# An Experimental Investigation on Strength Charactersitcs of The Concrete Using The Geo Polymer

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## I. INTRODUCTION

### 1.1 GENERAL

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO 2 emission caused due to cement industries. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous [1] .Any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Metakaolin orcalcined Kaolin, low calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined minerals and non-calcined minerals, combination of fly ash and metakolin, combination of granulated blast furnace slag and metakaolin have been studied as source materials [2] . The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.

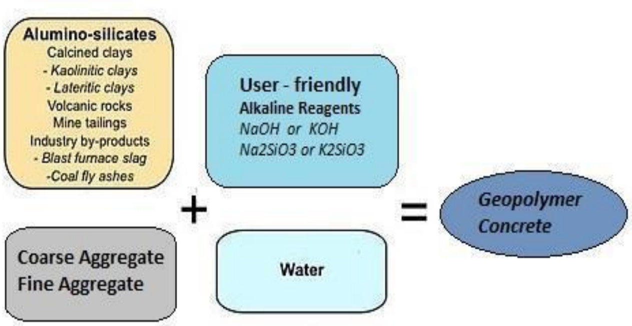



***Fig. 1.1*** *Geopolymer concrete*

In the past few decades, it has emerged as one of the possible alternatives to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. The temperature during curing is very important, and depending upon the source materials and activating solution, heat often must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature[3]. Geopolymer binders might be a promising alternative in the development of acid resistant concrete since it relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity.

### 1.2 NECESSITY OF GEOPOLYMER CONCRETE

Concrete is one of the widely used materials all over the world. Ordinary Portland cement (OPC) is used as the primary binder to produce the concrete. The demand of concrete is increasing day by day for the need of development of infrastructure facilities. However, it is well known that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere.

Environmental pollution is the biggest menace to the human race on this planet today. It means adding impurity to environmental. It has a severe effect on the ecosystem. There are many reasons which cause pollution. In our construction industry, cement is the main ingredient/ material for the concrete production. 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 also, the cement is manufactured by using the raw materials such as limestone, clay and other minerals. Quarrying of these raw materials is also causing environmental degradation. To produce a ton of cement, about 1.6 tons of raw materials are required and the time taken to form the limestone is much longer than the rate at which humans use it. On the other side the demand of concrete is increasing day by day for its ease of preparing and fabricating in all sorts of convenient shapes. So, to overcome this problem, the concrete to be used should be environmental friendly.

### 1.3 OBJECTIVE AND SCOPE

The main objective of this project is to study the performance of geopolymer concrete by considering two different pozzolanic materials and to investigate the effect of alumina-silicate source material and alkaline solution in Geopolymer concrete.

## II. REVIEW OF LITERATURE

### 2.0 INTRODUCTION

In carrying out the project work various codes, journals, books etc. are referred. A comprehensive literature survey on various aspects of Geopolymer Concrete (GPC) has been provided to understand the nature of GPC from engineering application's point of view, so that, a rational technical plan for development of GPC with given alumina-silicate sources can be formulated. 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. However, enough qualitative information is available on the mechanical strength so that, GPC mixes can be developed to achieve the desired level of strength for use in structures. Literature review done on this topic is briefly presented below.

### 2.1 LITERATURE REVIEWED

**N A Lloyd et al., [1]** studied the Geopolymer concrete with Fly ash, to produce the Geopolymer concrete the Portland cement is fully replaced with fly ash. Test data are used to identify the effects of salient factors that influence the properties of the geopolymer concrete and to propose a simple method for the design of geopolymer concrete mixtures. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined. To ensure further uptake of geopolymer technology within the concrete industry, research is needed in the critical area of durability. Current research is focusing on the durability of geopolymer in aggressive soil conditions and marine environments.

**V Supraja et al., [2]** has done Experimental study on Geopolymer concrete incorporating GGBS, to produce the Geopolymer concrete the Portland cement is fully replaced by GGBS and alkaline liquids that are NaOH and $Na_2Sio_3$ are used for the binding of materials. Using different molars of sodium hydroxide solution, i.e. 3M, 5M, and 7M and 9M are taken to prepare different mixes. Two different curing are carried, i.e. oven curing at 500°c and curing directly by placing the specimens to direct sunlight.

**Kolli Ramujee et al., [3]** studied the development of Low Calcium Fly ash Based Geopolymer Concrete. The Portland cement is fully replaced with Fly ash and alkaline solution that are (NaOH and $Na_2Sio_3$) are used to make geopolymer paste which binds the aggregates to form geopolymer concrete. The author also made an attempt to develop the mix design for Geopolymer concrete in medium grade and relative comparison has been made with equivalent mix proportions of the grade of OPC Concrete in both heat cured and ambient cured conditions. About 7 different mixes for each grade is cast, tested and optimized. From the investigation, it is clear that the water to binder ratio 0.21 and Alkaline liquid to fly ash ratio of 0.40 are suggested for G40 which indicates improvement in compressive strength of geopolymer concrete can be achieved by decreasing water binder ratio.

**More Pratap Kishanrao et al., (2013) [4]** had conducted the tests on the design of geopolymer concrete. This study is continuing, to investigate the behaviour of such geopolymer concrete under high temperatures ranging from 100ºC to 500ºC. Cubes of size 100mm×100mm×100mm are tested for their residual compressive strengths after subjecting them to these high temperatures. In the present investigation, Class-F fly ash and blast furnace slag are used in equal proportion (50% each) as cementitous materials for the preparation of GPC mixes. A mixture of analytical grade Sodium hydroxide and Sodium silicate solution is used in the present investigation as the catalytic liquid. They concluded that the geopolymer concrete gains about 60-70% of the total compressive strength within 7 days. The behaviour of the residual compressive strength of Geopolymer concrete cubes after exposure to various elevated temperatures tested at normal room temperature and while further increment of temperature, there is a loss in compressive strength graded.

## III. EXPERIMENTAL INVESTIGATIONS

### 3.0 INTRODUCTION

This chapter was planned to study the specifications and properties of the materials used in this investigation, which have been tested in the laboratory. All the materials used in the study were tested in accordance to the Indian standards. The experimental investigation is divided into two phases that are Phase - 1 and Phase - 2 that given below,

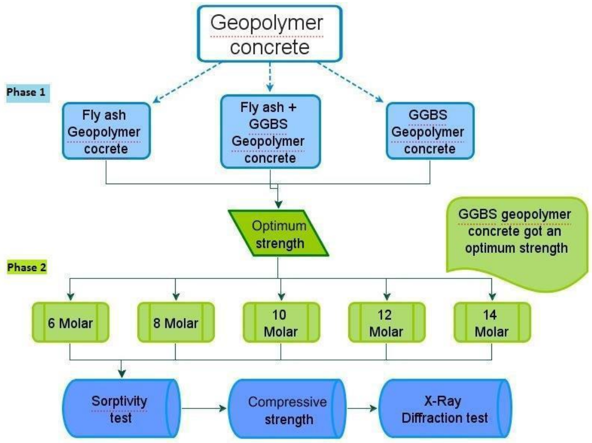



***Fig 3.1*** *Flow chart of the Experimental program*

**Phase 1 -** Comparison of materials in GPC.
**Phase 2 -** Comparisons of molars of NaOH solution in GPC.

## 3.2 CONSTITUENTS OF CONCRETE

Fly ash, known as pulverized-fuel ash, is precipitated electrostatically or mechanically from exhaust gases of coal-fired power stations. 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 3.2.1.1** Chemical Composition of Fly Ash (Mass %)

| S. No. | Major Components | Formula | Values |
|---|---|---|---|
| 1 | Silicon Dioxide | $SiO_2$ | 60.54% |
| 2 | Aluminium Oxide | $AL_2O_3$ | 26.20% |
| 3 | Ferric Oxide | $Fe_2O_3$ | 6.87% |
| 4 | Calcium Oxide | CaO | 2.91% |
| 5 | Magnesium Oxide | MgO | 0.38% |
| 6 | Potassium Oxide | $K_2O$ | 0.43% |
| 7 | Sodium Oxide | $Na_2O$ | 0.23% |
| 8 | Sulfur Trioxide | $SO_3$ | 0.44% |
| 9 | Loss On Ignition | LOI | 2.00% |

### 3.2.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy granular product that is then dried and ground into a fine powder. Slag is taken from Vizag steel plant in Andhra Pradesh and it is then grinded to get a fine powder form of GGBS. The chemical properties and the physical properties are given below,

### 3.2.3 Fine Aggregate

The river sand, passing through a 4.75 mm sieve and retained on 600µm sieve, conforming to Zone-II as per IS 383-1970 was used as fine aggregate in the present study. 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 3.2.3** Properties of Fine Aggregate

| S.NO | Particulars of test | Value |
|---|---|---|
| 1 | Specific gravity | 2.62 |
| 2 | Water absorption | 0.4% |
| 3 | Bulk density<br>Rodded bulk density<br>Loose bulk density | <br>1718kg/$m^3$<br>1518 kg/$m^3$ |
| 4 | Fineness Modulus | 2.69 |
| 5 | Zone | II |

### 3.2.4 Coarse Aggregate

Throughout the investigations, a crushed coarse aggregate of 20 mm and 10 mm size from the local crushing plants was used. The locally available crushed granite stone is used as coarse aggregate. 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 3.2.4** Properties of Coarse Aggregate

| S.NO | Particulars of test | Value |
|---|---|---|
| 1 | Specific gravity | 2.64 |
| 2 | Water absorption | 0.4% |
| 3 | Bulk density<br>Rodded bulk density<br>Loose bulk density | <br>1605 kg/$m^3$<br>1477 kg/$m^3$ |
| 4 | Fineness Modulus | 7.357 |
| 5 | Impact value | 17.4% |
| 6 | Crushing value | 26.13% |
| 7 | Flakiness Index<br>20 mm<br>10 mm | <br>12.81%<br>21.39% |
| 8 | Elongation Index<br>20 mm<br>10 mm | <br>20.5%<br>28.92% |

**Table 3.2.5** Properties of Sodium Hydroxide

| Properties | Values |
|---|---|
| Density | 2.13 g/$cm^3$ |

| | |
|---|---|
| Odor | Odorless |
| Molar mass | 39.997 g/mol |
| Appearance | White, waxy, opaque crystals |
| Density | 2.13 g/cm$^3$ |
| Melting point | 318ºC |
| Boiling point | 1388ºC |
| The amount of heat liberated | 266 Cal/gr |
| Storage | Air tight container |

**Table 3.2.6** Properties of Sodium Silicate Solution

| Properties | Values |
|---|---|
| Density | 2.40 g/cm$^3$ |
| Molar mass | 122.06 g/mol |
| Appearance | Liquid (gel) |
| Melting point | 1,088ºC |

## 3.3 **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.

- Density of concrete = 2400 kg/m$^3$ (assumed)
- Volume of combined aggregates is 70%
- Combined aggregates = 1680 kg/m$^3$
- Volume of fine aggregates is 40% of combined aggregates
- Fine aggregates = 672 kg/m$^3$
- Volume of coarse aggregates is 60% of combined aggregates
- Coarse aggregates = 1008 kg/m$^3$
- Volume of GGBS/Fly ash + Alkaline solution is 30% of density of concrete.
- Volume of GGBS/Fly ash + Alkaline solution = 720 kg/m$^3$
- Alkaline liquid to GGBS/Fly ash = 0.4 (based on journals)
- Alkaline Liquid : GGBS/Fly ash :: 2 : 5
- Volume of GGBS/Fly ash = 514.3 kg/m$^3$
- Volume of Alkaline liquid = 205.7 kg/m$^3$
- 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 = 146.92 kg/m$^3$
- Sodium hydroxide (NaOH) solution = 58.77 kg/m$^3$
- NaOH solution = NaOH solids + Distilled water
- NaOH solids (31%) = 18.22 kg/m$^3$
- Distilled water (69%) = 40.55 kg/m$^3$ (for 10 Molar concentration)

This is the mix design, which have been followed in this research work.

## 3.4 MIX PROPORTIONS

Studies on various mixes showed that this ratio provided near optimum strength and workability. These types of concrete mixes are cast into specimens and these specimens were tested for compression strengths.

### 3.4.1 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 3.4.1.1** Types of pozzolanic materials of Phase-1 study

### 3.4.2 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.

## 3.5 MIXING PROCEDURE

Mixing of ingredients is done in a pan mixer of capacity 40 litres. First Fly ash or GGBS depends upon the mix, Coarse aggregate and fine aggregate are mixed thoroughly for three minutes in a pan mixer and the alkaline solution which is added with extra water to dry materials and mixed about for five minutes.

## 3.6CURING OF THE SPECIMENS

The specimens are left in the moulds undisturbed at room temperature for about 24 to 36 hours as it was geopolymer concrete after casting. The specimens are then removed from the moulds and they are exposed to sunlight and air for desired periods.

### 3.8 TESTING OF SPECIMENS

#### 3.8.1 Slump test

Slump test is the most commonly used methods and measuring the consistency of concrete, which is employed in the laboratory or at the site work. In the present work, slump tests were 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.

The apparatus for conducting the slump test essentially consists a metal mould in the form of a frustum of a cone having the internal dimensions asunder:

Bottom diameter: 20 cm
Top diameter: 10 cm
Height: 30 cm

#### 3.8.2Sorptivity Test

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used of the test fluid.

The cubes after casting were immersed in water for 28 days curing. The specimen size 100mm × 100mm × 100mm after drying in oven at temperature of 85ºC or sunlight, it was drowned with water level not more than 5 mm above the base of the specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating or sealing with the plaster.The quantity of water absorbed in the time period of 30 minutes was measured by weighting the specimen on a top pan balance weighting up to 0.1 mg. Surface water in the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 seconds.

I=St

Where, S is sorptivity, I is the cumulative infiltration at time t . Therefore,
s=It

Where, S = sorptivity in mm, t = elapsed time in min.

I=ΔWAd

ΔW = change in weight = $W_2$-$W_1$
$W_1$ = Oven dry weight of the cylinder in grams
$W_2$ = Weight of cylinder after 30 minute capillary suction of water in grams.
A= surface area of the specimen through which water penetrated.
d = density of water

## IV. PRESENTATION OF RESULTS

### 4.1 INTRODUCTION

One of the most environmentally responsible ways of meeting the challenges of sustainability in construction is to reduce the production of OPC, by using the Fly ash and GGBS in concrete as a replacement of cement. The main objective of the present work of investigation is classfied in to two phases.

**Phase-1:** The effect of the Source materirial in geopolymer concrete which are rich in alumina-silica source such as GGBS and flyash.

**Phase-2:** The effect of molarity of alkaline liquid in Geopolymer concrete by varing as 6M, 8M, 10M, 12M and 14M.

The tests Carried out are

- Slump Test
- Sorptivity
- Compressive strength
- XRD

The major observations from this experimental work are as under:

### 4.2 SLUMP TEST

The slump test has been conducted for varying the materials of the mix in GPC with 100% Flyash, 50% Flyash + 50% GGBS and 100% GGBS.

**Table 4.2.1** Slump test result

| S.No | Mix Name | Type of Mix | Slump Value (mm) |
|---|---|---|---|
| 1 | FA-GPC | 100% Fly Ash | 96 |
| 2 | FG-GPC | 50% Fly Ash + 50% GGBS | 90 |
| 3 | G-GPC-10 | 100% GGBS | 87 |

## 4.3 SORPTIVITY

The sorptivity test has been conducted for the specimens of Phase-1 and Phase-2 after curing them for 28 days in sunlight.

**Table 4.3.1** Sorptivity test results of Phase-1

| S.No. | Mortar Type | Dry Wt. in grams ($W_1$) | Wet Wt. in grams ($W_2$) | Change in Wt. in grams ($W_2$-$W_1$) | Sorptivity value in $10^{-4}$ mm/min$^{0.5}$ |
|---|---|---|---|---|---|
| 1 | FA-GPC | 2362.3 | 2379.0 | 16.7 | 0.30 |
| 2 | FG-GPC | 2519.3 | 2534.7 | 15.3 | 0.28 |
| 3 | G-GPC-10 | 2551.7 | 2564.0 | 12.3 | 0.23 |

**Table 4.3.2** Sorptivity test results of Phase-2

| S.No. | Mortar Type | Dry Wt. in grams ($W_1$) | Wet Wt. in grams ($W_2$) | Change in Wt. in grams ($W_2$-$W_1$) | Sorptivity value in $10^{-4}$ mm/min$^{0.5}$ |
|---|---|---|---|---|---|
| 1 | G-GPC-6 | 2423.7 | 2443.3 | 19.7 | 0.36 |
| 2 | G-GPC-8 | 2449.0 | 2465.0 | 16.0 | 0.29 |
| 3 | G-GPC-10 | 2551.7 | 2564.0 | 12.3 | 0.23 |
| 4 | G-GPC-12 | 2578.7 | 2586.7 | 8.0 | 0.15 |
| 5 | G-GPC-14 | 2604.0 | 2610.0 | 6.0 | 0.11 |

## 4.4 COMPRESSIVE STRENGTH

### 4.4.1 Phase-1 Compressive strength results

In phase-1 of the project by varying the materials of the mix the compressive strength results are presented and the test results are taken for 7 days, 14 days and 28 days.

**Table 4.4.1** Compressive strengths of Phase-1

| S.No. | Type of specimen | Compressive Strengths in MPa | | |
|---|---|---|---|---|
| | | 7 days | 14 days | 28 days |
| 1 | FA-GPC | 15.66 | 31.00 | 34.33 |
| 2 | FG-GPC | 46.00 | 47.33 | 49.70 |
| 3 | G-GPC-10 | 58.00 | 63.67 | 68.33 |

### 4.4.2 Phase-2 Compressive strength results

In the phase-2 of the project the optimum mix of phase-1 material is taken that is GGBS based geopolymer concrete and by varying the molarity of the alkaline solution compression strength is presented for the 7 days, 14days, 28 days and 56 days.

**Table 4.4.2** Compressive strengths of Phase-2

| S.No. | Type of specimen | Compressive Strengths in MPa | | | |
|---|---|---|---|---|---|
| | | 7 days | 14 days | 28 days | 56 days |
| 1 | G-GPC-6 | 29.33 | 33.00 | 42.00 | 43.33 |
| 2 | G-GPC-8 | 35.33 | 36.33 | 54.33 | 56.66 |
| 3 | G-GPC-10 | 58.00 | 63.67 | 68.33 | 69.87 |
| 4 | G-GPC-12 | 63.70 | 68.33 | 70.66 | 71.66 |
| 5 | G-GPC-14 | 65.70 | 71.00 | 75.33 | 76.33 |

## 4.5 X-RAY DIFFRACTION TEST

Total four samples were tested for the X-Ray Diffraction (XRD) that is two samples in each phase. The samples that are tested,

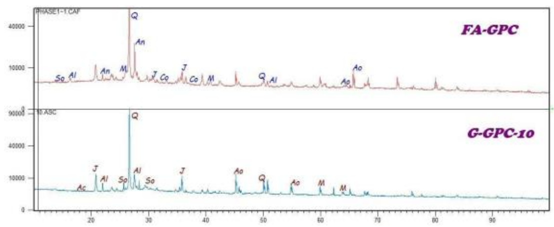
**Phase-1**

- FA-GPC (Fly ash based GPC)
- G-GPC-10 (GGBS based GPC)

**Phase-2**

- G-GPC-6 (GGBS based GPC of 6 Molar)
- G-GPC-14 (GGBS based GPC of 14 Molar)

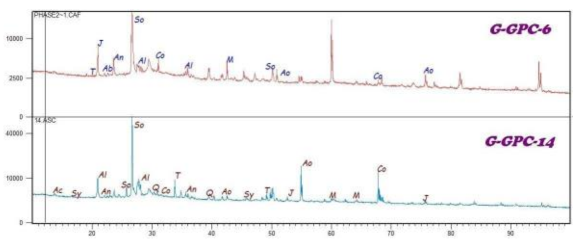
#### 4.5.1 X-Ray Diffraction graph of Phase-1



Position [°2Theta]

***Fig. 4.4.1*** *Comparisons of peaks in Phase-1 graph*

#### 4.5.2 X-Ray Diffraction graph of Phase-2



Position [°2Theta]

***Fig. 4.4.2*** *Comparisons of peaks in Phase-2 graph*

## V. RESULTS AND DISCUSSIONS

With the genetic information available on geopolymer, a rigorous trial-and-error method was adopted to develop a process of manufacturing geopolymer concrete following the technology currently used to manufacture Ordinary Portland Cement concrete. Many trails are done using different materials like Rice husk ash, Metakaoline, Fly ash, GGBS 3.5 mm, and GGBS 90 micron to react with the alkaline solution in geopolymer concrete.

- Rice husk ash, metakaoline and 3.5 mm GGBS are used for trial mixes which are light in weight and absorbing more water and not achieving the strength compared to the Fly ash based geopolymer concrete.
- Geopolymer concrete doesn't require water curing as it is giving good strength when it is cured in sunlight (Ambient curing).
- When the GGBS of size 3.5 micron based geopolymer concrete hasn't given the minimum strength as it has no workability and GGBS has the properties similar to sand and its microstructure is week compared to 75 micron GGBS.

### 5.1 SLUMP TEST RESULTS

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

- 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.
- FA-GPC specimen recorded 96 mm slump value whereas specimens of G-GPC-10 showed comparatively lower corresponding values of 87 mm respectively.

### 5.2 SORPTIVITY TEST RESULTS

#### 5.2.1 Phase-1 Sorptivity test

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

- 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. This may be attributed to the fact that alkali content in the mix gives better reactivity with the GGBS resulting in denser microstructure.
- FA-GPC specimen recorded 0.30 $mm/min^{0.5}$ sorptivity whereas specimens of G-GPC-10 showed comparatively lower corresponding values of 0.23 $mm/min^{0.5}$ respectively.
- Formation of microstructure in G-GPC10 is better than the FA-GPC due to the crystalline structure of GGBS reacting with alkaline solution, which reducing the Sorptivity.

#### 5.2.2 Phase-2 Sorptivity test

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

- Geopolymer concrete specimens G-GPC-14 manufactured with 14 Molar of NaOH resulted in lesser values of sorptivity when compared to the 12, 10, 8 and 6 Molars of NaOH, as in the case of G-GPC-12, G-GPC-10, G-GPC-8 and G-GPC-6 specimens respectively. This may be attributed to the fact that higher molar NaOH content in alkaline solution of the mix gives better reactivity with the GGBS resulting in denser microstructure.

### 5.3 COMPRESSION TEST RESULTS

### 5.3.1 Phase-1 Compressive strength

- From the graph we can observe that there is a gradual increase in G-GPC-10 with the age and it gives the higher strength than the FA-GPC and FG-GPC.
- Initial setting time of Fly ash based GPC is slower than the GGBS based GPC which attaining higher strength. The fly ash GPC is slower in drying as it takes a minimum of 48 hours to get demould.
- Water consumption of GGBS based GPC is little more than the Fly ash GPC.
- When the molarity of concentration, increased the workability of the concrete is increasing.

### 5.3.2 Phase-2 Compressive strength

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

- From the Fig.5.2.3 it is clear that after G-GPC-10 the rate of increase in the strength is decreased and that may not exceed more than the G-GPC-14. So, 10M, 12M can be the optimum strengths that can be considered.

### 5.4 X-RAY DIFFRACTION TEST RESULTS

### 5.4.1 Phase-1 Comparisons of Chemical compounds

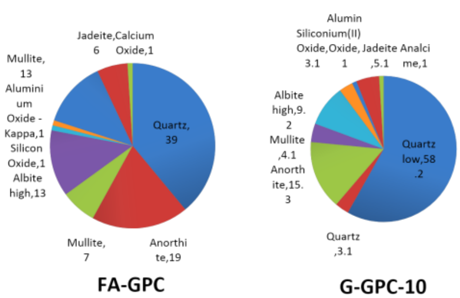



***Fig. 5.4.1*** *Phase-1 Contents of compounds in Pie Chart*

- The G-GPC specimens exhibits peaks of Quartz. Peaks of Silicon Oxide are also observed.
- In the above Pie chart the Quartz and Silicon oxide are in higher contents GGBS based GPC than the FLY Ash based GPC.
- The mix G-GPC-10 containing Quartz and Silicon Oxide higher, than the FA-GPC, which helped in strengthening the concrete.
- Analcime is an extra compound that found in the G-GPC-10, which also increases the strength of the concrete.

### 5.4.2 Phase-2 Comparisons of Chemical compounds

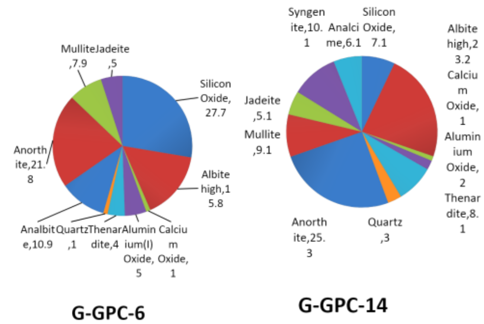



***Fig. 5.4.2 Phase****-2 Contents of compounds in Pie Chart*

- 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.
- Thenardite occured due to reaction between Na ions form the NaOH solution with sulfate ions leading to the formation of sodium sulfate decahydrate.
- The presence of the Anorthite phase indicates that calcium from the aggregate is reacting with the sodium silicate along with the alumina silicate forming Anorthite and Albite.
- Albite can be associated with the strength enhancement region of the geopolymer matrix.
- Thenordite is a compound which de-hydrates the material and resist the water absorption, it is also proved practically by the sorptivity test.

## VI. SUMMARY AND CONCLUSIONS

Based on limited experimental investigations of geopolymer concrete, the following conclusions are made regarding the resistance of Geopolymer concrete:

1. The compressive strength attained by GGBS based Geopolymer concrete is more than the Fly ash based Geopolymer concrete.
2. The Sorptivity and XRD analysis proves that GGBS based GPC absorbs less water due to its crystalline structure.
3. The reaction of GGBS in geopolymer concrete with alkaline solution attains higher strength and less sorptivity confirms GGBS is the best suitable material in Geopolymer concrete compared to fly ash.
4. The increase in molarity of NaOH leads to less voids and good crystalline structure that results in less water absorption.

5. NaOH plays a major role in attaining the strength of the concrete, hence it is recommended 10M concentrations for medium grade.
6. The rate of increase in strength after 10 Molar concentration is decreased. So, considering 10M and 12M as the optimum dosage for GPC mix.
7. Based on the molar concentration the grades of concrete can be designed and implemented in construction.

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