Parametric Study of Low Calcium Fly Ash Based Geopolymer Concrete

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Abstract

The production of cement has affected the environment. The production of one ton of cement releases same amount of CO2 to the environment. So, there is a need to look for some other materials such as Fly ash, GGBS which can replace OPC as a binding material. To achieve this geopolymer concrete is used, with fly ash, GGBS, and Lime powder replacing cement. The principal elements of fly ash are silica and alumina, which react with an alkaline activator solution to form a gel that binds the particles in Geopolymer concrete. The alkaline activator solution is made up of Na2SiO3 and NaOH. Some additives such as GGBS, OPC and Lime powder were added which helped the concrete to cure in ambient curing condition. Different mixes were prepared by adding GGBS, OPC and lime powder in 10%, 20% and 30% of binding material and casted. Mixtures were designed for AAS/Binder content ratio as 0.35 and 0.4. AAS content was prepared with NaOH concentration as 14M and 8M and Na2SiO3/NaOH ratio as 1.5.

Keywords—*Geopolymer, Compressive strength, Workability, Ambient Curing, Fly Ash.*

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I. INTRODUCTION

Concrete is widely utilized construction material. In concrete Ordinary Portland Cement (OPC) is the most important element in concrete because it binds all the aggregate together. Cement manufacture, on the other hand, emits a significant amount of CO2. However, the production of cement releases large amount of CO2 into the atmosphere. This has led to global warming. It is observed that of all the CO2 emissions, the contribution of cement industry is 7% [1].

As a result, a lot of effort has gone into reducing the use of Portland cement in concrete. As a cementing material, fly ash, GGBS, Lime powder have been used.

Fly ash and an alkaline activator solution are used to make geopolymer concrete. Fly ash contains silica and alumina. This are then reacted with alkaline activator solution to produce a gel known as alumino silicate gel which binds the loose aggregates such as sand and coarse aggregate. In this way a geopolymer concrete is prepared [4].

The various properties of Geopolymer concrete are:

- Geopolymer concrete acquire high early strength. According to various researches, geopolymer concrete may reach a compressive strength of 20MPa in just three days.
- Geopolymer concrete have good heat and fire resistance. Geopolymer concrete can resist temperature up to 600ºC.

- Geopolymer concrete shows good shrinkage resistance, good resistance to freezing and thawing, sulfate resistance, corrosion resistance etc.
- Geopolymer cement also shows good acid resistant. It is observed that Geopolymer cements are not dissolved in acidic solutions and do not rely on lime.

II. Experimental Work

In order to carry out the experimental work, we need to know about the materials required, mixture proportions, manufacturing, casting and curing of cube samples.

A. *Materials Required*

The materials used for making Geo polymer concrete specimens are

- Fly Ash - Fly ash is mostly made up of silica and alumina, which react with an alkaline activator solution to generate an alumino silicate gel, which is then mixed with particles to make Geopolymer concrete.

TABLE I. Chemical Composition of Fly Ash

Composition	Content (in %)
SiO_2	53.71
Al_2O_3	27.20
Fe_2O_3	11.70
CaO	1.90
Na_2O	0.36

- Aggregate - . The blended aggregate is chosen to closely resemble the typical grading curves. It is made up of 25% 20mm aggregates, 25% 12.5mm aggregates, 20% 10mm aggregate, and 30% fine sand
- Alkaline Liquid - A mixture of sodium silicate solution (Na_2SiO_3) and sodium hydroxide (NaOH) solution was utilized as the alkaline liquid. NaOH was dissolved in water to make the sodium hydroxide solution. Sodium silicate was also obtained in a liquid form. Alkaline Activator solution was created by combining the two solutions. Compressive strength is influenced by the ratio of sodium silicate to sodium hydroxide. The ratio of sodium silicate to sodium hydroxide used in this investigation was 1.5.
- Ordinary Portland Cement - OPC has a high concentration of calcium compounds and a low proportion of silica and alumina compounds. When it's mixed with fly ash, it causes a polymerization reaction as well as a heat of hydration reaction. It is commonly used in 10%, 20%, and 30% of the binding material (Fly ash + OPC). Because it includes more calcium and less silica and alumina, a higher proportion cannot be utilized because the geopolymerisation reaction will be disrupted.
- Ground Granulated Blast Furnace Slag- GGBS is high in silica, alumina, and calcium oxide. The combination of GGBS with fly ash can improve the setting and hardening of geopolymer concrete. GGBS is used as a binding material in percentages of 10%, 20%, and 30% (Flyash + GGBS).

TABLE II. Chemical Composition of GGBS

Composition	Content (in %)
SiO_2	29.96
Al_2O_3	12.25
Fe_2O_3	0.52
CaO	45.45
SO_3	3.62

- Lime Powder - Lime powder also contains a high percentage of calcium compound and a low amount of silica and alumina, which speeds up the hydration process and helps the concrete to set sooner.

B. *Experimental Data*

- Just as water-to-cement ratio which we choose in normal cement concrete, similarly here we choose alkaline activator solution-to-binder content ratio. In this study it is considered as 0.4, 0.35 to prepare different mixes.
- The AAS/Binder content was kept as 0.35 and 0.4. Based on this ratio the fly ash content was determined. Further, Na_2SiO_3 to NaOH ratio was kept as 1.5.
- Four mixtures were prepared.

- The first mix contain fly ash alone, the second mixture contained fly ash + OPC(10%, 20%, 30%) of binding material, the third mixture contained Fly ash + GGBS(10%, 20%, 30%) of binding material and the fourth mixture contained Fly ash + Lime powder(10%, 20%, 30%) of binding material
- After casting, the mixture in which fly ash was binding material is kept in oven at a temperature of 60°C for 24 hours. The specimens were taken out of the oven when curing was complete and let to cool at ambient temperature.
- The second and third mixture in which binding material is fly ash and some additives, this mixture is kept at room temperature directly after casting.
- The compressive strength was tested after 7 and 28 days, taking into account the average value of three specimens.

C. Mix Design of Fly Ash Based Geopolymer Concrete

TABLE III. TABLE SHOWING PROPORTION OF MATERIALS REQUIRED TO MAKE BINDER CONTENT AT AAS/BINDER CONTENT RATIO OF 0.4.

S. No.	Name of the mix prepared	AAS/ Binder content	Binder content (kg/m)	Fly ash (kg/m)	OPC/ GG BS Lime powder %	OPC/GGBS/ Lime powder (kg/m)
1.	F00	0.4	500	500	0	0
2.	F00	0.35	571.43	571.43	0	0
3.	F00	0.3	600	600	0	0

TABLE IV. TABLE SHOWING PROPORTION OF MATERIALS REQUIRED TO MAKE BINDER CONTENT AT AAS/BINDER CONTENT RATIO OF 0.4.

S. No.	Name of mix prepared	AAS/ Binder content	Binder content (kg/m)	Fly ash	OPC/GGBS/Lime powder (%)	OPC/GGBS/ lime Powder (kg/m)
1.	G10	0.4	500	450	10%	50
2.	G20	0.4	500	400	20%	100
3.	G30	0.4	500	350	30%	150
4.	O10	0.4	500	450	10%	50
5.	O20	0.4	500	400	20%	100
6.	O30	0.4	500	350	30%	150
7.	L10	0.4	500	450	10%	50
8.	L20	0.4	500	400	20%	100
9.	L30	0.4	500	350	30%	150

TABLE V. TABLE SHOWING PROPORTION OF MATERIALS REQUIRED TO MAKE BINDER CONTENT AT AAS/BINDER CONTENT RATIO OF 0.35.

S. No.	Name of mix prepared	AAS/ Binder content	Binder content (kg/m)	Fly ash	OPC/GGBS/ Lime powder (%)	OPC/GGBS/ Lime powder (kg/m)
1.	F00	0.35	571.43	571.43	0	0
2.	G10	0.35	571.43	514.287	10%	57.143
3.	G20	0.35	571.43	457.144	20%	114.286
4.	G30	0.35	571.43	400	30%	171.43
5.	O10	0.35	571.43	514.287	10%	57.143
6.	O20	0.35	571.43	457.144	20%	114.286
7.	O30	0.35	571.43	400	30%	171.43
8.	L10	0.35	571.43	514.287	10%	57.143
9.	L20	0.35	571.43	457.144	20%	114.286
10.	L30	0.35	571.43	400	30%	171.43

III. RESULTS AND DISCUSSIONS

Workability, 7-day compressive strength, and 28-day compressive strength results are included in the test results

A. Workabilty Test

The slump cone test was used to determine the workability of Concrete.

TABLE VI. SLUMP VALUE OF THE MIXTURE WITH FLY ASH ALONE AS A BINDER AT DIFFERENT AAS/BINDER CONTENT RATIO

S. NO.	Mixtures	AAS/Binder content	Slump value (mm)
1.	Fly ash alone is binder (F00)	0.4	19
2.	Fly ash alone is binder (F00)	0.35	18
3.	Fly ash alone is binder (F00)	0.3	18

Table VII. SLUMP VALUE OF DIFFERENT MIXTURES WHEN AAS/BINDER CONTENT RATIO IS 0.35

S. NO.	Mixtures	Slump value (mm)
1.	Fly ash + 10% GGBS (G10)	19
2.	Fly ash + 20% GGBS (G20)	17
3.	Fly ash + 30% GGBS (G30)	16
4.	Fly ash + 10% OPC (O10)	18
5.	Fly ash + 20% OPC (O20)	17
6.	Fly ash + 30% OPC (O30)	17

7.	Fly ash + 10% Lime powder (L10)	18
8.	Fly ash + 20% Lime powder (L20)	17
9.	Fly ash + 30% Lime powder (L30)	16

Table VIII. SLUMP VALUE OF DIFFERENT MIXTURES WHEN AAS/BINDER CONTENT RATIO IS 0.40

S. NO.	Mixtures	Slump value (mm)
1.	Fly ash + 10% GGBS (G10)	18
2.	Fly ash + 20% GGBS (G20)	16
3.	Fly ash + 30% GGBS (G30)	17
4.	Fly ash + 10% OPC (O10)	18
5.	Fly ash + 20% OPC (O20)	16
6.	Fly ash + 30% OPC (O30)	15
7.	Fly ash + 10% Lime powder (L10)	17
8	Fly ash + 20% Lime powder (L20)	16
9	Fly ash + 30% Lime powder (L30)	16

- Slump values for all geopolymer concrete types were found to be low. The slump value increased as the AAS/Fly ash ratio increased, and it was found to be higher at AAS/Fly ash ratio of 0.4. This behavior is similar to that of ordinary OPC concrete, in which the slump value rises as the water-to-cement ratio rises.
- For the same AAS/Fly ash ratio, slump values reduced as the amount of all additives increased from 10% to 30% for all types of geopolymer concrete. This is due to the presence of calcium compounds in OPC, lime powder, and GGBS. The rigidity of concrete increases as the quantity of calcium component increases, and hence workability diminishes.
- When fly ash is utilized alone as a binder, a greater slump value of 19mm is observed. The reason could be because fly ash does not react immediately with AAS at room temperature, so, the mixture does not set immediately, thus resulting in higher workability. Less amount of calcium content in the fly ash could be another reason, due to which it does not reacts early resulting in higher workability.

B. Compressive Strength

Table IX. 7-DAY & 28-DAYS COMPRESSIVE STRENGTH OF MIXTURE WITH FLY ASH ALONE AS A BINDING MATERIAL

Aas/ Fly Ash	7 Day Compressive Strength (MPa)	28 Day Compressive Strength (MPa)
0.4	10	21
0.35	12	24
0.3	14	26

Table X. 7-DAYS COMPRESSIVE STRENGTH OF MIXTURE WITH FLY ASH ALONG WITH ADDITIVES (10%, 20% AND 30%) OF BINDING MATERIAL

AAS/ Flyash ratio	Additives (OPC, GGBS, Lime powder)	7 Day Compressive strength (MPa)		
		Fly ash + GGBS as binder	Fly ash + OPC as binder	Fly ash+ Lime powder asbinder
0.35	10	12	17	15
0.35	20	14	19	16
0.35	30	15	20	18
0.4	10	11	15	13
0.4	20	12	16	14
0.4	30	14	18	16

Table XI. 28-DAYS COMPRESSIVE STRENGTH OF MIXTURE WITH FLY ASH ALONG WITH ADDITIVES (10%, 20% AND 30%) OF BINDING MATERIAL

AAS/ Flyash ratio	Additives (OPC, GGBS, Lime powder)	28 Day Compressive strength (MPa)		
		Fly ash + GGBS as binder	Fly ash + OPCas binder	Fly ash+ Lime powder as binder
0.35	10	20	23	20
0.35	20	22	27	24
0.35	30	24	30	25.5
0.4	10	18	23	21.3
0.4	20	21	26	23.2
0.4	30	22	29	24.4

- Compressive strength and the AAS/Binder content ratio have an inverse connection. The compressive strength was found to decrease when the AAS/Fly ash ratio increased from 0.35 to 0.4, as shown in the table.
- The strength of geopolymer concrete was also observed to increase with age. For all geopolymer concrete mixes prepared with varying AAS/Fly Ash ratios, the 28-day compressive strength was found to be higher than the 7-day compressive strength.
- The compressive strength of all forms of geopolymer concrete was shown to be higher when OPC was added as an additive. When 30% OPC was applied as an additive, the greatest compressive strength of 30MPa was observed. This could be due to formation of CSH compound along with CASH compound. OPC shows heat of hydration which binds the component of concrete together by strong bond thus resulting in higher compressive strength.

IV. Conclusions

- When additives like OPC, GGBS, and Lime powder were added, geopolymer concrete was created, which was then allowed to cure in the ambient environment.
- When fly ash alone is employed as a binder with an AAS/Fly ash ratio of 0.3, the maximum strength obtained with heat curing is 26MPa. When fly ash + 30% OPC is employed as an additive at an AAS/Binder content ratio of 0.35, the maximum strength achieved with ambient curing is 30MPa.
- The use of the geopolymerisation method in conjunction with OPC allows for ambient curing without the use of water.
- The workability of geopolymer concrete was shown to improve as the AAS/Binder content ratio was increased from 0.35 to 0.4. This could be attributed to a higher binder concentration in the concrete, which makes it denser and more compact.
- Workability was found to be reduced when the percentage of additives in each mixture was increased from 10% to 30%.
- When fly ash was utilized as a binder and GGBS was employed as a 10% additive with fly ash at an AAS/Fly ash ratio of 0.4, the maximum workability of 19mm slump was attained.
- When 30 percent lime powder was employed as an addition, the lowest slump value was attained.
- The AAS/Binder content ratio affects the compressive strength of geopolymer concrete. As the AAS/Binder content ratio increased from 0.35 to 0.4, compressive strength gradually decreased. At an AAS/Binder content ratio of 0.35, the greatest compressive strength of 24MPa was achieved for geopolymer concrete with fly ash alone as a binder.

- The compressive strength of all geopolymer concretes containing additives such as GGBS, OPC, and Lime powder was observed to increase as the quantity of additives increased from 10% to 30%.
- At an AAS/Binder content ratio of 0.35, the greatest compressive strength of 24MPa was observed when 30 percent GGBS was used as an addition.
- When lime powder is utilized as an addition, the highest compressive strength of 25.5MPa is achieved when 30% lime powder is employed.
- However, using 30% OPC as an addition resulted in the maximum compressive strength of 30MPa. Because OPC contains calcium compounds, an extra CSH gel forms, speeding up the hydration process and making the concrete denser, allowing it to gain significant strength.
- As a result, among all the geopolymer concretes tested, the geopolymer concrete using OPC as an additive produced the best results.

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