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The effect of type and concentration of activators on flowability and compressive strength of natural pozzolan and slag-based geopolymers

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HIGHLIGHTS

- Production of new geopolymer cement using by natural pozzolan and ground granulated blast furnace slag.
- The effects of different activator types on the flowability and mechanical properties of alkali activated slag.
- The effects of different level of natural pozzolan on the properties of slag-based geopolymer.
- Scanning electron microscopy studies of slag-based geopolymer containing natural pozzolan.

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ABSTRACT

Materials resulting from the alkali activation of GGBF slag show a wide range of workability, compressive strength and permeability. The main objectives of this work are to determine the effects of alkaline solution type and concentration, modulus of sodium silicate, sodium silicate to alkaline solution ratio and natural pozzolan replacement on the workability and mechanical properties of alkali activated GGBF slag. Results reveal that the geopolymer paste specimens containing KOH solution have higher compressive strength when compared with the geopolymer paste specimens containing NaOH solution. The optimum concentration of the alkaline solution is 6–8 molar. It can be concluded that in the presence of 6 and 8 molar alkaline solutions the maximum strength could be reached with 5% and 10% replacement respectively. The optimum range for each factor is suggested based on the different effects of these factors on the compressive strength.

1. Introduction

Concrete is the most widely used building material in the world which is because of its beauty, appropriate mechanical properties and durability in different environments. The concrete industry is one of the major consumers of natural resources. In Portland cement production process, natural resources which must be remained for next generations are being used. On the other hand Portland cement clinker production is an energy-intensive process. This energy is mostly supplied by fossil fuels which is cost-intensive in addition to producing a large amount of greenhouse gas emissions, mostly CO_2.

Therefore any reduction in Portland cement clinker usage reduces energy use and CO_2 emissions. One possible way to reduce energy consumption and greenhouse gas emissions in concrete industry is the replacement of clinker with supplementary cementitious materials (SCMs) that has been used considerably over past five decades. Various researchers reveal that the replacement of cement with SCMs such as GGBF slag, fly ash, rice husk ash, silica fume and natural pozzolan in the production of concrete improves the mechanical properties and durability of concrete in addition to reducing environmental impacts [1–3].

Nowadays, SCMs such as GGBF slag and fly ash are used up to 70% replacement with Portland cement in concrete, while it is possible to produce geopolymer concrete with only Si and Al rich materials and no Portland cement. Geopolymers are cohesive materials and have three dimensional polymeric chain and ring structure consisting of Si–O–Al–O bonds that are formed by alkali activation of Si and Al rich materials such as natural and artificial

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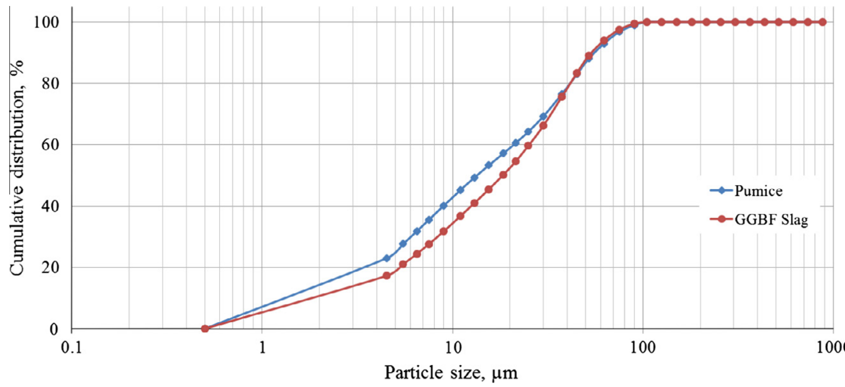

Fig. 1. Particle size distributions for GGBF slag and pumice.

Table 1
Chemical characteristics of raw materials.

Chemical components	GGBF slag	Pumice
Calcium oxide (CaO) (%)	36.75	7.4
Silicon dioxide (SiO_2) (%)	37.21	64.9
Magnesium oxide (MgO) (%)	8.52	1.98
Aluminum oxide (Al_2O_3) (%)	11.56	12.1
Ferric oxide (Fe_2O_3) (%)	1.01	5.2
Sulphate oxide (SO_3) (%)	0.97	0.22
Sodium oxide (Na_2O) (%)	0.61	2.49
Potassium oxide (K_2O) (%)	0.70	1.88
Titanium dioxide (TiO2) (%)	1.23	0.79
Manganese oxide (MnO) (%)	0.99	.123
Phosphor pentoxide (P_2O_5) (%)	0.03	0.2
LOI (%)	0.02	2.5

pozzolans and can be a real alternative to ordinary Portland cement for construction. Highly alkaline solutions are used to induce the silicon and aluminium ions in the raw materials to dissolve and form the geopolymer paste with three steps in the process including: dissolution of any pozzolanic compound, partial orientation of mobile precursors and re-precipitation of the particles from the initial solid phase. It has been found that geopolymer binders can be synthesized by activating natural pozzolans and condensing them with sodium silicate in a highly alkaline environment [4,5].

Geopolymers produced from solid waste as starting material have benefits such as reducing environmental impacts by using lesser amounts of calcium-based minerals, lower manufacturing temperature, lower fuel consumption and lower greenhouse gas emission in comparison with ordinary Portland cement and provides a route towards the concept of sustainable development. Blast furnace slag is a by-product that is formed during the production of hot metal in blast furnace. If the molten slag is cooled and solidified by rapid water quenching, ground granulated blast furnace (GGBF) slag is formed. When crushed or milled to very fine cement-sized particles, ground granulated blast furnace slag has cementitious properties, which is a suitable replacement with Portland cement.

It has been found that GGBF slag-based geopolymer binders can be synthesized by alkali activation of ground granulated blast furnace slag in presence of sodium silicate. The use of GGBF slag as geopolymer binding material requires its preparation involving grinding, alkali activation and hydration [6].

Geopolymer concrete made from granulated blast furnace slag requires less sodium silicate solution in order to be activated. They therefore have a lower environmental impact than geopolymer concrete made from pure metakaolin [7]. Slag-based geopolymer cements are capable of being mixed with a relatively low-alkali activating solution and must cure in a reasonable time under ambient conditions [8]. The physical and mechanical properties of the geopolymer correlated well with the concentration of alkaline solution. Cheng and Chiu [9] used three different KOH concentrations (5, 10 and 15 molar) for alkali activation of GGBF slag. The sample containing 10 M KOH showed the best strength. With increasing KOH concentration to 15 M, the compressive strength decreased which could be due to too much K^+ ions in the framework cavities [9]. The calcium in GGBF slag seems to increase the

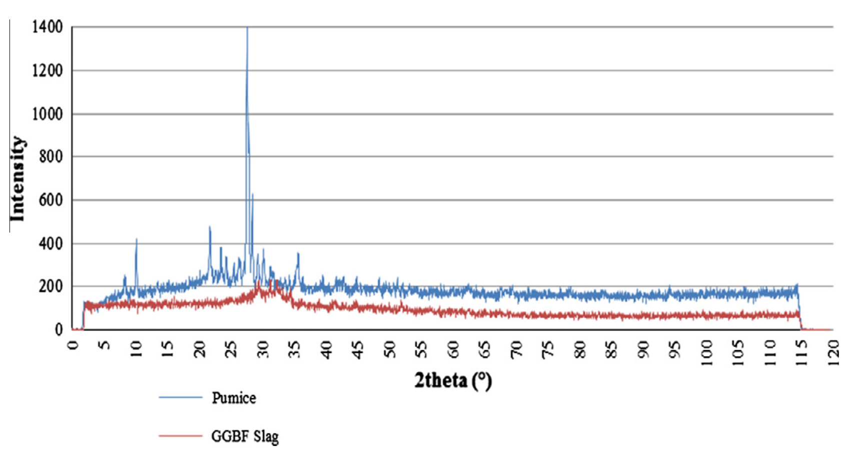

Fig. 2. XRD patterns of GGBF slag and pumice.