



Effect of phosphogypsum on the stability upon firing treatment of alkali-activated slag

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HIGHLIGHTS

- PG shortens the setting times of alkali activated slag cured at room temperature.
- During hydration process sodium sulfate forms in alkali activated specimens.
- The highest compressive strength of specimens is with 5% of PG.
- The specimens with 5% of PG exhibit greater residual strength.

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ABSTRACT

The paper analyses the preparation of alkali-activated slag with phosphogypsum additive. The specimens of alkali-activated slag were tested both at room and at elevated temperatures. It was determined that phosphogypsum shortened the setting times of alkali activated slag mixture cured at room temperature. During hydration process sodium sulfate formed in alkali activated specimens. Compressive strength depends on phosphogypsum amount too. The highest compressive strength MPa of specimens was with 5% of phosphogypsum. Similar situation was after exposure elevated temperatures. The inclusion of 5% phosphogypsum showed the optimum content in which higher residual strength was obtained after being treated at 400, 600, 800 and 1000 °C temperatures. These type specimens exhibited approximately an average of 1.2 times greater residual strength than specimens without phosphogypsum. This means that alkali-activated slag blended with phosphogypsum have great potential applications for fire resistance. It is possible to recycle phosphogypsum in alkali activated slag blends.

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1. Introduction

Alkali-activated materials are a rapidly emerging sustainable alternative to Portland cement binder because of their high strength and durability and low environmental impact. There is a growing interest in the development of new cementitious binders, which enhance optimal utilization of industrial by-products, such as phosphogypsum and slag. Great interest in alkali-activated materials resulted in a large amount of waste recycling. This type of binder has good fire resistance properties and low strength loss in elevated temperature, as well as spalling resistance. Alkali-activated binders are known for superior thermal stability and fire resistance. Several studies were devoted to investigating the durability of alkali-activated binders at elevated temperatures. Rashad et al. [1] investigated the possibility of using granulated

blast-furnace slag as partial or full natural silica sand replacement in alkali-activated slag mortar. The results indicated that the compressive strength of the mortar specimens before and after thermal treatment increased with increasing granulated blast-furnace slag sand content. Park et al. [2] studied alkali-activated fly ash/slag exposed to high temperatures. The strength increase below 400 °C was attributed to the binder gel, which formed after the exposure to heat, thus decreasing the porosity. The crystallization of the binder gel resulted in an increase in the porosity, thereby inducing a decrease in the strength above 400 °C. Lee et al. [3] investigated the influence of binder composition on the gel structure in alkali-activated fly ash/slag paste exposed to elevated temperatures. The amount of crystalline phase formed after exposure to 800 °C is highly dependent on the Ca/Al ratio of the precursor, slag and fly ash. The pore structure of the fly ash/slag paste with a lower slag content after exposure to 800 °C became more porous. Another study [4] focused on developing thermally-stable materials based on alkali-activation of slag, fly ash, and metakaolin

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compared to Portland cement mixtures. Minimal damage after the exposure to high temperature was confirmed. Rashad et al. [5] explained that the presence of quartz powder improved the workability and strength of alkali-activated fly ash pastes. The remaining strength of all types of pastes increased with elevated temperatures. The maximum residual strength was obtained at 1000 °C.

Alkali-activated materials are a new type of binder allowing the utilization of industrial by-products such as fly ash, slag, phosphogypsum is one of the mineral additives often used in alkali-activated materials systems. According to Khater et al. [6], phosphogypsum will enhance geopolymerization process when it added in a lower dose (10% of phosphogypsum was partially replaced fly ash in the fly ash and cement kiln dust mixtures). The results of the study showed that 10% phosphogypsum is the optimum ratio for geopolymer formation. Also elucidate the optimum dose of phosphogypsum that enhance both mechanical and microstructural properties. It can be noticed also, the increase of geopolymeric glassy phase that demonstrated in the XRD pattern in the region 17–35° 2 θ . In this case, the microstructure seems denser with the increase of geopolymer contribution as the excess sulphate in phosphogypsum enhance fly ash dissolution and oligomer formation which in turn forms cross linked geopolymer structure. Strength increase with 10%PG than the control mix which may be due to the lower dose of PG with its sulphate content can enhance geopolymer formation which is affected by both alkalis and sulphate, so both factors can possess an additional activation for pozzolanic or latent hydraulic fly ash materials.

Shen et al. [7] suggests using phosphogypsum as a new retarding agent for alkali-activated cement because the rapid setting process of alkali-activated cement is the main problem for its engineering application. A special admixture made with phosphogypsum retards the hydration process of alkali-activated cement and at the same time controls the setting process. In his previous study

Rashad [8] investigated the possibility of recycling calcined phosphogypsum as a partial replacement of fly ash in alkali-activated fly ash paste. The results showed that the compressive strength before and after firing increased with the inclusion of 5% and 10% calcined phosphogypsum, whilst the inclusion of 15% decreased the compressive strength. The effects of gypsum and phosphoric acid on the properties of sodium silicate-based alkali-activated slag paste was examined in another paper [9]. Phosphoric acid was used as a retarder and gypsum was used as a drying-shrinkage inhibitor. Bakharev et al. [10] reported the results of an investigation of concrete that incorporated alkali-activated slag and the admixture of gypsum (6% by weight of slag). Gypsum significantly reduced concrete shrinkage. Guo et al. [11] used sodium hydroxide and sodium silicate solution to create alkali-activated complex binders from class C fly ash and other Ca-containing admixtures including Portland cement, flue gas desulfurization gypsum, and water treatment residual. The maximum compressive strength of specimens reached 80.0 MPa. These binders can be widely utilized in various applications, such as in building materials, and for solidification/stabilization of other wastes, thus making the wastes more environmentally friendly.

The main purpose of this work was to study the preparation of alkali-activated material by alkaline activation of slag. The effectiveness of phosphogypsum additive on alkali-activated slag was investigated both at ambient and elevated temperatures.

2. Experimental procedures

2.1. Materials

In this study granulated blast furnace slag was used as cementing component. The chemical composition of the slag is given in Table 1. According XRF data, the biggest amount of oxides CaO

Table 1
Chemical composition (based on XRF analysis) of the slag and the hemihydrate phosphogypsum from Kovdor, wt%

Oxides	Phosphogypsum	Slag	Oxides	Phosphogypsum	Slag
CaO	39.06	45.20	Fe ₂ O ₃	0.04	0.793
SO ₃	52.71	1.85	Na ₂ O	–	1.02
SiO ₂	0.34	37.10	P ₂ O ₅ [*]	1.11	0.683
Al ₂ O ₃	0.07	6.44	P ₂ O ₅ ^{**}	0.5	–
MgO	0.21	5.76	SrO	–	0.069
F	0.06	–	BaO	–	0.068
ZrO ₂	–	0.02	TiO ₂	–	0.285
K ₂ O	–	0.517	Loss on ignition	6.4	–

* – Total.

** – Water soluble.

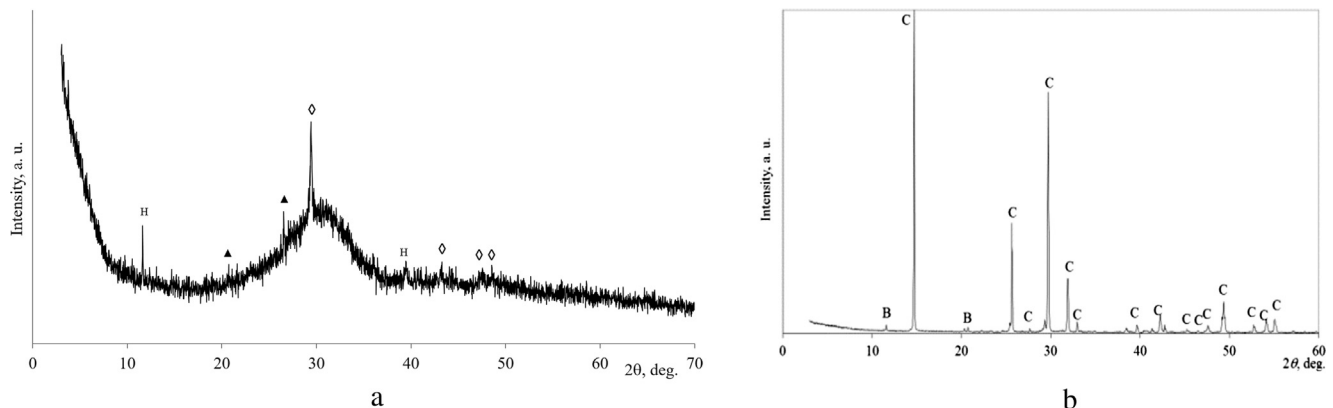


Fig. 1. The X-ray diffraction patterns of slag (a) and phosphogypsum (b). Notes: were H indicates hydrotalcite $Mg_6Al_2CO_3(OH)_{16} \cdot 4H_2O$ (14–191), ▲ – quartz SiO_2 (78–2315), ◇ – calcite $CaCO_3$ (72–1651), B – brushite $CaPO_3 \cdot (OH) \cdot 2H_2O$ (11–293), C – basanite $CaSO_4 \cdot 0.5H_2O$ (33–310).

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