Effect of Binder Index on Split Tensile 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 Split tensile 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 Split tensile strength of Geopolymer Concrete at ambient temperature.

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

1.Introduction

Concrete is the commonly used construction material. An important ingredient in the conventional concrete is the Portland cement. The production of Portland cement not only consumes natural resources but also contributes to the environmental pollution by releasing CO_2 to the atmosphere. It is estimated that 5-6% of all carbon dioxide greenhouse gases generated by human activities originates from cement production [1]. Geopolymer concrete is one of the green alternatives to the Portland cement concrete. Geopolymers are new group of binders developed by Joseph Davidovits in 1970's [2]. Fly ash based Geopolymers from wide range of Geopolymer family have attracted more attention since from 1990's. Geopolymer concrete result from polymerization process of Fly ash and GGBS as a binding material and alkaline liquid. Alkaline solution is combination of sodium silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH). Several publications were available describing Geopolymer pastes and Geopolymer concrete materials [3-4]. Keeping in view of the past research work done, the present research aimed at studying the effect of Fly ash, GGBS and molarity of alkaline activator on the Spilt tensile strength of Geopolymer concrete . A Parameter called **Binder Index** (B_i) is proposed to quantify the effect of binders on the Split Tensile strength of Geopolymer concrete developed at ambient temperature.

2. Experimental investigation: The experimental program consisted of determination of the Split tensile strength of Geopolymer Concrete by casting and testing cylinders of 100 mm diameter and 200 mm long. 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% [5]. 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]. 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 2400Kg/m^3.The Geopolymer Concrete mix proportions are shown in table 3.

Table 3. Geopolymer Concrete mix proportions.

FA:GGBS	Geopolymer Concrete mix proportions (Kg/m^3)							
	Coarse Aggregate	Fine Aggregate	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 solids 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 mixtures 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 Geopolymer concrete mixtures were usually very cohesive. The workability of the fresh Geopolymer concrete was measured by means of the conventional slump test. Compaction of fresh Geopolymer concrete in the 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 Split Tensile 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[7].Three identical specimens with each variation were cast and tested after 7 days and 28 days of ambient curing. A total of 126 cylinders using different Fly ash to GGBS proportions and different molarity's (8M,10 & 12M) were cast and tested after 7days 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[8, 9, 10].

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

3. 0 Results and Discussions

Table 4. Split Tensile Strength values for Geopolymer Concrete

FA:GGBS	[GGBS / (GGBS + Fly ash)]	Split Tensile Strength (Mpa)					
		8 moles/L		10 moles/L		12 moles/L	
		7D	28D	7D	28D	7D	28D
80:20	0.2	1.75	2.24	2.07	2.48	2.48	3.03
70:30	0.3	2.10	2.53	2.45	3.22	2.93	3.50
60:40	0.4	2.48	2.73	2.87	3.50	3.25	3.86
50:50	0.5	2.61	3.10	3.18	3.98	3.66	4.24
40:60	0.6	3.09	3.27	3.50	4.14	3.89	4.78
30:70	0.7	3.25	3.66	3.79	4.46	4.14	5.00
20:80	0.8	3.57	3.98	3.98	4.78	4.52	5.13

Table 5. Binder Index Vs Split Tensile Strength of Geopolymer concrete

Binder Index = [GGBS / (GGBS + Fly ash)]	Split Tensile Strength (Mpa)	
	7 days	28 days
	7D	28D
1.6	1.75	2.24
2	2.07	2.48
2.4	2.48	3.03
2.4	2.10	2.53
3	2.45	3.22
3.6	2.93	3.50
3.2	2.48	2.73
4	2.87	3.50
4.8	3.25	3.86
4	2.61	3.10
5	3.18	3.98
6	3.66	4.24
4.8	3.09	3.27
6	3.50	4.14
7.2	3.89	4.78
5.6	3.25	3.66
7	3.79	4.46
8.4	4.14	5.00
6.4	3.57	3.98

8	3.98	4.78
9.6	4.52	5.13

The effect of GGBS to Fly ash ratio on Split tensile Strength of Geopolymer concrete is shown in fig 1, fig 2. & fig 3.

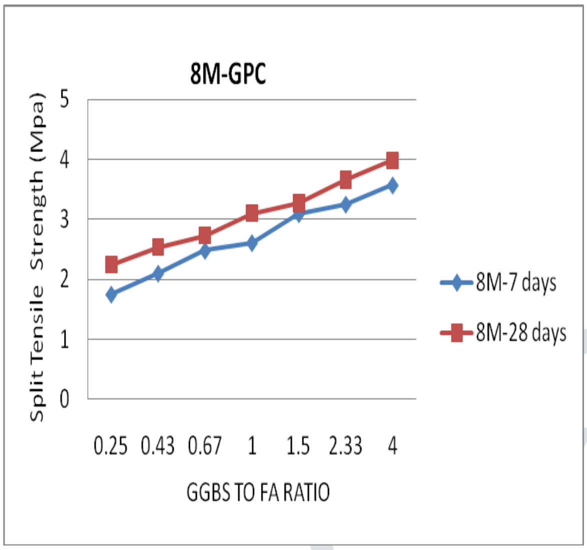

Fig 1. GGBS to Fly ash ratio Vs Split Tensile Strength Strength of GPC

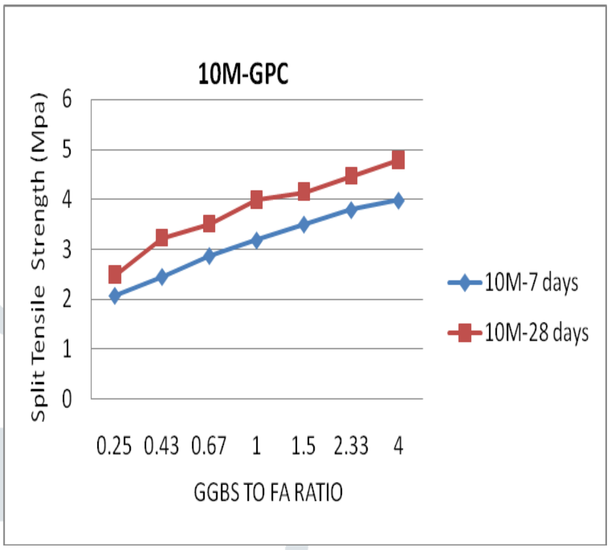

Fig 2. GGBS to Fly ash ratio Vs Split Tensile strength of GPC

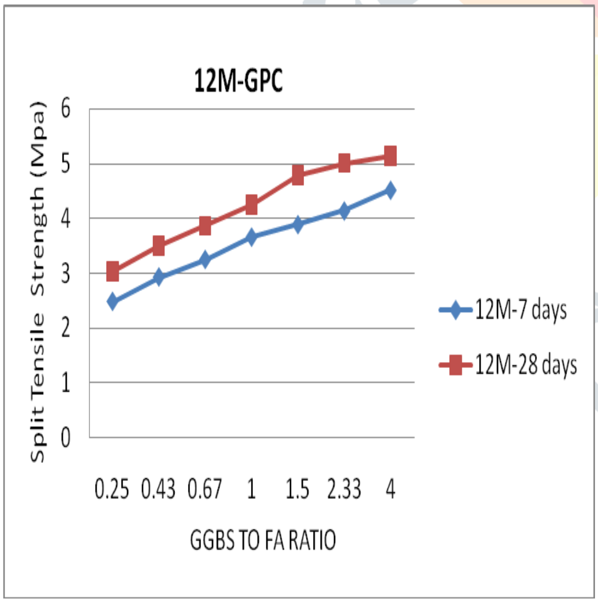

Fig 3. GGBS to Fly ash ratio Vs Split Tensile Strength of GPC

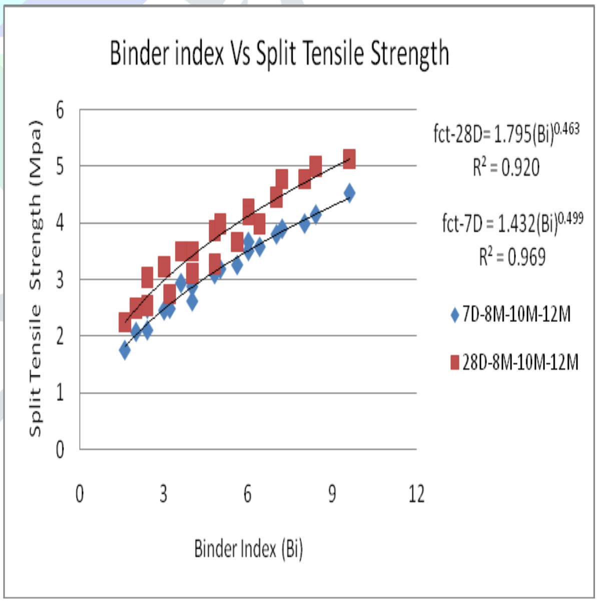

Fig 4. Binder index Vs Split Tensile Strength of GPC

3.1 Effect of GGBS to Fly ash ratio on Split Tensile strength of Geopolymer concrete(GPC).

The effect of GGBS to Fly ash ratio on Split tensile strength of 7 days and 28 days Geopolymer concrete for a particular molarity of alkaline activator is shown in fig 1. to fig 3.from figures it is observed that the Split tensile strength of Geopolymer concrete is increased with increase in GGBS to Fly ash ratio.

3.2 Effect of molarity of alkaline activator on Split tensile strength of Geopolymer concrete (GPC)

From fig 1. to fig 3. It is observed that the 7 days and 28 days split tensile strength of Geopolymer concrete increased with increase in the molarity of alakline activator for any choosen GGBS to Fly ash proportion.

3.3 Effect of Binder index on Split Tensile strength of Geopolymer concrete (GPC)

The Binder index has been used to study the combined effect of Fly ash , GGBS and molarity of alkaline activator on Split tensile strength of Geopolymer concrete .The Binder index (**B_i**) can be written as follows.

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

The variation of Split tensile strength of Geopolymer concrete with binder index is shown in fig .4. From the table 5, it is observed that the Split tensile strength of Geopolymer concrete increased with increasing binder index. The following best fit equations give the relation between Split tensile strength of Geopolymer concrete at 7 days and 28 days of ambient curing with binder index (B_i) along with the correlation coefficient (R^2).

$$f_{ct}\text{-}7D = 1.795\ (\mathbf{B_i})^{0.463} \quad , R^2 = 0.920 \text{….eq(2)}$$

$$f_{ct}\text{-}28D = 1.432\ (\mathbf{B_i})^{0.499} \quad , R^2 = 0.969 \text{….eq(3)}$$

Where f_{ct}-7D is split tensile strength of Geopolymer concrete for 7 Days

f_{ct}-28D is split tensile strength of Geopolymer concrete for 28 Days

4.0 Conclusions

The following conclusions can be made from the analysis of test results.

1. The Split tensile strength of Geopolymer concrete increased with increase in GGBS to Fly ash ratio for a particular molarity of alkaline activator used.
2. Binder index (B_i) which combines the effect GGBS, Fly ash and molarity of alkaline activator can be used for prediction of split tensile strength of Geopolymer concrete.
3. The 7 days and 28 days Split tensile strength of Geopolymer concrete increased with increase in Binder index and this increase can be approximated by a non-linear relation.
4. The Split tensile strength of Geopolymer concrete increased with increase in molarity of alkaline activator used for any chosen GGBS to fly ash ratio.
5. Fly ash and GGBS combination can be used for the production of Geopolymer concrete without the need of heat curing.
6. There is a non linear relation between the binder index and split tensile strength of Geopolymer concrete.

6.0 References

1. Malhotra, V.M.(1999). “Making Concrete Greener “with Fly ash. Concrete International.21 (5), 61-66.
2. J.Davidovits, Synthetic mineral polymer compound of the silico aluminates Fly ashmily and preparation process.US patent 4472199, 1978.
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. B.V. Rangan , Mix design and production of Fly ash based Geopolymer concrete, Indian concrete journal, 82, 7 (2008).
6. 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
7. IS516-1956, Indian standard methods of Test for Strength of Concrete.
8. 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.

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.