An Experimental Investigation on Fresh and Mechanical Properties of GGBFS and Flyash Based Geopolymer Concrete

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***Abstract*— The Cement contributes nearly 7% of the global carbon dioxide emission. Geo Polymer Concrete (GPC) is a special type of eco-friendly concrete alternative to Ordinary Cement concrete. This main aim of the research is to study the effect of class F Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) on the mechanical properties of Geo Polymer concrete (GPC) at different replacement levels using Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solutions as alkaline activator. The cubes and cylinders were casted in different replacement levels 90% fly ash+10% GGBFS, 80% fly ash+20% GGBFS, 70% fly ash+30% GGBFS. The cubes and cylinders were cast and cured in three different ages 7 days, 14 days, 28 days in ambient temperature to determine fresh and mechanical properties of geopolymer concrete. For the fresh concrete slump cone test was carried out. In G1 mix we achieved workable concrete compared to other mixes. Compressive and split tensile strength test results reveal that increase in 80% flyash+20% GGBFS replacement enhanced the mechanical properties of Geo Polymer Concrete.**

***Index Terms:* Geopolymer concrete, Class F Flyash, GGBFS, Slump cone, Compressive strength, Tensile strength.**

INTRODUCTION

Concrete is the most widely used construction material in the world and Ordinary Portland Cement (OPC) is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide (Co2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of Co2 is released into the atmosphere for every ton of Ordinary Portland Cement (OPC) produced. In view of this, there is a need to develop sustainable alternatives to conventional cement utilizing the cementitious properties of industrial by products such as fly ash and ground granulated blast furnace slag. On the other side, the abundance and availability of class F Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) worldwide create opportunity to utilize these by-products, as partial replacement or as performance enhancer for Ordinary Portland Cement.

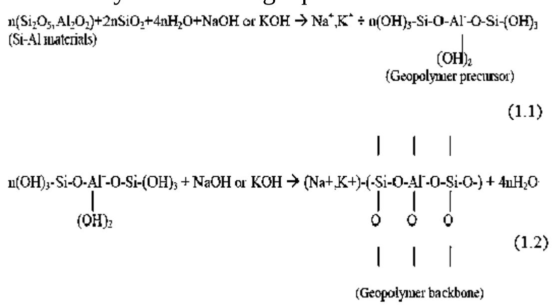
Ground Granulated Blast Furnace Slag (GGBFS) is a by-product from the blast-furnaces used to make iron. GGBFS is a glassy, granular, non-metallic material considering essentially of silicates and aluminates of calcium. GGBFS has almost the same particle size as cement. GGBFS, often blended with Portland cement as low-cost filler, enhances concrete workability, density. durability and resistance to alkali-silica reaction.

Alternative utility of FA and GGBFS in construction industry that has emerged in recent years is in the form of Geo Polymer Concrete (GPC), which by appropriate process technology utilize all classes and grades of FA and GGBFS, therefore there is a great potential for reducing stockpiles of these waste materials. Geopolymer concrete (GPC) are inorganic polymer composites, which are prospective concretes with the potential to form a substantial element of an environmentally sustainable construction by replacing or supplementing the conventional concretes. GPC have high strength, with good resistance to chloride penetration, acid attack, ect. These are commonly formed by alkali activation of industrial alumino-silicate waste materials such as

FA and GGBFS, and have a very small Greenhouse footprint when compared to traditional concretes.

GEOPOLYMER

In 1978, Davidovits proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash. These binders were termed as geopolymers, because the chemical reaction that takes place in this case is a polymerization process. 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 instead of crystalline. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds are formed The schematic formation of geopolymer material can be described by the following equations.



The last term in Equation 2 reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water, expelled from the geopolymer matrix during the curing and further drying periods, leaves behind nano-pores in the matrix, wich provide benefits to the formation of geopolymers. The water in geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process. A geopolymer can take one of the three basic forms, as a repeating unit.

- Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- Poly (sialate-siloxo), which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- Poly (sialate-disiloxo), which has [-SI-O-AL-O-SI-O-SI-O-] as the repeating unit.
- Sialate is an abbreviation of silicon-oxo-aluminate.

OBJECTIVE

The aim of the project is to study the effect of Ground Granulated Blast Furnace slag (GGBFS) on strength properties of fly ash based geopolymer concrete, curing condition on compressive strength of fly ash based geopolymer concrete at various ages.

SCOPE

- To study the effect of GGBFS on strength properties of fly ash based geopolymer concrete.
- To determine the compressive strength and tensile strength of fly ash based geopolymer concrete with the addition of different percentages of GGBFS at various ages such as 7 days, 14 days and 28 days by ambient curing.

MATERIALS

Fly ash

Fly ash is defined in cement and concrete terminology as the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases. Fly ash is a by-product of coal fired electric generating plants. Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases.

The chemical composition is mainly composed of the oxides of silicon (SiO_2), aluminum (AlO), iron (FeO), and calcium (CaO), whereas magnesium, potassium, sodium, titanium, and sulphur are also present in a lesser amount. The major influence on the fly ash chemical composition comes from the type of coal. The combustion of sub- bituminous coal contains more calcium and less iron than fly ash from bituminous coal. The physical and chemical characteristics depend on the combustion methods, coal source and particle shape. Fly ash that results from burning sub-bituminous coals is referred as ASTM Class C fly ash or high-calcium fly ash, as it typically contains more than 20 percent of CaO. On the other hand, fly ash from the bituminous and anthracite coals is referred as ASTM Class F fly ash or low-calcium fly ash. It consists of mainly an alumino-silicate glass, and has less than 10 percent of CaO.

Fig 1 Class F Flyash

Coarse aggregate

Locally available crushed granite stone aggregate of 20mm maximum size was used as coarse aggregate. The coarse aggregate passing through 20mm and retaining was used for experimental work. The following properties of coarse aggregates were determined as per IS: 2386-1963.

Fine aggregate

Natural river sand was used as fine aggregate. The properties of sand were determined by conducting tests as per IS:2386 (Part-I). The results obtained from sieve analysis and properties are furnished in Table 3. The results indicate that the sand conforms to Zone III of IS:383-1970

Alkaline solution

A combination of sodium silicate solution and sodium hydroxide solution was used as alkaline solution. The sodium silicate solution A53 with SiO_2 to Na_2O ratio by mass approximately 2, i.e (Na_2O = 14.7%, SiO_2=29.4% and water 55.9% by mass) was used. The sodium with 97-98% purity, in flake or pellet form was used. The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution as 10 Molar. The ratio of sodium silicate to sodium hydroxide solution by mass was fixed as 1. The sodium hydroxide pellets were prepared one to two days prior to the concrete batching to allow the exothermically heated liquid to cool to room temperature.

Water content of Mixture

In Ordinary Portland Cement (OPC) concrete, water in the mixture chemically reacts with the cement to produce a paste that binds the aggregates. In contrast, the chemical reaction that occurs in geopolymers produces that is eventually expelled from the binder. However, water content in the geopolymer concrete mixture affected the properties of concrete in the geopolymer concrete mixtures was expressed by a single parameter called 'water to geopolymer solids ratio' by mass. In this parameter, the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water in the sodium hydroxide solution, and the mass of extra water added to the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids, and the mass of solids in the sodium silicate solution. In this project work, the "water to geopolymer solids" ratio was fixed as 0.19 a constant value, to find out the influence of other parameters on the compressive strength of Geopolymer concrete.

Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS is a new pozzolanic material commercially available in the form of powder. It 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, granulated product that is then dried and ground into a fine powder. In this experimental investigation fly ash is replaced by 10%, 20%, 30% of GGBFS by weight.

Fig 2 GGBFS

Mix Design

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminum oxides in the low calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates and other un-reacted materials to form the 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. This component of geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste.

Experimental results have shown the following:

- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Higher the ratio of sodium silicate solution- to-sodium hydroxide solution ratio by mass, higher is the compressive strength of geopolymer concrete.
- The slump value of the fresh geopolymer concrete increases when the water content of the mixtures increases.

As can be seen from the above, the interactions of various parameters on the compressive strength and the workability of geopolymer concrete is complex. In order to assist the design of low-calcium fly ash-based geopolymer concrete mixtures, a single parameter called 'water-to-geopolymer solids ratio' by mass was devised.

Table 1- mix proportion per m3 of geopolymer concrete

Materials	Mass (kg/m^3)			
Mix ID	NG	G1	G2	G3
GGBFS	0%	10%	20%	30%
Fly ash	405	364.5	324	283.5
Coarse aggregate	1268.68	1268.68	1268.68	1268.68
Fine aggregate	683.13	683.13	683.13	683.13
Sodium hydroxide solution	70.88	70.88	70.88	70.88
Sodium silicate solution	70.88	70.88	70.88	70.88
Water	108.35	108.35	108.35	108.35

RESULTS AND DISCUSSION

Slump test

To determine the workability of concrete mix by slump test conducted by as per IS 1199-1959. The internal surface of the mould thoroughly cleaned and freed from superfluous moisture than mould placed on a smooth,rigid and nonabsorbent surface. The mould was filled in four layers, each approximately one-quarter of the height of the mould. Each layer was tamped with twenty-five strokes of the rounded end of the tamping rod. The bottom layer tamped throughout its depth. After the top layer has been rodded, the concrete was struck off level with a trowel or the tamping rod, so that the mould is exactly filled. The mould removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside and the slump shall be measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested. The test results are given in table 2.

Table 2- Slump Value

S.NO	MIX PROPORTION	SLUMP
1	NG	230mm
2	G1	180mm
3	G2	150mm
4	G3	100mm

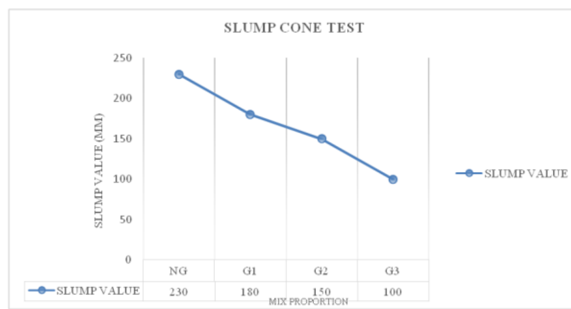


Fig 3 Slump of different groups of GPC mixture

From the Fig 3 slump cone test was carried out. In this test, workable concrete was achieved in G1 mix compared to other geopolymer concrete mixes.

Compressive strength test

The compressive strength test on hardened fly ash based geopolymer concrete was performed on standard compression testing machine of 2000kN Capacity, as per IS: 516 1959. For this study, experimental work involves casting of concrete cubes of size 150mm x 150mm x 150mm for determination of compressive strength for 7 days, 14 days and 28 days. Totally 27 cubes were casted. Cubes were casted for various percentage of addition of GGBFS to the concrete. Adding 10%, 20% & 30% of GGBFS to the concrete. For the study, solution to fly ash ratio of 0.35 is maintained uniformly.

Compressive strength = Ultimate Load/Area (N/mm^2)

Table 3- Compressive Strength for fly ash based geopolymer concrete

S.NO	Curing days	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Trial-1	Trial-2	Trial-3	
1	7 days	25.66	25.72	26.68	25.68
2	14 days	27.22	27	27.30	27.17
3	28 days	28.65	28	26.67	28.44

Table 4- Compressive Strength for geopolymer concrete (90%Fly ash+10% GGBFS)

S.NO	Curing days	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Trial-1	Trial-2	Trial-3	
1	7 days	26.66	26.72	26.63	26.68
2	14 days	28.32	28	28.30	28.20
3	28 days	29.33	29.34	29	29.22

Table 5-Compressive Strength for geopolymer concrete (80%Fly ash+20% GGBFS)

S.NO	Curing days	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Trial-1	Trial-2	Trial-3	
1	7 days	28.34	28.50	28.45	28.43
2	14 days	29.33	29.34	29.30	29.32
3	28 days	33.22	33.24	34.25	33.57

Table 6- Compressive Strength for geopolymer concrete (70%Fly ash+30% GGBFS)

S.NO	Curing days	Compressive Strength (N/mm^2)			Average Compressive Strength (N/mm^2)
		Trial-1	Trial-2	Trial-3	
1	7 days	24.23	24.33	25.25	24.60
2	14 days	28.33	28	28.26	28.19
3	28 days	29.31	29.35	29	29.23

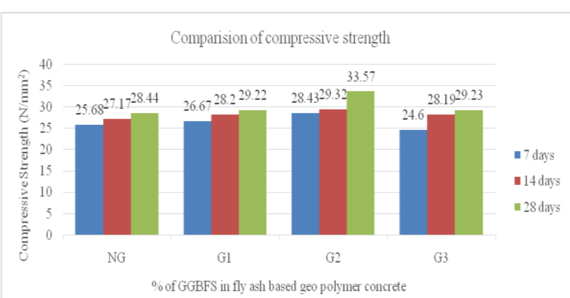


Fig 4 - The Variation of compressive strength for different % of GGBFS

From the Fig 4, 28 days Compressive test results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 84%. 14 days Compressive test results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 92%.7 days Compressive test results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 90%.

SPLIT TENSILE STRENGTH TEST

The concrete cylinder after casting is allow for 7 days, 14 days and 28 days curing. After curing, cylinders are tested in compression testing machine (CTM) of capacity of 2000KN to determine the ultimate Split Tensile load.

Split tensile strength= $2P/(\pi DL)$ (N/mm^2)

Table 7- Tensile Strength for normal geopolymer concrete

S.NO	Curing days	Tensile Strength (N/mm^2)			Average Tensile Strength (N/mm2)
		Trial-1	Trial-2	Trial-3	
1	7 days	0.98	0.96	0.93	0.95
2	14 days	1.10	1.44	1.56	1.36
3	28 days	1.00	1.55	1.68	1.41

Table 8-Tensile Strength for geopolymer concrete (90%Fly ash+10% GGBFS)

S.NO	Curing days	Tensile Strength (N/mm^2)			Average Tensile Strength (N/mm2)
		Trial-1	Trial-2	Trial-3	
1	7 days	1.22	1.35	1.40	1.32
2	14 days	2.56	2.44	2.35	2.45
3	28 days	2.77	2.55	1.55	2.62

Table 9- Tensile Strength for geopolymer concrete (80%Fly ash+20% GGBFS)

S.NO	Curing days	Tensile Strength (N/mm^2)			Average Tensile Strength (N/mm2)
		Trial-1	Trial-2	Trial-3	
1	7 days	1.52	1.63	1.55	1.56
2	14 days	2.68	2.59	2.64	2.63
3	28 days	2.69	2.60	2.71	2.66

Table 10- Tensile Strength for geopolymer concrete (70%Fly ash+30% GGBFS)

S.NO	Curing days	Tensile Strength (N/mm^2)			Average Tensile Strength (N/mm2)
		Trial-1	Trial-2	Trial-3	
1	7 days	1.32	1.24	1.13	1.23
2	14 days	2.46	2.32	2.10	2.29
3	28 days	2.55	2.35	2.19	2.36

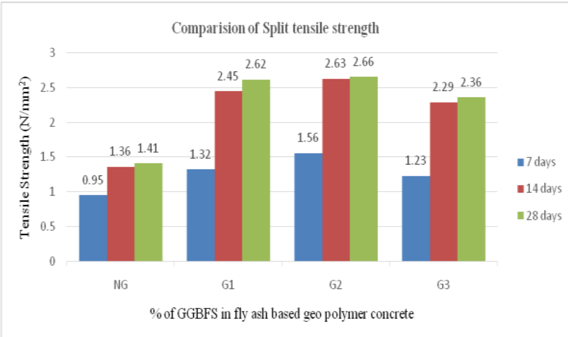


Fig 5 -The Variation of split tensile strength for different % of GGBFS

From the Fig 5, 28 days tensile strength test results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 53%. 14 days tensile strength results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 52%.7 days tensile strength results reveal that mix G2 enhances the mechanical properties of Geo Polymer Concrete by 60%.

CONCLUSION

Based on the test results,

- It concluded that the Ground Granulated Blast Furnace Slag (GGBFS) can be used in the geopolymer concrete at a percentage of 20% of fly ash to achieve appreciable compressive strength under ambient curing.
- Similar results were obtained for tensile strength.
- The addition of 100% of fly ash did not give the appreciable results compare to the addition of 80% of fly ash with 20% the Ground Granulated Blast Furnace Slag (GGBFS) under ambient curing.
- With the addition of 10%, 20%, 30% of the GGBFS by the weight of fly ash with GGBFS. Among that, with the addition of 20% of the Ground Granulated Blast Furnace Slag (GGBFS) gives higher compressive strength.
- The maximum tensile strength achieved in this project work for low calcium fly ash-based geo polymer concrete is 2.66 N/mm^2.
- The maximum compressive strength achieved in this project work for low calcium fly ash based geopolymer concrete is 33.6 N/mm^2.During ambient curing the compressive strength was highly increased from 7 days to 28 days.

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