

# Effect of water addition, plasticizer and alkaline solution constitution on fly ash based geopolymer concrete performance



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## HIGHLIGHTS

- Additional water improves workability up to 200% but reduces other properties by 27%.
- Admixture improves workability up to 115% but reduces other properties by 25%.
- The optimum molarity of NaOH solution and solution to fly ash ratio are 16 M and 0.40.
- Increasing NaOH to Na<sub>2</sub>SiO<sub>3</sub> ratio has negative effect on GPC properties.

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## ABSTRACT

Using fly ash based geopolymer concrete (GPC) instead of portland cement concrete, partially or totally, can reduce CO<sub>2</sub> emissions released during OPC production, which requires burning large quantities of fuel result in significant CO<sub>2</sub> emissions. Development of GPC became a major concern to widen its usage. This paper is a study of the influence of additional water content, plasticizer content, sodium hydroxide solution molarity, alkaline solution to fly ash ratio and sodium hydroxide to sodium silicate ratio on fly ash based GPC. The studied properties of fly ash based GPC was workability, compressive strength, splitting tensile strength, modulus of elasticity, absorption, and porosity. The results showed that, generally, increasing additional water content increased workability, but decreased other fly ash based GPC properties and the optimum additional water content was found to be 30 kg/m<sup>3</sup> which has slight effect on geopolymer properties. The increase of plasticizer content up to 10.5 kg/m<sup>3</sup> had acceptable effects on GPC properties due to improved workability. The optimum molarity of sodium hydroxide solution was found to be 16 M. GPC properties was significantly affected by alkaline solution to fly ash ratio and 0.40 was expected to be the optimum ratio. Increasing sodium hydroxide solution to sodium silicate solution ratio reduces geopolymer concrete properties; nevertheless, low ratio is not economic due to sodium silicate solution cost.

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## 1. Introduction

The geopolymer cement can contribute effectively to reduce Ordinary Portland Cement (OPC) industry in the future. Provis et al. [1] emphasized that alkali-activated binders are not intrinsically or fundamentally 'low-CO<sub>2</sub>' unless designed effectively to achieve such performance, but when mix design and raw materials selection are carried out with a view towards optimization of environmental performance, the outcomes can result in very significant savings. The use of geopolymer technology not only has the potential to substantially reduces the CO<sub>2</sub> emissions by the cement

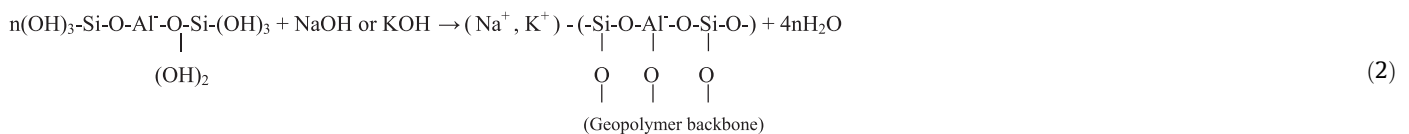
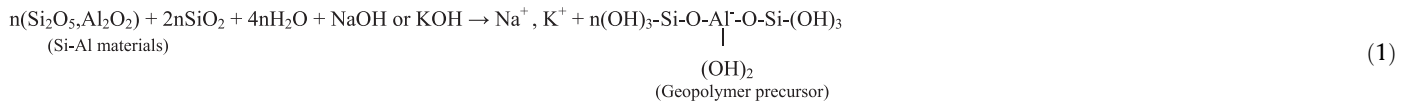
industries, but also utilizes the waste materials such as fly ash. It is to be noted that fly ash, one of the sources for making geopolymer binders, is available abundantly worldwide, and yet its usage to date is very limited [2]. Previous study published in the scientific literature indicated that fly ash based mixtures released 45% less CO<sub>2</sub> than an average Portland cement concrete mixture [3].

The name "Geo-polymer" was coined by Prof. J. Davidovits in 1978 who found that the polymerization process involves a fast chemical reaction under alkaline conditions on Si-Al minerals, that results in 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. The main concept behind this geopolymer is the polymerization of the Si-O-Al-O bond which develops when Al-Si source materials like fly ash is mixed with alkaline activating solution (NaOH or KOH solution with Na<sub>2</sub>SiO<sub>3</sub> or K<sub>2</sub>SiO<sub>3</sub>). The

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geopolymer can be in the form of  $-\text{Si-O-Al-O-}$  or  $-\text{Si-O-Al-O-Si-O-}$  or  $-\text{Si-O-Al-O-Si-O-Si-O-}$ .

The schematic formation of geopolymer material can be shown as described by Eqs. (1) and (2) [4–6]:



The last term in Eq. (2) reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water, expelled from the geopolymer matrix during the curing and further drying periods, leaves behind nano-pores in the matrix, which enhances the performance of geopolymers. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides workability to the mixture during handling.

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite, clays, etc., whose empirical formula contains Si, Al, and oxygen (O) [7]. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. Geopolymers are formed when aluminosilicates, such as fly ashes, dissolve in a strong alkaline solution, reorganize and precipitate in a hardened state [8]. Fly ash suitable for use in geopolymer consists mostly of glassy, hollow, spherical particles, which are cenospheres (thin walled hollow spheres) [9].

It is to be noted that the nanostructure of geopolymers is strongly dependent on the available calcium content of precursors; a high-calcium system such as alkali-activated blast furnace slag is dominated by a calcium aluminosilicate hydrate (C-A-S-H) gel with a tobermorite-like structure [10,11], while low calcium systems such as those based on metakaolin or fly ash tend to generate an alkali aluminosilicate (N-A-S-H) gel with a highly crosslinked, disordered pseudo-zeolitic structure [10,12,13]. These gels can coexist in binders based on blends of high-calcium and low-calcium precursors [14–15].

Geopolymer concrete showed good properties such as high compressive strength, low creep, good acid resistance and low shrinkage [16]. Compressive strength is an essential property for geopolymer concrete where it also depends on curing time and curing temperature for geopolymer concrete. When the curing time and temperature increase, the compressive strength also increases with curing temperature in the range of 60° to 90 °C, between 24 and 72 h [17].

Limited efforts have been made to study the effect of adding water and chemical admixture during the production of GPC in addition to the NaOH to Na<sub>2</sub>SiO<sub>3</sub> ratio [18,19]. So, this work

concentrates on the effect of water addition, chemical admixture (plasticizer) and the alkaline solution constitution on the workability and mechanical properties of fly ash based GPC to achieve more development in GPC industry.

## 2. Materials and experimental program

### 2.1. Materials

Any material that contains aluminum silicate of proper composition in amorphous form is a potential source material for the manufacture of geo-polymer binder. Geopolymer concrete consists of geopolymer cement paste and aggregates. Several mineral and industrial by-product materials have been investigated in the past. The calcined source materials such as fly ash, slag, calcined kaolin demonstrated a higher compressive strength when compared to non-calcined materials [20]. This section discusses in detail the used materials for producing fly ash based geopolymer concrete.

#### 2.1.1. Fly ash

In this study fly ash (ASTM Class F) was used as the main source material for aluminosilicates, the geopolymer binder. Specific gravity of the fly ash was 2.2 and 95% of fly ash was passing through the 45 μm sieve. The chemical composition as determined by chemical analysis is presented in Table 1.

#### 2.1.2. Aggregates

Natural siliceous sand with fineness modulus of 2.45 and pink limestone of 9.5 mm nominal maximum size, were used as natural aggregates. Table 2 presents the physical properties of the aggregates, and the sieve analysis is presented in Table 3.

#### 2.1.3. Alkaline solution

A mixture of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) solutions were used as the activator solution. Sodium hydroxide solution of desired concentration was prepared by mixing 97–98% pure NaOH pellets with tap water. Sodium silicate solution was obtained from a local commercial producer. The chemical properties of sodium silicate is shown in Table 4. The densities of sodium hydroxide solution and the total alkaline solution was about 1.15 and 1.5 g/cm<sup>3</sup>.

#### 2.1.4. Admixture

High range water reducer naphthalene-based admixture (ASTM Type F) was used to improve the workability.

**Table 1**  
The chemical composition of fly ash.

Chemical constituent	Content, mass%
Silicon dioxide ( <b>SiO<sub>2</sub></b> )	62.30
Iron oxide ( <b>Fe<sub>2</sub>O<sub>3</sub></b> )	2.10
Aluminum oxide ( <b>Al<sub>2</sub>O<sub>3</sub></b> )	28.10
Calcium oxide ( <b>CaO</b> )	0.50
Magnesium oxide ( <b>MgO</b> )	1.00
Sulfur trioxide ( <b>SO<sub>3</sub></b> )	0.40
<b>Na<sub>2</sub>O</b>	0.50
<b>K<sub>2</sub>O</b>	1.00
Loss on ignition ( <b>LOI</b> )	2.50

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