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Strength and Durability Studies on Geopolymer Concrete Blended with GGBS and Phosphogypsum

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Abstract : This paper presents the progress of the research on making Geopolymer Concrete with Flyash and mineral admixtures such as Ground Granulated Blast Furnace Slag (GGBS) and Phosphogypsum. The present paper gives the results of study on the development of compressive strength and studies on the durability of Geopolymer concrete. In this study an attempt has been made to create Flyash based Geopolymer concrete with partial blending of Flyash with Phosphogypsum) and GGBS (Ground granulated blast furnace slag and to study the strength and acid resistance of produced Geopolymer concrete. The study was conducted to know the compressive strength as well as durability properties of Geopolymer Conccrete such as acid resistance. The cube specimens of size 150 mm side having GGBS and Phosphogypsum as replacement from 0, 2.5, 5, 7.5, 10 % of Flyash . Acid Resistance evaluated by immersion of the above specimens in the solution of 5 % concentrated Sulphuric acid for a duration of 30, 60 and 90days and evaluated the changes in weight of specimens and residual compressive strength at these intervals.

The specimens visual appearance after exposure to Sulphuric acid solution showed that acid attack slightly damaged to specimen surface. The produced Geopolymer concrete sample showed less weight loss in Sulphuric acid solution and having more residual compressive strength at the end of test period. Geopolymer Concrete blended with Phosphogypsum and GGBS and are having higher compressive strength and more resistance against Sulphuric acid.
Key Words : Geopolymer, Flyash, Alkaline Liquids, Phosphogypsum, GGBS, Compressive Strength, Sulphuric Acid, Weight loss, Residual Strength.

I. Introduction

Geopolymer concrete is considered as future concrete as it is encouraging new cement alternative in the present construction materials. Ordinary Portland cement is traditionally used as the chief binder to make concrete. The quantity of the carbon dioxide released during the manufacture of OPC is in the order of one ton for every ton of OPC produced. Among the greenhouse gases, produced CO_2 contributes about 60 to 65% of global warming. Moreover, it has been reported that the durability of OPC concrete is under examination, as many structures those built with concrete in corrosive environments start to deteriorate. On the other side, the ample availability of Flyash gives opportunity to utilize the byproduct of burning coal, as blending to opc to manufacture concrete. Davidovits [1] initiate that binders can be produced by the polymeric reaction of alkaline liquids with silica and aluminium in source material such as Flyash, GGBS and Phosphogypsum. These binders are termed as Geopolymer. The word Geopolymer source group of mineral binders having chemical composition same as zeolites. Geopolymer isan inorganic alumino-silicate polymer made from predominantly silicon (Si) and aluminium (Al) materials like Flyash, Phosphogypsum and Granulated Blast furnace slag which were obtained from geological origin or as the byproduct. Thepolymerization process involves in a chemical reaction under alkaline condition on Silica-Aluminium

Geopolymer is an alumino-silicate polymer made from silicon (Si) and aluminium (Al) materials like flyash, Phosphogypsum and Granulated Blast furnace slag which were obtained from geological origin or as the byproduct. The polymerization process involves in a chemical reaction under alkaline condition on Silica-Aluminium Geopolymer binders have emerged as alternative to OPC binders due to their high early strength and resistance against[2][5] acid as well as environmental friendliness.

Geopolymer made by using Flyash are one branch in the Geopolymer family and these have attracted more attention. As a binder, the performance of fly ash based Geopolymer is promising, in aggressive situations where ordinary cement concretes are vulnerable. Geopolymer binders are suitable alternative in the production of acid resistant concrete.

Since Geopolymer are novel binders that rely on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity, they have been reported as being acid resistant. This study comprised of determination of compressive strength of Flyash based Geopolymer concrete blended with GGBS and Phosphogypsum and also the durability properties of Geopolymer concrete such as visual appearance changes in weight, residual compressive strength of the specimens as a measure of its resistance against acid. The results of the present study is useful in determining durability and hence the applicability of Geopolymer materials for use in acidic environments.

II. Literature Review

Davidovits and Sawyer (1985) made use of ground blast furnace slag to make Geopolymer binders. This type of binders patented under the name Early High-Strength Mineral Polymer, it is used as a supplementary cementing material in the production of precast concrete products.

Palomo(1999) showed that alkaline liquid type shows significant part in the polymerisation process. Xu and van Deventer (2000) proved that by adding the sodium silicate to the sodium hydroxide enhanced the reaction between the source material and the solution. After study it is concluded that the NaOH solution response to higher amount of minerals dissolution than the solution of KOH.

Lee et al (2004) have experimented and reported the micro structure and the bonding strength of the edge between ordinary siliceous aggregates and fly ash based Geopolymers. It was know that when activating solution that contained no or slight soluble silicates, the compressive strength of the Geopolymer binders and concretes were weaker than that of activated with high dosage of soluble silicates. The existence of soluble silicates in the preliminary activating solution alsoactive in reducing alkali saturation in the concrete pore solution even when a highly alkali-concentrated activating solution was used.

Anurag Mishra (2008, 2009) conducted experiments on Flyash based Geopolymer concrete by different concentration of NaOH solution and curing time. The investigation showed that by increasing concentration of NaOH there is increase in compressive strength and curing time. Compressive strength of 46 MPa was obtained with curing at 60ºC.

3. Experimental Programme

3.1 Materials and mix proportions

3.1.1 Flyash

Fly ash belonging to class-F obtained from Rayalaseema thermal Power Station in Andhra Pradesh was used in the present investigation. The specific gravity of the Fly ash was 1.975.It had mineral and chemical composition as in Table-1

Table 1: Flyash properties

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	LOI
Percentage of content %	56.01	29.8	3.58	1.75	2.36	0.3	0.73	0.61	1.8	0.44	0.4

3.1.2 Alkaline Liquid

Commercially available Sodium Silicate Solution with water content as 56.6% and 100% pure Sodium Hydroxide pellets are used for creating alkaline activator.

3.1.3 Natural fine aggregate

Locally available clean river sand was used as Fine Aggregate in the study which was having fineness modulus as 2.74, specific gravity as 2.61 and conforming to grading zone-II as per IS 383-1970 .

3.1.4 Natural coarse aggregate

Used is bought from locally available crushed granite of maximum size 20mm and specific gravity of Coarse Aggregate is 2.75.

3.1.5 Water

Potable fresh water available from local sources free from deleterious materials was used formixing and curing of all the mixes tried in this investigation.

3.1.6 Super plasticizer

The super plasticizer used in this experiment is Naphthalene Sulphate based super plasticizer. It is manufactured by MYK SCHOMBURG, Hyderabad. MYK Savemix SP200 compiles with IS: 9103:1999 and has specific gravity of 1.24.

3.1.7 GGBS and Phosphogypsum

The GGBS and Phosphogypsum are bought commercially from Chennai. The specific gravity of GGBS and Phosphogypsum are 2.9 and 2.35 respectively.

3.1.8 The acid used in the investigation is H_2SO_4 of 5% concentration.

3.2 Mix Design of Geo Polymer Concrete

The mix proportion of Geopolymerhas been carried out by using 1: 1.405: 3.28 and the relative mix proportions are presented in Table 2

Table 2: Geopolymer concrete mix proportions

Materials	Quantity Kg/m^3
Fly Ash	394.3
C.A 20 mm	906
C.A 10 mm	388
F.A	554
NaoH Solids	14.135
Na_2Sio_3 Solids	48.85

3.3 Experimental Programmme

3.3.1 Methodology

Preparation of alkaline liquid

Sodium hydroxide (NaoH) and Sodium silicate (Na_2SiO_3) were used as alkaline liquids. The molarity of NaoH used for the present study was 10. The ratios of Na_2SiO_3 to NaoH selected was 2.5. A solution of 10M of sodium hydroxide is prepared by dissolving 415g of sodium hydroxide pellets in a litre of water and stored separately. For particular ratio of sodium silicate to sodium hydroxide both the solutions were taken and mixedin the beaker one day of casting of specimens.

Casting of Geopolymer concrete specimens

The size of the specimens used for the present study was cubes of size 150 x 150 mm for both compressive strength and acid resistance. Two type of mixes i.e.Flyash +Phosphogypsum and Flyash+GGBS[11] were mixed with fine aggregate, coarse aggregates and the alkaline liquid (combination of Sodium silicate and sodium hydroxide) were poured to dry mix and mixed thoroughly to form homogenous mixture for a period of 3 min approximately. The required quantity of super plasticizer was added as 3% by mass of Flyash. after mixing process was done the mould was filled by the fresh concrete in three layers and compacted well. For each mix three specimens were casted to test the compressive strength of concrete.

Curing of Geopolymer concrete specimens

After the specimens were cast they were kept in hot air oven properly wrapped by a steel plate with a constant temperature of 60^{O}C for a period of 24 hours. Then the specimens were taken out to keep in room temperature for the preferred rest period The molarity used for the present study was kept constant as 10. Since alkali activators were used for thestudy the specimens were kept in hot air oven for thermal curing to a temperature of 60^{o} C and after that the specimens were cured at ambient temperature for the 30 ,60 and 90 days.

Placing of specimens under acidic environment

After curing the specimens were immersed at 5% concentrated solution of Sulphuric acid for a period of 30, 60 and 90 daysand then specimens were removed to measure the percentage weight loss and residual strength at the end of the period.

4. RESULTS AND DISCUSSIONS

4.1 Compressive strength test

Compression test on the cubes was conducted on the 2000 KN. AIMIL digital compression testing machine. The pressure gauge of the machine indicating the load has a least count of 1 KN. The cube was placed in the compression-testing machine and the load on the cube is applied at a constant rate up to the failure of the specimen and the ultimate load is noted. The cube compressive strength is calculated and is presented in Table 3 and Table 4.For each mix three specimens were tested and average values are taken.

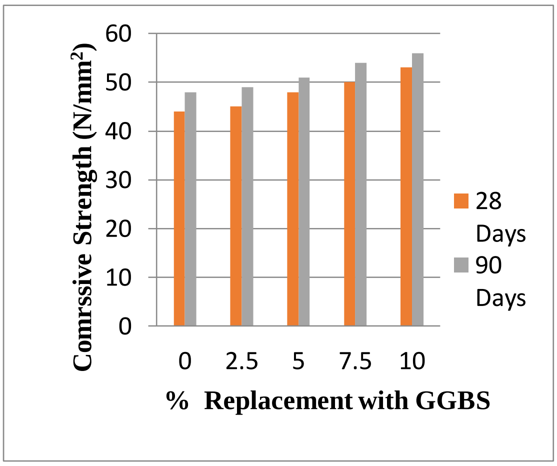
The 28 and 90 days compressive strength of Geopolymer concrete specimens with different percentages of blending is shown in the figures 1 and 2. It is observed that compressive strength is increased linearly up to 10 % in case of GGBS blended specimens and in case of Phosphogypsum blended specimens strength is gradually increased up to 7.5 % blending and then later decreased.

Table 3: Compressive Strength of GPC Made by Replacement of Flyash with GGBS

Sl No	% Replacement	Compressive Strength (N/mm^2)	
		28 Days	90 Days
1	0	44	48
2	2.5	45	49
3	5	48	51
4	7.5	50	54
5	10	53	56

Table 4: Compressive Strength of GPC made by Replacement of Flyash with Phosphogypsum

Sl No	% Replaceme nt	Compressive Strength (N/mm^2)	
		28 Days	90 Days
1	0	44	48
2	2.5	45	49
3	5	48	50
4	7.5	49	52
5	10	45	49



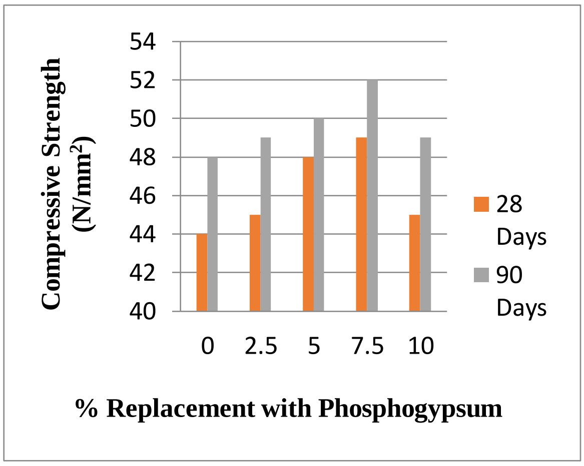


Fig 1: Compressive strength Vs % Replacement with Phosphogypsum

Fig 2:Compressive strength Vs% Replacement with GGBS

4.2 Acid resistance

The sulphuric acid resistance of Geopolymer concrete is evaluated. To perform the acid attack in the present investigation the specimens of size 150 x 150 x 150 mm are used.After casting and curing, specimens were immersed in H_2SO_4solution. The concentration of Sulphuric acid solution is 5%. The evaluation is conducted after 30, 60 and 90days. The solution is kept at room temperature and the solution is stirred regularly. The influenceof acid on the specimens were constantly monitored throughvisual inspection, weight change measurements and strength tests are done after exposure period.

4.2.1 Visual Inspection

Specimens showed no noticeable change in colour in sulphuric acid. After expose in 5 % sulphuric acid, specimens of both GGBS and Phosphogypsum blended showed slight damage on surface of specimens. The deterioration has been increasing from 30,60 and 90 days. The photographs of acid attacked specimens at the end of 90 days is presented in Figure 3 and figure 4. The deterioration of the surface was seen to increase with time through extent of deterioration among three intervals of time,could not be easy differentiated through visual inspection.

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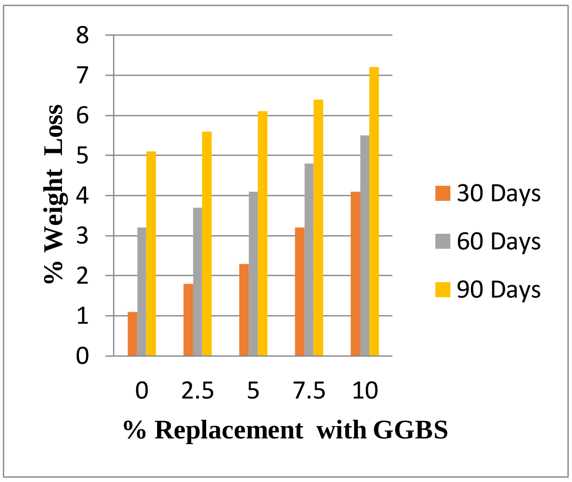
Fig 3:Acidattacked GGBS Specimen **Fig 4:Acid attacked Phosphogypsum Specimen**

4.2.2 Change in weight

Results of the weight changes of the Geopolymer concrete specimens immersed sulphuric acid is shown in the figures 5 and figures 6. In the case of specimens blended with GGBS and Phosphogypsum,when immersed in the 5% concentrated sulphuric acid showed gradual increase in weight loss for the percentages of 2.5, 5, 7.5 and 10%. The loss is less during initial period of 30 days and increased at later time intervals of 60 and 90 days both in case of GGBS and Phosphogypsum. The maximum weight loss is found at the end of 90 days as 7.2% in case of 10% blended GGBS specimens and 7.5% in case of 10% blended Phosphogypsum specimens.



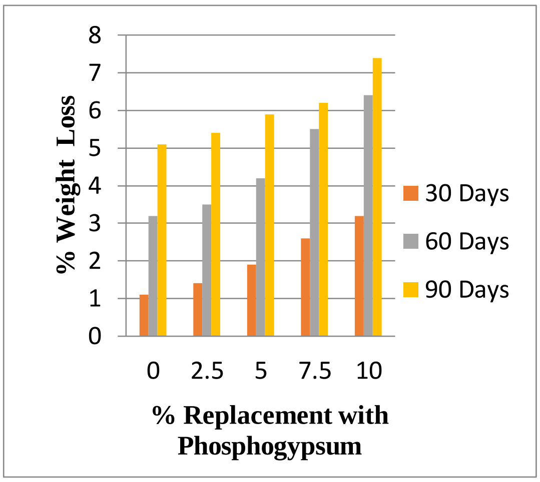


Fig 5: Weight loss in %
Vs
% Replacement with GGBS

Fig 6: Weight loss in %
Vs
% Replacement with Phosphogypsum

4.2.3 Residual Compressive Strength

The figure 7 and figure 8 shows the compressive strength evolution of Geopolymer concrete specimens blended with GGBBS and Phosphogypsum in5% concentrated sulphuric acid at regular intervals. In case of Geopolymer specimens blended with GGBS has increased up to 7.5% and later decreased. In case of Phosphogypsum blended specimens the residual strength has increased up to 5% of blending and then showed decreasing residual strength. The specimen blended with 7.5% of GGBS and 5% of Phosphogypsum has showed minimum loss of strength by having more residual strength at 30,60 and 90 days of exposure to sulphuric acid.

Table 5: Residual compressive strength Of GGBS specimens immersed in $H_2SO_4H_2SO_4$

Sl No	% Replacement	Compressive Strength (N/mm^2)		
		30 Days	60 Days	90 Days
1	0	40	38	35
2	2.5	42	40	37
3	5	44	41	38
4	7.5	47	44	40
5	10	41	38	34

Table 6: Residual compressive strength of Phosphogypsums pecimens immersed in

Sl No	% Replacement	Compressive Strength (N/mm^2)		
		30 Days	60 Days	90 Days
1	0	40	38	35
2	2.5	43	41	39
3	5	46	43	41
4	7.5	44	41	38
5	10	42	39	36

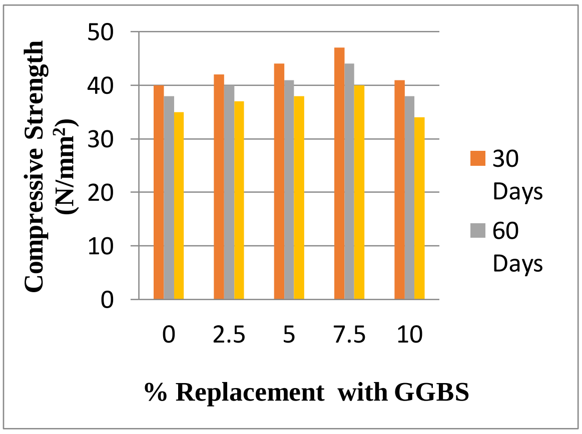


Fig 7: Compressive Strength Vs % Replacement With GGBS

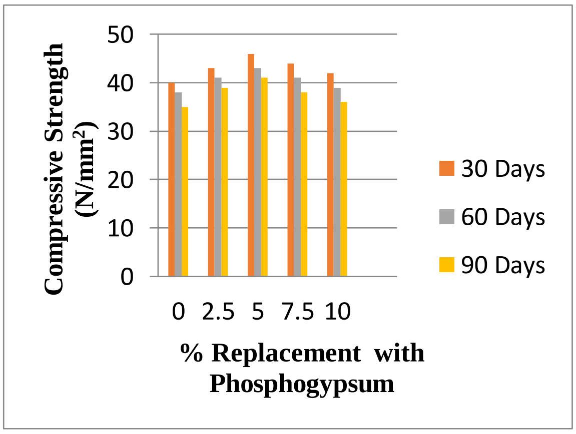


Fig 8: Compressive Strength Vs % Replacement with Phosphogypsum

5. Conclusions

The use of by products like Flyash, GGBS and Phosphogypsum has gained significant importance because of the requirement of environmental protection and sustainable construction in future.

On the basis of this study, the following conclusions can be drawn

1. GGBS and Phosphogypsum helps in increasing the mechanical properties on Geopolymer concrete.
2. The compressive strength of Geopolymer concrete blended with GGBS and Phosphogypsum is higher than plain Geopolymer concrete.
3. Geopolymer concrete blended with GGBS showed gradual increase in compressive strength from 0 to 10%.
4. Geopolymer concrete blended with Phosphogypsum showed gradual rise In compressive strength up to 7.5% replacement of Flyash and then decreased.
5. The loss of weight when immersed in H_2SO_4 was observed higher in specimens blendedwith GGBS and Phosphogypsum compared to the normal Flyash basedGeopolymer concrete, at the end of 30,60 and 90 days
6. The residual compressive strength has increased up to 7.5% and later decreased in case of Flyash based Geopolymer concrete blended with GGBS specimens.
7. In case of Phosphogypsum specimen's residual compressive strength increased up to 5% replacement of Flyash and then decreased.

8. The specimens blended with GGBS and Phosphogypsum when exposed to acidic environment yielded very low weight loss during initial stages and at later time intervals weight loss is more in case of both blended specimens.
9. By incorporation of GGBS and Phosphogypsum in Flyash based Geopolymer concrete as partial blending showed better mechanical properties and better durability to acid attack .

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