An Experimental Investigation on Strength Characteristics Of the Concrete using the Geo Polymer

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Abstract – In present days world facing major problem due to huge quantity of CO2 emission from cement industries while making OPC (Ordinary Portland Cement) for construction industries. To reduce this effect from environment we are going to introduce GPC (Geo Polymer Concrete) by fully replacement with Geo polymer concrete like GGBS, Fly ash and alkaline liquids {NaOH (Sodium Hydroxide), Na2Sio3 (Sodium Silicate)}.

This Experimental investigation shows the GPC (15cm X 15cm) concrete cube Strength Characteristics with different ages of cubes curing at room temperature 27°C . The above all strengths are also based on different molarities like 6M, 8M, 10M, 12M, and 14M.

Key Words: (*Geopolymer*, Fly Ash, Ground Granulated Blast-furnace Slag, compressive strength, Sorptivity, Slup test and XRD)

1.Introduction

In the 1950s, Viktor Glukovsky, of Kiev, USSR, developed concrete materials originally known under the names "soil silicate concretes" and "soil cements", but since the introduction of the geopolymer concept by Joseph Davidovits. 1991, the terminology and definitions of 'geopolymer' have become more diverse and often conflicting.

1.1 Necessity of Geo Polymer Concrete

After ordinary Portland cement (OPC) concrete, geopolymer concrete (GPC) is the most advanced form of concrete. GPC has many advantages including improved strength and durability properties. High early age strength and ambient curing of GPC helps to reduce the construction. But the production of cement means the production of pollution because of the emission of CO_2 during its production [4]. There are two different sources of CO_2 emission during cement production. Combustion of fossil fuels to operate the rotary kiln is the largest source and other one is the chemical process of calcining limestone into lime in the cement kiln also produces CO_2. In India about 2,069,738 thousand of metric ton of CO_2 are emitted in the year of 2010. The cement industry contributes about 5% of total global carbon dioxide emissions [5]. And the cement is manufactured by using the raw materials such as limestone, clay and other minerals.

2. Literature Review

In carrying out the project work various codes, journals, books etc. are referred. The science of GP has not yet reached the stage where GPC mix can be made by user by just adding water as it has happened in the case of Portland cement technology.

More Pratap Kishanrao et al., (2013) [4]

studied the Performance of Geopolymer concrete mixes at elevated temperatures. It is an established fact that the greenhouse gas emissions are reduced by 80% in Geopolymer concrete vis-a-vis the conventional Portland cement manufacturing, as it does not involve carbonate burns etc. Thus, Geopolymer based Concrete is highly environment friendly and the same time it can be made a high-performance concrete. In the present study, fly ash, blast furnace slag and catalytic liquids have been used to prepare Geopolymer concrete mixes. This study is continued to investigate the behaviour of such Geopolymer concrete under high temperatures ranging from 100°C to 500°C. Cubes of size 100mm × 100mm × 100 mm are tested for their residual compressive strengths after subjecting them to these high temperatures.

3. Experimental Investigations

All the materials used in the study were tested in accordance with the Indian standards. This investigation shown in below figure.

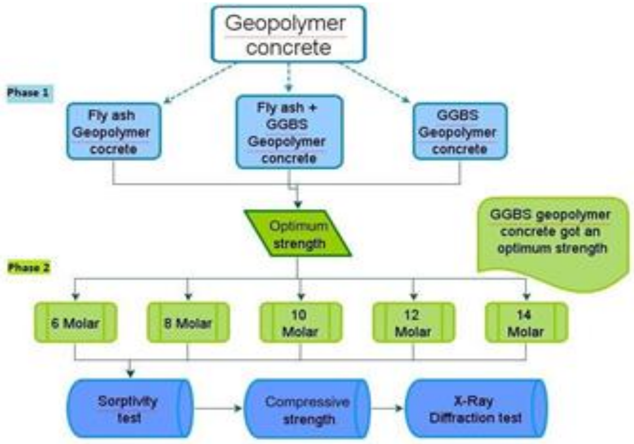

Fig 3.1 *Flow chart of the Experimental program*

Phase 1 - Comparison of materials in GPC.

Phase 2 - Comparisons of molars of NaOH solution in GPC.

3.1 Constituents of Concrete

3.1.1 Fly Ash:

In this study, low-calcium Fly ash (Class F) from NTPC, Visakhapatnam was used as the main source material as 100% replacement of cement. The fly ash particles are spherical and grey in colour.

Table 3. 1 Chemical Composition of Fly Ash (Mass %)

S. No.	Major Components	Formula	Values
1	Silicon Dioxide	SiO_2	59.8%
2	Aluminium Oxide	AL_2O_3	25.8%
3	Ferric Oxide	Fe_2O_3	7.8%
4	Calcium Oxide	CaO	2.8%
5	Magnesium Oxide	MgO	0.42%
6	Potassium Oxide	K_2O	0.62%
7	Sodium Oxide	Na_2O	0.2%
8	Sulfur Trioxide	SO_3	0.56%
9	Loss On Ignition	LOI	2.00%

Table 3.2 Physical Properties of Fly Ash

Properties	Values
Fineness Modulus (passing through 45µm)	6.7
Specific Gravity	2.25

3.1.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS) is a good aluminosilicate source as it contains high amounts of alumina and silica which are necessary for the geo-polymerization reaction to take place. The Degree of reaction was evaluated for all the percentage variations of the geopolymer concrete at 7 days of curing. The chemical properties and the physical properties are given below.

Table 3.3 Chemical Composition of GGBS

S. No.	Major Components	Formula	Values
1	Silicon Dioxide	SiO_2	33.50%
2	Aluminium Oxide	AL_2O_3	20.80%
3	Ferric Oxide	Fe_2O_3	0.25%
4	Calcium Oxide	CaO	31.70%
5	Magnesium Oxide	MgO	8.8%
6	Potassium Oxide	K_2O	0.65%
7	Sodium Oxide	Na_2O	0.60%
8	Sulfur Trioxide	SO_3	0.5%
9	Loss On Ignition	LOI	3.20%

Table 3.4 Physical Properties of GGBS

Properties	Values
Specific Gravity	2.2
Particle Size	< 45µm
Specific Area	400- 440 m^2/kg

3.1.3 Fine Aggregate (FA)

The river sand, passing from 4.75 mm sieve and retained on 600µm sieve as per IS:383-1970, Zone-2 was used as FA. The aggregate was typically the same materials used in the normal concrete mixture and the fine aggregate is clean, inert and free from organic matter, silt and clay.

Table 3.5 Properties of Fine Aggregate

S.NO	Particulars of test	Value
1	Specific gravity	2.56
2	Water absorption	0.6%
3	Bulk density Rodded bulk density Loose bulk density	 1720kg/m^3 1520kg/m^3
4	Fineness Modulus	2.62
5	Zone	II

3.1.4 Coarse Aggregate (CA)

The aggregate was tested for its physical requirements that are given below in accordance with IS 2386 (Part-3)-1963, IS 2386 (part-1)-1963, IS 4031 (part-4)-1996 and IS: 383-1970

Table 3.6 Properties of Coarse Aggregate

S.NO	Particulars of test	Value
1	Specific gravity	2.62
2	Water absorption	0.5%
3	Bulk density Rodded bulk density Loose bulk density	 1610 kg/m^3 1462 kg/m^3
4	Fineness Modulus	7.45
5	Impact value	15.2%
6	Crushing value	16.4%
7	Flakiness Index 20 mm 10 mm	 5.5% 7.6%
8	Elongation Index 20 mm 10 mm	 8.5% 12%

3.1.5 Sodium Hydroxide (NaOH)

Concentration of sodium hydroxide is the most important factor for geopolymer synthesis. The solubility of aluminosilicate increases with increase in hydroxide concentration. The use of higher concentration of sodium hydroxide yields higher compressive strength of geopolymer concrete.

The sodium hydroxide is calculated in molars or moles. The NaOH solids (pellets) were dissolved in water to make the solution.

Table 3.7 Properties of Sodium Hydroxide

Properties	Values
Density	2.2 g/cm^3
Odor	Odorless
Molar mass	39.82 g/mol
Appearance	White, waxy, opaque crystals
Density	2.12 g/cm^3
Melting point	318^{o}C
Boiling point	1380^{o}C
The amount of heat liberated	265 Cal/gr
Storage	Airtight container

3.1.6 Sodium Silicate (Na_2SiO_3)

In this investigation, sodium silicate solution is used as another alkaline activator. Sodium silicate solution is also known as water glass or liquid glass, available in liquid (gel) form. As per the manufactured, silicate were supplied to detergent company and textile industry as bonding agent, the same sodium silicate is used for making of geopolymer concrete, which we brought from local supplier.

Table 3.8 Properties of Sodium Silicate Solution

Properties	Values
Density	2.450 g/cm^3
Molar mass	122.2 g/mol
Appearance	Liquid (gel)
Melting point	1,098^{o}C

3.1.7 Distilled Water

Water is an important ingredient of Mortar as it actually participates in the chemical reaction with NaOH pellets. Since it helps to from the strength giving binder gel, the quantity and quality of water are required to be looked into very carefully.

3.2 MIX DESIGN

As Geopolymer concrete is a new technology to the world, that it have not reached the stage of standards codes or mix design. The methods used to design, prepare and test the Geopolymer concrete are based on many previous journals.

***Fig. 3.2** Constituents in Mix design of Geopolymer Concrete*

Geopolymer concrete is nothing but a 100% replacement of cement with cementious materials and alkaline liquids. Initially, many number of trials were carried out by using different materials such as Rice husk ash, Metakaoline, Ground granulated blast furnace slag and Fly ash. In those trials, we found Fly ash and GGBS are suitable materials for the replacement of cement to get significant strength to OPC.

- Density of concrete = 2480 kg/m^3 (assumed)
- Volume of combined aggregates is 70%
  - Combined aggregates = 1736kg/m^3
- Volume of fine aggregates is 40% of combined aggregates
  - Fine aggregates = 694.4 kg/m^3
- Volume of coarse aggregates is 60% of combined aggregates
  - Coarse aggregates = 1041.6 kg/m^3
- Volume of GGBS/Fly ash + Alkaline solution is 30% of density of concrete.

- Volume of GGBS/Fly ash + Alkaline solution = 744 kg/m³
- Alkaline liquid to GGBS/Fly ash = 0.4 (based on journals)
  - Alkaline Liquid : GGBS/Fly ash :: 2 : 5
    - Volume of GGBS/Fly ash = 531.4 kg/m³
    - Volume of Alkaline liquid = 212.6 kg/m³
- Alkaline liquid
  - Sodium hydroxide (NaOH)
  - Sodium silicate (Na_2SiO_3)
- Ratio of Sodium silicate to Sodium hydroxide is 2.5
  - Na_2SiO_3 : NaOH :: 5 : 2
    - Sodium silicate (Na_2SiO_3) solution = 151.86 kg/m³
    - Sodium hydroxide (NaOH) solution = 60.74 kg/m³
- NaOH solution = NaOH solids + Distilled water
  - NaOH solids (31%) = 18.84 kg/m³
  - Distilled water (69%) = 41.9 kg/m³ (for 10 Molar concentration)

This mix design have been followed in this research work.

3.2.1 Phase-1 Mix proportions

It deals with the comparison of pozzolanic material into three different following mixes with constant 10 molar concentration of NaOH.

Table 3.9 Types of pozzolanic materials of Phase-1 study

Mix. No	Type of Mix	Mix Name
Mix - 1	100 % Fly ash as cement replacement	FA-GPC
Mix - 2	50 % Fly ash and 50 % GGBS as cement replacement	FG-GPC
Mix – 3	100 % GGBS as cement replacement	G-GPC-10

S.No	ls	Mix-1	Mix-2	Mix-3
1		531.4	265.7	0
2		0	265.7	531.4
3	regate	694.4	694.4	694.4
4	Coarse e	720	720	720
5	mm Coarse e	321.6	321.6	321.6
6	ilicate	151.86	151.86	151.86
7	ydroxide	18.84	18.84	18.84
8	Water	41.9	41.9	41.9
9		10 M	10 M	10 M

Table 3.10 Phase-1 Mix proportions (kg/m³)

3.2.2 Phase-2 Mix proportions

It deals with the comparisons different molar concentration of Sodium hydroxide of alkaline solution with constant pozzolanic material, which got optimum strength in Phase-1 study. The following molars are compared.

Note: Mix-3 (GGBS based GPC) is the one, which is obtaining the optimum strength in Phase-1 study.

Table 3.11 Types of molars and mixes of Phase-2 study

Mix. No	Type of Mix	Mix Name
Mix – 4	6 Molar	G-GPC-6
Mix – 5	8 Molar	G-GPC-8
Mix – 6	10 Molar	G-GPC-10
Mix – 7	12 Molar	G-GPC-12
Mix – 8	14 Molar	G-GPC-14

Table 3.12 Phase-2 Mix proportions (kg/m³)

S.No	Materials	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8
1	GGBS	531.4	531.4	531.4	531.4	531.4
2	Fine	694.4	694.4	694.4	694.4	694.4

	aggregate					
3	20 mm Coarse aggregate	720	720	720	720	720
4	10 mm Coarse aggregate	321.6	321.6	321.6	321.6	321.6
5	Sodium silicate	151.86	151.86	151.86	151.86	151.86
6	Sodium hydroxide	12.76	15.8	18.84	21.88	24.91
7	Distilled Water	47.98	44.94	41.9	38.86	35.83
8	Molarity	6 M	8 M	10 M	12 M	14 M

3.3 Testing of Specimens

Tests Conducted

3.3.1 Slump test

Slump test is the most commonly used methods and measuring the consistency of concrete, it is conducted as per IS: 1199 – 1959 for all mixes. It is not a suitable method for vary wet or dry concrete. This method is suitable for medium slump.

3.3.2 Compressive Strength Test

The cube of sizes 100mm × 100mm × 100mm was cast. After 24 hours to 36 hours, the specimens are removed from the moulds and subjected to curing for 7, 14 and 28 days of phase-1 and the specimens of phase-2 are removed from the moulds and subjected to curing for 7, 14, 28 and 56 days exposed to sunlight. GPC cubes casting and curing and testing wasa done as per IS: 516 – 1959.

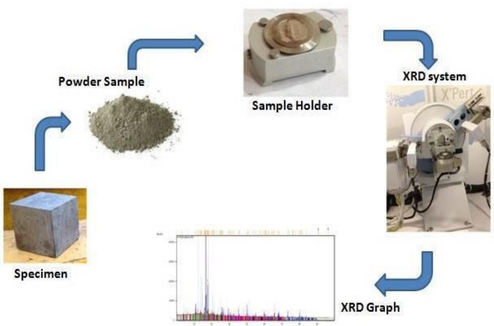

Fig 3.3 *Compressive Strength machine*

The maximum load at failure is taken. The average compressive strength of concrete specimens is calculated by using the following equation.

$$Compressive\ Strength = \frac{Load\ in\ N}{Area\ in\ mm^2}$$

3.3.3 Sorptivity Test

Sorptivity is **a material's ability to absorb and transmit water through it via capillary suction** and provides an engineering measure of microstructure and properties important for durability. Sorptivity is increasingly being used as a measure of concrete resistance to exposure to aggressive environments.

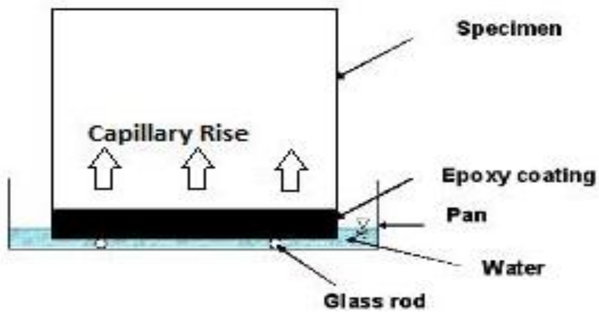

Fig. 3.4 *Process of the sorptivity test*

GPC cubes (15 cm X 15 cm) were immersed in water after casting . The specimen size 100mm × 100mm × 100mm

3.3.4 X-Ray Diffraction Test (XRD)

X-ray diffraction (XRD) pattern confirms the presence of sodalite after fly ash alkaline activation, whose content highly depends on the compact particle's percentage. These results highlight the thermal stability of geopolymers in the 25–1000 °C temperature range through the use of thermogravimetric analysis, differential thermal analysis, and XRD. X-rays are electromagnetic waves similar to light, but whose wavelength is much shorter (= 0,2 - 200 Å). XRD is produced as a reflexion at well defined angles. Every crystalline phase has its own diffraction image.

Fig. 3.5 *X-Ray Diffraction process*

4. Results and Discussions

4.1 Slump Test Results

The slump test of GPC by varying the source material which is rich in silica.

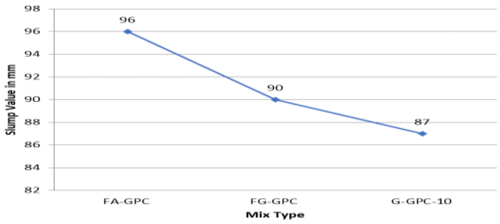

Fig. 4.1 *Slump test results*

- Geopolymer concrete specimens G-GPC-10 manufactured with 100% GGBS resulted in lesser values of slump when compared to the 100% Fly ash and 50% Fly ash + 50% GGBS based geopolymer concrete as in the case of FA-GPC and FG-GPC specimens respectively.
- When the Percentage of Flyash decreases the strength increases due to the decrease in slump value.

4.2 Sorptivity Test Results

Phase-1 Sorptivity test

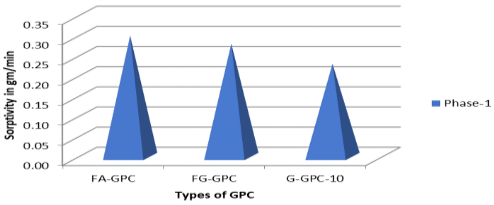

Fig. 4.2 Phase-1 *Sorptivity test results*

Geopolymer concrete specimens G-GPC-10 manufactured with 100% GGBS resulted in lesser values of sorptivity when compared to the 100% Fly ash and 50% Fly ash + 50% GGBS based geopolymer concrete as in the case of FA-GPC and FG-GPC specimens respectively.

Phase-2 Sorptivity test

The sorptivity test of GGBS based GPC by varying the with Molarity of Sodium Hydroxide.

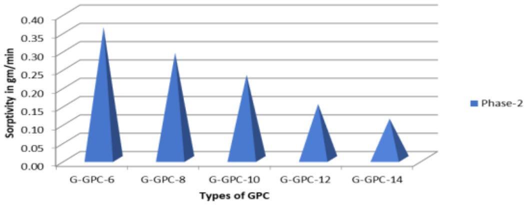

Fig. 4.3 Phase-2 *Sorptivity test results*

- G-GPC-14 specimen recorded 0.11 mm/min$^{0.5}$ sorptivity whereas specimens of G-GPC-12, G-GPC-10, G-GPC-8 and G-GPC-6 showed comparatively higher corresponding values of 0.36, 0.29, 0.23 and 0.15 mm/min$^{0.5}$ respectively. Compressive strength after 28 days was found maximum for G-GPC-14 specimen which contained 14 M NaOH.

4.3 Compression Test Results

Phase-1 Compressive strength

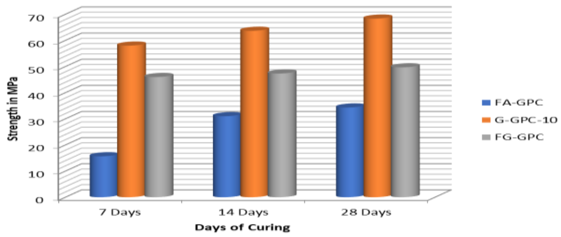

Fig.4.4 Phase-1 *compressive strength results*

- When the molarity of concentration, increased the workability of the concrete is increasing.

Phase-2 Compressive strength

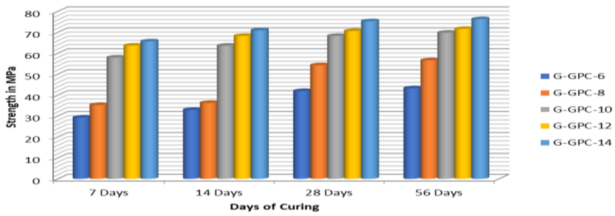

Fig.4.5 *Phase-2 compressive strength results*

- We observed that the compressive strength is increased with the increase in the molarity of sodium hydroxide.

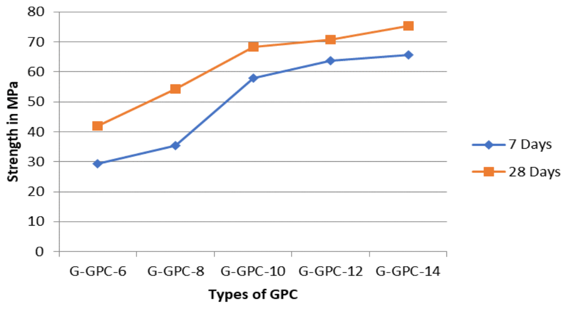

Fig.4.6 Phase-2 Rate of Increase in Strength

4.4 X-Ray Diffraction Test Results

Phase-1 Comparisons of Chemical compounds

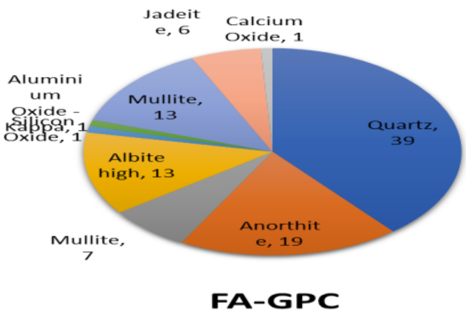

Fig. 4.7 Phase-1 Contents of compounds in Pie Chart

- In the above Pie chart the Quartz and Silicon oxide are in higher contents GGBS based GPC than the FLY Ash based GPC.

Phase-2 Comparisons of Chemical compounds

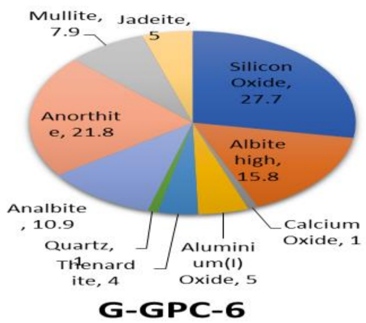

***Fig. 4.8 Phase**-2 Contents of compounds in Pie Chart*

- XRD analysis of the G-GPC's Specimen showed the presence of Quartz, Analcime, Anorthite, Mullite, Jadeite and Albite.
- The G-GPC specimens exhibits peaks of syngenite. Peaks of Thenardite are also observed.

5. Conclusions

From the past research studies, it can be sequel that:

- The reduced CO2 emissions of Geopolymer cements build them a good alternative to Ordinary Portland Cement.
- Geopolymer cement produces a substance that is comparable to or better than traditional cements with respect to most properties.
- Higher concentration of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Geopolymer concrete has excellent properties within both acid and salt environments.
- Low calcium fly ash based geopolymer concrete has excellent compressive strength, exposure to aggressive environment, workability, exposure to high temperature and is suitable for structural applications.

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