



# An exploratory study on alkali-activated slag blended with quartz powder under the effect of thermal cyclic loads and thermal shock cycles



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## HIGHLIGHTS

- The inclusion of QP increased workability and compressive strength of AAS pastes.
- The inclusion of QP showed better performance after H/C cycles compared to neat AAS.
- Compressive strength decreased with increasing H/C cycles and peak temperature.
- Most of strength loss at the first 7 H/C cycles, then marginal loss was observed.
- The inclusion of QP with high amount improved cyclic thermal shock resistance.

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## ABSTRACT

Ground granulated blast-furnace slag (slag) in alkali-activated slag (AAS) paste was partially replaced with quartz powder (QP) at levels ranging from 0% to 30% with an increment of 5%, by weight. Workability and compressive strength of different mixtures were measured. After 28 curing days, some specimens were exposed to 7, 14, 21 and 28 heating/cooling (H/C) cycles. To complete one cycle, the temperature was kept constant at either 200 °C or 400 °C for 6 h, followed by 18 h cooling. Compressive strength after each cyclic regime was measured. Other specimens were exposed to rapid temperature changes to determine their thermal shock resistance. The various decomposition phases formed and the morphology of formed hydrates were identified using X-ray diffraction (XRD), thermogravimetric analysis (TGA), scanning electron microscopy (SEM) and energy dispersive X-ray spectra (EDS). The results showed an increase in the workability with the inclusion of QP. A reduction in the compressive strength after exposure to H/C cycles was observed. This reduction increased as the heating peak temperature and H/C cycles increased. As QP content increased as the improvement in the compressive strength before and after H/C cycles increased. In addition, high QP content increased the thermal shock resistance.

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## 1. Introduction

Portland cement (PC) production process requires a lot of energy [1,2–5] and emits a large amount of CO<sub>2</sub> into the atmosphere [1,2–7]. The IEA (International Energy Agency) holds the cement industry responsible for emitting between 6% and 7% of all the CO<sub>2</sub> emission into the atmosphere [8]. The projections for the global demand of PC showed that in the next 40 years it will have a twofold increase reaching 6 Gt/year [9]. Among the greenhouse gases, CO<sub>2</sub> contributes about 65% of global warming. The scientific community reported that the global mean temperature is likely to rise by 1.4–5.8 °C over the next 100 year [10]. This is particularly serious in the current context of climate change caused by

CO<sub>2</sub> emissions worldwide, causing a rise in sea level and the occurrence of natural disasters and being responsible for future meltdown in the world economy [11]. Not only CO<sub>2</sub> releases from cement manufacture, but also SO<sub>3</sub> and NO<sub>x</sub> that can cause the greenhouse effect and acid rain [6]. In addition, PC production consumes considerable amounts of virgin materials, producing each tonne of PC of which approximately 1.5 tonnes of raw materials is needed [2,3–5]. Furthermore, concrete made of PC subjected to certain durability problems that are difficult to solve. In the light of these problems, the scientific community has undertaken to seek new processes, technologies and materials to provide the construction industry with alternative binders [3]. The promising exploratory alternative is the geopolymer or alkali activation of slag, fly ash (FA), calcined clay and other aluminosilicate materials.

Today the focus is no longer on obtaining new binders, but on developing materials with sustainably high mechanical strength,

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fire resistance, higher durability and other characteristics. One option to improve some special properties of AAS system is to replace part of source slag with other materials such as silica fume (SF), FA, metakaolin (MK) and QP. Rashad and Khalil [12] partially replaced slag with SF at levels of 0%, 5%, 10% and 15%, by weight, in alkali-activated pastes activated with sodium silicate. The results showed an enhancement in the compressive strength with the inclusion of SF. The residual strength after exposure to 400, 600 and 800 °C decreased, whilst it increased after exposure to 1000 °C. The hardened neat AAS paste showed higher residual strength at 1000 °C than the other specimens containing SF. The hardened neat slag paste showed 1.75 times greater thermal shock resistance than other pastes containing SF. For a comprehensive study on the influence of different additives on AAS system, Rashad [3] has collected the previous works that carried out on this area.

In PC system, there are many studies that used QP to improve some properties of concrete/mortar/paste [13–15] as compressive strength [16,17] and fire resistance [17] in which Rashad and Zee-dan [17] reported higher fire resistance of PC blended with QP compared to the neat PC paste. On the contrary, in AAS system, there is only one investigation related to slag blended with QP in which Rashad et al. [18] partially replaced slag with QP at levels of 0%, 5%, 10%, 15%, 20%, 25% and 30%, by weight, in alkali-activated pastes activated with sodium silicate. The pastes were exposed to autoclave conditions at a pressure of 8 bars and a temperature of 170 °C for different autoclaving times of 0, 0.5, 1, 4, 6 and 10 h. They reported that the replacement of slag with QP increased the compressive strength values of rather autoclaved or un-autoclaved specimens. The composite of 30% QP coupled with 70% slag showed the highest compressive strength.

Indeed, though researches on AAS as a binder have been plentiful, but the study its behavior under the effect of thermal cyclic loads is still un-investigated and there is no published literature related to this topic. Therefore, this study aims to investigate a number of composition and processing conditions on strength before and after exposure to 7, 14, 21 and 28 H/C cycles at different heating temperatures of 200 °C and 400 °C of alkali-activated pastes when source slag was partially replaced with QP at levels ranging from 0% to 30% with an interval of 5%, by weight. In addition, the effect of rapid temperature changes (thermal shock resistance) of different alkali-activated slag/QP has been investigated. Furthermore, the workability of different mixtures of alkali-activated slag/QP has been included. In fact, this investigation will therefore add valuable knowledge to the alkali activation system.

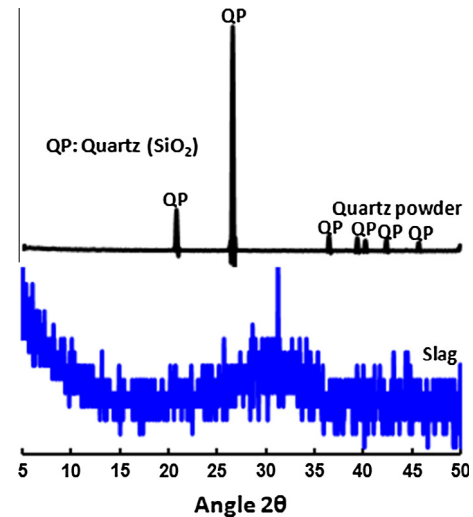
## 2. Experimental details

### 2.1. Materials

The primary raw material used in this study was water quenched slag that obtained from disposal waste resulting from Helwan steel factory (in Cairo-Egypt). Slag that was employed as a source material of alkali activation was ground in lab to reach a Blaine surface area of 300 m<sup>2</sup>/kg. The QP which was used in this study was brought from the Egyptian Company for Manufacturing Electrical Insulators. QP had specific weight and bulk density of 2.46 and 1.04 g/cm<sup>3</sup>, respectively. Table 1 shows the sieve analysis of the QP. The mineral compositions of the slag and QP are shown in Fig. 1. The chemical composition of the slag as well as QP as evaluated by X-ray

**Table 1**  
Sieve analysis of QP.

Residue on sieve %	Particle size distribution
90 μm ≤ 1	>90 μm 1
63 μm 2–4	63–90 μm 1–3
45 μm 7–10	45–63 μm 5–6
32 μm 15–20	32–45 μm 8–10
	<32 μm 80–85



**Fig. 1.** XRD pattern of slag and QP.

**Table 2**  
Chemical composition of the cementitious materials.

Oxide composition	Slag (%)	QP (%)
SiO <sub>2</sub>	36.95	98.81
Al <sub>2</sub> O <sub>3</sub>	10.01	0.14
Fe <sub>2</sub> O <sub>3</sub>	1.48	0.05
CaO	33.07	0.51
MgO	6.43	0.02
Na <sub>2</sub> O	1.39	0.04
K <sub>2</sub> O	0.74	0.03
SO <sub>3</sub>	3.52	0.03
TiO <sub>2</sub>	0.52	0.02
P <sub>2</sub> O <sub>5</sub>	0.1	0.32
MnO <sub>2</sub>	0.52	0
Cl <sup>-</sup>	0.05	0
L.O.I.	0	0.32

fluorescence (XRF) spectrometry are given in Table 2. Liquid sodium silicate which had a density of 1.38 g/cm<sup>3</sup> and a composition comprising of 8.2% Na<sub>2</sub>O, 27% SiO<sub>2</sub> and 64% H<sub>2</sub>O was employed as an alkali activator.

### 2.2. Mixture proportions

Seven alkali-activated mixtures were prepared. The first mixture comprised AAS without any addition of QP. The other six mixtures were prepared by partially replacing slag with QP, by weight. The replacement levels were ranging from 0% to 30% with an interval of 5%. Fixed concentration of sodium silicate dosage of 25 wt.%, from slag/QP weight, was used to activate the various paste mixtures. The w/b ratio was fixed for all mixtures at 0.15, by weight. The mixture proportions are given in Table 3.

### 2.3. Methods

The binders were mixed in slag/QP at proportions of 100%/0%, 95%/5%, 90%/10%, 85%/15%, 80%/20%, 75%/25% and 70%/30% (wt.%). The slag/QP were mixed together for a period of 2 min, followed by 2 min resting period and a further 2 min mixing,

**Table 3**  
Details of paste mix proportions.

Mix	%Slag	%QP
QP0	100	0
QP5	95	5
QP10	90	10
QP15	85	15
QP20	80	20
QP25	75	25
QP30	70	30

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