Effect of Binder index on Compressive Strength of Geopolymer Concrete

HathiRam Gugulothu [1] B.Sesha Sreenivas [2] D.Rama Seshu [3]

[1] Research Scholar, Kakatiya Univ., Warangal, India

[2] Professor and principal, University College of Engg, Kothagudem, Kakatiya Univ., India.

[3] Professor of Civil Engineering, National Institute of Technology, Warangal, India.

Abstract. *The objective of this article is to present and discuss the effect of Class F Fly ash (FA), Ground Granulated Blast Furnace Slag (GGBS) and molarity of alkaline activator on the Compressive strength of Geopolymer Concrete (GPC). Sodium Silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution with 8, 10 and 12 alkaline molar activators have been used. The proportions for Fly ash to GGBS used are 80:20, 70:30, 60:40, 50:50, 40:60, 30:70 and 20:80. Alkaline liquid content to Fly ash ratio is taken as 0.36 and fine aggregate to total aggregate ratio is taken as 32%. The ratio of sodium silicate solution to sodium hydroxide solution is kept as 2.5. Three identical specimens for each variation were cast and tested after 7 days and 28 days ambient curing. A Parameter called* ***Binder Index*** *is introduced to quantify the effect of Fly ash, GGBS and molarity on the Compressive strength of Geopolymer Concrete at ambient temperature.*

Key words*: Geopolymer Concrete (GPC), Fly ash(FA), Ground Granulated Blast Furnace Slag(GGBS), Compressive Strength(f_{ck}), Binder Index(B_i), Ambient temperature.*

---

1. Introduction

The production of Portland cement consumes considerable amount of energy and at the same time contributes a large volume of CO_2 to the atmosphere. The climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases such as carbon dioxide (CO_2) to the atmosphere by human activities. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [1]. However, Portland cement is still the main binder in concrete construction prompting a search for more environment friendly materials. Several efforts are in progress to supplement the use of Portland cement in concrete in order to decrease the global warming. These include the utilization of supplementary cementing materials such as fly ash, silica fume, GGBS, rice-husk ash and metakaolin are in the development of alternative binders to Portland cement. One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials. In 1978, Davidovits proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash and GGBS. He termed these binders as Geopolymers [2]. The most common industrial by-products used as binder materials are fly ash and GGBS [3-4]. Several publications were available describing Geopolymer pastes and Geopolymer concrete materials. Keeping in view of the past research work done, the present research aimed at studying the effect of GGB ,fly ash ratio and molarity on Compressive strength of Geopolymer concrete . A Parameter called **Binder Index** is proposed to quantify the effect GGBS, fly ash and molarity on the Compressive strength of Geopolymer concrete developed at ambient room temperature.

2. Experimental investigation. The experimental program consisted of determination of the Compressive strength of Geopolymer concrete by casting and testing cubes of size 100 mm. Seven different fly ash to GGBS proportions (80:20, 70:30, 60:40, 50:50, 40:60, 30:70 and 20:80) are used. Alkaline liquid content to fly ash ratio is taken as 0.36 and fine aggregate to total aggregate ratio is taken as 32 %. 8, 10 and 12 alkaline molar activators are used throughout the experimental investigation. Three identical specimens for each variation were cast and tested after 7 days and 28 days ambient curing.

2.1 Materials: Fly ash is obtained from Kothagudem Thermal Power Station, Bhadradri Kothagudem Dist, Telangana, India. GGBS is obtained from Blue way exports supplier, from Vijayawada, Andhra Pradesh, India. Specific gravity of Fly ash and GGBS are 2.17 and 2.90 respectively. Chemical composition details of Fly ash and GGBS are shown in Table 1. Natural river sand confirming to grading zone II of IS 383:1970 was used. Specific gravity and fineness modulus of sand used were 2.32 and 2.81 respectively. Coarse aggregate of maximum size 12 mm from local source was used. The molarities of sodium hydroxide solution used are 8, 10 and 12. The sodium hydroxide pellets used for preparation of NaOH solution is given in table 2. The NaOH solution thus prepared is mixed with Na_2SiO_3 solution. The ratio of sodium silicate solution to sodium hydroxide solution is fixed as 2.5[5, 6, 7]. The mixture was stored for 24 hours at room temperature before casting. Super Plasticizer conplast Sp-430 is used to obtain the desired workability.

Table 1. Chemical Composition of Fly Ash and GGBS percentage by mass.

Material	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	LOI
Fly ash	60.12	26.63	4.22	0.32	4.1	1.21	0.2	0.85
GGBS	34.16	20.1	0.81	0.88	32.8	7.69	nd	.

Table 2. Materials used for NaOH solution preparation.

	8 moles/L	10 moles/L	12 moles/L
Sodium hydroxide pellets , (grams)	262	314	361
Potable Water (grams)	738	686	639

2.2 Mix proportions: The unit weight of Geopolymer concrete is taken as 2400 Kg/m^3.The Geopolymer Concrete mix proportions are shown in table 3.

Table 3. Geopolymer Concrete mix proportions.

FA:GGBS	GeopolymerConcrete mix proportions (Kg/m^3)							
	Coarse Aggre gate	Fine Aggre gate	Fly ash (FA)	GGBS	NaOH Solution	Sodium Silicate	Super Plasticizer(2 % of the Binder)	Extra water (7.5% of the Binder)
80:20	1100	517.45	460.16	115.04	59.10	148.25	11.50	43.15
70:30	1100	517.45	402.64	172.56	59.10	148.25	11.50	43.15
60:40	1100	517.45	345.12	230.08	59.10	148.25	11.50	43.15
50:50	1100	517.45	287.6	287.6	59.10	148.25	11.50	43.15
40:60	1100	517.45	230.08	345.12	59.10	148.25	11.50	43.15
30:70	1100	517.45	172.56	402.64	59.10	148.25	11.50	43.15
20:80	1100	517.45	115.04	460.16	59.10	148.25	11.50	43.15

2.3 Casting of Geopolymer Concrete specimens: The solid constituents of the Geopolymer concrete i.e. the aggregates, fly ash and GGBS were dry mixed for about three minutes. The liquid part of the mixture i.e. the alkaline solution, added water and the super plasticizer were premixed then added to the solids. The wet mixing usually continued for another four minutes. The fresh Geopolymer Concrete was dark in color and shiny in appearance. The mixtures were usually very cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. Compaction of fresh concrete in the cube moulds was done in three equal layers followed by compaction on a vibration table for ten seconds. The demoulding was done after 24 hours and kept for ambient curing.

The Geopolymer concrete specimens for compressive strength were tested on Universal Testing Machine of capacity 1000KN. The load was increased gradually at constant rate until failure. The maximum loads applied on various specimens were recorded as per IS 516-1956[8].Three identical specimens with each variation were cast and tested after 7 days and 28 days of ambient curing. The test results are given in table 4. The **Binder Index (B_i)** has been used to study the combined effect of GGBS, fly ash and molarity of alkaline activator. [9, 10, 11].

Binder Index = Molarity x [GGBS / (GGBS + Fly Ash)]......eq (1)

Table 4. Compressive Strength values for Geopolymer concrete

FA:GGBS	GGBS TO FA RATIO	[GGBS / GGBS + Fly Ash)]	Compressive Strength (Mpa)								
			8 moles/L			10 moles/L			12 moles/L		
			7D	28D	7D/28D	7D	28D	7D/28D	7D	28D	7D/28D
80:20	0.25	0.2	15.5	22	0.70	20.4	35	0.58	27.5	39	0.71
70:30	0.43	0.3	20	26	0.77	29	41	0.71	35	54	0.65
60:40	0.67	0.4	24	42.5	0.56	33	48.5	0.68	40	59.5	0.67
50:50	1	0.5	32	49	0.65	40	58	0.69	45	65	0.69
40:60	1.5	0.6	42	55.2	0.76	44.9	62.5	0.72	51.2	76	0.67
30:70	2.33	0.7	46	59	0.78	52	68	0.76	55	81	0.68
20:80	4	0.8	58	68	0.85	62	74	0.84	66.5	86	0.77

Table 5. Binder index Vs Compressive Strength of GPC

Binder Index = [GGBS / (GGBS + Fly Ash)]	Compressive Strength (Mpa)		Ratio of 7 day strength to 28 day strength of GPC
	7 days	28 days	7D/28D
	7D	28D	
1.6	15.5	22	0.70
2	20.4	35	0.58
2.4	27.5	39	0.71
2.4	20	26	0.77
3	29	41	0.71
3.6	35	54	0.65
3.2	24	42.5	0.56
4	33	48.5	0.68
4.8	40	59.5	0.67

4	32	49	0.65
5	40	58	0.69
6	45	65	0.69
4.8	42	55.2	0.76
6	44.9	62.5	0.72
7.2	51.2	76	0.67
5.6	46	59	0.78
7	52	68	0.76
8.4	55	81	0.68
6.4	58	68	0.85
8	62	74	0.84
9.6	66.5	86	0.77

The variation of Compressive strength with GGBS to fly ash ratio are shown in fig 1, fig 2 and fig 3. The variation of Compressive strength with Binder index is shown in fig 4.

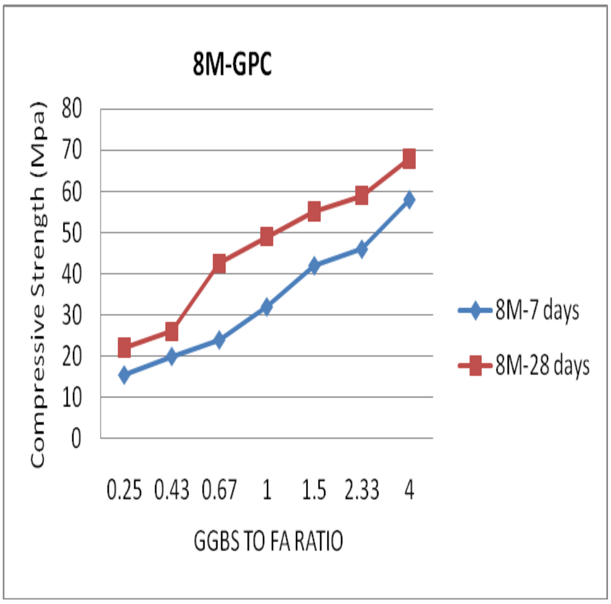

Fig 1. GGBS to fly ash ratio Vs Compressive Strength of GPC, 8 moles/L.

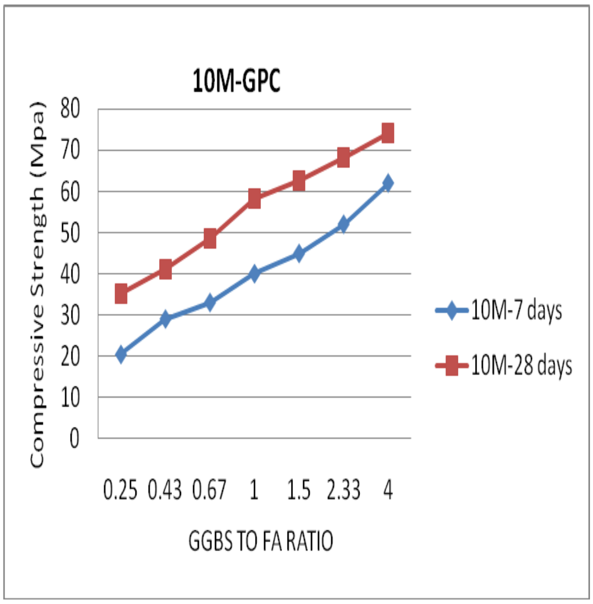

Fig 2. GGBS to fly ash ratio Vs Compressive Strength of GPC, 10 moles/L.

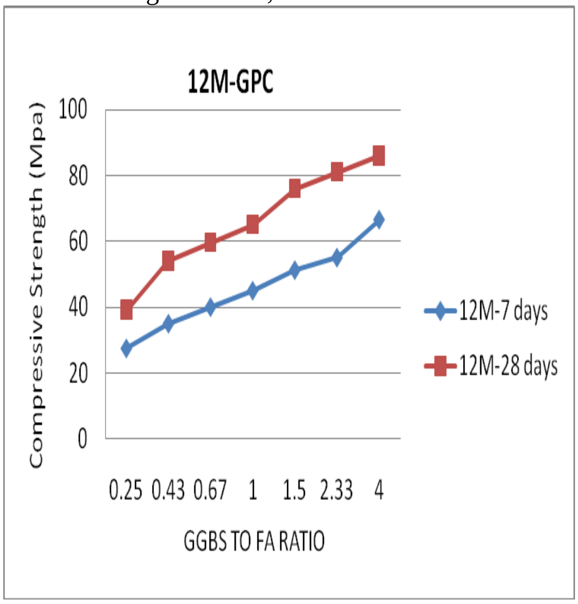

Fig 3. GGBS to fly ash ratio Vs Compressive Strength of GPC, 12 moles/L.

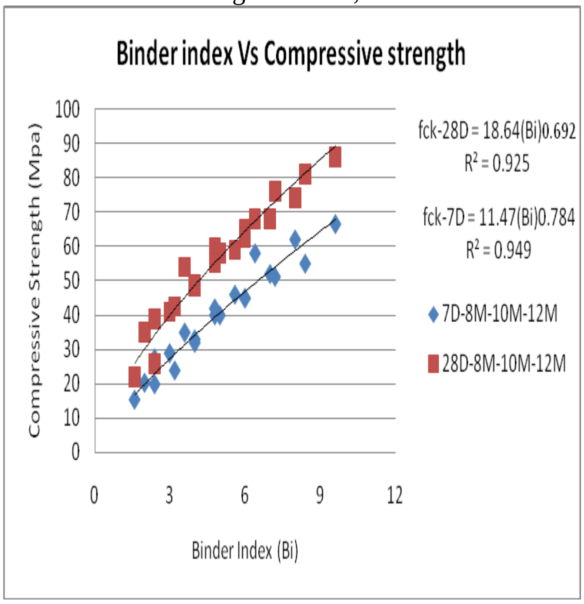

Fig 4. Binder index Vs Compressive Strength of GPC.

From above figures it is observed that the Compressive strength of Geopolymer concrete has increased with increase in GGBS to Fly ash ratio , molarity of alkaline activaort and Binder index.

3.1 Effect of Molarity of alkaline activator on Compressive strength of Geopolymer concrete

The effect of molarity of alkaline activator for different GGBS to flyash ratio's is shown in fig 1., fig 2 & to fig 3. In general as the molarity of alkaline activator increased the Compressive strength of Geopolymer concrete increased.

3.2 Effect of Binder index on Compressive strength of Geopolymer concrete.

The Compressive strength of Geopolymer concrete increased with the increase in binder index values. The variation of Compressive strength along with the binder index is shown in fig 4. The binder index has been used to study the combined effects of GGBS to fly ash proportion, molarity of alkaline activator on Compressive strength of Geopolymer concrete. The following best fit equations give the relation between the compressive strength at 7 days and 28 days of air curing with binder index along with the correlation coefficient (R^2).

f_{ck}-7day=11.47($\mathbf{B_i}$)$^{0.784}$, $R^2 = 0.949$…. eq (2)

f_{ck}-28day=18.64($\mathbf{B_i}$)$^{0.692}$, $R^2 = 0.925$ …. eq (3)

Where $\mathbf{B_i}$ is binder index.

5. Conclusions

From the analysis of experimental results the following conclusions were drawn.

1. The 7 days and 28 days Compressive strength of Geopolymer concrete has increased with increase in GGBS proportion.
2. The 7 days and 28 days Compressive strength of Geopolymer concrete has increased with increase in GGBS to fly ash ratio.
3. The 7 days and 28 days Compressive strength of Geopolymer concrete has increased with increase in molarity of alkaline activator.
4. The 7 days and 28 days Compressive Strength of Geopolymer concrete has increased with increase in Binder index.
5. Fly ash and GGBS combination can be used for the production of Geopolymer concrete without the need of heat curing.
6. The proposed Binder Index which combines the effect of GGBS, fly ash and molarity of alkaline activator is reasonably well in predicting the Compressive strength of Geopolymer concrete.
7. There is a non linear relation between the binder index and Compressive strength of Geopolymer concrete.

6. References

1. Malhotra, V.M.(1999). "Making Concrete Greener "with Fly ash. Concrete International.21 (5), 61-66.
2. Davidovits, J. (1981). "The Need to Create a New Technical Language for the Transfer of Basic Scientific Information", Proceedings of the Transfer and Exploitation of Scientific and Technical Information Symposium, Luxembourg.
3. Ravikumar, D., Peethamparan, S., and Neithalath, N. (2010). "Structure and strength of NaOH activated concretes containing fly ash or GGBFS as the sole binder", Cement & Concrete Composites , 32(6), 399–410.
4. Oh, J.E., Monteiro, P.J.M., Jun, S.S., Choi, S., and Clark, S.M. (2010). "The evolution of strength and crystalline phases for alkali-activated ground blast furnace slag and fly ash-based Geopolymers", Cement and Concrete Research, 40(2), 189–196.
5. R.Anuradha, et al , Modified Guide lines for Geopolymer concrete mix design using Indian standard, Asian journal of Civil Engineering (Building and Housing), Vol.13 No.3(2012)
6. D. Hardjito, S. E. Wallah, D. M. J. Sumajouw, B. V. Rangan, On the development of fly ash- based Geopolymer concrete, ACI Mater. J., 101, 6, 467 (2004).
7. B. V. Rangan, Mix design and production of fly ash based Geopolymer concrete, Indian Concrete J., 82, 7 (2008).
8. IS516-1956, Indian standard methods of Test for Strength of Concrete.
9. G.Hathiram, B.Seshasreenivas, D.Rama seshu , (2018), Experimental investigation on compressive strength of combined fiber reinforced Geopolymer , Journal of Emerging technologies and Innovative Research.(ISSN 2349-5162), volume 4, Issue 6, Pages 530-536.
10. G.Hathiram, B.Seshasreenivas, D.Rama seshu , (2018), Experimental investigation on compressive strength of fiber reinforced Geopolymer concrete, International journal of Civil Engineering and Technology(IJCIET) , ISSN 0976-6316, volume 9, Issue 12, Pages 1162-1173.
11. D.Rama seshu, R.Shankaraiah, B.Sesha Srenivas, (2017), A study on the effect of Binder index on compressive strength of Geopolymer concrete, CWB -3/2017. Pages 211-215.