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Mechanical and durability properties of alkali activated slag coating mortars containing nanosilica and silica fume

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HIGHLIGHTS

- Nanosilica addition resulted in better mechanical and durability properties of AAS mortars.
- Addition of silica fume more than 5% didn't contribute in better properties of AAS mortars.
- Alkali activated slag mortars disintegrated after thermal exposure.
- Alkali activated slag mortars revealed acceptable chloride penetration resistance.
- KOH mixtures revealed better mechanical properties, however, NaOH mixtures performed better against chloride ingress.

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ABSTRACT

Mechanical and durability performances of alkali activated slag (AAS) mortars are evaluated. Nanosilica at the dosages of 2% and 4% and silica fume at the dosages of 5%, 7.5% and 10% were incorporated into mortar mixtures as ground granulated blast furnace slag (GGBFS) replacement. Mixtures of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) were used to activate the GGBFS. Flowability, compressive strength, sorptivity, chloride permeability, and bond strength tests were applied to single, binary, and ternary blended AAS mortars in order to assess the effect of the variables on mechanical, durability, and bond strength performances of the AAS mortars. Results indicated that nanosilica incorporation significantly improved the performance of AAS mortars, while silica fume addition more than 5% didn't contribute in performance improvement. Migration and diffusion coefficients obtained from chloride durability tests revealed the high influence of nanosilica on microstructural development also NaOH activated mortars showed better performance against chloride penetration. A microstructural analysis was performed through scanning electron microscope (SEM) micrographs and energy dispersive X-ray (EDX) analysis. Results showed proof on filler effect of nanosilica particles, silica fume agglomeration and disintegration of AAS system as a result of thermal exposure during sorptivity test.

1. Introduction

The use of ordinary Portland cement (OPC) as the main binder material in concrete production has been widely criticized over the last decades due to the environmental and engineering concerns. It is known that OPC clinker production is responsible for about 1.5 billion tons of CO_2 emission every year, which is estimated to be 6% of total man made CO_2 emissions [1,2]. In addition, concrete exposure to various destructive environments such as acidic and corrosive environments has caused major durability problems for concrete structures, some of which are attributed to deficiencies originated from OPC hydration products [3,4].

During the past 3 decades, the idea of alkali activation of materials has received researcher's attention due to the considerable contribution in OPC usage mitigation, and superior properties when compared to that of OPC mixtures [5,6]. Alkali activated materials (AAMs) are sometimes wrongly referred as geopolymers, which is a term coined by Davidovits at 1981 [7]. However, the terminology is imperative since "AAM"s and "geopolymer"s paste are totally different in structure [8]. Alkali activated slag (AAS) mixtures have attracted attention among researchers due to comparable mechanical and durability properties than that of OPC mixtures, and rapid-hardening properties [9–12]. Incorporation of AAMs into the construction industry is also an effective

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approach for waste management purposes, since a large proportion of the raw materials used for AAMs fabrication are selected from industrial by-products [1].

It is worthwhile mentioning that, although AAMs are expected to be incorporated into the construction industry as an effort for carbon footprint and embodied energy mitigation of construction materials, the environmental impact of AAMs remains a recent open debate due to contradictory reports of life cycle assessment of these materials [13–17]. Compared to other pozzolaniac materials, several environmental benefits can be pursued by applying ground granulated blast furnace slag (GGBFS) as the base material in AAMs, some of which are as follows: 1 – GGBFS based AAMs generally do not require heat curing for strength development according to high reactivity of this pozzolan [13,18], 2 – less sodium silicate solution is required in the activation of GGBFS as compared to other AAM base materials, and 3 – high temperature calcination step is not required for activation of pozzolaniac properties in GGBFS. In the present study, low concentration of alkaline activators (6 M), and sodium silicate-to-alkaline activator ratio (0.4) were employed, also the mortars were cured in water and under ambient condition, as an effort to overcome the main challenges facing the industrialization of AAMs.

Nano materials have been incorporated into concrete due to recent innovations in nanotechnology and significant influence on the microstructure of concrete. Various types of nanomaterial are being used in concrete production, among which nanosilica has engaged considerable attention due to its profound influence on the microstructure of concrete [19,20]. Nanosilica is effective in case of setting time reduction and mechanical properties improvement of concrete due to high pozzolaniac reactivity [21]. Nanosilica is reported to improve mechanical and durability properties and bond strength of geopolymer mortars and pastes as well [22]. However, there are limited research works studying the effect of nanosilica addition on AAS durability and microstructure.

Silica fume has been utilized as a supplementary cementitious material (SCM) for decades. This by-product of elemental silicon or ferrosilicon industries, has been reported to be influential on concrete properties. Silica fume is known to decrease the workability of OPC concrete due to its very high specific surface area [23]. It has been confirmed that addition of silica fume up to 20% improves OPC concrete mechanical properties. Khan and Siddique [24] have reported that this is due to the interfacial transition zone (ITZ) characteristics enhancement and contribution towards further C-S-H gel production. However, several studies have reported that AAMs workability is improved by the silica fume addition [25], and the limited studies investigating the effect of silica fume addition on AAM properties remains to be a gap in literature.

Introducing novel applications for AAMs would result in durability improvement and carbon footprint reduction of concrete involved projects, worldwide. The possibility of employing AAM as a more sustainable repair material compared to OPC concrete has been suggested by researchers in the last two decades [26–28]. The feasibility of the usage of AAS mortars as coating mortars has been investigated in this study through mechanical, durability and bonding tests.

Nanosilica at the dosages of 1% and 2% and silica fume at the dosages of 5%, 7.5%, and 10% have been used to replace GGBFS and produce binary and ternary mixtures. Also the effect of solution-to-pozzolan ratio and chemical activator type are evaluated. Two different mixes were used as chemical activators; combination of a 6 M solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH), and sodium silicate solution with a silicate modulus of 2.33 were prepared to produce AAS mortars. Sodium silicate-to-alkaline solution ratio was set to be 0.4 on the basis of former work accomplished by the same researcher [18]. The present study includes 2 stages, at the first stage 36 mortar mixes were tested for flowability and 3, 7, 28, and 90 days compressive strength. Based on results obtained in the first stage, 8 mixtures were selected to be tested for durability and bond strength properties in the second stage. Rapid chloride migration test (RCMT), bulk diffusion test, capillary water absorption, and pull-off test were applied in order to evaluate performance of AAS mortars. Also, microstructural analysis is performed through scanning electron microscope (SEM) micrographs and energy dispersive X-ray (EDX) analysis in order to evaluate the microstructure and identification of the elemental composition of AAs mortar samples.

2. Experimental program

2.1. Materials

GGBFS with a specific surface area of 3383 cm^2/g, mean particle size of 25.97 μm and a specific gravity of 2.79 g/cm^3 was obtained. Silica fume with average particle size of 2.5 μm and nanosilica powder with average particle size of 12 nm were also obtained from local companies. Chemical composition of GGBFS, silica fume and nanosilica are obtained through X ray fluorescence (XRF) analysis as illustrated in Table 1.

X-ray diffraction patterns were obtained using the EQuniox 3000 machine, in order to assess the amorphous silica and alumina content of materials which control the effectiveness of the pozzolans. Diffraction patterns have indicated that almost all ashes used in this study are in amorphous phase since low level of crystallinity was observed. Fig. 1 shows the XRD patterns of GGBFS,

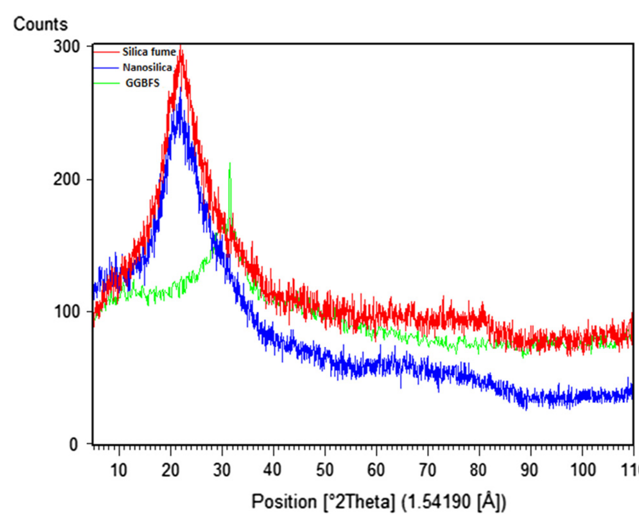

Fig. 1. X-ray diffraction patterns of GGBFS, nanosilica and silica fume.

Table 1
Chemical analysis of GGBFS, silica fume and nanosilica.

Chemical Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	P_2O_5	TiO_2	LOI
GGBFS, %	37.21	11.56	1.01	36.75	0.97	8.52	0.61	0.7	0.03	1.23	0.02
Silica fume, %	88.5	1.4	2.1	1.5	–	2	–	0.75	–	0.15	3
Nanosilica, %	99.5	0.001	0.001	–	–	–	–	–	–	–	0.94