

# Experimental Investigation on Compressive Strength Enhancement of Geopolymer Paste Fly Ash/ Slag Based Cured at Ambient Condition

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## Abstract

In this paper, the effects of ground granulated blast furnace slag (GGBFS) content proportion on the development of compressive strength of geopolymer pastes were studied. Eleven geopolymer pastes mixes replacement (0% to 100%) by increment (10%) of binder (Fly Ash) by GGBFS with three mini-size specimens (50-mm cube) compression tests were conducted at ambient condition ( $30 \pm 2$  °C). Class F-fly ash (FA) and GGBFS were used as aluminosilicate source. The alkaline activator was a combine of sodium silicate (SS) solution and sodium hydroxide (SH) solution with (SS/SH) ratio of (2.0) and molarity of sodium hydroxide of (10M). Based on the test results, it was found that the addition of ground granulated blast furnace slag (GGBFS) to geopolymer paste based fly ash caused increase significantly of compressive strength when cured at ambient condition, and the optimum mix was found to have GGBFS content of 100%, can be improved the compressive strength as high as (74% and 62%) at 7 and 28 days respectively. The reason for this trend is that the increasing forming of calcium silicate hydrate C-S-H gel of geopolymer pastes containing a large amount of GGBFS caused more denser microstructure. Lastly, it is worth noting that this test methodology used in this study is for the purpose of determining the best ratio of slag replacement with fly ash in geopolymer paste, to give the highest improvement ratio in compressive strength compared with the reference (Fly Ash based geopolymer paste).

**Keywords:** fly ash, slag, geopolymer paste, compressive strength and ambient curing.

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## 1. Introduction

Currently, climate change due to global warming occurs is proven by scientific consensus overwhelming majority. Climate change is one of the major sociality politically, economically and environmentally affair that will own long term impact over living creatures on this whorl [1]. The climate change is due to the resurrection of greenhouse gases, like carbon di-oxide CO<sub>2</sub>, into the

atmosphere through human activities. Among other greenhouse gases, carbon di-oxide CO<sub>2</sub> forms about 68% of universal warming. The Manufacture of Ordinary Portland cement OPC is responsible for about 6-8% of all CO<sub>2</sub> emissions, because the cement production process emits a huge amount of carbon di-oxide CO<sub>2</sub> to the atmosphere that significantly contribute greenhouse gas emissions [2,3,4]. It was evaluated that for one ton of Ordinary Portland cement manufacture one ton of carbon di-oxide CO<sub>2</sub> is released into the atmosphere, this is creating a challenging situation in the world of concrete [1,2,5,6]. In view of this, various researchers have attractive extensive research attention to utilize cementitious properties of fly ash and ground granulated blast furnace slag (GGBFS) by-products industries to develop sustainable alternatives for conventional cement [7]. On the other hand, the abundance and availability of slag and fly ash worldwide promote to usage these by-products, as performance enhancer and partially or totally replacing the OPC [8]. Therefore, the French researcher Davidovits in 1978 invented geopolymer material [3,5]. Geopolymer materials have a major ability to substitution OPC raw source materials and greatly reducing energy consumes and emission of carbon di-oxide CO<sub>2</sub> [7]. Ingredients of the geopolymer materials are important source of aluminosilicate that react with alkaline activator via polymerization process [1,7,9]. Hence, It was found that the chemical composition of source materials and alkaline activators have been influenced significantly on the mechanical properties of the geopolymer materials [7,10,11]. However, to access high mechanical properties of geopolymer based- fly ash essentially required high temperature (i.e. over 40 °C) in early curing stage to achieve enough rate of strength development [12-18]. This limited the utilization of geopolymer with structural construction. Therefore, a significant amount of research has been conducted to explore the increase compressive strength of geopolymer with ambient curing. That have been achieved in geopolymers by improving the microstructure of geopolymer matrix after addition of more calcined source materials. So, the previous studied reported that to reduce the requirement of elevated curing temperature, was adding calcium-carrying materials such as ground-granulated blast furnace slag (GGBFS) that have been added to geopolymers incorporating GGBS in fly ash-based geopolymer mortar due to increase in

compressive strength but accelerate setting times, and reduce workability, to improve it was adding superplasticizers in mixes [18]. Hence, predicts incorporation of GGBFS in the geopolymer specimens is attributed to the forming of more compact microstructure of the binder [19,20]. In the latter case, is produced a C-S-H gel as a hydration process result, in addition to N-A-S-H gel at the early duration [3,9,10,11]. To date, there are not any published studies on the compressive strength of the geopolymer paste made of replacement ratio (i.e. 50% to 100%) of fly ash by slag under ambient condition. Accordingly, the aim of this work is to show the effectiveness of GGBFS incorporation with fly ash type F on the compressive strength development of geopolymer paste when cured under ambient condition. This paper, illustrate the first experimental study on producing geopolymer paste over extensive range of the fully replacement fly ash with slag from 0% to 100% by increment 10%, thus introduced as novel approaches to promote compressive strength of the geopolymer paste based on slag at ambient condition. That made it provides of the potential utilization of geopolymer paste as an in situ construction material cured at ambient temperatures.

## 2. Experimental Scheme

### 2.1 Material

Eleven types of geopolymer paste (GP) mixture were produced to analysis the effect of GGBS on the compressive strength development at the same flowability. Ground granulated blast furnace slag (GGBFS) and low calcium 'Class F' fly ash (FA) according to ASTM C618 [21] were utilized as binder materials in current research. Table 1 shows the X-Ray Fluorescence (XRF) for chemical oxides composition of the fly ash (FA) and slag. That was conducted at the Science and Technology Center in Baghdad.

Activator solution was admixture of sodium silicate (SS) solutions ( $\text{Na}_2\text{SiO}_3$ ) and sodium hydroxide (SH) solutions (NaOH) (Kuwait origin). Chemical composition of sodium silicate (SS) was obtained from the regional source that shown in Table 2. The sodium hydroxide (SH) had 95–97% purity and (10M) was chosen as a molarity, was prepared by melting with distilled water, which had been suggested to obtain sensible compressive strength development in another research [22]. The materials used are given in Figure 1.

Table 1: The chemical composition of GGBFS and FA.

Chemical oxides analyze	FA (w. %)	GGBFS (w. %)
$\text{SiO}_2$	11.75	9.808
$\text{Al}_2\text{O}_3$	2.513	1.305
CaO	1.175	25.35
$\text{Fe}_2\text{O}_3$	6.461	0.9038
MgO	0.106	0.36
$\text{SO}_3$	0.1303	0.4169
$\text{K}_2\text{O}$	1.763	0.6969
$\text{Na}_2\text{O}$	< 0.3	< 0.39
LOI	1.57	1.64
Specific gravity	2.24	2.79418

Note: w.%, that mean a percentage of the compound weight.

Table 2: The chemical composition of sodium silicate.

chemical composition	$\text{Na}_2\text{O}$	SiO	specific gravity	viscosity
Sodium silicate (%)	13-13.5	29-32	1.54-1.552	620-1180



Figure 1: The materials used.

## 2.2 Preparing Geopolymer Mixture

Totally eleven geopolymer paste (GP) mixtures were prepared. Table 3 shows the proportions of the mixtures. The primary binder had been FA with exchange (%0 to 100% increment 10%) by slag with increasing activator solution to obtain the same flowability of geopolymer paste, because the increasing of slag replacement ratio

addition lead to decreasing the flowability. The alkaline activator was prepared at least 24 hours before casting. The mass ratio of sodium silicate (SS) solution to sodium hydroxide (SH) solution (SS/SH) was constant as (2). In this study, concentration of (NaOH) solution is taken as (10M), at each mixture. The samples were labeled according to the (GGBFS) proportion usage in the mixture.

Table 3: Mixture proportions of geopolymer pastes.

Mixture	Binder (w%)		F/B	Solution (kg/m <sup>3</sup> )	
	FA	GGBFS		NaOH (10M)	Na <sub>2</sub> SiO <sub>3</sub>
GP- F100S0 <sup>a</sup>	100	0	0.330	236	474
GP- F90S10	90	10	0.360	236	474
GP- F80S20	80	20	0.387	236	474
GP- F70S30	70	30	0.418	236	474
GP- F60S40	60	40	0.448	236	474
GP- F50S50	50	50	0.478	236	474
GP- F40S60	40	60	0.508	236	474
GP- F30S70	30	70	0.518	236	474
GP- F20S80	20	80	0.528	236	474
GP- F10S90	10	90	0.538	236	474
GP- F0S100	0	100	0.548	236	474

**Note:** <sup>a</sup> GP-F100S0 represents the geopolymer paste mixture having: 100% fly ash (FA) and 0% slag (GGBFS). F/B represents the fluid to binder ratio.

## 2.3 Mixing and Curing

Firstly, The activator solution was prepared in the laboratory at least 24 hours before using. To get the required molarity sodium hydroxide flakes were dissolved in distilled water and mixing sodium silicate (SS) solution and sodium hydroxide (SH) solutions at the desired ratio about half hour before factual mixture of the geopolymer paste [9,23].

This was followed by putting weighted Fly ash and limited replacement proportion of GGBFS for each mix and mixed together, by using electric-mixer for 2 minutes. Then, adding the activator solutions to the dry

mixture and the mixing continued further for about 4 minutes to produce fresh geopolymer paste [9,10,23]. Accordance to the ASTM C109 [24], three standard specimens mold (50×50×50 mm cubes) were prepared to estimate the compressive strength. The GP specimens were casting in two layers and for compact the specimens using a vibration table for about 30 second. To avoid excessive moisture loss of the GP specimens were completely covered by plastic bagging through curing duration and cured at ambient temperature (30 ± 2 °C). Then, demolded and storage in room temperature even testing day. At the age 7 and 28 days compressive strength was tested. Figure 2 shows stages of the experimental work.



Figure 2: Experimental work stages (casting and curing).

### 3. Results and discussion

#### Compressive strength development

Compressive Strength is the most important properties usage as an indicator of the other mechanical properties .Where the other properties frequently connected well with the compressive strength .Figure 3 shown the impact of the various concentrations of GGBFS on the compression in (7 and 28) days. The graph shows that the

increase GGBFS content in the mix (three cubes of specimens cured at ambient temperature) leads to increase the compressive strength development. Figure 4, shows that the mixture containing 100% slag have biggest compressive strengths than the other mixtures, its highest than the reference ( Fly ash only ) mixture by (74% and 62%) at (7 and 28) days respectively. Generally, it was noticed that there was a significant development in compression with the raising of percentage GGBFS in all curing period, when compared with the reference mix.

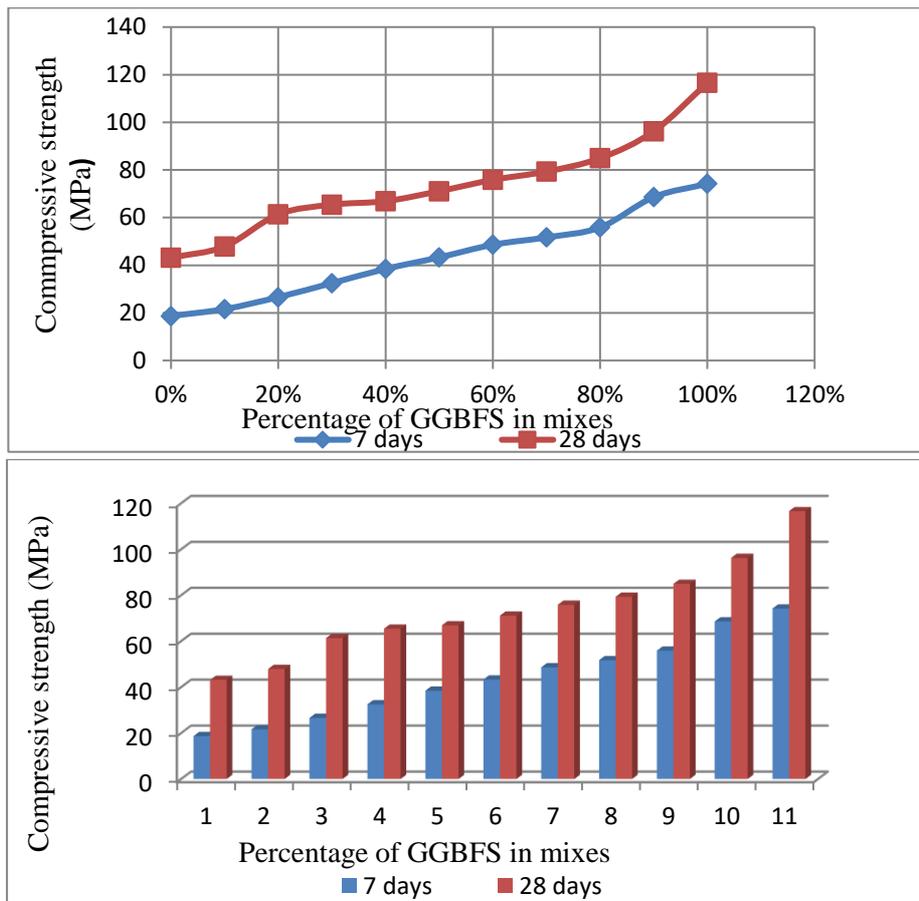


Figure 3: Compressive strength development.

Compressive strength of geopolymer paste for mixes containing (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) GGBFS, at 7 and 28 days, were increased by percentage (14%, 29.7%, 42.4%, 51.3%, 56.8%, 61.5%, 63.83%, 66.53%, 72.7%, and 74.8%) and (10%, 29%, 34%, 35.5%, 39.3%, 43.1%, 45.6%, 49.2%, 55.16%, and 62%) respectively. The reason for this trend is that the increasing forming of calcium silicate hydrate C-S-H gel of geopolymer pastes containing a large amount of GGBFS caused more denser microstructure [9, 14]. The variation of compressive strength at 7 days had a higher trend compared with the 28 days due to formation sufficient amount of calcium silicate hydrate gel (C-S-H) as a result of CaO content in GGBFS is high along with sodium aluminate silicate hydrate gel (N-A-S-H) in microstructure to become very denser in early stage.

#### 4. Conclusions

Eleven geopolymer paste GP mixtures were tested to investigate the impact of different slag content at room temperature. The following conclusions can be summarized as follows:

1. Addition of ground granulated blast furnace slag (GGBFS) to geopolymer paste based fly ash caused increase significantly in compressive strength when cured at ambient condition.

2. Ambient curing temperatures for in situ construction could be used for geopolymer paste with 50% to 100% GGBS content.
3. An increase in the alkali-activator solution content produced a more flowability of geopolymer paste that required longer durations to set.
4. The optimum replacement percentage of GGBFS in mixture which shown the better increment in compressive strength is 100% of binder. Compression at the optimal proportion mixture of GGBFS was bigger than the reference by (74% and 62%) at 7 and 28 days respectively.

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