EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF FLY ASH AND GGBS BASED GEOPOLYMER CONCRETE

Ajay Takekar[1], Prof.G.R.Patil[2]

[1] PG Student, Department of Civil Engineering, JSPM's Rajarshi Shahu college of Engg., Pune, MH, India
[2] Professor, Department of Civil Engineering, JSPM's Rajarshi Shahu college of Engg., Pune, MH, India

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Abstract - *The present investigation aims at studying the mechanical properties of fly ash and GGBS based geopolymer concrete. In this study, fly ash was replaced at different levels (0%, 25%, 50%, 75% and 100%) by GGBS. Sodium hydroxide (14 M) and Sodium silicate solution is used as alkaline activator in 1:1 ratio. M-25 grade of geopolymer concrete is tested for mechanical properties Viz, compressive strength, split tensile strength and flexural strength at 3,7 and 28 day and compared with normal OPC M-25 grade concrete and also the effect of ambient curing and oven curing is studied. The result shows that replacement of fly ash by GGBS eliminates heat curing of geopolymer concrete. Geopolymer concrete shows better result than normal conventional concrete. Rate of gain of strength of geopolymer concrete is high at early stage however geopolymer concrete is more advantageous, economical and ecofriendly. This experimental investigation is for research purpose for strength properties of geopolymer concrete using fly ash and ground granulated furnace slag (GGBS).*

Key Words: **Geopolymer Concrete, Fly ash, Ground granulated furnace slag (GGBS), Alkaline solutions, oven curing, ambient curing, compressive strength, Split tensile strength, Flexural strength.**

1. INTRODUCTION

The major problem the world is facing today is environmental pollution. In the construction industry mainly the production of Portland cement causes emission of pollutants results in environmental pollution. It is widely known that the production of Portland cement consumes considerable energy and at the same time contributes a large volume of CO2 to the atmosphere. However, Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials [1].One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials.

Davidovits proposed that an alkaline liquid which can react with the silicon (Si) and aluminum (Al) in a source material of geological origin or industrial by product can be used to produce binders. Since chemical reaction in this process is of polymerization therefore, he termed it as "Geopolymer" [2,3]. Thus geopolymer constitutes of two main compounds namely source materials and alkaline liquids. The alkaline liquids are from soluble alkali metals which are mainly sodium or potassium based. Sodium hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium silicate or Potassium silicate are most widely used alkaline liquid. The primary difference between concrete produced using Portland cement and geopolymer concrete is the binder.

Geopolymer consists of silicon and aluminum atoms bonded via oxygen into a polymer network. Geopolymer are prepared by dissolution and poly condensation reactions between alumino silicate binder and an alkaline silicate solution such as a mixture of an alkali metal silicate and metal hydroxide is obtained. The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBS). GGBS has been widely used as a cement replacement material due to its latent hydraulic properties, while fly ash has been used as a pozzolanic material to enhance the physical, chemical and mechanical properties of cement and concrete. Increasing emphasis on the environmental impacts of construction materials such as Portland cement has provided immense thrust in recent years to the increased utilization of waste and by-product materials in concretes. Activation of alumina silicate materials such as fly ash, blast furnace slag, and metakaolin using alkaline solutions to produce binders free of Portland cement is a major advancement towards increasing the beneficial use of industrial waste products and reducing the adverse impacts of cement production.

It has been reported that fly ash and ground granulated blast furnace slag (GGBS) are very effective as starting materials for cement- free binder concretes because of the soluble silica and alumina contents in these materials that undergo dissolution, polymerization with the alkali, condensation on particle surfaces, and solidification that eventually provides strength and stability to these matrices[4]. Investigation and discussions for mix design code for geopolymer concrete are in process to add up in IS standards. However in this study mix design for geopolymer concrete is used from theory of mix design proposed by Subash V.Patankar.

2. EXPERIMENTAL WORK

Entire experimental work carried out is briefly explained as follows.

2.1 Materials

Fly ash used in this study is low calcium class F Fly ash from Dirk India private limited under the name of the product POZZOCRETE 60. Ground granulated blast furnace slag (GGBS) used is obtained from JSW cements. The chemical and physical properties of GGBS and Fly Ash used are shown in the Table 1 and Table 2 respectively. The most commonly used alkaline activators are a mixture of sodium hydroxide (NaOH) with sodium silicate (Na2SiO3). For preparation of alkaline liquids, sodium hydroxide with 98% purity in the form of flakes and sodium silicate were obtained from local manufacturer. Locally available 20 mm crushed aggregates have been used as coarse aggregates. Locally available river sand is used as fine aggregate in the mixes. Crushed granite stones of size 20mm are used as coarse aggregate. As per IS: 2386 (Part III)-1963, the bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.58 and 0.3% respectively. The fineness modulus of 20mm coarse aggregates are 6.68. As per IS: 2386 (Part III)-1963, the bulk specific gravity in oven dry condition and water absorption of the sand are 2.62 and 1% respectively. The fineness modulus of sand is 2.47.

TABLE 1. Chemical properties of Fly Ash and GGBS

Chemical Composition	Class F fly ash	GGBS
% silica (SiO_2)	65.6	30.61
% Alumina (Al_2O_3)	28.0	16.24
% Iron oxide (Fe_2O_3)	3.0	0.584
% Lime (CaO)	1.0	34.48
% Magnesia (MgO)	1.0	6.79
% Titanium (TiO_2)	0.5	-
% Sulpher Trioxide (SO_3)	0.2	1.85
Loss on Ignition	0.29	2.1

TABLE 2. Physical properties of Fly Ash and GGBS

Properties	Class F fly Ash	GGBS
Specific Gravity	2.24	2.86
Fineness (m^2/kg)	360	400

2.2 Specimen Details and its Schedule

Specimen size and its number are determined as per the respective IS guidelines used for determining mechanical properties of Concrete. Thus total 99 cubes + 66 beams + 66 cylinders = 231 specimens are casted and tested as per their IS provisions. Cubes are tested as per IS 516-1959.

Table 3. Schedule of Specimen

Concrete	Concrete Grade	Binding Material	Curing Type	Cube (Compressive Strength)			Beam (flexural)		Cylinder (Split Tensile Strength)	
				3 Day Test	7 Day Test	28 Day Test	7 Day Test	28 Day Test	7 Day Test	28 Day Test
Batch-O	M25	OPC-43 Cement-100%	Water curing	3	3	3	3	3	3	3
Batch-A	G25	Fly Ash-100% GGBS- 0 %	Hot Curing	3	3	3	3	3	3	3
			Ambient Curing	3	3	3	3	3	3	3
Batch-B	G25	Fly Ash- 75 % GGBS- 25 %	Hot Curing	3	3	3	3	3	3	3
			Ambient Curing	3	3	3	3	3	3	3
Batch-C	G25	Fly Ash- 50 % GGBS- 50 %	Hot Curing	3	3	3	3	3	3	3
			Ambient Curing	3	3	3	3	3	3	3
Batch-D	G25	Fly Ash- 25 % GGBS- 75 %	Hot Curing	3	3	3	3	3	3	3
			Ambient Curing	3	3	3	3	3	3	3
Batch-E	G25	Fly Ash- 0 % GGBS- 100 %	Hot Curing	3	3	3	3	3	3	3
			Ambient Curing	3	3	3	3	3	3	3

Beams are tested according to IS 516-1959 provisions and cylinders are tested according to IS 5816-1999 provisions.

2.3 Mix Design

Mix design of geopolymer concrete of G-25 grade is made according to theory of mix design proposed by Subash V.Patankar [7]. Alkaline liquid ratio is kept constant at 1. The sodium hydroxide solution of 14 M concentration is used and it is kept constant throughout investigation. Cubes of size 150 mm × 150 mm × 150 mm are used for compressive strength test. Beams of size 100 mm × 100 mm × 500 mm are used to determine flexural strength and cylinder of 150 mm (dia) × 300 mm are used to determine split tensile strength.

Table 4. Mix proportions of Geopolymer Concrete (G-25)

FA or GGBS	Sand	Coarse Agg. (20mm)	NaOH	Na_2SiO_3	Water
405 Kg/m^3	587.3 Kg/m^3	1283.08 Kg/m^3	70.88 Kg/m^3	70.88 Kg/m^3	82.42 Kg/m^3
1	1.45	3.16	0.35		0.20

2.4 Curing

In this experimental work effect of oven curing and ambient curing on mechanical properties of geopolymer concrete is also studied. After casting the test specimens, specimens are demoulded after 24 hours and kept for oven curing at 60°C for 24 hours and then after are kept at ambient surroundings while some specimens are directly kept for ambient curing.

2.4 Testing of Specimens

Specimens are tested at 3, 7 and 28 day of testing for compressive strength, flexural strength and split tensile strength.

2.4.1 Compressive Strength testing of Cubes

Cubes as casted of size 150 x 150 x 150 mm were tested using Compression testing machine (CTM) of capacity 250 ton, capable of giving load at the rate of 140 kg/sq.cm/min. Testing of the cubes was done at the age of 3rd, 7th and 28th day. Cubes were placed in the machine between wiped and cleaned loading surfaces and load is given approximately at the rate of 140 kg/sq.cm/min. and ultimate crushing load is noted to calculate crushing strength of concrete according to IS: 516-1959.

The measuring strength of specimen is calculated by dividing the maximum load applied to the specimen during the test by the cross section area.

$$F_{ck} = \frac{P}{A} = \frac{Load\ taken \times 1000}{150 \times 150} = \ldots\ldots\ldots N/mm^2$$

(Eq.1)

Fig.1 Compressive testing

2.4.2 Split Tensile Testing of Cylinder

Cylinders as casted of size 150 mm (dia) × 300 mm were tested using CTM machine of capacity 250 ton, capable of giving load at the rate of 140 kg/sq.cm/min. Testing of the cubes was done at the age of 7th and 28th day. The cylinders were placed in the machine between wiped and cleaned loading surfaces and load is given approximately at the rate of 140 kg/sq.cm/min. and ultimate crushing load is noted to calculate crushing strength of concrete according to IS: 516-1959.

The measuring strength of specimen is calculated by dividing the two times maximum load applied to the specimen during the test by the cross section area

$$F_t = \frac{2P}{\pi DL} = \ldots\ldots\ N/mm^2$$

(Eq.2)

Fig.2 Split tensile testing

2.4.2 Flexural Testing of Beams

Beams casted as of size 100 mm × 100 mm × 500 mm are tested for flexural strength under the UTM machine of 600 KN capacity as per the guidelines given in IS 516-1959.The flexural strength of beam is calculated by following equation

$F_b = \frac{Pl}{bd^2} =$ ……….N/mm^2 (Eq.3)

3. RESULTS AND DISCUSSION

All the specimens are tested according to their respective IS provisions and results are shown as below,

Table 6. Compressive Strength Results

Batch	3 Day Result (N/mm^2)		7 Day Result (N/mm^2)		28 Day Result (N/mm^2)	
	Ambient Curing	Oven Curing	Ambient Curing	Oven Curing	Ambient Curing	Oven Curing
Batch- O	11.81	-	19.17	-	26.67	-
Batch- A	5.71	12	8.33	14.89	14.66	19.33
Batch- B	20.94	26.60	25.48	38.33	32.64	41.04
Batch- C	29.65	32.81	33.12	40.07	39.52	43.24
Batch- D	37.55	40.56	41.57	46.11	47.91	50.47
Batch- E	40.13	41.86	43.75	48.49	47.98	53.11

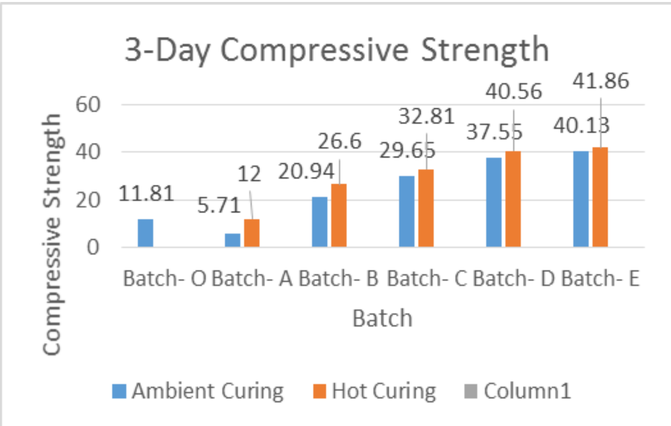

Fig.3 3 Day Compressive Strength

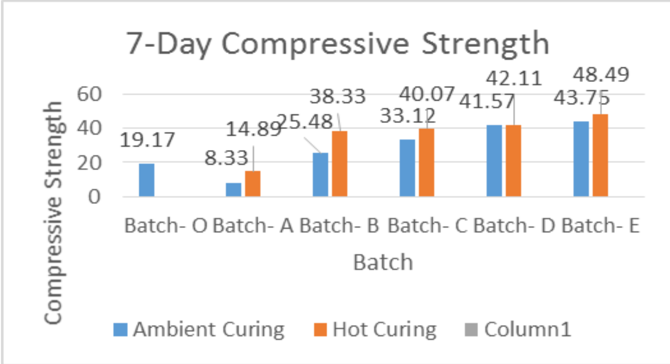

Fig.4 7 Day Compressive Strength

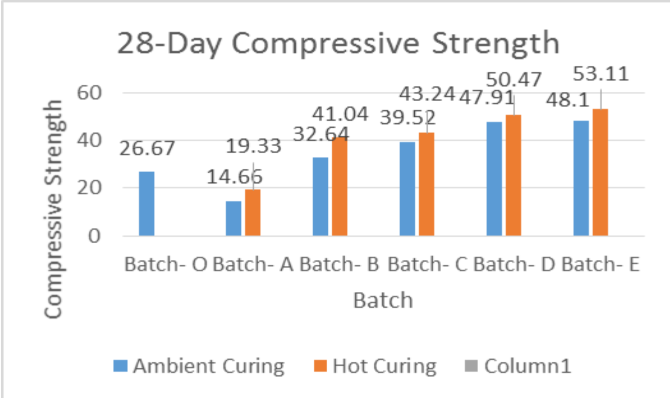

Fig.5 28 Day Compressive Strength

The Above graph shows Compressive Strength results of concrete. From the graph it is clearly seen that Fly ash based geopolymer concrete doesn't show good strength but however GGBS based geopolymer concrete shows the best result of compressive strength. Also, oven cured specimens shows more strength than the ambient cured specimens.

From the above results batch B gives optimum mix design with satisfactory results however Batch E gives the highest strength for the mix design combination.From Batch B onwards we can replace Conventional Concrete by geopolymer concrete since it is giving better results than it.

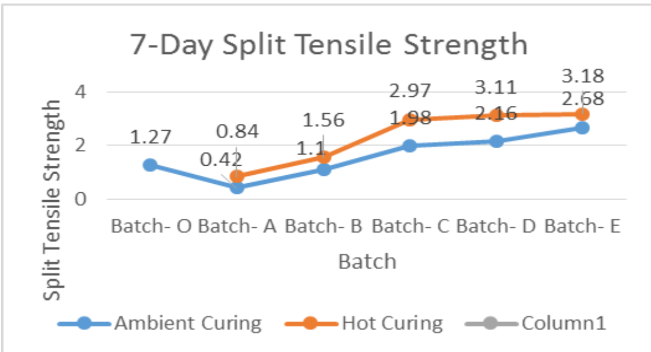

Fig.6 7 Day Split Tensile Strength in N/mm^2

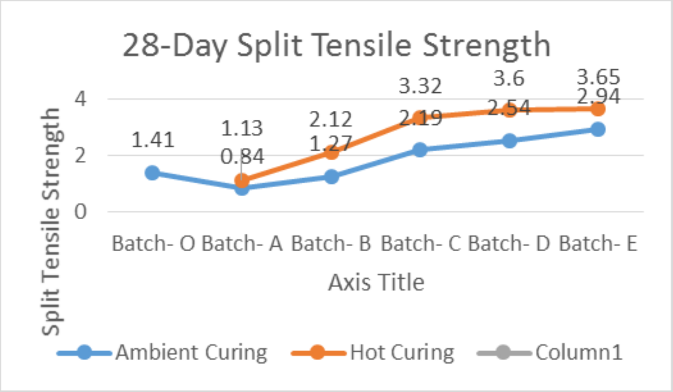

Fig.7 28 Day Split Tensile Strength in N/mm^2

The above graph shows the results of Split tensile strength of concrete. From the graph it is clearly seen that split tensile strength increases as we increase replacement of fly ash by GGBS. The highest split strength is achieved in Batch E that is in GGBS based geopolymer concrete giving highest strength.

From the graph it is seen that oven cured specimen gives more strength than ambient cured specimen. Also early stage strength gain is high in geopolymer concrete than the normal conventional concrete.

Table 7. Flexural Strength Results

Batch	7 Day Result (KN)		28 Day Result (KN)	
	Ambient Cured	Oven Cured	Ambient Cured	Oven Cured
Batch- O	10.38	-	13.50	-
Batch- A	8.85	9.12	9.25	9.90
Batch- B	10.11	10.83	12.20	12.94
Batch- C	12.84	13.08	14.92	15.20
Batch- D	13.08	14.80	15.46	16.10
Batch-E	14.40	15.08	16.46	17.10

Flexural strength of geoplymer concrete gives much more flexural strength than the conventional concrete from Batch B onwards. Also the same nature that oven cure specimen gives more strength than the ambient cured specimen. Highest flexural strength from above is given by GGBS based geopolymer concrete that by Batch E. Fly ash based geopolymer concrete strength results are less than the normal conventional concrete. Flexural strength result is shown as load taken in KN.

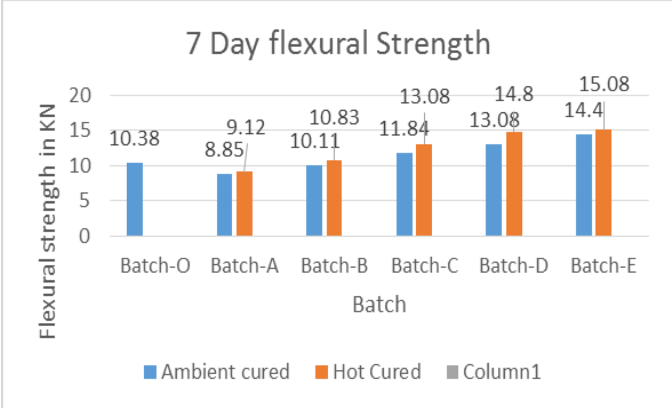

Fig.8 7 Day Flexural Strength Results in KN

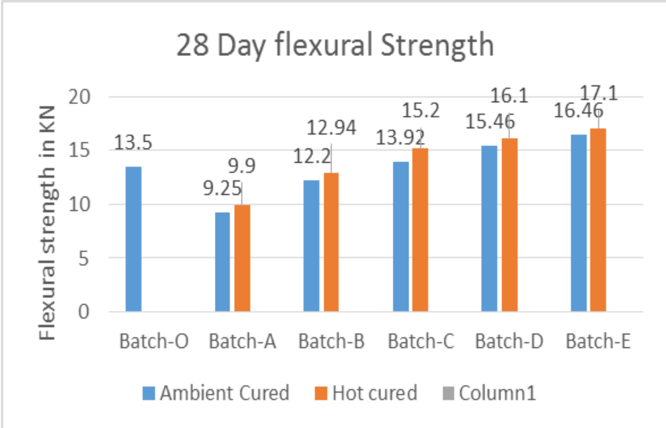

Fig.9 28 Day Flexural Strength Results in KN

Failure of geopolymer concrete and conventional concrete was brittle failure. Flexural strength of geopolymer concrete is more than the conventional concrete except in Batch A. however the same nature of being more strength in oven cured than the ambient cured is found. Maximum of flexural strength is achieved in Batch E that GGBS based and oven cured specimen.

4. CONCLUSIONS

Based on above experimental work carried out, following conclusions are made

1) It is observed that an increasing trend has been observed in compressive strength of GPC mixes up to full replacement level of fly ash by GGBS.
2) The rate of gain in compressive strength, split tensile strength and flexural strength of geopolymer concrete is very fast at 7 days curing period and the rate gets reduces with age.
3) Almost 90 % of strength is achieved at 7th day. Therefore speedy construction is possible with geopolymer concrete.
4) Oven curing gives higher result than ambient curing

5) Addition of GGBS eliminate the necessity of oven curing.
6) The geopolymer concrete using GGBS as a sole binder achieves more strength than that of normal control concrete when oven curing is done. A higher concentration of GGBS result in higher compressive strength, split tensile strength and flexural strength of geopolymer concrete.
7) High Strength Concrete is achieved by using geopolymer concrete.
8) Fly ash and GGBS based geopolymer concrete can be used for structural use.
9) Mix design with 75% fly ash and 25% GGBS as binding material gives economic design with better strength.
10) However GGBS based geopolymer concrete give best results in all aspect.
11) Thus Geopolymer concrete can be recommended as an innovative construction material for the use of construction.

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BIOGRAPHIES

Ajay M. Takekar (PG 2nd year student)
Department of Civil (Structural) Engg.
JSPM's Rajarshi Shahu college of Engineering,Tathawade,pune-411033

Prof.G.R.Patil (Guide & PG coordinator)
Department of Civil (Structural) Engg.
JSPM's Rajarshi Shahu college of Engineering, Tathawade, Pune-411033