ₂ O ₅	MnO	BaO	LOI	Total
GGBFS	38.70	11.90	0.51	32.90	4.08	0.68	0.78	2.42	0.49	–	3.92	3.29	–	99.97
CW	68.30	19.50	5.29	1.57	0.26	1.08	1.88	0.06	0.90	0.29	–	–	0.72	99.99
RCBW	58.13	14.15	8.26	8.89	1.03	1.09	1.37	2.35	1.17	0.19	–	–	3.32	99.95
CoW	30.63	1.79	1.59	37.45	3.87	0.02	0.24	1.07	0.15	0.06	–	–	23.10	99.98

Table 2 Mix compositions of investigated mixes, wt.%.

Mix no.	Mix name	GGBFS	CW	RCBW	CoW
1	MS	100	–	–	–
2	MSC10	90	10	–	–
3	MSB10	90	–	10	–
4	MSCo10	90	–	–	10

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