International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.4., Issue.6., 2016
Nov-Dec.

RESEARCH ARTICLE

ISSN: 2321-7758

AN EXPERIMENTAL STUDY AND PERFORMANCE OF GEOPOLYMER CONCRETE

D.PRASAD[1], A.ROOPA[2]

[1]M.Tech Structural Engineering & Shree Institute of Engineering Technology, Tirupati, AP

[2]Dept. of Civil Engineering, Assistant Professor& Shree Institute of Engineering Technology Tirupati,AP

ABSTRACT

In the construction industry there are two commonly used structural materials i.e. The major problem that the world facing today is global warming. The cement industry is one of the major reasons for emission of greenhouse gases, such as CO_2 which causes global warming. A lot of energy and natural resources are consumed in production of Ordinary Portland cement (OPC). Geopolymer concrete (GPC) is one of the processes that reduces cement usage and increases the usage of industrial by-products in concrete. In the present study, OPC is fully replaced by pozzolanic materials and alkaline liquids such as Sodium hydroxide (NaOH) and Sodium silicate (Na_2Sio_3) to produce the Geopolymer concrete.

The present investigation is to study the effect of pozzolanic materials and concentration of NaOH. The experimental programme is divided into two phases. In Phase-1, two mixes were taken one is Fly ash based GPC and other is GGBS based GPC with 10M concentration and out of these two mixes the optimum mix GGBS based GPC is taken for further study. In Phase-2 the mix GGBS based GPC is considered and concentration of NaOH is varied (i.e. 6M, 8M, 10M, 12M and 14M) to study the compressive strength. The test specimens prepared were concrete cubes of size 100×100×100 mm and cured under sunlight. The GPC specimens were tested for their compressive strength at the ages of 7, 14, 28 and 56 days. The sorptivity and XRD analysis were also carried out after 28 days of curing. The results show that the GGBS based GPC specimens gives higher compressive strength and lesser sorptivity than the Fly ash based GPC in phase-1 study and in phase-2 with the increase in concentration of NaOH the compressive strength increased and sorptivity value decreased. The XRD analysis also carried out to study the minerals of GPC.

Keywords- Geo polymer concrete,Opc,Sodium Hydroxide & GGBS

1. INTRODUCTION

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 or calcined 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.

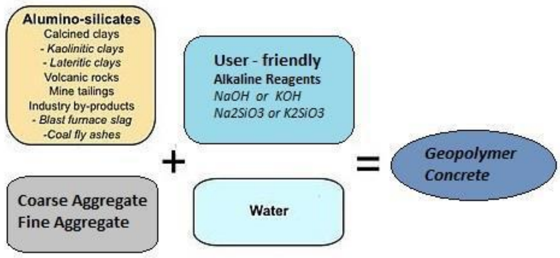


Fig -1: Geo-Polymer Concrete

1.1. 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.

1.2. Necessity of GeoPolymer Concrete

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. The scope in geopolymer concrete is usage of recycled coarse aggregates as fresh coarse aggregates, SEM tests can be done for GGBS based GPC, Fine aggregates can be replaced by the industrial by-products.

2. LITERATURE REVIEW

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. Test data on various short-term and long-term properties of the geopolymer concrete and the results of the tests conducted by large-scale reinforced geopolymer concrete member's show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments.

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^oc 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.

More Pratap Kishanrao et al., [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 100^oC to 500^oC.

Mohd Mustafa Al Bakri Abdullah et al., [5] has studied on Fly Ash-based geopolymer lightweight concrete using foaming agent and by this he reports the results of his investigation on the possibility of producing foam concrete by using a geopolymer system. Class C fly ash was mixed with an alkaline activator solution (a mixture of sodium silicate and NaOH), and foam, was added to the geopolymer mixture to produce lightweight concrete.

3. EXPERIMENTAL INVESTIGATIONS

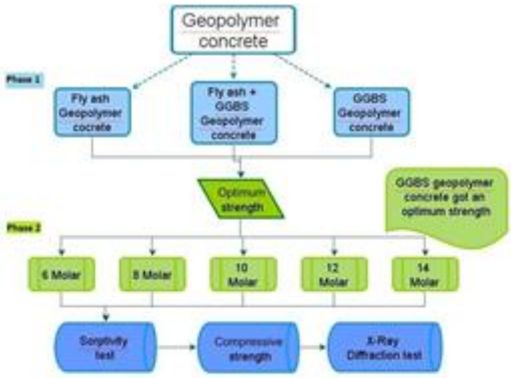


Fig -2: Comparison of Materials on GPC

3.1. Fly Ash

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.

Fig -2: Fly ash Composition

Table -1: Chemical Composition of fly ash

S.NO	Major Components	Formula	Percentages
1	Silicon Dioxide	Sio_2	60.54
2	Aluminium Oxide	AL_2O_3	26.20%
3	Ferric Oxide	Fe_2O_3 CaO	5.87%
4	Calcium Oxide	MgO	1.91%
5	Magnesium Oxide	Na_2O_3	0.38%
6	Sodium Oxide	Na_2O	0.23%
7	Potassium oxide	K_2O	0.40%
8	Sulphur Oxide	SO_3	0.44%
9	Loss On Ignition	LOI	2.00

3.2. **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,

Fig -2: Ground Granulated Blast Furnace Slag

3.3. **Ground Granulated Blast Furnace Slag (GGBS)**

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.

Fig -3: Fine Aggregate

3.4. **Coarse Aggregte**

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.

Fig -4: Coarse Aggregate

3.5. **Sodium Hydroxide- Naoh**

Generally the sodium hydroxide are variable in the solid state by means of pellets and flakes. The cost of sodium hydroxide varies according to the purity of the substance. Since our geopolymer concrete is homogeneous materials and its main process to activate the sodium silicate so it is pellet sodium hydroxide is recommended to use as it is the lowest cost, i.e., up to 94% to 96% purity. The sodium hydroxide is calculated in molars or moles. The NaOH solids (pellets) were dissolved in water to make the solution.

Fig -5: Sodium Hydroxide Pellets-Naoh

3.6. **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.

Fig -6: Sodium Silicate Solution (Na_2Sio_3)

3.7. **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.

Fig -7: Distilled Water

4. **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 -8: Constituents in Mix Design of Geo Polymer 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.

4.1. **Mix-1 Proportions**

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

4.2. **Mix-2 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.

4.3. **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.

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste, that binds the loose coarse and fine aggregates and other unreacted materials to form the geopolymer concrete.

4.4. **Molarity Calculation**

The solids must be dissolved in water to make a solution with the required concentration. The Concentration of sodium hydroxide solution can vary in different molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution.

Considering 14M concentration, where in solution consists of 44.1% of solids (Pellets or Flakes) and 55.9% of water. For instance NaOH solution with 14 molars consists of 14x40=560grams of NaOH solids per litre of water, where 40 is the molecular weight of NaOH.

4.5. **Alkaline Liquid**

Generally alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate solution at the room temperature.When the solution mixed together the both the solutions start to react that is poly erization takes place.

Fig -9: Preparation of Alkaline Liquid

4.6. **Alkaline Liquid**

The cast iron moulds are cleaned of dust particles with mineral oil on all sides before the concrete is poured into the moulds.

Fig -10: Cubes casted in Iron Moulds

4.7. **Curing 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.

Fig -11: Specimens were cured under the sunlight

4.8. **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.

Fig -12: Slump Test in Progress

4.9. **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. After curing, the specimens are tested for compressive strength using compression testing machine of 2000 KN capacity (IS: 516 - 1959).

Fig -13: Compressive Strength Machine

Fig -14: Before & After application of Load

In each case the cube was positioned in such a way that the load was applied perpendicularly to the direction of casting with a loading rate of 140 $kg/cm^2/min$ was maintained and it was continued till the specimen fails, i.e. with a further increment of load, no resistance was offered by the specimen, that maximum load was recorded. The test was repeated for the three specimens and the average value was taken as the mean strength.

4.10. Sorptivity

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.

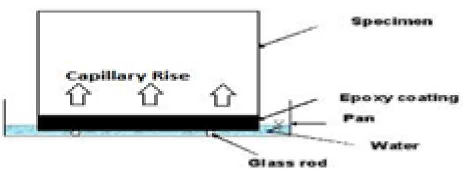


Fig -15: Sorpitivity Test

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 85°C 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.

Fig -15: Specimens testing for Sorptivity

4.11. X Ray Diffraction

Diffraction is a physical phenomenon that consists in electromagnetic waves avoiding obstacles if the size of the obstacles compared to the wavelength. This phenomenon can be applied to the analysis of materials as the atom plans are placed at comparable distances to X ray lengths. 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. The diffraction image contains a small number of maximum points that is not all the families of crystallographic planes give maximum diffraction points; all the crystalline phases with the same type of elementary cell will exhibit the same succession of Miller indices for the crystalline planes families giving a diffraction maximum points. For the XRD analysis, we use diffraction devices (diffractometers), mainly according to the Bragg–Brentano system (the sample rotates at a diffraction angle ”θ”, while the detector rotates at the angle ”2θ".

Fig -16: X Ray diffractometer

4.12. Sample Preparation for Thermal Analysis

Samples tested for the compression strength after 28 days curing of both Phase-1 and Phase 2 are then carried out for the XRD testing. In Phase-1 the samples of lower strength and samples of higher strength were compared in XRD testing. Same thing followed for the Phase-2 samples.

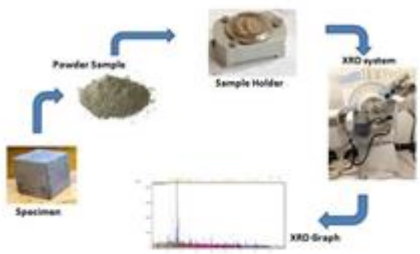


Fig -17: X Ray diffraction Processes

5. PRESENTATION OF RESULTS

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.

5.1. 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 -2: Phase-1 sorptivity test results

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}
1	FA-GPC	2362.3	2379.0	16.7	0.30
2	FA-GPC	2519.3	2534.7	15.3	0.28
3	FA-GPC-10	2551.7	2564.0	12.3	0.23

Table -3: Phase-2 sorptivity test results

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}
1	FA-GPC-6	2423.7	2443.3	19.7	0.36
2	FA-GPC	2449.0	2465.0	16.0	0.29
3	FA-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-12	2604.0	2610.0	6.0	0.11

5.2. COMPRESSIVE STRENGTH

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: Phase-1 Compressive Strength results

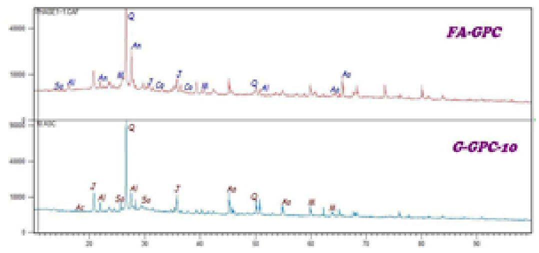
S.NO	**Type of Specimen**	**Compressive Strengths in Mpa**		
		7 Days	**14 Days**	**28 Days**
1	FA-GPC	15.66	31.00	34.33
2	FG-GPC	46.00	47.33	49.70
3	G-GPC-10	58.00	63.67	68.33

Table -5: Phase-1 Compressive Strength results

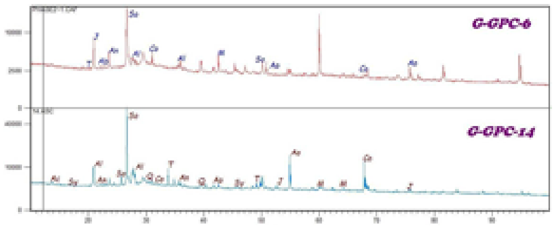
S.NO	**Type of Specimen**	**Compressive Strengths in Mpa**			
		7 Days	**14 Days**	**28 Days**	**56 Days**
1	G-GPC-6	29.33	33.00	42.00	43.33
2	G-GPC-8	35.33	36.33	54.33	56.66
3	G-GPC-10	58.00	63.67	68.33	69.87
4	G-GPC-12	63.70	68.33	70.66	71.66
5	G-GPC-14	65.70	71.00	75.33	76.33

5.3. 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,



Graph 1: Comparisons of Peaks in phase-1 graphs



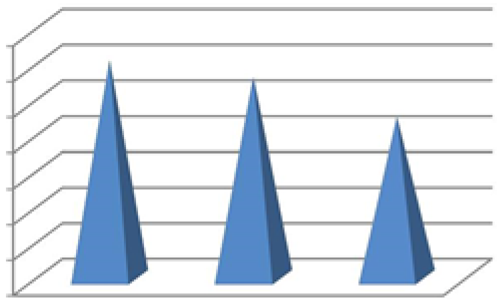
Graph 2: Comparisons of Peaks in phase-2 graphs

6. RESULTS & 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.

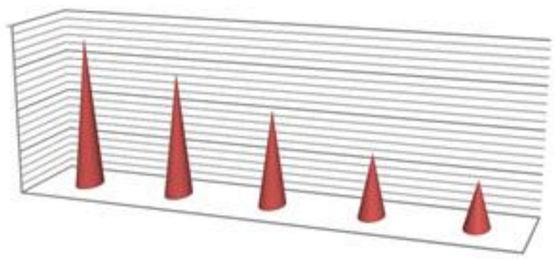
6.1. SORPTIVITY TEST RESULTS

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



Graph 3: Phase-1 Sorptivity test results

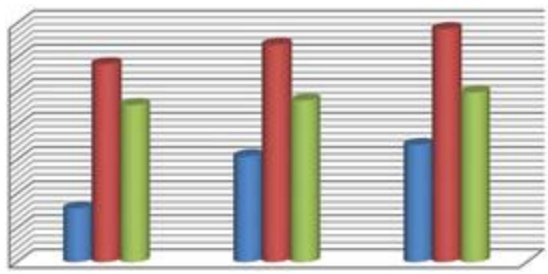
Geopolymer concrete specimens G-GPC-10 manufactured with 100% GGBS resulted in lesser values of sorptivity when compared to the 100% Fly ash and 50% Fly ash + 50% GGBS based geopolymer concrete as in the case of FA-GPC and FG-GPC specimens respectively. This may be attributed to the fact that alkali content in the mix gives better reactivity with the GGBS resulting in denser microstructure.



Graph 4: Phase-2 Sorptivity test results

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.

6.2. COMPRESSIVE STRENGTH RESULTS



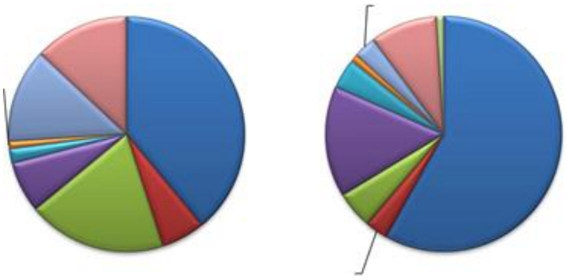
Graph 5: Compressive strength test results

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.

6.3. X-RAY DIFFRACTION TEST RESULTS

The results of an X-Ray diffraction study of the GPC is shown the following figures.



Graph 6: Comparisons of Chemical Compounds

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.

6. CONCLUSION

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

- The compressive strength attained by GGBS based Geopolymer concrete is more than the Fly ash based Geopolymer concrete.
- The Sorptivity and XRD analysis proves that GGBS based GPC absorbs less water due to its crystalline structure.
- 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.
- The increase in molarity of NaOH leads to less voids and good crystalline structure that results in less water absorption.
- NaOH plays a major role in attaining the strength of the concrete, hence it is recommended 10M concentrations for medium grade.
- The rate of increase in strength after 10 Molar concentration is decreased. So, considering 10M and 12M as the optimum dosage for GPC mix.
- Based on the molar concentration the grades of concrete can be designed and implemented in construction.
- The geopolymer concrete can be innovative supplementary to OPC in construction material but judicious decisions are to be taken by engineers.

REFERENCES

[1]. N A Lloyd and B V Rangan., *Geopolymer Concrete with Fly Ash*, Second International Conference on Sustainable Construction Materials and Technologies Volume 3, 2010, pp. 1493-1504.

[2]. V. Supraja, M. Kanta Rao., *Experimental study on Geo-Polymer concrete incorporating GGBS*, International Journal of Electronics, Communication & Soft Computing Science and Engineering ISSN:2277-9477, Volume2, Issue 2.

[3]. Kolli Ramujee and M. Potharaju., *Development of Low Calcium Flyash Based Geopolymer Concrete*, IACSIT International Journal of Engineering and Technology, Vol. 6, No. 1, February 2014.

[4]. More Pratap Kishanrao., *Design of Geopolymer Concrete*, International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 5, May 2013

[5]. Prakash R. Voraa, Urmil V. Daveb., Parametric Studies on Compressive Strength of Geopolymer Concrete, Science direct

[6]. Mohd Mustafa Al Bakri Abdullah, Kamarudin Hussin, Mohamed Bnhussain, Khairul Nizar Ismail, Zarina Yahya and Rafiza Abdul Razak., *Fly Ash-based Geopolymer Lightweight Concrete Using Foaming Agent*, Int. J. Mol. Sci. 2012, 2013, 7186-7198; doi:10.3390/ijms13067186.

[7]. Shankar H. Sanni, Khadiranaikar, R. B., Performance of geopolymerconcrete under severe environmentalconditions, International Journal of Civil and Structural Engineering.