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Research Paper

EXPERIMENTAL INVESTIGATIONS ON OPTIMAL STRENGTH PARAMETERS OF FLY ASH BASED GEOPOLYMER CONCRETE

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The present experimental program is aimed for optimal values of compressive strength, flexural strength and split tensile strength of Geopolymer concrete by varying the fly ash content and also intended to study the general properties of fresh Geopolymer concrete. As we know that compressive strength of concrete is important parameter for design aspect of structural member. IS: 456-2000 Code of practice specifies that the flexural strength of concrete (fcr)can be correlated with compressive strength (fck)by the equation, $fcr = 0.7\sqrt{fck}$, which is experimentally validated with conventional concrete. Here the flexural strength of Geopolymer concrete is experimentally investigated and check the validation as specified for conventional concrete. The split tensile strength of the Geopolymer concrete was conducted in relevance with IS: 5816 the results which varies from 8 to 10% of the compressive strength of Geopolymer concrete. Present experimental results of hard state Geopolymer concrete are almost in similar with conventional concrete.

Keywords: Geopolymer concrete, Fly ash concrete, Geopolymer binders, GPC, Polymers.

INTRODUCTION

Nowadays, there is a big concern about the development of alternative materials to Portland cement concrete. The invention of Geopolymer concrete provides an alternative solution for production of conventional concrete. Geopolymer concrete is environmental friendly and substantially reduces emissions of CO_2. The Geopolymer concrete are manufactured by source material activated by alkaline liquid. The industrial waste material which having pozzolanic properties could be used as the source material, Fly ash, Silica fume, Ground Granulated Blast Furnace Slag (GGBS), Metakaoline are the general source materials to produce the Geopolymer concrete.

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The concept of Geopolymer concrete is the emerging technology in the field of concrete technology. From the available literature, it is noticed that experimental works have been carried on the properties of Geopolymer concrete and the obtained results were correlated with conventional concrete. It is a well-known fact to all the researchers in the field of concrete technology that the significant factors contributing to the strength of conventional concrete are percentage of the constituents, type of the binding material, admixtures, size of the aggregate and water binder ratio. Apart from these parameters the strength of Geopolymer concrete also depends on other parameters like type of curing, curing temperature, type of alkaline solution used as activator and aluminium-silica proportion in the binding material. In the present experimental study it is aimed at strength parameters of Geopolymer concrete by varying percentage of fly ash content. The fly ash content corresponds to maximum strength is taken as the optimal value.

BASIC MATERIALS

Following are the basic materials used for the preparation of Geopolymer concrete:

a) Fly ash (source material), b) Aggregates (Coarse and Fine aggregate) c) Alkaline solution (Activators), d) Water e) Plasticizers.

FLY ASH

In the present experimental work, low calcium, Class F fly ash is used and it is obtained from the Raichur thermal Power station, RTPCL, Karnataka state, Southern India. The physical and chemical properties of the fly ash presented in Table 1.

AGGREGATES

Fine Aggregate

Locally available clean river sand was used as fine aggregate in the study. Fineness modules of fine aggregate are 2.64 and Specific gravity is 2.61. The fine aggregate used conforms to Zone-II as per IS: 383-1970.

Table 1: Physical and Chemical Properties of Fly Ash

S. No.	Description	Values	Requirement as per IS:3812:2003
Physical Properties			
1.	Specific gravity	2.05	–
2.	Fineness (Blain's air permeability- m^2 /kg)	333	320
Chemical Properties			
3.	SiO_2 (% by mass)	62.92	35
4.	Al_2O_3 (% by mass)	30.96	–
5.	$SiO_2 + Al_2O_3 + Fe_2O_3$ (% by mass)	93.88	70
6.	Mg O (% by mass)	0.74	5
8.	Total sulphur as sulphur trioxide SO_3(% by mass)	0.23	3
9.	LOI (% by mass)	0.59	5

Coarse Aggregate

The locally available crushed granite of size 12.5 mm below was used as the coarse aggregate. Specific gravity of coarse aggregate is 2.62 and water absorption is 0.3 %.

Minimum void content test was conducted for the combined mixture of both coarse and fine aggregate, by considering the combined specific gravity as 2.62. The minimum void content was in the ratio of 56:44 for combined mixture of the coarse aggregate and fine aggregate. The same proportion was used throughout the experimental work.

Alkaline Solution

Sodium silicate and sodium hydroxide were used to prepare alkaline solution to react with the aluminum and the silica in the fly ash. Commercially available sodium silicate was used for this experimental work with water content of 33.53% and specific gravity of 1.53. Sodium hydroxide of 16 molars concentration solution was prepared by dissolving sodium hydroxide flakes with 97% purity in the water. The ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. The alkaline solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use.

Water

Potable tap water is used for preparation of alkaline solution

Plasticizers

To improve the workability of the fresh Geopolymer concrete, Poly carboxyl ether based High-performance super plasticizer (Glenium B233) was used through out the experimental work. The specified plasticizers were supplied by BASF chemicals India.

Preparation of Geopolymer Concrete Mixture

The solids constituents of the fly ash-based Geopolymer concrete, i.e., the aggregates and the fly ash, were dry mixed in the tilting drum mixer of capacity 100 L for about 3 min. Then the alkaline solution is added with super plasticizer. The mixing is continued for about 5 min. The Mix is named as FGC-M (Fly ash based Geopolymer concrete-Mix). The different mix proportions used in this study are tabulated in Table 2

The fresh fly ash-based Geopolymer concrete was dark in color with shiny appearance and the mixtures were usually cohesive. The workability of the fresh concrete was measured by means of the conventional Slump test, Vee-bee consistometer test and by Compaction factor test. The workability test results are tabulated in Tables 3 and 4.

Two mixes were prepared with 110 L and three mixes were prepared with 120 L which shown in Table 3, further addition of fly ash content in respective mixes were found to be of improper consistency. The slump test results itself is not able to carried properly for further increment of fly ash content in the respective mix and that's the reason we limited to slump test and not carried Vee-bee test and Compaction factor test. We are aimed at least six mixes to find optimal strength, hence we have taken water content of 130 L/m^3, in which we have got nine number of trial mixes with better consistency and suits with specified test and the results which are presented in Table 4.

Percentage of fly ash v/s Vee-bee in seconds is plotted in Figure 2, from which it is seen that Vee-bee seconds increases with the increase in fly ash content. For every 2% of fly ash increment

Table 2: Mix Proportions

Mixtures	Fly ash %	Fly ash kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	Plasticizer kg/m^3
Geopolymer concrete 110 liter mix							
FGC-M1	15	320.11	1015.84	798.16	75.96	189.92	3.20
FGC-M2	17	362.80	991.93	779.38	75.96	189.92	3.63
Geopolymer concrete 120 liter mix							
FGC-M1	15	316.49	1004.33	779.12	82.87	207.18	3.16
FGC-M2	17	358.69	980.7	770.55	82.87	207.18	3.59
FGC-M3	19	400.89	957.07	751.98	82.87	207.18	4.02
Geopolymer concrete 130 liter mix							
FGC-M1	15	312.86	992.82	780.08	89.78	224.46	3.13
FGC-M2	17	354.58	969.46	761.72	89.77	224.45	3.54
FGC-M3	19	396.29	946.10	743.37	89.77	224.45	3.96
FGC-M4	21	438.01	922.74	725.01	89.77	224.45	4.38
FGC-M5	23	479.73	899.38	706.66	89.77	224.45	4.80
FGC-M6	25	521.44	876.02	688.30	89.76	224.44	5.21
FGC-M7	27	563.16	852.66	669.94	89.76	224.44	5.63
FGC-M8	29	604.87	829.30	651.59	89.76	224.44	6.05
FGC-M9	31	646.59	805.94	633.23	89.75	224.43	6.46

Table 3: Workability Test Results for 110 litre and 120 L mix

Mixtures	Fly ash (%)	Slump (mm)
110 L mix		
FGC1-M1	15	68
FGC1-M2	17	46
120L mix		
FGC2-M1	15	120
FGC2-M2	17	95
FGC2-M3	19	73

there is an increment of 1 to 2 s were observed. We limited up to 31% of increase of fly ash content in our experiment and the maximum Vee-bee time found to be 33 s. In contrary to this, the slump value decreases with increase in fly ash content for the same mix as shown in Table 4 and Figure 1. Whereas there is no significant variation in compaction factor with respect to the fly ash content as noticed from Figure 3.

Casting

The fresh concrete was cast into moulds immediately after mixing and it is important to note that the fresh fly ash-based Geopolymer concrete could be handled up to at least two hours without any sign of setting and degradation in compressive strength (Hardjito and Rangan, 2005). The fresh

Table 4: Workability Test Results for 130 L Mix

Mixtures	Fly ash(%)	Slum p(mm)	Vee bee test (s)	Compaction Factor Test
FGC3-M1	15	217	20	0.985
FGC3-M2	17	207	22	0.981
FGC3-M3	19	200	25	0.977
FGC3-M4	21	196	26	0.969
FGC3-M5	23	190	28	0.965
FGC3-M6	25	188	30	0.962
FGC3-M7	27	186	30	0.958
FGC3-M8	29	172	32	0.956
FGC3-M9	31	156	33	0.952

Figure 1: Effect of Fly Ash Content on Slump for 130 L Mix

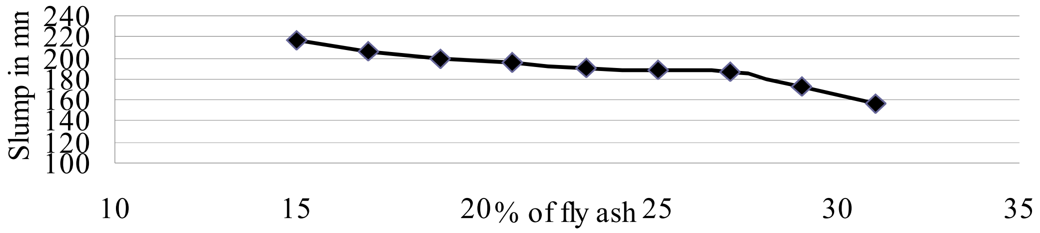


Figure 2: Effect of Fly Ash Content on Vee bee Consistency for 130 L Mix

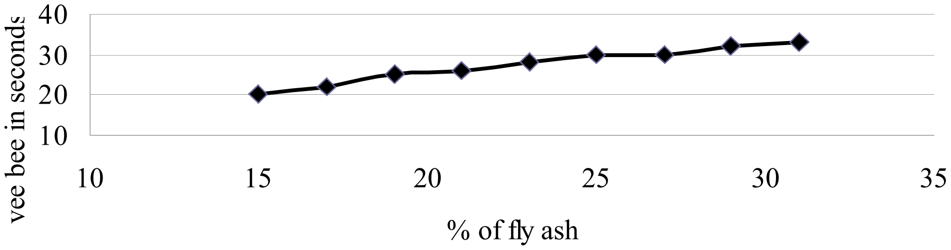
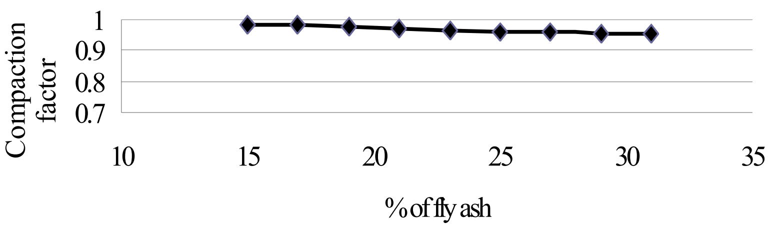


Figure 3: Effect of Fly Ash Content on Compaction Factor for 130 L Mix



concrete is casted in to 150 X 150 X 150 mm Cubes, 150 X 300 mm Cylinders and 100 X 100 X 500 mm Prisms, to find the compressive strength, split tensile strength and flexural strength respectively. The specimens were prepared in accordance with IS-516:1959. The compaction is achieved by giving sixty manual strokes for each layer by using tamping rod and followed by compaction on vibrating table for about 30 s.

Curing

After casting all the specimens were covered using polythene sheets to avoid the quick evaporation of moisture from the concrete and then all the specimens were kept at room temperature for three days. It is stated in the literature that postponing the curing for period of time causes an increase in the compressive strength of concrete (Hardjito and Rangan, 2005). At the end of three days the specimens were placed inside the hot air curing chamber [HACC][4] and cured at 60^{O}C for 24 h. After curing, the specimens were taken out from the chamber and kept to air-dry at room temperature and after achieving the room temperature the specimens were demoulded. Further the specimens were left in the laboratory at ambient temperature until the day of testing. All the test specimens were tested for 7th day from the date of casting.

Compressive Strength Test

The compressive strength test is conducted on the 2000 kN capacity compressive testing machine. Compressive strength test is carried out on the various mixes by varying fly ash as well as water content by keeping all other parameters as constant. The main objective of conducting the tests on various mixes is to find out the most suitable mix of having higher compressive strength with better workability. The same is used to cast split and flexural strength test specimens. The tests results on various mixes are shown in the Tables 5-7.

By considering all these mixes, Geopolymer concrete having water content of 130 L are selected because these mixes is having good workability and compressive strength. These mixes are used for casting of split tensile strength and flexural strength specimens.

Figure 4 shows the variation of compressive strength with variation in percent of fly ash content. We can see that the compressive strength increase with increase in fly ash content up to

Table 5: Compressive Strength of Cube Specimen (110 L mix)

Mixtures	% of Fly Ash	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
FGC1-M1	15	635	28.22	28.14
		620	27.55	
		645	28.67	
FGC1-M2	17	675	30	29.63
		680	30.22	
		645	28.67	

Table 6: Compressive Strength of Cube Specimen (120 L Mix)

Mixtures	% of Fly Ash	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
FGC2-M1	15	565	25.11	25.47
		580	25.77	
		575	25.55	
FGC2-M2	17	645	28.66	28.51
		630	28	
		650	28.88	
FGC2-M3	19	685	30.44	30.81
		705	31.33	
		690	30.67	

certain extent but further increase in fly ash content will decreases the compressive strength. From this graph we can see that the Geopolymer concrete mixtures of FGC3-M6, FGC3-M7 and FGC3-M8 are having optimum compressive strength and the same mixtures are used for casting the split tensile strength and flexural strength test specimens.

Split Tensile Strength Test

The three suitable mixes of optimal compressive strength were taken for the casting of split tensile test specimens. The test conducted on 150 X 300 mm cylindrical specimen according to IS: 5816-1959, the tests results are shown in Table 8.

From the graph (Figure 5) we can see that, increase in fly ash content intern slightly increases the split tensile strength. FGC-M6 Mix shows 2.82 N/mm^2. FGC-M7 and FGC-M8 shows 4% and 7% of increments over FGC-M6 Mix respectively. The variations of split tensile strength were not much significant among these three optimal mixtures.

Flexural Strength Test

The Geopolymer concrete mixtures FGC3-M6, FGC3-M7, FGC3-M8 (Optimal compressive strength mixtures) were used for the flexural strength. Tests carried on 100 X 100 X 500 mm specimens according to IS: 516-1959, the tests results are shown in Table 9.

Figure 4: Effect of Fly Ash Content On Compressive Strength (130 L mix)

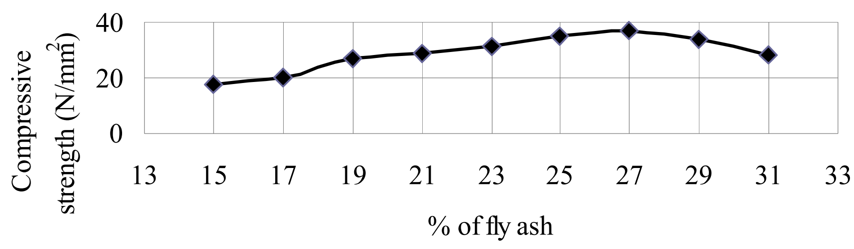


Table 7: Compression Strength of Cube Specimen (130 L Mix)

Mixtures	% of Fly Ash	Density (KN/m^3)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
FGC3-M1	15	23.53	405	18	17.48
		23.37	385	17.11	
		23.45	390	17.33	
FGC3-M2	17	23.49	440	19.56	19.92
		23.37	475	21.11	
		23.33	430	19.11	
FGC3-M3	19	23.46	610	27.11	26.59
		23.57	590	26.22	
		23.54	595	26.44	
FGC3-M4	21	23.58	630	28.00	28.44
		23.66	655	29.11	
		23.64	635	28.22	
FGC3-M5	23	23.67	695	30.89	31.55
		23.63	725	32.22	
		23.59	710	31.56	
FGC3-M6	25	23.67	785	34.89	35.25
		23.59	805	35.78	
		23.53	790	35.11	
FGC3-M7	27	23.63	805	35.78	37.11
		23.56	835	37.11	
		23.69	865	38.44	
FGC3-M8	29	23.46	745	33.11	33.55
		23.38	785	34.89	
		23.68	735	32.67	
FGC3-M9	31	23.49	640	28.44	28.07
		23.35	660	29.33	
		23.58	595	26.44	

Figure 6 shows that flexural strength of mix is increased by 4.69% for FGC-M7 mix and decreased by 3.05% for FGC-M8 mix over FGC-M6 Mix respectively. Significant variations in

Table 8: Split Tensile Strength of Cylindrical Specimens

Mixtures	Load (kN)	Split Tensile Strength $f_{ct} = 2P/\pi ld$ (N/mm²)	Average Split Tensile Strength (N/mm²)
FGC-M6	200	2.82	2.82
	210	2.97	
	185	2.61	
FGC-M7	220	3.1	2.94
	195	2.75	
	215	2.97	
FGC-M8	205	2.90	3.06
	225	3.18	
	220	3.1	

Table 9: Flexural Strength of Prism Specimens

Mixtures	Load (kN)	Distance From Fracture to nearer support (mm)	Flexural Strength (N/mm²) $f_{cr}=PL/bd^2$	Average Flexural Strength (N/mm²)
FGC-M6	10	178	4.0	4.26
	11.5	135	4.6	
	10.5	183	4.2	
FGC-M7	11	165	4.4	4.46
	10.5	167	4.2	
	12	178	4.8	
FGC-M8	9.5	174	3.8	4.13
	10.5	166	4.2	
	11	168	4.4	

Figure 5: Effect of Fly Ash Content on Split Tensile Strength

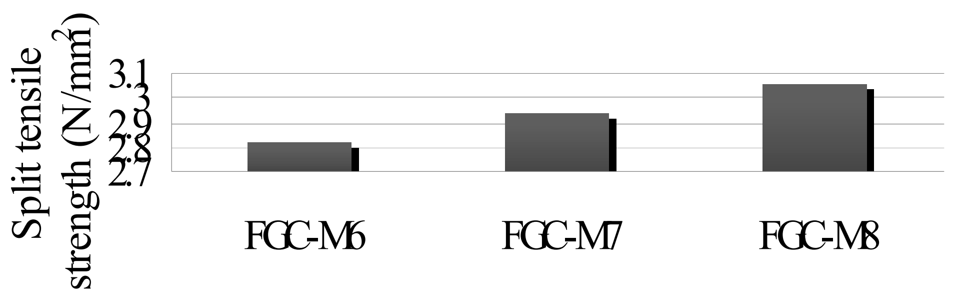
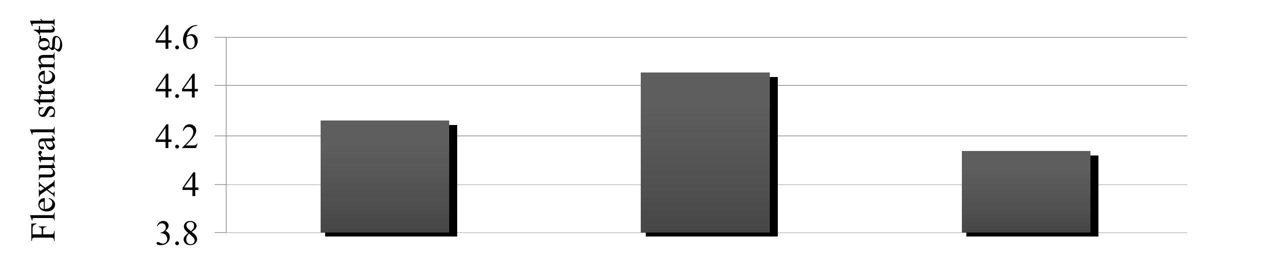


Figure 6: Effect of Fly Ash Content on Flexural strength



flexural strength were not found among these three optimal mixtures.

CONCLUSION

The slump value of the fresh fly ash based Geopolymer concrete decreases with the increases in fly ash content of the mixture. The flexural strength of fly ash-based Geopolymer concrete is a fraction of the compressive strength, as in the case of Portland cement concrete. The measured values are higher than recommended values in IS: 456-2000. As compressive strength increases the flexural strength is also increases in Geopolymer concrete, this behavior is similar to the OPC concrete. The compressive strength, flexural strength and split tensile strength increases with increase in fly ash content up to 27 % and decrease in strength with further increase of fly ash content.

REFERENCES

1. Davidovits J (1994), "Man Made Rock Geosynthesis And Resulting Development of Very Early High Strength Cement", *NASTS award1994, J. Material Education,* Vol. 16, Nos. 2&3, pp. 91-139.
2. Davidovits J (2002), "30 Years of Successes and Failures in Geopolymer Applications", *Market Trends and Potential Breakthroughs*. Geopolymer Conference, October 28-29, Melbourne, Australia,
3. Hardjito D and Rangan B V (2005), "Development and Properties of Low Calcium Fly Ash Based Geopolymer Concrete", *Research Report GC1Curtin University of technology Perth*, Australia.
4. Pradeepa J, Kumar S and Ravindra P M (2012), "Cost Effective Curing Arrangement for Geopolymer Concrete Specimens" *International Journal of Emerging Trends on Engineering and Development*, RS Publications, No. 2, Vol. 7, pp. 227-223.
5. Rangnath R V and Mohammad Saleh (2008), "Some Optimal Values In Geopolymer Concrete Incorporating Fly Ash", *Indian Concrete Journal,* October, pp. 26-35.
6. Ravindra N Thakur and Somnath Gosh (2009), "Effect of Mix Composition on Compressive Strength and Micro Structure of Fly Ash Based Geopolymer Concrete", *Arpn Journal of Engineering and Applied Science*, Vol. 4, No. 4.
7. Sumajouw M D J and Rangan B V (2006), "Low Calcium Fly Ash Based Geopolymer Concrete: Reinforced Beams and Columns", *Research Report GC 3*, Curtin University of technology Perth, Australia.
8. Wallah S E and Rangan B V (2006), "Low Calcium Fly Ash Based Geopolymer Concrete", Research Report GC 2, Curtin University of technology Perth, Australia.