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Flexural & Tensile Strength Properties of GGBS and Phosphogypsum Blended Geopolymer Concrete

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Abstract : In order to address environmental effects associated with Portland cement there is need to use other binders to make concrete. An effort in this regard is the development of Geopolymer concrete synthesised from the materials of geological origin which are the byproduct materials such as Flyash, GGBS(Ground Granulated Blast Furnace Slag), Phosphogypsum which are rich in silica and aluminium. The alkaline liquids are used for activation of these materials. The alkaline liquids used in this study for the polymerisation are the solutions of sodium hydroxide which is of 10 Molarity and sodium. This paper presents results of an experimental study on strength properties such as Split Tensile strength and Flexural strength.

The experiments were conducted on Flyash based Geopolymer concrete made by replacing Flyash with GGBS and Phosphogypsum in percentages ranging from 0, 2.5, 5, 7.5, 10%.The studyinclude assessment of Split Tensile Strength and Flexural Strength of Geopolymer concrete specimens at the age of 28 and 90Days. The results shows that the strength of Geopolymer concrete made by blending withGGBS has increased with increase in GGBS percentage and in case of Phosphogypsum the strength has increased upto certain limit and then the strength decreases with increase in Phosphogypsum percentage.
Key Words : Geopolymer, Flyash, GGBS,Phosphogypsum, Alkaline liquids, Split Tensile Strength, Flexural Strength.

I. Introduction

The Geopolymer technology is proposed by Davidovits[1] and gives considerable promise for the application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the Geopolymer technology could reduce the CO_2 emission in to the atmosphere, caused by cement and aggregate industries by about 80%. In this technology, the source material that is rich in Silica (Si) and Aluminium (Al) is reacted with a highly alkaline solution through the process of Geopolymerisation[2] to produce the binding material. The term "Geopolymer" describes a family of mineral binders that have a polymeric silicon-oxygen-aluminium framework structure, similar to that found in zeolites, but without the crystal structure. The polymerization process involves a substantially fast chemical reaction under highly alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymer concrete is emerging as a new environmentally friendly construction material for sustainable development, using Flyash and alkali in place of OPC as the binding agent. This attempt results in two benefits, viz. reducing CO_2 releases from production of OPC and effective utilization of industrial waste by products such as Flyash,GGBS and Phosphogypsumetc by decreasing the use of OPC[3].

The objective of the study is to evaluate the different strength properties of Geopolymer concrete mixture made by replacement of Flyash with GGBS and Phosphogypsum[9]in different percentages by producing workable, high strength and durable Geopolymer concrete without usage of ordinary Portland cement.

II. Literature Review

Joseph Davidovits (1988) proposed that an alkaline liquid could beused to react with the Silica (Si) and the Aluminium (Al) in a source materialof geological origin or in byproduct materials such as Flyash and rice husk ashto produce binders. He coined the name "Geopolymer" to represent these binders because of the reaction that took place was a polymerisation process.He also reported that Geopolymers were members of the family of inorganic polymers similar to natural zeolitic materials.

Palomo et al (1999) concluded that the type of alkaline liquid plays animportant role in the polymerisation process. Reactions occur at a high rate whenthe alkaline liquid contains soluble silicate, either sodium or potassium silicate,compared to the use of only alkaline hydroxides. Xu and van Deventer (2000)confirmed that the addition of sodium silicate solution to the sodium hydroxidesolution as the alkaline liquid enhanced the reaction between the source materialand the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higherextent of dissolution of minerals than the KOH solution.

Lee et al (2004) have experimented and reported the micro structure and the bonding strength of the interface between natural siliceous aggregates and fly ash based Geopolymers. It was found that when the activating solution that contained no or little soluble silicates, the compressive strength of the Geopolymer binders, mortars and concretes were significantly weaker than those activated with high dosage of soluble silicates. The presence of soluble silicates in the initial activating solution was also effective in reducing alkali saturation in the concrete pore solution even when a highly alkali-concentrated activating solution was used.

Hardjito et al (2005) conducted experiments to study the materials and the mixture proportions, the manufacturing process and the influence of various parameters on the properties of fresh and hardened Geopolymer concrete

Sumajouw and Rangan (2006) tested the beam specimens undermonotonically increasing load until failure. As the load increased, the beamstarted to deflect and flexural cracks developed along the span of the beams.Eventually, all beams failed in a typical flexure mode. An idealized loaddeflectioncurve at mid-span of beams shows the progressiveincrease ofdeflection at mid-span as a function of increasing load. The load-deflectioncurves indicate distinct events that were taking place during the test. Theseevents are identified as first cracking (A), yield of the tensile reinforcement(B), crushing of concrete at the compression face associated with spalling of concrete cover (C), a slight drop in the load following the ultimate load (C'),and disintegration of the compression zone concrete as a consequence ofbuckling of the longitudinal steel in the compression zone (D). These featuresare typical of flexure behaviour of reinforced concrete beams (Warner et al1998).

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 Flyash 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

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid.

3.1.3 Natural fine aggregate

Locally available river sand passing through 4.75 mm IS. Sieve with a fineness modulus of 2.79. The specific gravity of the sand is found to be 2.625[11].

3.1.4 Natural coarse aggregate

Crushed granite metal with 50% passing through 12.5mm and retained on 10mm sieve and50% passing through 20mm and retained on 12.5mm sieve was used. Crushed graniteaggregate available from local sources with a fineness modulus of 6.94, and waterabsorption of 0.68% in SSD condition has been used. The specific gravity of coarseaggregate is found to be 2.723[11]. The maximum size of the coarse aggregate was 20mm.

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 Sulphonate based super plasticizer.It is manufactured by MYK SCHOMBURG, Hyderabad. MYK Savemix SP200 complies with IS: 9103:1999 standard having Specific gravity of 1.24

3.1.7 GGBS and Phosphogypsum

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

3.2. Mix Design of GEO Polymer Concrete

The mix proportion of Geopolymer has been obtained as1 : 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[7] 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 before of casting of specimens.

Casting of Geopolymer Concrete Specimens

Cylinders of 150 mm diameter and 300 mm height and beams of size 500 x 100 x 100 mm were cast and tested for determining the split tensile and flexural strengths respectively.Flyash,GGBSand Phosphogypsum were mixed with sand, coarse aggregates and the alkaline liquid (combination of Sodium silicate and sodium hydroxide) was poured to dry mix and mixed thoroughly to form homogenous mixture for a period of 3 minutes approximately. The required quantity of super plasticizer was added as 3% by mass of Flyash. Once the mixing process was over the mould was filled by the fresh concrete in three layers and compacted well. In each mix three specimens were cast to test the 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°C for a period of 24 hours[13]. Then the specimens were taken out and kept at room temperature for the desired 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 28 and 90 days.

4. Results and Discussions

4.1 Split Tensile Strength Test

Split tensile strength test[14] is conducted on the cylindrical specimen in the 2000 kN capacity, AIMIL digital compression testing machine. The cylinders prepared for testing are150mm in diameter and 300mm in height. The diametrical linesare drawn on the two ends, such that they are in the same axial plane. Then the cylinder isplaced on the bottom compression plate of the testing machine and is aligned such that the lines marked on the ends of the specimen are vertical. Then the top compression plate isbrought into contact at the top of the cylinder. The load is applied at uniform rate, until thecylinder fails and corresponding load is recorded (P). From this load, the splitting tensilestrength is calculated for each specimen from Equation 1 and the results are presented in Table3 and 4. For each mix, three specimens were tested for 28 days and another three specimens for 90 days and average values are reported.

Split Tensile Strength (MPa) = $2P/\pi DL$ Eq. 1

Where, D and L are diameter and length of cylinder specimen

The 28 and 90 days split tensile strength of Geopolymer concrete specimens with different percentages of blending is shown in figures 1 and 2. It is observed that split tensile strength increased from 0 to 10% in case of GGBS blended specimens both at 28 and 90 days age of concrete. In case of Phosphogypsum blended specimens the split tensile strength gradually increased upto 7.5% and then later decreased at both 28 and 90 days age of concrete. The best split tensile strength is obtained as 4.6 MPa in case of GGBS blended specimens and 4.7 MPa in case of Phosphogypsum blended specimens at 90 days age of concrete. By incorporating GGBS and Phosphogypsum as partial replacement of Flyash enhanced the mechanical properties of concrete.

Table 3: Split Tensile Strength of Geo Polymer Concrete made by Replacement Of Flyash with GGBS

Sl No	% Replacement Of Flyash by GGBS	Split Tensile Strength (N/mm^2)	
		28 Days	90 Days
1	0	3.4	3.8
2	2.5	3.5	3.9
3	5	3.7	4
4	7.5	3.9	4.2
5	10	4.3	4.6

Table 4: Split Tensile Strength of Geo Polymer Concrete made by Replacement of Flyash with Phosphogypsum

Sl No	% Replacement of Flyash by Phosphogypsum	Split Tensile Strength (N/mm^2)	
		28 Days	90 Days
1	0	3.4	3.8
2	2.5	3.7	4
3	5	4.2	4.4
4	7.5	4.4	4.7
5	10	4	4.2

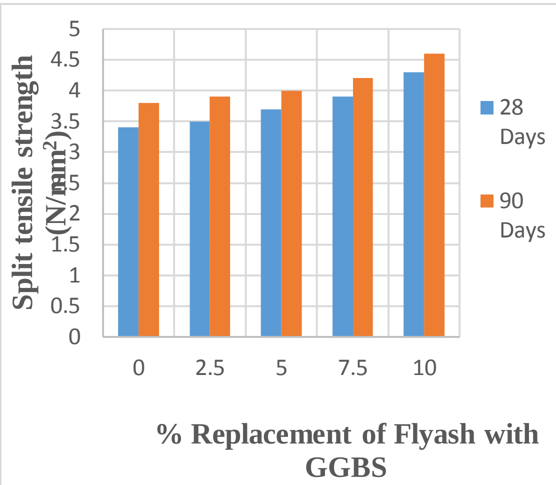


Fig 1: Split Tensile Strength Vs % Replacement Of Flyash with GGBS

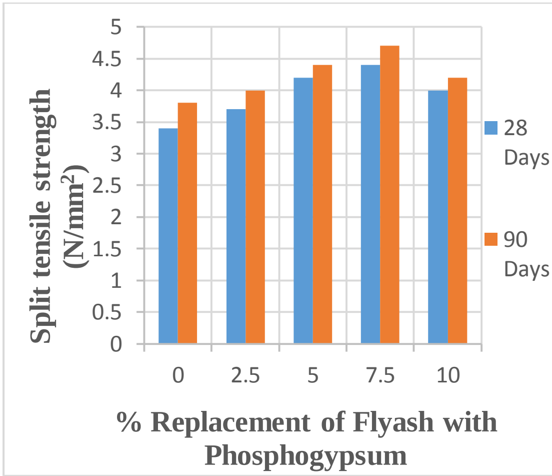


Fig 2: Split Tensile Strength Vs % Replacement of Flyash with Phosphogypsum

4.2 FlexuralStrength Test

The bending test is conducted on a loading frame to determine the flexuralstrength on beam specimens of size 500 x 100 x 100mm. The beam element is simplysupported on two rollers of 5 cm diameter over a span of 400 mm. The loading wasapplied on the specimen through hydraulic jacks and was measured using a 15 ton precalibrated proving ring. The bending moment (M) on the beam specimen has been calculatedfrom the recorded flexural load and the flexural strength is calculated as the ratio of thebending moment and section modulus of the beam specimen and is presented in Table 5 and 6. For each mix, three specimens were tested for 28 days and another three specimens for 90 days and average values are reported.

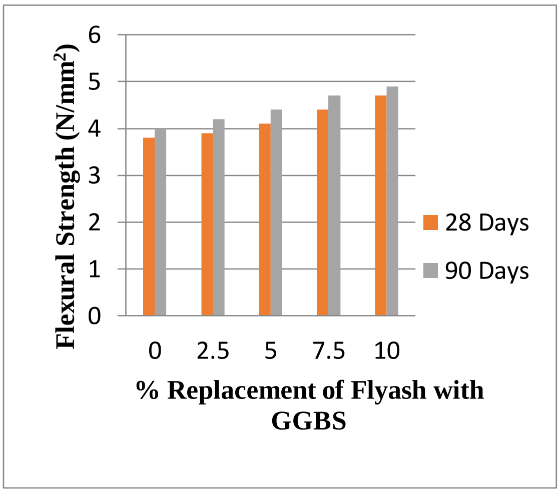
The 28 and 90 days flexural strength of Geopolymer concrete specimens with different percentages of blending is shown in figures 3 and 4. It is observed that flexural strength increased from 0 to 10% in case of GGBS blended specimens both at 28 and 90 days age of concrete. In case of Phosphogypsum blended specimens the flexural strength gradually increased upto 7.5% and then later decreased at both 28 and 90 days age of concrete. The best flexural strength is obtained as 4.9 MPa in case of GGBS blended specimens and 4.5 MPa in case of Phosphogypsum blended specimens at 90 days age of concrete. The above statement clearly indicates that there is no much gain in flexural strength for 90 days age compared to 28 days.

Table 5: Flexural Strength of GeoPolymer Concrete made by Replacement of Flyash with GGBS

Sl No	% Replacement of Flyash by GGBS	Flexural Stress (N/mm^2)	
		28 Days	90 Days
1	0	3.8	4
2	2.5	3.9	4.2
3	5	4.1	4.4
4	7.5	4.4	4.7
5	10	4.7	4.9

Table 6 :Flexural Strength of Geo Polymer Concrete made by Replacement Flyash with Phosphogypsum

Sl No	% Replacement of Flyash by Phospogypsum	Flexural Stress (N/mm^2)	
		28 Days	90 Days
1	0	3.8	4
2	2.5	3.9	4.1
3	5	4	4.2
4	7.5	4.2	4.5
5	10	3.8	4



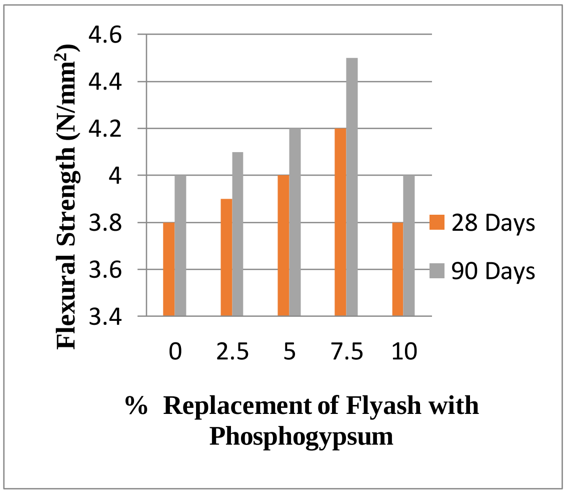


Fig 3: Flexural Strength Vs % Replacement Fig 4 :Flexural Strength Vs Of Flyash with GGBS % Replacement of Flyash with Phosphogypsum

5. Conclusions

From the study reported herein, the following conclusions are drawn :

1. The mechanical properties of the Geopolymer concrete are enhanced by the blending of Flyash with GGBS and Phosphogypsum.
2. The split tensile strength and flexural behaviour of Flyash based Geopolymer concrete blended with GGBS and Phosphogypsum is better compared to plain Geopolymer concrete.
3. Geopolymer concrete specimens blended with GGBS has the split tensile strength increased gradually from 0 to 10% at age of 28 and 90 days.
4. Geopolymer concrete specimens blended with Phosphogypsum has the split tensile strength increased gradually from 0 to 7.5% and then decreased at later percentage at age of 28 and 90 days.
5. The flexural behaviour of specimens blended with GGBS and Phosphogypsum have shown satisfactory results compared to normal Geopolymer specimens.
6. The flexural strength has increased when replacement of Flyash was made from 0 to 10 % in case of GGBS.
7. And in case of Phosphogypsum it is increased up to 7.5% and then decreased at later percentages.
8. The split tensile strength and flexural behaviour of the specimens made by the replacement of Flyash with GGBS and Phosphogypsum are better when compared to the plain Geopolymer concrete.
9. It is concluded that overall behaviour of Geopolymer concrete blended with GGBS and Phosphogypsum is better when compared to without replacement of Flyash.

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