Studies on Mechanical and Durability Properties of Geo Polymer Concrete with Fly ash and Slag for Different Molarities

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Abstract— The objective of this project is to study the effect of class F fly ash (FA) on the mechanical and durability properties of Geo Polymer concrete (GPC). Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solution has been used as alkaline activator with different molarities like 4 molarity, 6 molarity, 8 molarity and 10 molarity. In the present investigation it is proposed to study the mechanical properties viz. compressive strength after 7, 14, 28, 56 and 112 days and split tensile strength after 28, 56 and 112 days ambient room temperature curing and durability properties viz. loss of unit weight and compressive strength in acid curing for 28 and 56 days.

Key words: Geo Polymer concrete; Fly ash; Compressive strength; splitting tensile strength; Flexure strength

I. INTRODUCTION

Concrete is one of the most widely used construction material and it is usually associated with Portland cement as the main component for making concrete. Geo Polymer can be considered as the key factor which does not utilize Portland cement, nor releases greenhouse gases. The Geo Polymer technology proposed by Davidovits [1-2] shows considerable promise for application in concrete industry as an alternative binder to Portland cement. Davidovits proposed that the binders could be produced by a polymeric action of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product material such as fly ash and slag. He termed these binders as Geo Polymers. Among the waste or by-product materials, fly ash and slag are the most potential source of Geo Polymers.

II. GEO POLYMERS

In general the source materials and alkaline liquids are treated as major materials in the Geo-polymers. By mixing the two solutions, named sodium hydroxide *(NaOH)* and sodium silicate *(Na_2So_3)* we can prepare an alkaline liquid which is used in geo-polymers. The reaction takes place by sodium hydroxide and sodium silicate solutions is treated as the geo-polymerization process for our convenience. And also we have to consider that Silica *(Si)* and Aluminum *(Al)* are key elements in geo-polymers. The percentage of aluminum and silicon are to be taken into account in the materials which are used. The source materials like Fly ash, silica fume, slag, rice husk-ash etc are to be used. The source material selection is also economical.

A. *Applications of Geo polymers*

The various applications of Geo polymers include Industrial floor repairs, Airfield repairs *(in war zones),* Fireproof composite panels, External repair and structural retrofit for aging infrastructure, For storage of toxic and radioactive wastes, Potential utilizations in Art and Decoration, *LTGS* Brick, Railways sleepers, Electric power poles, Marine structures, Waste containments etc. [3]

III. INVESTIGATIONS

This study involves the details of development of the process of making low calcium *(ASTM Class F)* fly ash based geo polymer concrete. The physical and chemical properties of fly ash, aggregate and water used in the investigation were analyzed based on standard experimental procedures laid down in *IS*, *ASTM* and *BS* codes. The experiments conducted on coarse aggregate are specific gravity and water absorption, Bulk density & Sieve analysis by using respective codes [4-9]. The experiments conducted on fine aggregates are specific gravity, moisture content, sieve analysis and bulking of fine aggregate using volume method.

The tests conducted on geo polymer concrete are Compressive strength [10-12], Split Tensile strength [13-14], Flexural strength [10, 15-16] are as per the respective *IS*, *BS* and *ASTM* codes.

A. *Materials used*

1) *Fly ash*

According to *ASTM C 618* [17] the fly ash can be divided into two types based on amount of calcium present in the Fly ash. The classified Fly ashes are Class F (low-calcium) and Class C (high-calcium). In the Present investigation Class F fly ash [18] produced from Rayalaseema Thermal Power Plant *(RTPP)*, Muddanur, Andhra Pradesh was used.

2) *Coarse Aggregate*

Coarse aggregate of size 20 mm and 10 mm are used here. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm and 10mm as per *IS* code [7] were 2.58 and 0.3% respectively. The gradation of the coarse aggregate was determined by sieve analysis as per *IS* code [8]. The grading curves of the coarse aggregates as per *IS* code are shown in Chart 1& 2. *(Quantity taken=5 Kg)*

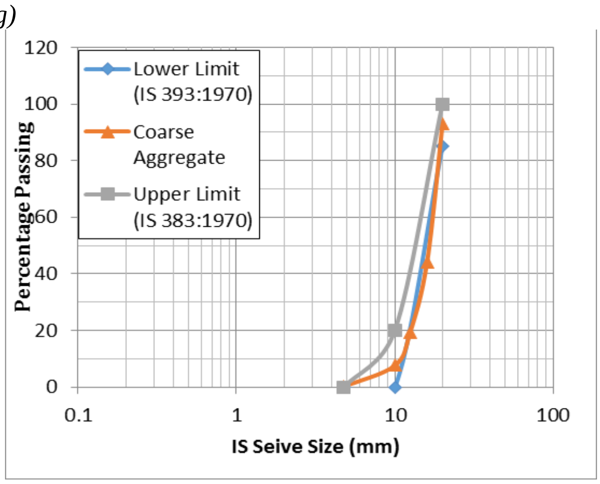

Fig. 1: Grading curve of 20 mm Coarse aggregate

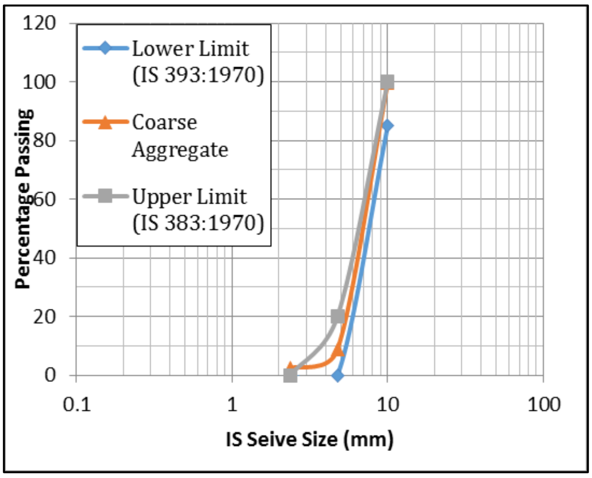

Fig. 2: Grading curve of 10 mm Coarse aggregate

3) Fine Aggregate

The slag used throughout the experimental work was obtained from the Lanko industries in Chittoor district. The bulk specific gravity in oven dry condition and water absorption of the slag as per *IS* code were 2.62 and 1% respectively. The gradation of the slag was determined by sieve analysis as per *IS* code. The grading curve of the fine aggregate as per *IS* code is shown in Chart 3. Fineness modulus of sand was 2.59. *(Quantity taken=1 Kg)*

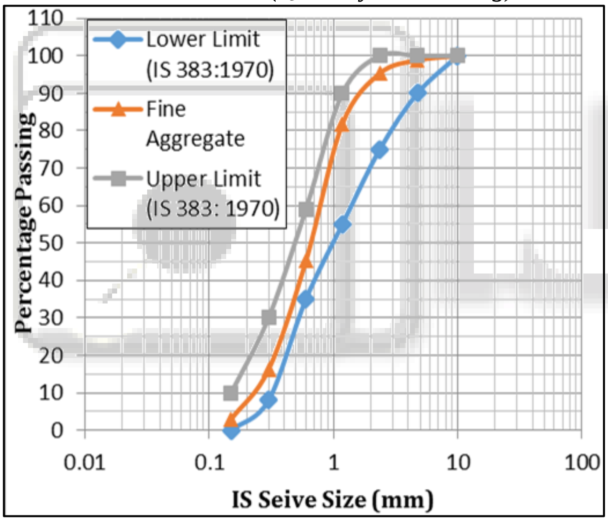

Fig. 3: Grading curve of Fine aggregate

4) Alkaline Liquid

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution (Na_2O= 13.7%, SiO_2=29.4%, & water=55.9% by mass) was purchased from a local supplier. The sodium hydroxide (*NaOH*) in flakes or pellets from with 97-98% purity was also purchased from a local supplier. The sodium hydroxide (*NaOH*) solution was prepared by dissolving either the flakes or the pellets in required quantity of water. The mass of *NaOH* solids in a solution varied depending on the concentration of the solution expressed in terms of molarity, M. For instance, *NaOH* solution with a concentration of 8M consisted of 8x40 = 320 grams of *NaOH* solids (in flake or pellet form) per litre of the solution, where, 40 is the molecular weight of sodium hydroxide (*NaOH*) pellets or flakes.

IV. MIXTURE PROPORTIONS

Based on the limited past research on *GPC* [19], the following proportions were selected for the constituents of the mixtures –

The combined mass of coarse and fine aggregates are taken as 77% of the mass of concrete. Ratio of activator solution-to-fly ash and slag, by mass, in the range of 0.3 and 0.4. This ratio was fixed at 0.35. Class F fly ash *(FA100)* was used and the Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, of 0.4 to 2.5. For the most of the cases the ratio was fixed at 2.5, because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution. Molarity of sodium hydroxide (*NaOH*) solution was kept at 4M, 6M, 8M &10M. The geo polymer concrete mixture proportions are given as follows:

Materials		Mass (kg/m^3)				
		M25	4M	6M	8M	10M
Coarse aggregate	20 mm	683.4	774	774	774	774
	10 mm	455.6	516	516	516	516
Fine aggregate	Slag	-	549	549	549	549
Fly ash *(Class F)*		-	409	409	409	409
Sodium silicate solution			102	102	102	102
Sodium hydroxide solution			41	41	41	41
Extra water		192	55	55	55	55
Alkaline solution/ (*FA*) (by weight)		-	0.35	0.35	0.35	0.35
Water/Geo Polymer solids (by weight)		-	0.35	0.33	0.31	0.29

Table 1: GPC Mix Proportions

V. METHODOLOGY

In the course of investigation, normal fine aggregate for the study of various properties, different specimens have been cast and tested. The physical and chemical properties of fly ash, slag and water used in the investigation were analyzed based on standard experimental procedures laid down in *IS ASTM* and *BS* codes. The tests conducted on Geo polymer concrete are Compressive strength, Split Tensile strength, and Flexural strength as per the respective *IS, BS* and *ASTM* codes [10-16].

A. Compressive Strength test

The compressive strength of the *GPC* was conducted on the cubical specimens for all the mixes after 7, 28 and 90 days of curing as per code. 9 No's of 150 mm cube specimen were made for each mix and 3 samples in each were cast and tested for 7 days, 28 days and 90 days respectively. The average value of these 3 specimens was taken for study.

Fig. 4: Testing of cubes for Compressive strength

The compressive strength (f'_c) of the specimen was calculated by dividing the maximum load applied to the specimen by the cross-sectional area of the specimen as given below.

$f'_c = P/A$

Where, f'_c = Compressive strength of the concrete (in N/mm^2)

P = Maximum load applied to the specimen (in Newton)

A = Cross-sectional area of the specimen (in mm^2)

B. Split Tensile Strength test

Splitting Tensile Strength *(STS)* test was conducted on the specimens for all the mixes after 28 days of curing as per code [13-14]. Three cylindrical specimens of size 150 mm x 300 mm were cast and tested for each age and each mix. The load was applied gradually till the failure of the specimen occurs. The maximum load applied was then noted. Length and cross-section of the specimen was measured. The splitting tensile strength (f_{ct}) was calculated as follows:

$f_{ct} = 2P/(\Pi\, l\, d)$

Where, f_{ct} = Splitting tensile strength of concrete (in N/mm^2)

P = Maximum load applied to the specimen (in Newton)

l = Length of the specimen (in mm)

d = cross-sectional diameter of the specimen (in mm)

Fig. 5: Testing of cylinders for Split tensile strength

VI. Results and Discussions

This section describes the Compressive strength, Split tensile strength and flexural strength of *GPC* at ambient room temperature curing. The compressive strength values of *GPC* mixes were measured after 7, 14, 28, 56and 112 days of curing. The split tensile strength and flexural strength values of *GPC* mixes were measured at 28, 56 and 112 days of curing. The above all strengths are also based on different molarities like 4M, 6M, 8M & 10M.

A. Compressive Strength

The compressive strength of *GPC* mixes with fly ash *(FA100)* at different molarities like 4M, 6M, 8M &10M as shown in the below table. In the table we also notice that the average strengths test specimens are calculated for 7days, 14days, 28days, 56days and also 112days. And also the strengths are going to increase whenever the molarities are increased. So, Molarity of solution gives further strength to the sample after curing.

Mechanical property	Age (days)	Mix type				
		M25	4M	6M	8M	10 M
Compressive strength, f'_c (MPa)	7	10.98	9.8	20.5	29.1	39.1
	14	22.3	14.7	27.2	37.6	45.4
	28	31.12	18.3	32.3	42.4	50.2
	56	35.84	24.6	38.1	50.2	59.3
	112	39.05	25.5	40.2	53.1	61.2

Table 2: Compressive strength of GPC

It was observed that there was a significant increase in compressive strength in the percent Fly ash 100% in all curing periods as shown in Chart 4. The *GPC* with 100% fly ash sample exhibited compressive strength values of 9.8MPa, 20.5 MPa, 29.1 MPa & 39.1MPa in 4M, 6M, 8M & 10M condition for 7days. Usually 14.7 MPa, 27.2MPa 37.6MPa, 45.4MPa in 4M, 6M, 8M & 10M conditions after 14days Similarly 18.3MPa, 32.3MPa, 42.4MPa & 50.2MPa strengths are attained in 4M, 6M, 8M &10M after 28days. Similarly, for 56days the strengths are as follows 24.6MPa, 38.1MPa, 50.2MPa & 59.3MPa in 4M, 6M,8M &10M situations and similarly 25.5MPa, 40.2MPa, 53.1MPa & 61.2MPa strengths are gained in 4M, 6M,8M & 10M conditions after 112 days of curing respectively at ambient room temperature.

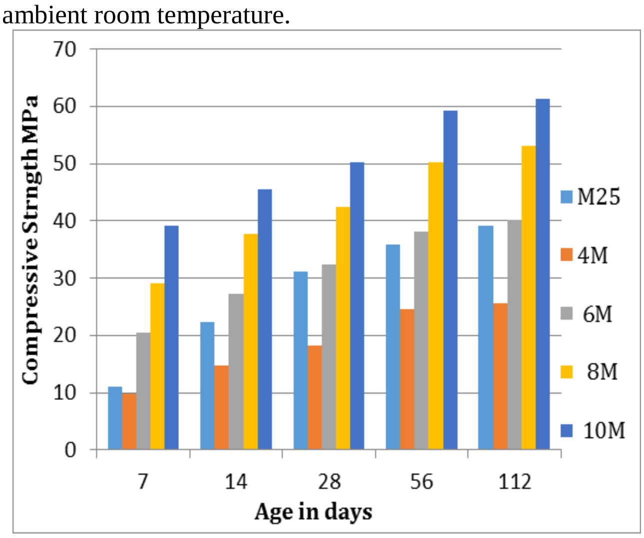

Fig. 6: Compressive strength versus Age

B. Split Tensile Strength

Mechanical property	Age (days)	M25	Mix type			
			4M	6M	8M	10M
Splitting tensile strength, f_{ct}	28	3.68	2.25	3.75	4.83	5.44
	56	3.96	2.35	3.97	5.14	5.96
	112	4.24	2.52	4.27	5.45	6.40

Table 3: Split tensile strength of GPC

The above table shows the split tensile strength of *GPC* mixes with fly ash *(FA100)* at different molarities like 4M, 6M, 8M & 10M at different curing periods. The tensile strengths are increased slightly based on the increasing level of molarities.

It was observed that there was a significant increase in splitting tensile strength with the percentage of 100% Fly ash in all curing periods as shown in Chart 5. The *GPC* with 100% Fly ash sample exhibited splitting tensile strength values of 2.25 MPa, 3.72 MPa, 4.83 MPa, & 5.44MPa after 28days. And 2.35MPa, 3.97MPa, 5.14MPa & 5.96MPa strengths after 56days and 2.52MPa, 4.27MPa, 5.45MPa &6.4MPa strengths after 112 days of curing respectively at 4M, 6M,8M and 10M conditions at ambient room temperature.

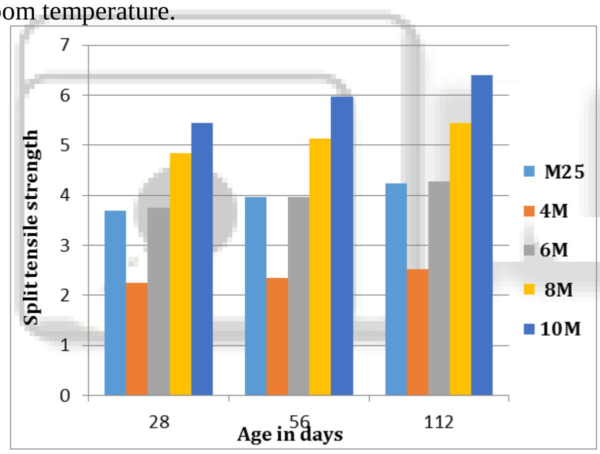

Fig. 7: Split tensile strength of mixes

C. Performance of Gpc After Acid Attack

property		M25	Mix type			
			4M	6M	8M	10M
Unit weight Kg/m^3	Initial weight	2269.5	2254.81	2275.56	2343.7	2405.93
	After acid attack	2123.4	2173.5	2212.3	2297.23	2389.2
Loss of unit weight % for 28 days		6.43	3.6	2.77	1.98	0.69
Compressive strength (mpa)	Initial strength	31.12	18.3	32.3	42.4	50.2
	After acid curing	28.76	15.92	29.89	39.42	47.23
Loss of strength in 28 days		7.583548	13.00546	7.4613	7.028302	5.916335

Table 4: shows loss of compressive strength and unit weight of GPC mixes FA 100% with different molarities at 28 days curing period before and after acid attack.

property		M25	Mix type			
			4M	6M	8M	10M
Unit weight Kg/m^3	Initial weight	2269.5	2254.81	2275.56	2343.7	2405.93
	After acid attack	2102.5	2105.32	2205.32	2289.5	2358.8
Loss of unit weight % for 56 days		7.35	6.62	3.08	2.31	1.95
Compressive strength (mpa)	Initial strength	31.12	18.3	32.3	42.4	50.2
	After acid curing	27.12	14.58	28.13	37.91	45.89
Loss of strength in 56 days		12.85	20.32	12.91	10.58	8.58

Table 5: shows loss of compressive strength and unit weight of GPC mixes FA 100% with different molarities at 56 days curing period before and after acid attack.

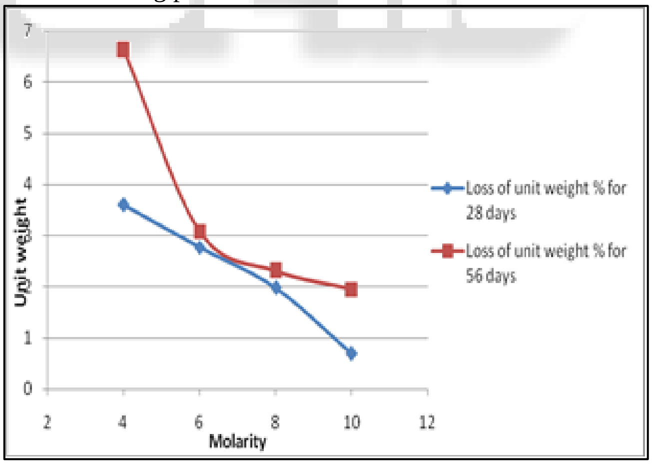

Fig. 8: Graphical representation of % Loss of unit weight

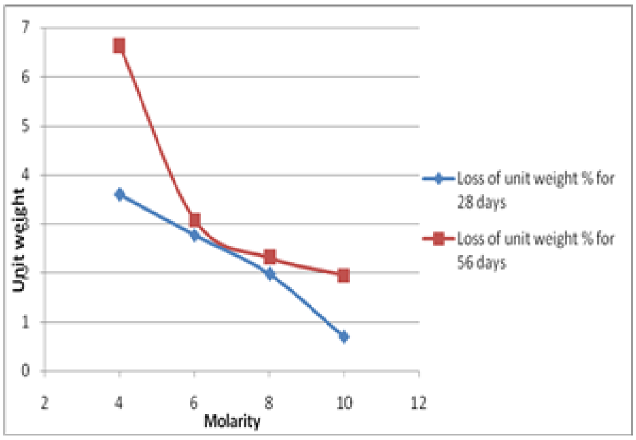

Fig. 7: Graphical representation of Loss of compressive strength

From the results explains as increasing the molarity in GPC the loss of unit weight decreases in acid curing for 28 days and 56 days and also loss of strength decreases with increases the molarity.10M shows better results for high resisting against acid attack. For 4M and 6M shows a poor results against acid attack

VII. Conclusions and Scope of Future Work

The primary aim of this research was to develop *GPC* with the fine aggregate and study the mechanical properties of *GPC* mixes at ambient room temperature. Based on the investigation, the following conclusions have been drawn.

1) There was a significant increase in Compressive strength and Split tensile strength while increase in molarity.
2) The 28th day strength of GPC mix with 6M is equivalent to M25 grade of concrete.
3) The percentage loss of unit weight and compressive strength is decreased with increasing molarity in acid environment.
4) Eco-friendly GPC can be recommended as sustainable construction material.

A. *Scope of Future Work*

Further research is recommended to study the bond strength between concrete and steel reinforcement and the other durability properties viz. water absorption, chloride penetration of *GPC* mixes. Keeping in view of the availability of natural resources and environmental aspects, it is recommended to replace some percentage of slag with in *FA* based *GPC* mixes and study all *GPC* hardened and durability properties. The research towards the development of cost effective *FA* and based *GPC* mixes is also encouraged.

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