Performance Of Ggbfs As Replacement On Workability, Setting Time And Compressive Strength Properties Of Fly Ash Geopolymer Concrete Precast Elements Cured In Ambient Temperature

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Abstract: This paper illustrates the posterior results of the experiments that are done to testify the functionality of Ground Granulated Blast-furnace Slag (GGBS) as a replacement of workability, time set, and compressive force features of geopolymer concrete fly ash precast elements treated by ambient temperature.The rapid setting is a common disorder characterized by difficulty of the casting of the geopolymer concrete fly ash which needs materials to be added to limit the rapid setting and enhance the properties. Therefore, the curing process of the geopolymer concrete fly ash must be determined to decrease the growth of cracking resulting from the hydration of the mix.Three mixes were examined with various ratios of GGBS (10%, 30%, 50%) and the one mix without any replacement is contained 100% fly ash as a control mix.Throughout a rational mix,the design was occupied to get an optimum the optimum mix proportions, the alkaline Alkali, which is a solution that is utilized for the sake of this study, and it consists of sodium hydroxide sodium and silica fume solution were added to the binder at a concentration of 25%.Tests were executed on the following three dimensions: 100x, 100x , and 100mm cube Geopolymer mortar samples.Two fly ash types are used in this study, and they are class C and class F, and they were examined via Energy Dispersive X-ray (EDX) and scanning electron microscope (SEM) in order to preserve their phases. The incorporation of GGBS with Class F fly ash helped in reaching achievable time setting and compressive strength for precast elements in comparison to those of class C Fly ash geopolymer concrete. Another substantial finding was achievingground highly amount of GGBS on fly ash geopolymers, and it is appropriate for restoration without the presence of high heat.

Keywords: geopolymer (GP) ,geopolymer concrete (GPC), fly ash (FA), ground granulated blast-furnace slag (GGBFS), precast elements.

I. INTRODUCTION

In the new global environment, greenhouse gas emissions have become a central issue for environmental protection agencies. The main source of greenhouse gas emissions from human activities in most world countries is from burning fossil fuels for energy. Human activities are accountable for almost all of the inflation in greenhouse gases in the atmosphere over the last two decades [1]. The CO_2 emissions of concrete are a common disorder characterized by some effects on human health. A major component of concrete is cement, which has its own environmental and civil impacts and contributes broadly to those of concrete. A considerable literature has been published on industrial waste materials such as slag and fly ash, these researches have stated and explaining the significance of exploitation of these materials to convert it into positive effects particularly to enhance the concrete properties and make it environmental friendly [2].

There is a consensus among researchers and scientists that more recent attention has focused on the reduction of CO_2 emissions by using waste materials as an alternative with cement content in the concrete paste. Meanwhile, it is worth trying to find new methods and designs to gain the best performance of concrete [3]. Geopolymer concrete can be defined as configuration resulting by polymerizing the aluminosilicates materials such as fly ash (FA), Aluminium trihydrate (ATH), metakaolin (MK), slag (SG), rice husk ash (RHA), and high calcium wood ash (HCWA) through activation and current chemical reaction using an alkaline solution like hydroxide sodium. Therefore, the sufficiency in generating geopolymer concrete is tremendously dependent on the activators as well as and the types of aluminosilicates qualities, features, and resources [4], Geopolymer Concrete (GPC) also known as Earth Friendly Concrete (EFC). The use of GPC/EFC is distinguished by low environmental impact through the reduction of greenhouse gas emissions and low cost. It is reported that GPC is fast becoming a key instrument in improving the durability and strength of concrete [5].

High-early strength is one of the considerable characteristics of geopolymer concrete whether under ambient temperature or oven cured, predominantly room temperature curing is common for geopolymer concrete [6]. It was used to produce precast elements for structures such as pre-stressed concrete building members. This strength obtain is a feature that can be the most outstanding thing in the precast concrete manufacture where kind of curing or heated plays a virtual role in the increase of precast elements productions[7].

The durability and strength of concrete are of valuable meaningful which is confirmed the performance of precast concrete components during structure life. Chemical attacks should avoid it in concrete structures where is one of the major durability aspects, causing huge costs to be spent globally in retrofit and strengthening of concrete structures [8].

The fly ash with low level of calcium (ASTM Class F) based geopolymer is can be defined as the binder replacement with ordinary or further types of cement paste to generate concrete mixture. This Class F fly ash-based geopolymer paste combines the unconstrained aggregates and further non-reaction materials to make the geopolymer concrete whether admixtures been added or not [9]. Numerous studies have attempted to investigate that The fly ash with low level of calcium (ASTM Class F) is better source material than high level of calcium (ASTM Class C) fly ash [10]. The main differentiation among Class F and Class C is that the amount of calcium in Class F is lower than Class C [11] accumulations that may cause a decrease in strength [12] and low rate of reaction and hydration [13]. The low-calcium fly ash (class F) based geopolymer is can be defined as the binder replacement with conventional or other types of cement paste to produce a concrete mixture. This sort of fly ash-based geopolymer concrete consolidates the unaffected aggregates and further non-response materials along together to prepare the geopolymer concrete paste whether adding of admixtures or without it [9]. Due to the low amount of calcium in Class F fly ash there will be reduction in strength due to accumulations [12] and reduced rate of reaction [13]. Whilst, several authors have found that class C fly ash has pozzolanic properties more than the class F, which it has cementitious property [14]. And calcium content is a fundamental role in enhancing the fresh and hardened properties [15].

To date, various methods have been developed to improve fly ash-based geopolymer concrete whether at room or oven temperature, considerable studies destined to boost the hydration of fly ash in the alkaline atmosphere resulting in gaining the strength of geopolymer concrete [16] and by combining additional chemical components like silica fume and GGBFS, metakaolin and any supplementary materials [17]. This study is limited to use low and high calcium fly ash (Class F and C) based geopolymer concrete in as replacement GGBS at 0, 10, 30 and 50% in an ambient and oven temperature (75ºC) cured system and its impact on compressive strength and fresh, chemical and mechanical properties such as workability, chemical composition (SEM and EDX), setting time and consistency were tested at different ages up to 28 days.

II. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Fly ash

Throughout this paper, Class F fly ash, which has a lower amount of calcium than class C, was utilized as the main material [18]. Specific gravity is 2.1 and fineness is 390 m^2/kg. The color and shape of the fly ash class F demonastrated in Figure 1(a). Another Fly ash type was used in the concrete mortar which is named Class C dry fly ash [18] obtained froma commercially availablelocal company. Specific gravity is 2.74 and fineness is 316 m^2/kg. The chemical compositions of two types of fly ash are determined by EDX analysis, also the particle size of two types is 5 µm and given in Table1.The color and shape of the fly ash class C illustrated in Figure 1 (b).

(a)

(b)

Figure 1. Fly Ash powder: (a) Class F and (b) Class C

2.1.2 Ground Granulated Blast furnace slag (GGBFS).

GGBS is used as cementitious substance according to HS 2618 [19] and used as a partial alternative to the Fly Ash with 10%, 30%, and 50% by weight. The chemical mixture of slag majorly depends on the type and how the steel is manufactured and many other secondary factors as well. The most known chemical constitution oxides ranges are simply listed in Table 1 satisfied with the ASTM C989-04 requirement is presented.

Table 1 Chemical composition for Fly ash class C, class F and GGBFS by EDX

Chemical Composition%	Fly-Ash class C	Fly-Ash class F	ASTM C618-15 requirement	GGBS	ASTM C989-04 requirement
C	2.1	-	-	-	-
MgO	5	1.3	-	6.2	-
Al2O3	18.56	29.61	-	16.46	-
SiO2	30.23	49.45	-	31.5	-
SO3	2.35	0.27	5% Max.	3.69	4% Max.
KO2	1.55	0.54	-	-	-
CaO	17.13	3.47	-	41.26	-
Fe2O3	23.08	10.72	-	1.33	-
S	-	-	-	1.87	2.5% Max.
Al2O3+ SiO2+ Fe2O3	71.87	87.78	70% Min.	-	-

2.1.3 Alkaline Activator

The alkaline liquid used was a combination of silica fume solution and sodium hydroxide solution. Silica fume activator (SFA) used represents a solution a product gained from a defined suspension of silica fume and water solution of alkali compound.Sodium hydroxide is used as a high pH activator of sodium persulfate. Sodium hydroxide is most commonly used in the field at a concentration of 25%.

2.1.4 Aggregate

The locally available crushed stone coarse aggregate has been used. The physical properties of the coarse aggregate used are 2.65 specific gravity and water absorption of 0.88%. This sand used in this study is satisfying to [20] standard for sieve analysis, [21] and [22] standard for specific gravity and water absorption. The specific gravity and water absorption of the sand are 2.52 and 1.68% respectively.

2.1.5 Superplasticizer

DynmoBT4 superplasticizer was used as a liquid admixture with specific gravity 1.10 at 25ºC for quality concrete with a reduced loss in concrete. The volume of DynamoBT4 from 0.5 to 1.5 liter per 100 kg of cement with density according to ISO 758 (g/cm^3). Regarding the sieve analysis procedure and specific gravity and water absorption tests**,**the testing method used to determine the aggregate grading is in accordance with [24]. Dry sample with constant weight ata temperature of ± 5 ºC. Select sieve sizes as specified by ASTM for aggregate grading. Aggregate the sieves in order of decreasing from the top to bottom. Shake the sieve using a mechanical apparatus for a sufficient period. Determine the weight of material retained on each sieve.

2.2 Methods

2.2.1 Mix proportion

Four mixes were used in this study for testing. W/b ratio is constant at 28%. The Fly Ash is replaced with GGBS at different percentages of 0%, 10%, 30%, and 50% by weight to produce binary blended GP concrete. The mix ratios are listed in shown Table 2 for GPC where all the units in kg and the amount of aggregate divided into half fine aggregate and another half coarse aggregate.

Table 2 Mix Ratios for GPC

No	Mix	FA(class F and class C)	GGBFS	NaOH	SF	SP	Water	Aggregate
1	100F0GGBFS	474	_	61.6	46.2	1.5 % Cement content	163	1586
2	90F10GGBFS	426	48	61.6	46.2	1.5 % Cement content	163	1586
3	70F30GGBFS	332	142	61.6	46.2	1.5 % Cement content	163	1586
4	50F50GGBFS	237	237	61.6	46.2	1.5 % Cement content	163	1586

Preparing and weighing the materials for each mix then adding some water to wet particles as absorption percentage to the coarse and fine aggregate to make layer cover the aggregates layer to reach the saturated surface dry condition where dividing the water at this stage as 60% to coarse aggregate and 40% to fine aggregate and mix them with the Fly Ash in the case of preparation of single binder GP concrete specimen, mix them with FA and GGPS in case of binary blended GP concrete and to produce ternary blended GP concrete the prepared aggregate is mixed FA, GGBS. The alkaline activator and the admixtures were separately added and the whole mixture blended for three minutes to make up the Geo-polymer concrete. All the mixtures then cast in 100×100×100 mm steel cube molds were cast and tested as per [25] and compacted through vibration using table vibration for two minutes. And then, kept at the laboratory temperature and humidity. All specimens are cured at the ambient temperature to be tested for compressive strength, workability, and setting time after 28 days of curing.

2.2.2 Procedure of Mixing, Casting, and Curing

Prior to commencement, all required dry and wet batch constituents should be weighed/measured. Then starting to mix by adding water gradually for wetting the raw and fine aggregate to reach the recommended condition of saturated surface dry and mix them with the Fly Ash in the case of preparation of single binder GP concrete specimen, mix them with FA and GGPS in case of binary blended GP concrete and to produce ternary blended GP concrete the prepared aggregate is mixed FA, GGBS. The alkaline activator and the admixtures were separately joined the mixture and blend it for five minutes. All the mixtures then cast in 100 mm steel cube molds and compacted by table vibration for two minutes. The molds were demolded after 24 hours and then, kept it at the laboratory temperature and humidity. The specimens are cured at the ambient temperature to be tested for compressive strength at 3,7,14 and 28 days after curing.

2.2.3 Chemical Composition

Microstructure for Fly-Ash class C, GGBS and Fly ash Class F was investigated through scanning electron microscope images for three It was found that Fly-Ash particles are amorphous and spherical shaped of 150 µm to even less than 1 µm, while, the GGBS's particles are irregular in shape, ranging from 1µm to 100 µm, which in accordance to Chindaprasirt et al. 2009 shown in Figure 2, these results are satisfactory. For fly ash SEM analysis for class C shown in Figure 3.a, and for fly ash class F shown in Figure 3.b.

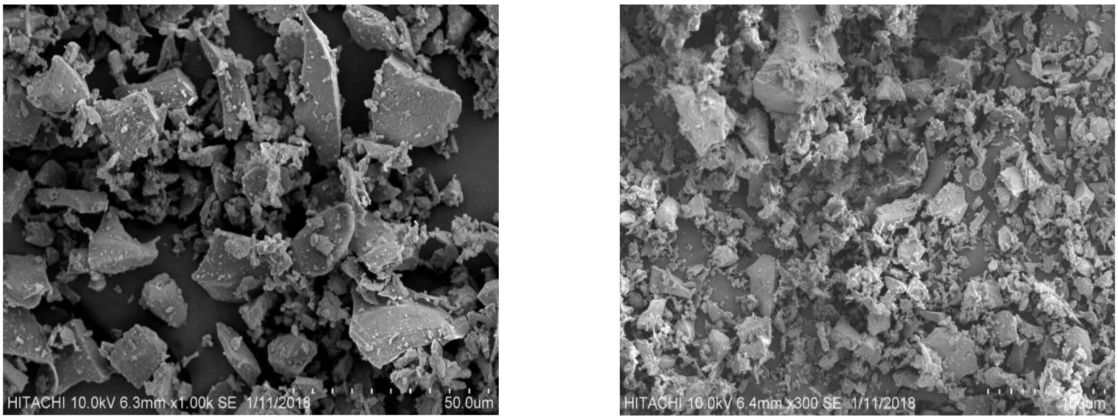
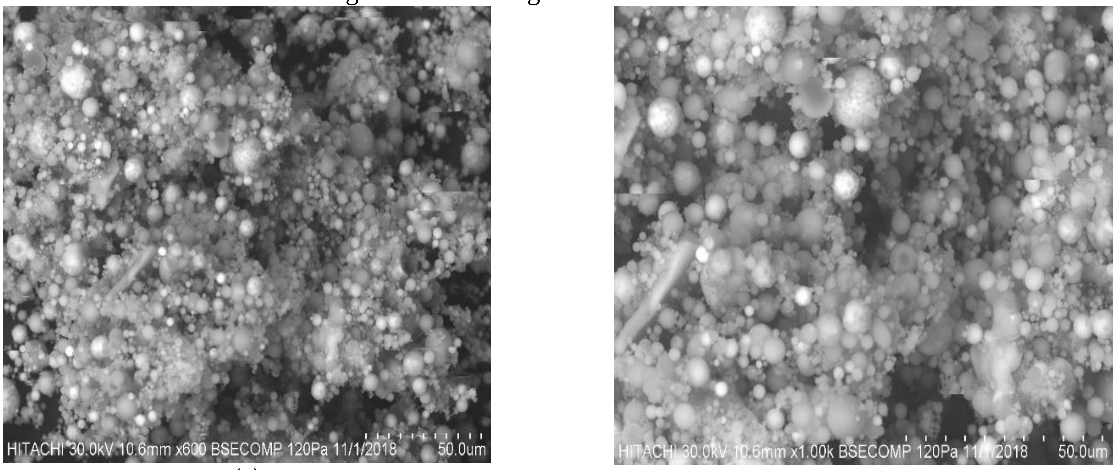


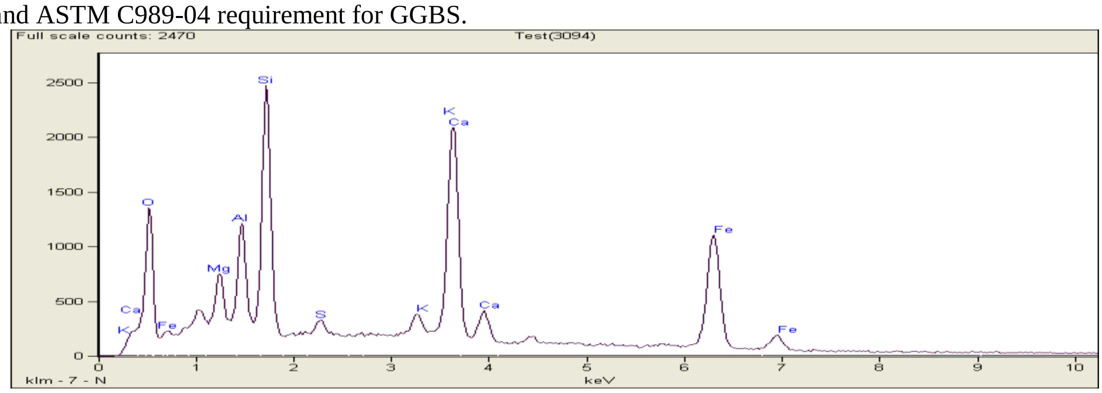
Figure 2. SEM image for GGBS



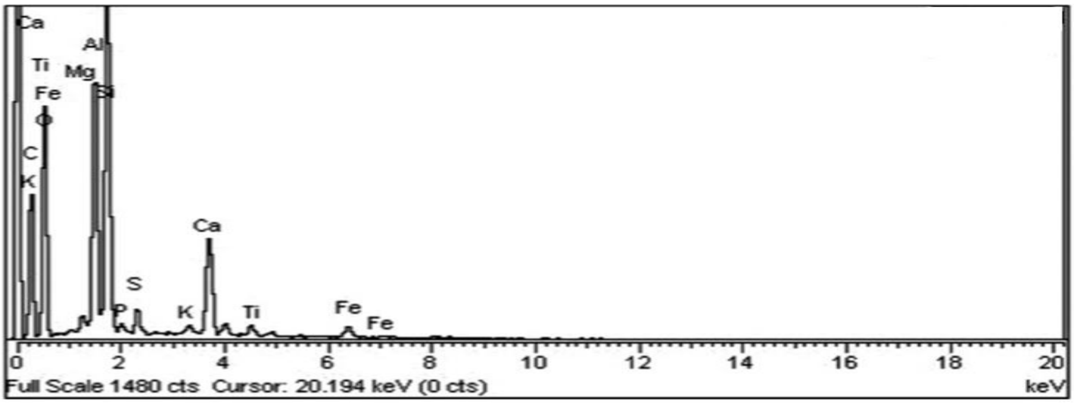
(a) (b)

Figure 3. SEM image for Fly ash: (a)Class C and (b) Class F

The chemical composition for GGBS is listed in Table 3.1. It indicates that GGBS is rich in CaO which is of much importance to developing high strength at ambient temperatures. As shown in Table 3.1, CaO content in GGBS much higher than that of Fly-Ash class C and much lower than class F, CaO forms 41.26% of the GGBS while it was 17.13% and 3.47 % respectively of Class C and Class F. Due to this property, replacing Fly-Ash at a specific amount increasing strength and helps to overcome heat curing in geopolymer concrete. Results of the chemical composition are satisfactory in accordance with the ASTM C618-15 requirement for Fly-Ash and ASTM C989-04 requirement for GGBS.



(a)



(b)

Figure 4. Energy Dispersive X-ray Spectrograph for : (a) class C and (b) Class F

2.2.4 Workability Test

For testing the workability of Fresh Geopolymer concrete. The slump test is used in accordance with ASTM C 143/C 143M – 03.

Table 3 Workability criteria

No	Flow diameter	Workability
1	> 250 mm	Very high
2	(180 mm to 250mm)	High
3	(150 mm to 180mm)	Moderate
4	(150 mm to 120mm)	Stiff
5	< 120 mm	Very stiff

2.2.5 Setting time

According to ASTM C 191-08 (ASTM Standards, 2008b), the Vicat apparatus test as shown in Figure 5 is used to determine the setting time of GP pastes.

Figure 5. Vicat apparatus

2.2.5 Compressive strength

The compressive strength of Geopolymer concrete, as well as the ordinary Portland cement concrete, is tested based on BS EN 12390-3:2009. The compressive strength values of samples are taken before and after the exposure to the elevated temperatures, so, comparison can be made between Fly ash class F and class C. The ratio of strength after exposure to the strength before exposure represents the residual strength. 48 cubes of each type of fly ash (class f and C) cast and cured under ambient temperature to test compressive strength, every 12 cubes tested on 3,7, 14 and 28 days respectively for two types of fly ash divided into 3 cubes of each mix (0%,10%,30%,50%). Also, another 9 cubes of each fly ash (Class F and C) under oven temperature (60^{O}C) for 1 day, here used two sorts of treatment to investigate the temperature and surrounding environment effect on the compressive strength, that means the total of specimens is 90 cubes where examined on different duration.

IV .TEST RESULTS AND DISCUSSION

3.1 Fresh properties

3.1.1 Workability test

24 specimens were tested of each fly ash type (class C and class F) for slump test; the results of the slump test of fly ash class C and F are shown in Figure 6 respectively. All geopolymer concrete mixes are having higher workability. Whenever the content of Fly-Ash is high the mix shows higher workability. As it can be seen in Table 4, the workability gradually reduces with the reduction

of both Fly-Ash type's content and increment of GGBS content. This may happen due to the high demand of GGBS for water when compared with Fly-Ash.

Table 4 Experimental results of the slump test

Fly ash type	Mixes	Slump value (mm)			Average (mm)
		Sample 1	Sample 2	Sample 3	
Class C	100 % FA 0% GGBS	185	177	181	181
	90 % FA 10% GGBS	161	166	165	164
	70 % FA 30% GGBS	140	138	142	140
	50 % FA 50% GGBS	129	122	130	127
Class F	100 % FA 0% GGBS	193	201	185	193
	90 % FA 10% GGBS	159	166	152	159
	70 % FA 30% GGBS	144	150	141	145
	50 % FA 50% GGBS	136	122	129	129

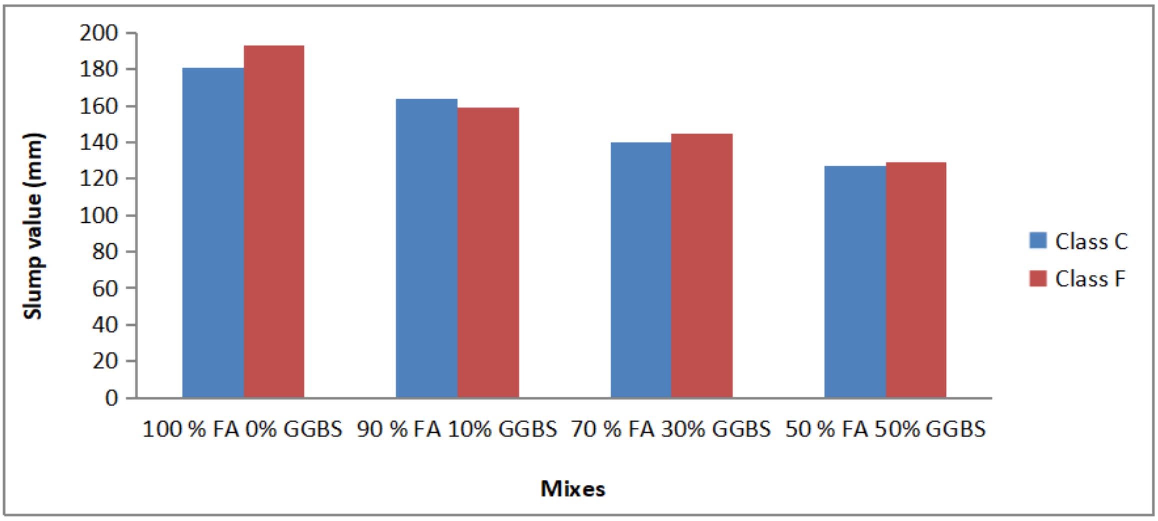


Figure 5. Slump test results of Fly ash (class F and C)

3.2 Setting time test results

Even though the workability of the GPC samples was high, the setting time results were better for Class F than Class C. The setting time of GPC based Class F was always less than that of GPC based on fly ash Class C. However, the setting time in this study was as short as 9 minutes. This issue may be attributed to the type of Fly-Ash class C used. The brown Fly-ash (class C) used in this study is high calcium Fly-Ash with high mineral content (Al_2O_3 and Fe_2O_3) which causes the mix to set in a very short time. High calcium content of fly ash contributes to a faster setting time of geopolymer paste due to the double reaction of the polymerization and hydration process, the results shown in figure 6.

Table 5 Setting time test results

Fly ash type	Mixes	Setting time (min)	
		Initial	Final
Class C	100 % FA 0% GGBS	18	42
	90 % FA 10% GGBS	13	49
	70 % FA 30% GGBS	11	33
	50 % FA 50% GGBS	9	28
Class F	100 % FA 0% GGBS	51	115
	90 % FA 10% GGBS	47	107
	70 % FA 30% GGBS	40	99
	50 % FA 50% GGBS	38	92

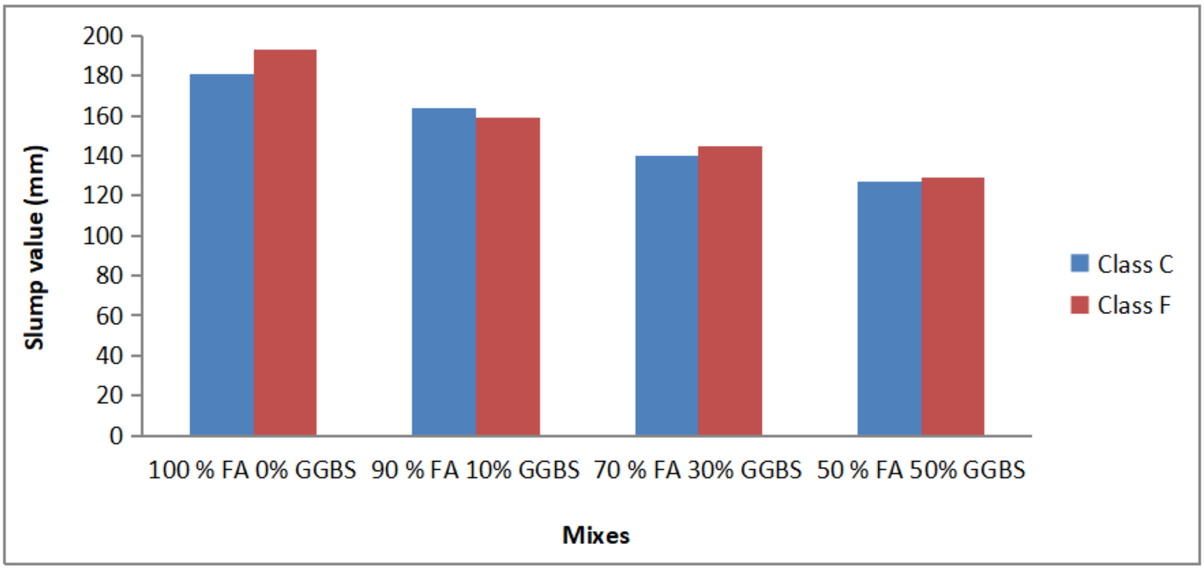


Figure 6. setting time test results of fly ash class C

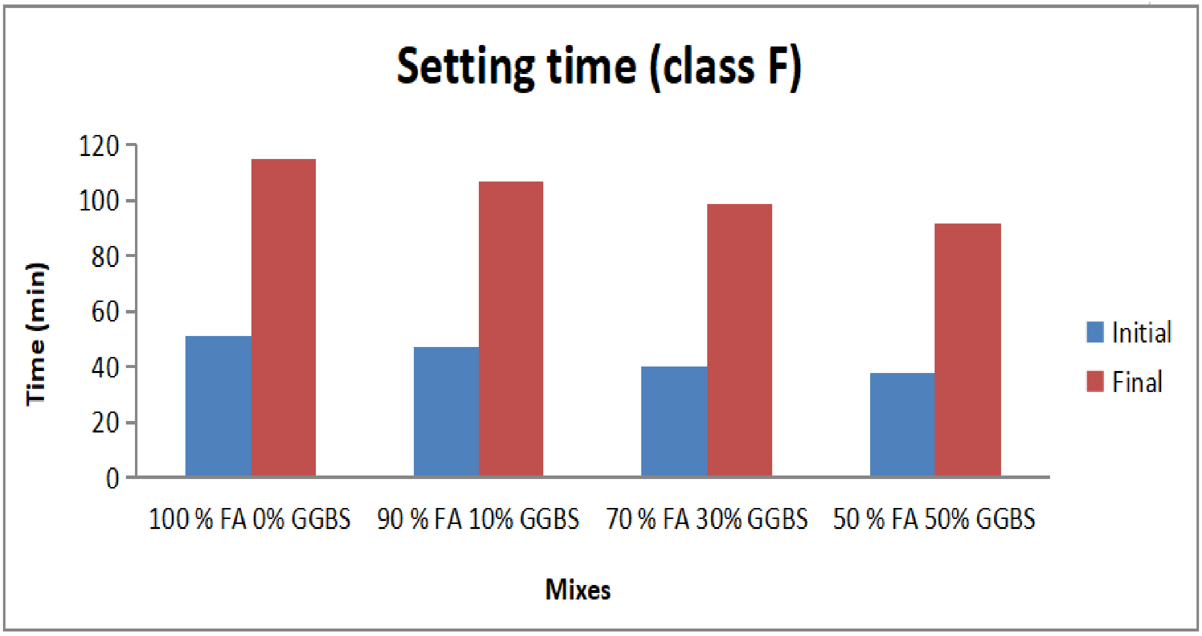


Figure 6: setting time test results of fly ash class F

3.3 Compressive Strength

The negative effects of GGBS on the compressive strength of the Fly Ash class C and F based geopolymer concrete shown in figure 7&8. As it is shown in the figures below, the GGBS advantageously affected the compressive strength of the fly ash class C geopolymer concrete to be maximized up to 83.34 MPa under ambient temperature. Same with Fly ash Class F, when its replacement by 10% GGBS got maximum strength 59.85 MPa under ambient. It is worth mentioning that the use of GGBS was playing a vital role to give the mixture adequate temperature to achieve satisfying results.

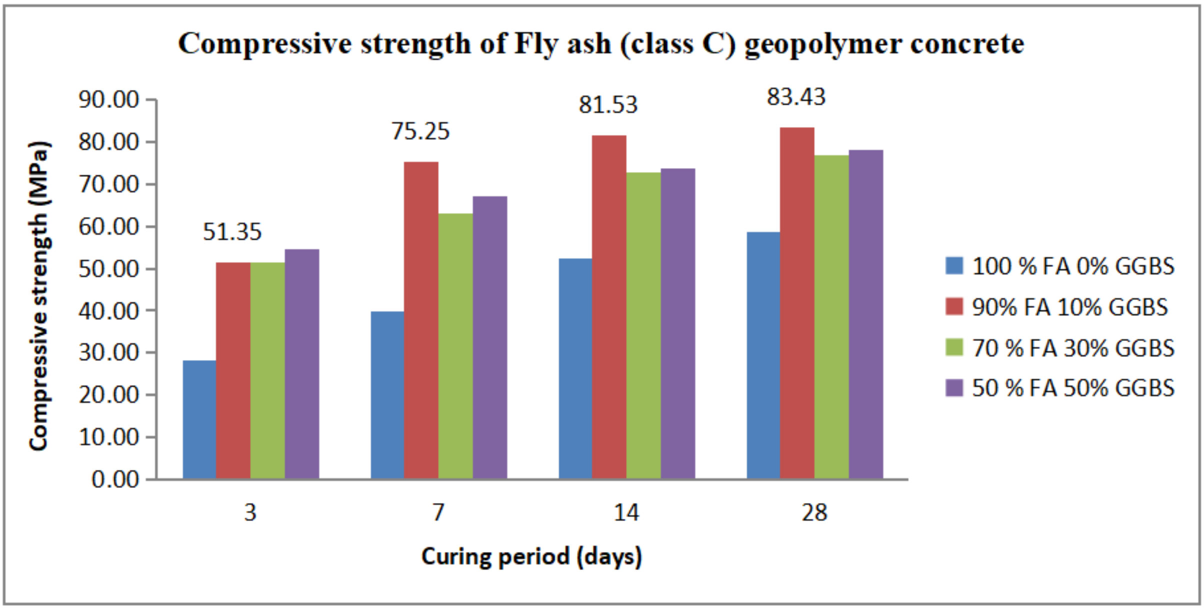


Figure 7. Compressive strength of fly ash class (C) geopolymer concrete

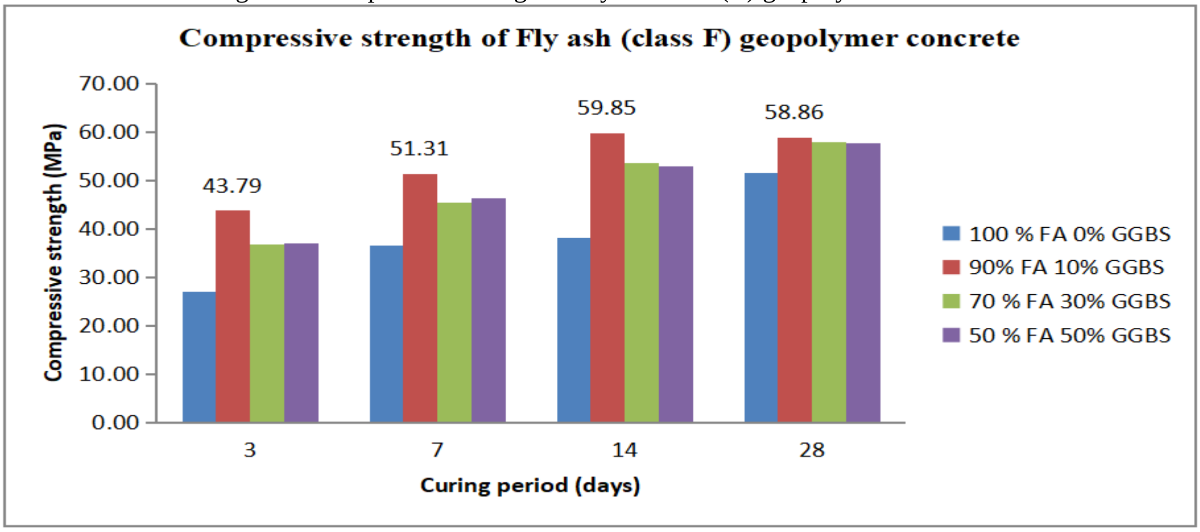


Figure 8. Compressive strength of fly ash class (F) geopolymer concrete

The chosen density of geopolymer concrete is 2400kg/m3 approximately, which is sort of equal to the density of traditional concrete. Plus, geopolymer concrete plays a vital role in industrial construction, and let's not forget the fact that it is friendly to the environment. It also helps in facilitating the fly ash utilization, which can be gained from the remaining of the coal-burning of industries.The findings as illustrated in the above figure confirm that the vital role of GGBS which effects the compressive strength results and its increase in replacement by GGBS was detected particularly at 10% GGBS replacement with fly ash. The compressive strength of test results generally shows a slight improvement in the compressive strength. Whilst, there is a significant increase in the compressive strength of Fly ash class C geopolymer concrete tested cubes especially when replaced 10% of GGBS. However, the results generally show a significant enhancement in the compressive strength of the mixes by overtime of using GGBS in most cases.

Table 5 Effect of GGBFS on compressive strength of fly ash class C and F geopolymer concrete

Fly ash type	**Sample ID**	**Curing Period(days)**	**Compressive strength (MPA)**			**Average (MPa)**
			Sample 1	Sample 2	Sample 3	
Class C	100 % FA 0% GGBS	3	26.62	29.53	28.57	28.24
		7	41.49	37.75	39.92	39.72
		14	64.24	61.61	61.05	62.30
		28	70.44	71.36	74.23	72.01
	90% FA 10% GGBS	3	50.2	52.08	51.77	51.35
		7	76.69	73.09	75.97	75.25
		14	77.51	80.74	86.35	81.53

		28	79.58	87.27	83.43	83.43
	70 % FA 30% GGBS	3	50.43	52.49	51.22	51.38
		7	58.45	64.62	66.46	63.18
		14	73.98	71.58	72.93	72.83
		28	76.31	78.86	75.39	76.85
	50 % FA 50% GGBS	3	50.87	57.34	55.25	54.49
		7	63.87	71.73	65.68	67.09
		14	78.59	70.04	72.63	73.75
		28	78.52	79.06	76.94	78.17
Class F	100 % FA 0% GGBS	3	28.23	24.7	28.4	27.11
		7	37.98	34.79	37.3	36.69
		14	37.73	40.05	36.88	38.22
		28	50.44	51.09	53.33	51.62
	90% FA 10% GGBS	3	40.03	44.54	46.8	43.79
		7	49.84	53.47	50.62	51.31
		14	62.89	57.37	59.3	59.85
		28	58.26	61.74	56.58	58.86
	70 % FA 30% GGBS	3	36.1	35.46	38.63	36.73
		7	43.65	47.83	44.66	45.38
		14	55.24	53.81	51.81	53.62
		28	60.35	56.47	57.05	57.96
	50 % FA 50% GGBS	3	35.09	36.58	39.51	37.06
		7	48.01	45.9	45.05	46.32
		14	53.35	51.74	53.85	52.98
		28	58.25	57.34	57.95	57.85

V. CONCLUSIONS

These findings found that necessary to produce N-A-S-H Gel which is responsible for the compressive strength in geopolymer concrete. However, this action depends on the percentages of GGBS used, as it can be seen that 30% and 50% of GGBS showed lower strength than that of 10% GGBS specimens. These results suggest that GGBS advantageously troubled the compressive strength of the GPC to be increased up to 83.43 MPa when 10% of GGBS is used in class C and up to 59.85 MPa when also 10% of GGBS is used in class F. This increment in the compressive strength is due to the higher content of SiO_2, CaO, and Al_2O_3 in GGBS chemical composition than fly ash. These compositions are responsible for different parameters; it is responsible for generating heat during the hydration process that allows the concrete to produce higher strength in the early age of GPC as well as the compressive strength at age 28 days.

The brown Fly-ash (class C) used in this study is high calcium fly ash with high mineral content (Al_2O_3 and Fe_2O_3) which causes the mix to set in a very short time. High Calcium Hydroxide content in the fly ash leads to a less setting time of geopolymer paste due to the greater reaction of geopolymerization and hydration process. Hence fly ash Class F will be reduced in the following steps, it showed a good setting time that can preserve the workability of the GPC for more than an hour. It's obvious that all geopolymer concrete mixes are having higher workability; the content of fly-Ash is high where the mix shows higher the workability of concrete.

The identity of suitable mixes using GGBS base on GPC based on the compressive strength test at ambient and oven temperature, 90% fly ash with 10% GGBS is the optimum mix among the mixes those having 10%, 30%, and 50% GGBS. Besides, to assess the effect of Class C and Class F fly ash on fresh and hardened properties of GPC through study the effect of the fly ash class C on GPC fresh and hardened properties which were better than the effect of fly ash class F. Finally, they determine the suitability of the ambient and heat curing method to improve the early-age compressive strength of GPC where the research findings showed binary blended GPC is better performance in terms of maintained strength under ambient and oven temperatures when compared with single binder GP concrete.

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