# Geopolymer Concrete

Subjects: Others

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Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with a caustic activator, such as fly ash or slag from iron and metal production. It can be a suitable substitute for ordinary Portland cement (OPC).

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## 1. Introduction

Considering the high consumption of concrete and the increasing necessity for cement production, high attention to the environmental degradation effects of this substance is needed [1][2]. These effects include 7% of $CO_2$ emission and the considerable consumption of energy such as electricity and fossil fuels. Hence the provision of alternative products in order to move towards sustainable development is essential. Therefore, the use of an eco-friendly concrete enables the reduction of consumption of ordinary Portland cement (OPC) with activated pozzolanic binders as a replacement, leading to lower emission of $CO_2$ in the atmosphere [3].

Geopolymers are in the family of mineral polymers, in which their chemical combinations are similar to zeolite materials, whereas their microscopic structure is amorphous rather than crystalline. The use of polymers such as concrete adhesives result in the production of geopolymer concrete (GPC) that can be a suitable substitute for OPC [4][5].

Regarding other beneficial aspects of GPC, numerous studies have been presented in favor of usage of GPC as an alternative for Portland cement concrete (PCC). For instance, Albitar et al. [6] presented the arguments to emphasize that durability of GPC is typically superior to that of PCC under similar curing condition, and fly ash (FA) is more chemically stable compared to conventional concrete. Additionally, Liew et al. [7] advocated that the utilization of green concrete provides numerous environmental, technical and economic benefits such as high strength, increased durability, improved workability, reduced permeability, controlled bleeding, superior resistance to acid attack, and reduction of plastic shrinkage cracking. These properties promote faster concrete production, reduction of curing waiting time, reduction of construction costs, early project completion, reduction of maintenance costs, and increased service life of construction projects. The recent study by Li et al. [8] concluded that the green GPC made with a binder of ground granulated blast-furnace slag (GGBS), desulfurization gypsum (DG) and electric arc furnace reducing slag (EAFRS) as cementitious materials and W/S ratio of 0.32 have a high compressive strength, over 50 MPa at 28 days of age. The hydration mechanism of the GGBS-DG-EAFRS system was experimentally investigated utilizing isothermal calorimetry (IC), thermogravimetric analysis (TGA), X-ray diffraction (XRD), and scanning electron microscopy equipped with energy dispersive X-ray spectroscopy (SEM-EDX), which demonstrated that the combination of GGBS-DG-EAFRS pastes as the specific type of geopolymer materials have significantly lower hydration heat in comparison with OPC. GGBS was activated through $Ca(OH)_2$, available in EAFRS and gypsum from DG [8].

Most experimental programs have been carried out in this case, nevertheless what needs to be considered in the present research is the evaluation of the comparative study between GPC and PCC, as well as the assessment of the various combination of GPC, which is based on three central issues:

- The effects of chemical admixtures such as silicon dioxide ($SiO_2$) powder on the improvement of physical and mechanical properties of this concrete type.
- The efficiency of chemical activators at different molar concentrations for the performance of GPC concrete using various ratios of these solutions in the mix design.
- The effect of FA and other pozzolanic admixtures such as GPC content in concrete mix design in order to achieve optimal combination and the optimum ratio of alkaline activator.

## 2. Properties of Portland Cement Concrete with Geopolymer Materials as Partial or Entire Replacement

In experimental tests, the 28-day compressive strength is typically examined at the laboratory, however, considering the acquired results from geopolymer compressive strength, it seems that there is a slight increase over the period from 28 to 90 days; hence it is deeply suggested that the compressive strength would be measured for this type of concrete at age of 90 days as well. Despite the slight increment in the compressive strength of GPC observed at 28 days, most of its compressive strength was developed at seven days due to heat curing accelerating the geopolymerization reaction, resulting in the increase of compressive strength.

Direct comparison of GPM and PCM mixes prepared with the same paste amount and two different classes (normal of 37.5 MPa and high of 60 MPa) exhibited that workable GPC mixes could be provided by minimum water value compared to PC mixes. Thus, GPCs have much shorter initial and final setting times than those obtained by PC, which causes GPCs to obtain very rapid enhancement for compressive strength which is 55–66% of their entire strength at 28 days in comparison with PCs which achieved 18–28% over this time period [9].

Fly ash class and superplasticizer type are the key factors in the improvement of workability for GPC. The type of activator, such as simple or multi-compound, has a notable role in the workability and the compressive strength of fly ash. The experimental test with multi-compound activator and the ratio of $Na_2SiO_3/NaOH = 2.5$ and has higher slump and compressive strength compared to fly ash activated by NaOH. With regard to the better performance of PC for FA class C (low silicate, high calcium), this phenomenon is probably due to the high dispersive capability that appeared in class C, which is strongly related to the presence of positively charged calcium cations leading to the stiffness reduction and fluidity enhancement in concrete mixes [10].

The specific reason that PC was the most effective SP in AAMs, especially where w/b is 0.4, could be due to the presence of several lateral chains on PC molecules causing steric repulsion improving the plasticizing effect of PC [11]. Besides the effect of N-based SP in workability, it can drastically decrease the alkaline activator to slage ratio resulting in notable improvements for compressive strength, provided that FA-based GPC is activated by only NaOH solution [12]. This can be justified due to the fact that N-based SP is the unique type of SP which is chemically compatible with NaOH solution [13].

According to the investigation by Mehta and Siddique [14], it is clear that the values of compressive strength at all ages were gradually increased due to OPC replacement by 20%, and exceeding that, this trend was reduced. Based on this study, the highest value of 66.81 MPa compressive strength was obtained for the specimens with 20% OPC at 365 days due to further reaction occurring between OPC and the use of alkaline solutions in this research. C-A-S-H and C-S-H were achieved as an additional hydrated product which has coexistence with N-A-S-H as additional phases [15][16][17][18]. The extra heat increased the effective curing temperature for polymerization and further enhanced the formation of N-A-S-H because of the exothermic nature of the hydration reaction. The additional calcium also accelerated hardening and dissolution by preparing extra nucleation sites. On the other hand, the enhancement of OPC beyond 20% led to an increase in calcium content and consequently, a reduction of silica and alumina values, which was due to high calcium amount and low silica and alumina in OPC. On the contrary, in the chemical combination of fly ash, less calcium and high amount of silica and alumina are available. Thus, this led to the lack of sufficient alumina and silica in order to produce N-A-S-H polymerization in this concrete mix design. Also, higher calcium increased the water demand for hydration, which was released from water-filled pores resulting in extra void spaces. Therefore, it can be concluded that the optimal amount of OPC that would be effective for the high compressive strength of this type of concrete is 20% based on the findings achieved in this research.

Based on the study by Moon et al. [19], it is known that the compressive strength is directly associated with porosity and water absorption. This means that an increase in compressive strength resulted in the reduction of porosity and water absorption up to 20% OPC, whereas there was a slight increase for the rate of water absorption and porosity while increasing the value of OPC by 30% in this attempt. Other obtained observations from the specimens at ages of 90 and 365 days are in accordance with the previous test (28 days). The main significant reason for this phenomenon is the fact that the addition of OPC co-existed with GPC products (N-A-S-H, C-A-S-H) due to the additional hydration products. This resulted in incremental concrete strength and the reduction of water absorption in a concurrent manner. As discussed above, there is a substantial increase in the compressive strength of concrete with the high amount of fly ash after seven days more than that of OPC due to pozzolanic reactions. The difference of approximately 10% can be seen in the mean values of compressive strength of fly ash.

Type V cement plays the main role in terms of the sulfate attack as it contains limited values of $C_3A$ (tricalcium aluminate) and $C_4AF$ participating in the process of chemical sulfate attack, however most companies are struggling to find a more comprehensive solution which resists against sulfate attack better than this type of cement. Some literature in recent years have proved that the use of fly ash, particularly low-calcium or class F, effectively enables an increase in concrete resistance against sulfate attacks [20][21][22][23][24][25][26][27]. However, the improvement of concrete resistance to sulfate attack by the use of class C fly ash containing a high value of calcium is suspected as the materials with rich lime have the ability to produce their own calcium hydration independently. Therefore, the concrete containing fly ash with a high value of calcium is to be exposed against sulfate attack. It also can be realized that class F fly ash is quite effective on the permeability reduction of concrete, however, the optimum percentage of fly ash as the major factor should be considered to obtain more appropriate results [28].

It was noted that a 50% cement replacement ratio has the highest value of mechanical properties such as compressive strength comparable to other concrete mixtures produced by the replacement ratio of 0%, 25%, 75%, and 100% [29]. Furthermore, "Does this cement replacement have similar effects on other concrete mixtures produced from other Portland types (Portland type 2)?" is arguably an important question to be investigated, however other significant factors such as binder materials and activator solution ratio can be considered towards a more profound understanding of the chemical solution role in different concrete mixtures in the near future.

Workability is typically attributed to liquid-to-solid ratio in most concrete mixtures such as natural pozzolan-based alkali-activated concrete. In laboratory schedule by Ibrahim et al. [30], very low slumps were measured for concrete mixtures composed of different binder content and alkaline material, which revealed a number of gaps and shortcoming in this case. Based on the outcomes of this research, it seems that the higher binder content is beneficial for the concrete mixtures containing the low ratio of water-to-solid compared to those with lower values of binder content and sufficient workability, which was achieved from the mixtures including high concrete binder in spite of the low ratio of water to solid.

Generally, the improvement of compressive strength in the concrete mixtures thoroughly consisted of pozzolanic additives (100% natural pozzolan) as the replacement of cement Portland is associated with the following factors:

- Binder content (fly ash quantity)
- Sodium silicate-to-sodium hydroxide (SS/SH) ratio
- Alkaline solution-to-binder ratio

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