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A Study on Performance of Fly Ash and GGBS Based Green Concrete

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***Abstract*: Concrete is the most consumable material after water in the world. Primary binding material used in concrete production is Ordinary Portland cement (OPC). The manufacturing of Ordinary Portland cement contributes an average of 5-7% of total green house gases, such as Carbon dioxide emission. Huge amount of natural resources are consumed in production of 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 (Na2Sio3) to produce the Geopolymer concrete. In this experiment the effect of pozzolanic materials and concentration of NaOH on concrete is studied. The experimental programme is divided into two phases. In Phase-1, three mixes were taken one is 100% Fly ash based GPC, second is mixture of 50% Fly ash and 50% GGBS based GPC and the other is 100% GGBS based GPC with 10M of NaOH concentration. From phase-1, out of these three mixes the optimum mix is taken for further study. In Phase-2 the Optimum mix i.e., 100% GGBS based GPC with 10M of NaOH concentration 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 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 X-Ray Diffraction analysis were also carried out after 28 days of curing. The XRD analysis is carried out to study the minerals composition of GPC.**

***Keywords*: pozzolanic materials, GGBS, GPC, sorptivity and XRD analysis**

1. Introduction

Concrete is worldwide used construction material after water. With rapid increase in population the demand for construction as well as concrete is also increasing. The main constituent of concrete is ordinary Portland cement which is manufactured by burning the natural materials such as lime, sand which leads to the emission of carbon dioxide. The production of OPC contributes 5-7% of total greenhouse gases. In order to replace the usage of cement in concrete various researches has been carried out to adopt a better alternative for ordinary Portland cement.

Geopolymer concrete is an ecofriendly concrete in which OPC is replaced by mineral admixtures such as flyash and ground granulated blast furnace slag which are the bi-products of thermal and steel plants. 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, three mixes were taken one is Fly ash based GPC, second is mixture of Fly ash and GGBS based GPC and the other is GGBS based GPC with 10M concentration and out of these three mixes the optimum mix is taken for further study. In Phase-2 the Optimum mix 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 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 XRD analysis is carried out to study the mineral composition of GPC.

2. Geopolymers

Geopolymers is an invention of Davidovits that belongs to the family of inorganic polymers. The main constituents of geopolymers are pozzolonic materials and alkaline activator. The chemical composition of pozzolonic material considered for geopolymer should be rich in silica and alumina. The by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as pozzolonic materials. Alkaline activators in the form of alkaline liquids such as Sodium hydroxide (NaOH) and Sodium silicate (Na2Sio3) or potassium hydroxide (KaOH) and potassium silicate (Ka2SiO3) is used to produce the Geopolymer concrete. The chemical reaction that takes place in the manufacturing of geopolymers is polymerization.

3. Necessity of geopolymer concrete

The production of Ordinary Portland Cement not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere. 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. 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.

To produce environmentally friendly concrete, we have to replace the cement with the industrial byproducts such as fly-ash, GGBS (Ground granulated blast furnace slag) etc. In this respect, the new technology geopolymer concrete is a promising technique.

4. 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.

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

5. Constituents of concrete

A. 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) was used as the main source material as 100% replacement of cement. The fly ash particles are spherical and grey in colour. The specific gravity of fly ash is 2.30.

B. Blast furnace slag

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 grinded to get a fine powder form of GGBS.

C. 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.

D. 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.

E. 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. The pH of distilled water is between 5.6 and 7.

F. 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.

G. 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.

6. Mix design and concrete production

Since geopolymer concrete is a recent technology, it dosent have any codal provisions for mix design. Therefore the general codal provisions that are available for ordinary portland cement is adopted for the manufacture of geopolymer concrete.

As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete with 30% of it being fine aggregate. The alkaline liquid to fly ash and GGBS ratio is kept as 0.4. The ratio of sodium hydroxide to sodium silicate is kept as 2.5

In trail-1, three mixes were adopted in which one is fly ash based GPC. The second mix is 50% of fly ash and 50% of GGBS based GPC and the final mix is GGBS based GPC and concentration of NaOH is 10M. Out of these three mixes the optimum mix GGBS based GPC is taken for further study.

In second trail the GGBS based Geopolymer concrete is considered and the concentration of sodium hydroxide is varied as 6M, 8M, 10M, 12M, 14M and the performance of GPC is analyzed in terms slump cone, compression strength, sorptivity.

A. Test specimens

Three cubical and cylindrical specimens of size 150mm X 150mm X 150mm and length 300mm, 150 mm diameter were cast and tested for determining various properties of Geopolymer concrete. The compressive and split tensile strength was tested after 7, 28 and 90 days of curing. For impact test 75mm length and 150mm diameter specimens were casted and cured for a period of 28 days. In case of sorptivity, the specimens having 100mm X 100mm X 100mm surface area were casted and cured for a period of 28 days and it is coated with non-absorbent material on all sides expect on side of contact with the water.

B. Curing of test 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.

Table 1
Trail-1 Mix proportions (kg/m^3)

S. No.	Materials	Mix-1	Mix-2	Mix-3
1	Fly ash	514.3	257.15	0
2	GGBS	0	257.15	514.3
3	Fine aggregate	672	672	672
4	20mm Coarse aggregate	705.6	705.6	705.6
5	10 mm Coarse aggregate	302.4	302.4	302.4
6	Sodium silicate	146.92	146.92	146.92
7	Sodium hydroxide	18.22	18.22	18.22
8	Distilled Water	40.55	40.55	40.55
9	Molarity	10 M	10 M	10 M

Table 2
Trail-2 Mix proportions (kg/m^3)

S. No.	**Materials**	**Mix-4**	**Mix-5**	**Mix-6**	**Mix-7**	**Mix-8**
1	GGBS	514.3	514.3	514.3	514.3	514.3
2	Fine aggregate	672	672	672	672	672
3	20 mm Coarse aggregate	705.6	705.6	705.6	705.6	705.6
4	10 mm Coarse aggregate	302.4	302.4	302.4	302.4	302.4
5	Sodium silicate	146.9	146.9	146.9	146.9	146.9
6	Sodium hydroxide	11.75	14.69	18.22	20.57	23.51
7	Distilled Water	47.02	44.08	40.55	38.20	35.26
8	Molarity	6 M	8 M	10 M	12 M	14 M

7. Testing of specimens and results

After demoulding, specimens of desired age of curing are considered and various tests are performed to know the strength characteristics. Slump test is performed on fresh concrete and other tests are performed on specimens after desired age of curing.

A. Slump test

Slump test is the most commonly used methods and measuring the consistency of fresh 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 very 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 cone having the internal dimensions as 20 cm bottom diameter, 10cm top diameter and 30 cm height.

B. Sorptivity 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.

Table 3
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

Table 4
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	2551.7	2564.0	12.3	0.23

Table 5
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

C. Compressive strength test

The specimens are tested for compressive strength using compression testing machine of 2000 KN capacity.

The average compressive strength of concrete specimens is calculated by using the following equation.

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

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.

1) Trail-1 compressive strength results

In trail-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. The test results are tabulated as follows.

Table 6
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

2) Trail-2 compressive strength results

In the trail-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 7
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

D. 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,

- *Trail-1*
  - FA-GPC (Fly ash based GPC)
  - G-GPC-10 (GGBS based GPC)
- *Trail-2*
  - G-GPC-6 (GGBS based GPC of 6 Molar)
  - G-GPC-14 (GGBS based GPC of 14 Molar)

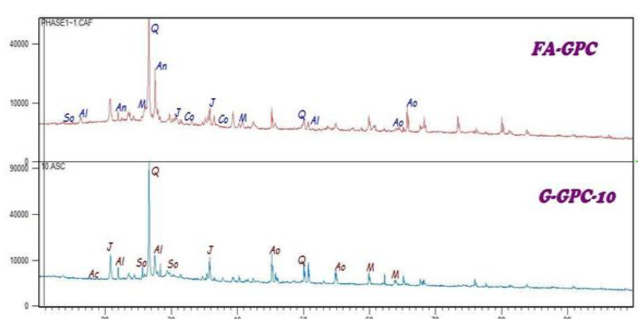

Fig. 1. Trail-1 XRD analysis graph

In the x-ray diffraction analysis of trail-1 specimens, GGBS based geopolymer concrete specimens exhibits peaks of Quartz and Silicon Oxide observed.In the above XRD analysis graph the Quartz and Silicon oxide are in higher contents in 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.

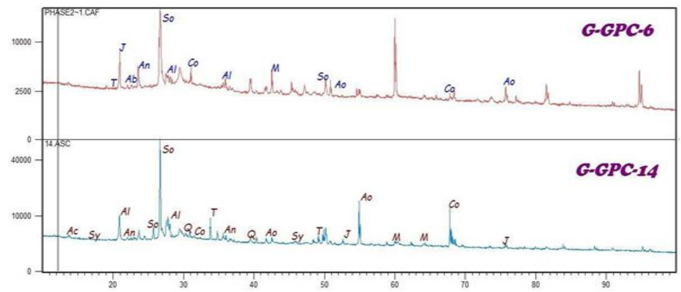

Fig. 2. Trail-2 XRD analysis graph

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.

8. Conclusion

Based on the experimental investigations of geopolymer concrete, the following conclusions are made regarding the perfomance 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.

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