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## Microstructural alteration of alkali activated slag mortars depend on exposed high temperature level



Hakan Tacettin Türker<sup>a</sup>, Müzeyyen Balçikanlı<sup>a</sup>, İbrahim Halil Durmuş<sup>b</sup>, Erdoğan Özbay<sup>a,\*</sup>, Mustafa Erdemir<sup>b</sup>

<sup>a</sup> *İskenderun Technical University, Civil Eng. Department, 31200 İskenderun, Turkey*

<sup>b</sup> *Adana Cement Industry Inc., Adana, Turkey*

### HIGHLIGHTS

- Microstructural and mechanical properties of the AAS mortars were investigated.
- Variation in mechanical and microstructural properties depend on elevated temperature and curing type were investigated.
- Applied curing regime and exposed temperature level had a significant effect on the TGA, XRD and SEM images of AAS mortars.

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### ABSTRACT

This article reports a study on the microstructural and mechanical properties of the Alkali Activated Slag mortars (AAS) upon exposing to the elevated temperatures up to 800 °C. Slag cement is activated by sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) and sodium hydroxide (NaOH) solutions with silicate modulus ( $M_s = \text{SiO}_2/\text{Na}_2\text{O}$ ) of 1.0 and sodium (Na) dosages of 5%. AAS mortars were being subjected to the ambient and high temperature curing (6 h under 60 °C) after undisturbed for 24 h in mold at room temperature. Ordinary Portland cement (OPC) mortar was also prepared as control. Bending and compression tests were conducted at ambient temperature and after exposure to high temperatures at 28 days. Both AAS and OPC mortars were subjected to the X-ray diffraction (XRD), scanning electron microscope (SEM), and thermogravimetric analysis (TGA) tests to find out the microstructural variation due to the exposed temperature level. Test results revealed that the high temperature resistance of the alkali activated slag mortars and Portland cement mortars are clearly different from each other's. Contrary to the expectations, brilliant mechanical and high temperature resistance might not be observed at the alkali activated slag mortars irrespective of the applied cured conditions. Additionally, applied curing regime and exposed temperature level had a significant effect on the TGA, XRD and SEM images.

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## 1. Introduction

Ordinary Portland cement (OPC) is the main ingredient used in the production of concrete that is most widely used construction material in the world due to its superior thermal, mechanical and durability properties. [1]. Production of one ton of Portland cement, however, requires about 2.0 ton raw materials, including fuel and other materials and generates 5 to 10 % of dusts. Altogether 6000–14,000 m<sup>3</sup> dust-containing air-streams are generated per ton cement manufacture, which contain between 0.7 to 800 g/m<sup>3</sup> of dust and accounts for about one ton of greenhouse

gas CO<sub>2</sub> released to the atmosphere as a result of de-carbonation of lime in the kiln during manufacturing of cement [2,3]. It is predicted that by 2015 the world production of cement will reach 3.5 billion tones [4–6] and this will make the share of cement production to CO<sub>2</sub> emissions as high as 18% [6,7]. With the escalating pressure on cement industry to lessen energy demands and CO<sub>2</sub> emission, the rummage of alternative cementitious materials that can reduce energy consumption and pollution has become an important focus [8]. As a result of extensive research has been undertaken by academics and engineers, alkali activated or geopolymer materials attracted a great deal of consideration as a new environmental-friendly engineering technology for producing supplementary materials to the ordinary Portland cement (OPC) due to their brilliant mechanical and thermal properties [9]. Geopolymer is a term used to describe inorganic polymers based

\* Corresponding author.

E-mail address: [erdoganozbay@gmail.com](mailto:erdoganozbay@gmail.com) (E. Özbay).

on aluminosilicates [10] and can be produced by synthesizing pozzolanic compounds or aluminosilicate source materials with highly alkaline solutions [11]. The base material for geopolymerisation might be a single material or combination of various materials [12]. Materials such as low calcium fly ash [13,14], high calcium fly ash [15], metakaolin [16], slag cement [17,18] and a combination of fly ash and slag cement [19] have been used to produce geopolymer binders. As compared to the OPC, the geopolymer technology can reduce CO<sub>2</sub> emission up to 80–90% [9,20], and it possesses higher thermal durability in high temperature environments as well [9,21]. Furthermore, the geopolymer materials have early strength, low permeability, excellent resistance to chemical attacks, good freezing–thawing cycles, and a tendency to immobilize the heavy metal ions in the geopolymeric structure [9,22–26].

Currently there is sufficient evidence to suggest that alkali activated materials or geopolymers have better resistance to elevated temperatures than OPC concrete [27–30]. Zhang et al. [8] investigated the fire resistance of the metakaolin (MK) and fly ash (FA) blended geopolymers. Bending and compression tests were conducted at ambient temperature and after exposure to high temperatures on geopolymer specimens. Test results illustrate that MK–FA based geopolymer specimens exhibit comparable bending and compressive strength as that of ordinary Portland cement specimens both at ambient temperature and after exposure to high temperatures. It was mentioned that MK–FA based geopolymers offer a feasible alternative to conventional Portland cement in practical building applications. Nath and Sarker [31] studied on the fly ash based geopolymers which was produced without elevated heat curing. Test results showed that fly ash based geopolymer concrete for curing in ambient condition can be proportioned for desirable workability, setting time, and compressive strength using slag cement as a small part of the binder. Inclusion of slag cement with Class F fly ash helped achieve setting time and compressive strength comparable to those of ordinary Portland cement (OPC).

Despite a number of publications suggesting the advantages of geopolymers in high temperature applications and showing evidences of their ability to have high residual strengths after exposure to elevated temperature, not all of its microstructural alteration at high temperatures have focused on and have been investigated in detail. In order to explore the high temperature resistance and microstructural and mechanical properties of alkali activated slag mortars produced at ambient curing and elevated temperature conditions and Ordinary Portland cement mortars

were firstly investigated after the specimens exposed up to 800 °C. This paper research anticipates (1) to explore the influences of high temperature on compressive and flexural strengths and (2) to find the microstructure alteration at high temperature by means of XRD, SEM, and TGA tests.

## 2. Experimental program

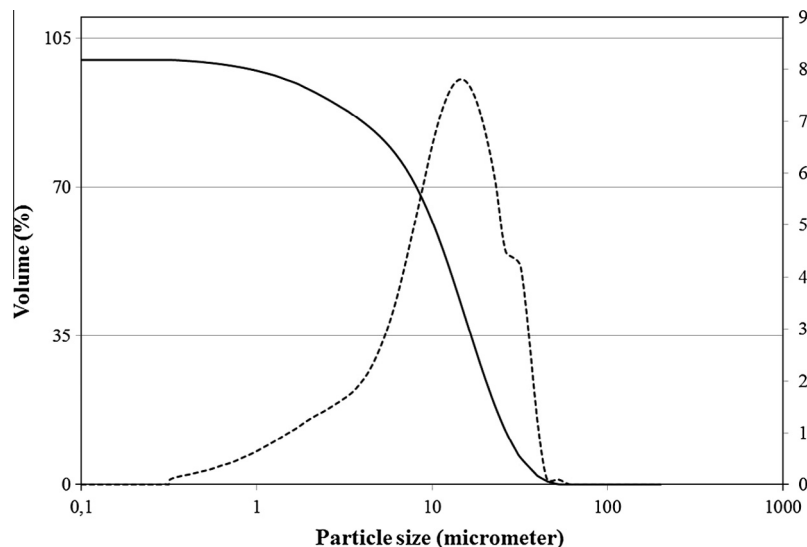
### 2.1. Material characterization

The Turkish slag cement that is obtained from Iskenderun Iron-Steel Factory was used. It has a vitreous content of 99% and a specific surface area of 540 m<sup>2</sup>/kg. The particle size distribution of the slag was determined using a Malvern Mastersizer 2000 and presented in Fig. 1. The fineness of slag was 92% passing through a 30 μm sieve. The chemical composition determined by X-ray Fluorescence (XRF) and XRD analysis of the ground granulated blast furnace slag are given in Table 1 and Fig. 2, respectively. The XRD analysis of the slag shown in Fig. 2 displayed an amorphous hump characteristic at about 30° indicating the presence of large amounts of glass.

Alkali activating solutions of the desired composition were formulated by blending of a commercial sodium silicate solution and laboratory-grade >99% pure NaOH pellets. Physical and chemical properties of sodium silicate and sodium hydroxide used are given in Table 2. The sodium silicate, Na<sub>2</sub>O · xSiO<sub>2</sub> · nH<sub>2</sub>O, where *x* represents the degree of polymerization and *n* represents the moles of water, was a 39.4 Baume solution with a solids content of 35.61% (thus containing 64.39% water) and a SiO<sub>2</sub>/Na<sub>2</sub>O weight ratio of 3.18. Sodium hydroxide pellets was dissolved in sodium silicate solution to decrease silicate modulus to 1 and allowed to cool to room temperature prior to mixing with slag cement. After an initial mixing of the slag cement with the activator solution, crushed limestone sand having a nominal maximum size of 4 mm was added to mixture as fine aggregate with fineness modulus of 2.82 and mixed again, diluted water added to satisfied predefined

**Table 1**  
Chemical composition of ground granulated blast furnace slag used.

Oxide	Composition by weight (%)
SiO <sub>2</sub>	43.08
Insoluble residue	–
Al <sub>2</sub> O <sub>3</sub>	11.34
Fe <sub>2</sub> O <sub>3</sub>	0.74
CaO	36.25
MgO	6.10
SO <sub>3</sub>	0.60
Sulfide Sulfur as S <sup>2-</sup>	0.51
Loss on ignition	0.00
Na <sub>2</sub> O	0.28
K <sub>2</sub> O	0.75
Na <sub>2</sub> O + 0.658K <sub>2</sub> O	0.77
Free Lime	–



**Fig. 1.** Particle size distribution of ground granulated blast furnace slag used.

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