Study on Fresh and Hardened Properties of Fly Ash Based Geopolymer Concrete

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Abstract- *The increase in the green house effect causes ecological imbalance contributing to global warming which is at alarming rate. The cement industry is responsible for about 5-8% of all CO2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO2 into the atmosphere. Geo-polymer concrete is totally different in materials and chemistry which is synthesized from waste material like fly-ash (Class F or C), rice husk along with binding solution which is free of cement. Thus, Geopolymer based Concrete is highly environment friendly and the same time it can be made a high-performance concrete. In the present study, fly ash and catalytic liquids have been used to prepare geopolymer concrete mixes. This paper describes the experimental work conducted by casting different geopolymer concrete mixes to evaluate the effect of various parameters affecting its the compressive strength in order to enhance its overall performance. The mechanical properties like tensile strength, flexural strength and workability were also studied and compared with that of normal concrete.*

I. INTRODUCTION

Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. We are constantly faced with ever-larger ecological problems associated with the emissions of CO_2 into the atmosphere. It is well known that for every ton of Portland cement produced, approximately one ton of CO_2 is released. It is reported that the worldwide cement industry contributes around 1.65 billion tons of the greenhouse gas emissions annually. Due to the production of PC (Portland cement), it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels. Also, other adverse environmental impact of Portland cement production refers to the high energy consumption. After aluminum and steel, the manufacturing of Portland cement is the most energy-intensive process. So as to reduce the emission of CO_2 concerning the production of cement, we must reduce the use, and therefore the demand of Portland cement.

To decrease the production several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement. In this respect, the geopolymer technology shows considerable promise for application in concrete industry. By using the geopolymer concrete we can reduce the release of 7 to 8% of CO_2 in atmosphere. That's why geopolymer concrete is also known as Eco friendly concrete.

To produce environmental friendly concrete, we have to replace the cement with the industrial by products such as fly-ash, GGBS (Ground granulated blast furnace slag) etc. In this respect, the new technology geo-polymer concrete is a promising technique. There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. Geopolymer concrete is manufactured by source material activated by alkaline liquid. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

India is facing the problem of depletion on natural resources such as limestone which is the most important ingredient to produce cement and in turn the concrete in India. In this situation, detailed study of geopolymer concrete which is the concrete with zero cement in concrete naturally becomes very important. Therefore, an attempt has been made in the present investigation by casting geopolymer concrete mixes with 100% replacement of OPC with fly ash. Indian standards have always emphasized on the importance of compressive strength amongst various mechanical properties of concrete. The mechanical properties like tensile strength, Young's modulus, and modulus of rupture also studied and compared with that of normal concrete.

Geopolymers

Davidovits .J proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders.

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. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, which result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

II. BASIC MATERIALS

Following are the basic materials used for the present investigation:

a) Cement b) Fly ash (source material), c) Aggregates (Coarse and Fine aggregate) d) Alkaline solution (Activators), e) Water, f) Super plasticizers.

a) Cement: The type of cement used all throughout the experiment was Ordinary Portland Cement of grade 53.The specific gravity of the fly ash was 3.10.

b) Fly ash

Class F fly ash conforming to IS: 3812-(1981) from Wanakbori Thermal Power station was used in the present study. Its chemical composition and physical properties are given in Table 1 & Table 2.

Table 1: Chemical composition of Fly Ash

Sr. No.	Property	Value
1	Colour	Light grey
2	Specific surface area (Blaine) m^2/kg	340
3	Lime reactivity N/mm^2	5.48
4	Loss on ignition (max) %	1.30
5	$SiO_2 + Al_2O_3 + Fe_2O_3$	94.49
6	SiO_2 (% by mass)	61.55
7	MgO	0.7
8	SO_3	0.4
9	Na_2O	1.00
10	Total Chlorides	0.037

Table 2: Physical Properties of Fly Ash

Sr.No	Property	Test Result
1	Retention on 350 micron sieve	12%
2	Fineness by Blaine permeability method	400+
3	Lime reactivity Avg comp strength	6.2
4	Avg comp strength on 30% replacement	98%
5	Soundness Auto clave method	0.05
6	Dry shrinkage percentage	0.04
7	Specific gravity	2.25

c) Aggregates:

Fine aggregate: Sand confirming to Zone –III of IS: 383-1970 having specific gravity 2.51 and fineness modulus of 2.70.

Coarse aggregate: Crushed granite metal confirming to IS: 383-1970 having specific gravity 2.70.

d) Alkaline liquid

The alkaline liquid used was a sodium silicate solution and sodium hydroxide solution. The sodium silicate solution was purchased from a local supplier in bulk. The sodium hydroxide (NaOH) in flakes or pellets form with 97%-98% purity was also purchased from a local supplier in bulk. The NaOH solids were dissolved in water to make the solution. For making NaOH solution eg 12M in one liter of water the 480 gm (molar* molecular weight) of flakes is dissolved.

e) Water:

Clean Potable water available from local sources was used for both mixing and curing confirming to IS 456:2000.

f) Superplasticiser:

To improve the workability of the fresh geopolymer concrete conventional and commercially available Naphthalene Sulphonate based super plasticizer was used.

III. MIX DESIGN OF GEOPOLYMER CONCRETE

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 7% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m3 (Rangan, 2008). The details of mix design and its proportions for different grades of GPC are given in Table 3.

IV. MIXING AND CASTING

The sodium hydroxide flakes were dissolved in distilled water to make a alkaline activator solution with a desired concentration at least one day prior to use. The role of alkaline activator solution is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium for condensation polymerization reaction. The fly ash and the aggregates were first mixed together in a pan mixer for about 2-3 minutes until homogeneous mix was obtained.

The sodium hydroxide and the sodium silicate solutions were mixed together with superplasticizer and the extra water and then added to the dry materials and mixed for about 4-5 minutes. Extra water was added only when workability was demanded. Then the geopolymer concrete was poured into the moulds and was compacted with manual strokes or in a vibrating table machine. Then the top surface is well finished. The sizes of the moulds used were cube (150mm x 150mm x 150mm), cylinder - (150mm dia and 300 mm height), beam - (500 mm x 100 mm x 100 mm).

Curing of concrete specimen

Heat curing of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC (Hardjito, 2004 and Mustafa Al Bakri, 2011). In our investigation curing temperature selected is 60°C for 24 hours. After the curing period, the test specimens left in the moulds for at least 4-6 hours in order to avoid a major change in the environmental conditions. After demoulding, the concrete specimens are allowed to become air-dry in the laboratory until the day of the testing.

Table 3: Mix proportions of Geo-Polymer Concrete mix

Materials	Mix of concrete		
	M-1	M-2	M-3
Fly ash	380.69	394.29	408.89
Coarse aggregates			
20 mm	431.33	431.33	431.33
12 mm	862.66	862.66	862.66
Fine sand	554.40	554.40	554.40
Na_2SiO_3/ NaOH	2.50	2.50	2.50
SiO_2/Na_2O	2.00	2.00	2.00
NaOH solution	48.95	45.06	40.89
Na_2SiO_3 solution	122.36	112.65	102.22
Super Plasticizer	5.70	5.91	6.13
Extra water	38.06	39.42	40.88

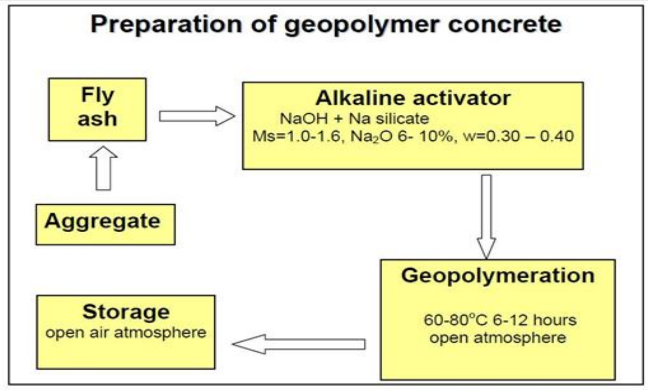

FIG.1. Preparation of Geo-polymer concrete

V. RESULTS AND DISCUSSIONS

Workability Fresh GPC mixes were found to be highly viscous and cohesive with medium to high slump. The workability of the geopolymer concrete decreases with increase in the grade of the concrete, this is because of the decrease in the ratio of water to geopolymer solids. As the morality of the NaOH solution increases the workability of the geopolymer concrete decreases, because of the decrease in the water content. Thus we can say that as the grade of the concrete increases, the mix becomes stiffer decreasing the workability.

Compressive strength Cube compression tests were carried out at 7 days, 28 days, 56 days cured at ambient indoor room temperature and on heat cured specimens. The test was conducted as per IS: 516(1959).

Table 4: Compressive Strength for different mix of concrete

Age of concrete in days	Compressive Strength of concrete (N/mm^2)					
	M-1		M-2		M-3	
	Control	GPC	Control	GPC	Control	GPC
7days	25.55	33.80	34.98	39.38	46.30	48.40
28 days	35.60	37.41	44.25	47.82	53.94	54.98
56 days	38.22	42.60	49.52	52.42	57.42	59.62

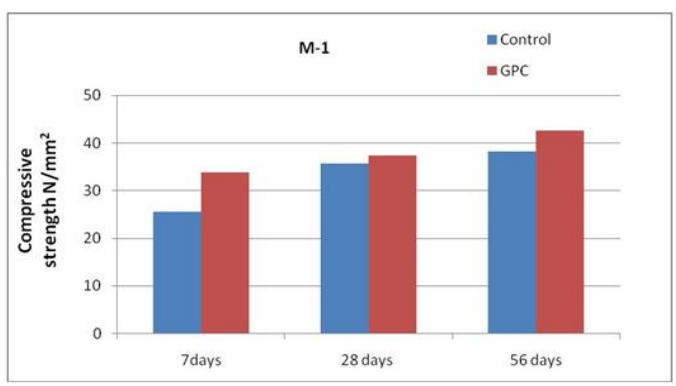

FIG.2. Compressive strength of Geo-polymer concrete with age for mix M-1

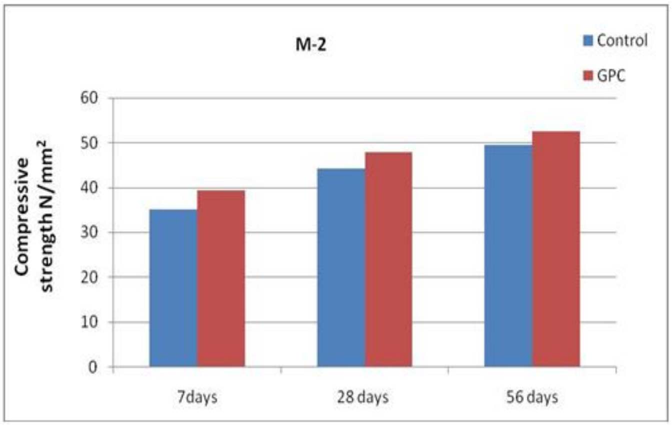

FIG. 3. Compressive strength of geopolymer concrete with age for mix M-2

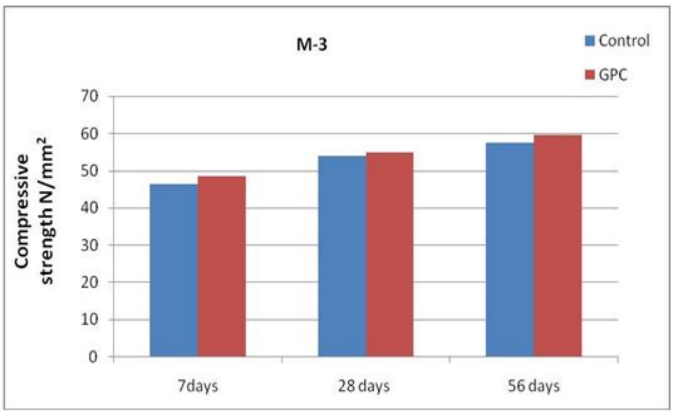

FIG. 4. Compressive strength of geopolymer concrete with age for mix M-3

Split tensile strength The tensile property of geopolymer concrete was ascertained by testing the split tensile strength. The split tensile strength was found as per IS: 5816(1999). Split tensile strength is indirect way of finding the tensile strength of concrete by subjecting the cylinder to a lateral compressive force. Cylinders of size 150mm diameter and 300mm long were cast with and without fly ash. After 24 hours the specimen were demoulded and subjected to water curing. After 7 days, 28 days and 56 days of curing of specimens were taken and allowed to dry and tested in universal testing machine by placing the specimen horizontal.

Table 5: Split Tensile strength for different mix of concrete

Mix	Control	M1	M2	M3
Test age (days)	Tensile strength (MPa)			
7 days	2.9	3.3	3.3	3.7
28 days	3.4	4	4.2	4.4
56 days	3.7	4.2	4.4	4.7

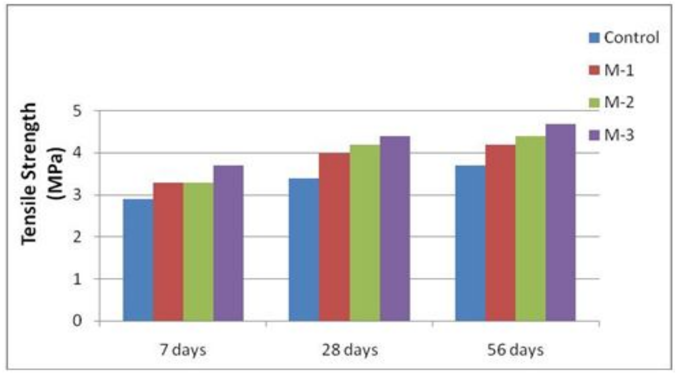

FIG.5. Split Tensile strength of Geo-polymer concrete with age

FLEXURAL STRENGTH

The flexural strength was determined according to IS:516(1959).The flexural strength test results of fly ash concrete are given in figure , it can be seen that flexural strength increases than control mix.

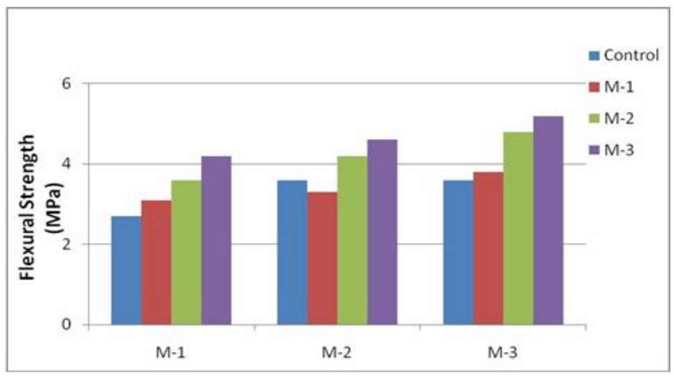

FIG.6. Flexural strength of Geo-polymer concrete at 28 days

VI. CONCLUSIONS

- The compressive strength, flexural strength and split tensile strength increases with increase in fly ash content.
- The average density of geopolymer concrete was equal to that of OPC concrete.
- GPC attains higher early strength than Normal concrete.
- The flexural strength of fly ash-based Geopolymer concrete is a fraction of the compressive strength, as in the case of Portland cement concrete. The measured values are higher than recommended values in IS: 456-2000. As compressive strength increases the flexural strength is also increases in Geopolymer concrete, this behavior is similar to the OPC concrete.
- The fly ash can be used to produce geopolymeric binder phase which can bind the aggregate systems consisting of

sand and coarse aggregate to form geopolymer concrete (GPC). Therefore these concretes can be considered as eco-friendly materials.

- The fresh geopolymer concrete is easily handled up to 120 min without any sign of setting and without any degradation in the compressive strength.
- It has been observed from the above discussion that wide variety of parameters affect the mechanical properties of the geopolymer concrete. As the geo-polymer is a whole new concept of structural concrete than the conventional cement concrete so there should be a new concept of designing it. As there is no mix-design code is available or any type of Standards are available so it needs a very important review on the results which had came out up to till date work done all over the world.

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