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An experimental study on fly ash based geopolymer concrete

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Abstract— ***Concrete is the most abundant manmade material in the world. One of the main ingredients in a normal concrete mixture is Portland cement. However the production of cement is responsible for approximately 5% of the world's carbon dioxide emissions. In order to create a green world it is needed to develop the replacement of cement as a green building material. It is estimated that the production of cement will increased to 3.2 billion tons from 2.2 billion tons till 2018. On the other hand, the climate change due to global warming and environmental protection has become major concerns. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide to the atmosphere by human activities. The production of Portland cement and the mortar preparation involves the emission of carbon dioxide, thus by replacing the Portland cement there can be reduction in the carbon dioxide emission. The thermal power plants produce fly ash in a very large amount. More than 175 million tonnes of fly ash is produced every year; this would require 40000 hectares of land for disposal. The Ministry of Power, Govt. of India estimates 1800 million tonnes of coal to be used every year and 600 million tonnes of fly ash generated by 2031-2032.Now the problem arises for its disposal. Continuing on working in direction to find the alternative for the cement, the concept that the fly ash is also having binding property has been employed. This leads to the direction to work on the replacement of cement from the concrete by fly ash. Therefore the focus to work in this direction acquainting with the idea that the replacement of cement is possible with fly ash and this alternative to regular concrete is known as Geopolymer Concrete (GPC). In this paper full replacement of cement with fly ash to produce the Geopolymer concrete was studied in detail. To produce the Geopolymer concrete, the constituent materials used are fly ash (which is a bye product obtained from thermal power plants) and the alkaline activators. The alkaline activators used in this study for the polymerization are sodium hydroxide (NaOH) in flakes form and sodium meta-silicate (Na_2SiO_3) in gel form. The objective of the present work is to compare the strength parameters of the Geopolymer concrete with Concrete made with Ordinary Portland cement (OPC) and also to see the effect of various conditions such as the curing time, curing temperatures on the strength of geopolymer concrete by the replacement of the cement with Fly Ash and Alkaline Activators. For this cube specimens are casted of size 150mm x 150mm x 150mm for compressive strength test & the cylinder specimen of size 150mm dia., 300mm height for split tensile strength test. The casted specimens were kept in the oven at 60°C and 120°C for 24, 48 and 72 hrs to ascertain the behaviour of geopolymer concrete, and to know the maximum strength we can achieve by Geopolymer concrete.***

Keywords— Compressive strength, Elevated temperature curing, Alkaline Binder, Fly ash, Geopolymer, Green Concrete, Inorganic Polymer, Molarity.

I. Introduction

The term 'geopolymer' was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium- silicate-hydrates (CSHs) for matrix formation and strength, but utilise the poly-condensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source materials on alumino-silicate should be rich in silicon (Si) and aluminium (Al). They could be the by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. Geopolymers are also unique in comparison to other aluminosilicate materials (e.g. aluminosilicate gels, glasses, and zeolites). The concentration of solids in geo-polymerisation is higher than in aluminosilicate gel or zeolite synthesis. 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. Almost all the states in India have thermal power plants and abundant availability of fly ash. The ingredients of the alkaline solution viz. sodium hydroxide and sodium silicates are locally available. In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the

atmosphere caused by the cement industries. Studies on the fly ash based geopolymer concrete dates back to three decades only. Most of the studies are done under heat cured regime. At 60^{o}C to 90^{o}C temperature the polymerization process is fast. Most parts of India come under tropical region where the normal temperature during summer is above 30^{o}C. Geopolymer which is naturally cured at ambient outdoor temperature can be considered as a curing free concrete.
Objective of the Present work is to analyse the effect of elevated temperature curing on the strength of Geopolymer Concrete (Fly ash based) and comparison with the normal concrete prepared with OPC.

II. EXPERIMENTAL PROGRAM

The experimental program involves various process of mix proportioning, mixing, casting, curing and testing of specimens which are elaborated in the following sections.

2.1 Material Used

Fly ash

Fly ash, also known as "pulverised fuel ash", is finely divided residue resulting from the combustion of ground or powered coal. The hardened fly ash concrete shows increased strength together with a lower permeability, where the latter leads to a higher resistance towards aggressive admixtures in addition, partial replacement of cement with fly ash reduces the production cost of concrete due to the lower price of fly ash compared to cement. The fly ash used is collected from NTPC, Seepat, Bilaspur (C.G.).

Coarse aggregate

Locally available coarse aggregate is used .coarse aggregate passing through IS 20mm sieve and retained on 10mm sieve are used and its specific gravity is 2.65. The coarse aggregate was used in saturated surface dry (SSD) condition.

Fine aggregate

Clean and surface dry sand available locally was used which is free from clay, silt and organic particles. Sand passing through IS 4.75 mm sieve was used for casting all the specimens. Specific gravity and fineness modulus is 2.7 and 2.85 respectively.

Cement

OPC Cement or Ordinary Portland Cement (OPC) is manufactured by grinding a mixture of limestone and other raw materials like argillaceous, calcareous, gypsum to a powder. This cement is available in three types of grades, such as OPC 33 grade, OPC 43 grade and OPC 53 grade. The cement used is OPC 43 grade cement.

Sodium Hydroxide

Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. The solution of NaOH is formed by dissolving it in water based on the Molarity required. It is recommended that the NaOH solution should be made 24 hours before casting and should be used with 36 hours of mixing the pellets with water as after that it is converted to semi-solid state. It is obtained from SURI Chemicals, Bhilai (C.G.).

Sodium Silicate

It is also known as water-glass which is available in the market in gel form. The ratio of SiO_2 and Na_2O in sodium silicate gel highly affects the strength of geopolymer concrete. Mainly it is seen that a ratio ranging from 2 to 2.5 gives a satisfactory result. Solution is obtained from the SURI Chemicals, Bhilai (C.G.).

Water

As per IS: 456-2000 recommendations, the water to be used for such a mix and curing works should be free from any type of deleterious materials. Generally potable water should be used. This is to ensure that the water is reasonable free from such impurities as suspended solids, organic matter and dissolved salts, which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value, etc.

2.2 Mix Design of geopolymer concrete

TABLE-I
MIX PROPORTION FOR 1 CUBIC METER OF CONCRETE

Description	Mass in Kg
Mass of cement or fly ash in kg/m^3	480
Mass of water in kg/m^3	240
Mass of fine aggregate in kg/m^3	884
Mass of coarse aggregate in kg/m^3	1702
Water cement or Alkaline solution fly ash ratio	0.5
Na_2SiO_3/NaOH ratio	1

III. TESTS

A. *Tests on Fly ash and OPC:* To compare physical properties following tests were done for fly ash and OPC.

TABLE-II
TESTS FOR FLY ASH WITH ORDINARY PORTLAND CEMENT (OPC)

Physical properties
Consistency Test
Setting Time i. Initial Setting Time ii. Final Setting Time
Fineness of Cement by Dry Sieving

B. *Tests on fine aggregate:* Following tests were done for physical properties of fine aggregate.

TABLE-III
TESTS FOR PHYSICAL PROPERTIES OF FINE AGGREGATE

Physical properties
Specific Gravity
Fineness Test (fineness modulus)
Bulking of Sand

C. *Tests on coarse aggregate:* Following tests were done for physical properties of coarse aggregate.

TABLE-IV
TESTS FOR PHYSICAL PROPERTIES OF COARSE AGGREGATE

Physical properties
Specific Gravity
Fineness Test (fineness modulus)
Impact value
Abrasion Value
Flakiness Index
Elongation Index
Water absorption

D. *Curing*: De-moulding of the specimens were done after 24, 48 and 72 hours of oven curing at temperature varies from 60^oC to 120^oC for fly ash based Geopolymer concrete and all the specimens were left at the room temperature in ambient curing till the date of testing. Further OPC based normal concrete were de-moulded after 24 hours and kept in water tank for curing till the date of testing.
E. *Compression strength test:* The test was performed as per IS 516-1959. Cubes of size 150mm were prepared and tested after being cured in ambient temperature (Fly ash based Geopolymer concrete) and water (OPC based normal concrete) for 28days. For specimens with uneven surfaces capping was done.
F. *Split tensile strength test:* Cylinders of size 150mm x 300mm were prepared and tested for each mix in accordance with the recommendations of IS 5816-1999. The test was done by applying the compression line load along the opposite directions of the cylinder placed with its axis horizontal.

IV. RESULTS & DISCUSSIONS

Different tests conducted with OPC and fly ash for comparing their physical properties. It was found that OPC taken have consistency, setting time and fineness of cement is within the permissible limit as recommended by different codes. On the other hand, fly ash if compared with OPC have more consistency and just above the permissible limit. Also the setting times are less as compared to OPC. Fineness is relatively very high nearly double because of the presence of granular particle of unburnt coal presence. Comparative study of physical properties of fly ash and OPC is shown in Table V below.

TABLE-V
COMPARISION OF PHYSICAL PROPERTIES OF FLY ASH WITH ORDINARY PORTLAND CEMENT (OPC)

Physical properties	Fly ash	OPC
Consistency Test	34%	31 %
Setting Time iii. Initial Setting Time iv. Final Setting Time	 12 minutes 80 minutes	 40 minutes 435 minutes
Fineness of Cement by Dry Sieving	19%	8.67%

Physical properties of fine and coarse aggregate were also investigated to confirming the quality. The physical properties of fine and coarse aggregate are shown in Table VI and Table-VII respectively.

TABLE-VI
PHYSICAL PROPERTIES OF FINE AGGREGATE

Physical properties	Value
Specific Gravity	2.81
Fineness Test (fineness modulus)	3.23
Bulking of Sand	18%

TABLE-VII
PHYSICAL PROPERTIES OF FINE AGGREGATE

Physical properties	Value
Specific Gravity	2.68
Fineness Test (fineness modulus)	6.87
Impact value	8.06 %
Abrasion Value	13.15%
Flakiness Index	19.05 %
Elongation Index	17.15%
Water absorption	1.52%

The variation of compressive strength (3, 7 & 28 days) with varying curing temperature (60°C and 120°C) and curing time (24, 48 and 72 hrs.) for geopolymer (fly ash based) and normal concrete (OPC based) are shown in figure 1, 2 & 3. From figure 1, It was observed that the compressive strength of fly ash based geopolymer concrete cured at elevated temperature for 24 hr, 48hr , 72 hr at 60°C and for 24hr, 48hr at 120°C is nearly equal to OPC based normal concrete cured in water i.e. 10 Mpa. The cubes kept at 60°C show an increase of 2.08% in compressive strength when cured for 48 hr w.r.t 24 hr of curing. Specimens kept at 120°C show an increase of 1.23% in compressive strength when cured for 48 hr w.r.t 24 hr of curing. The cubes kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

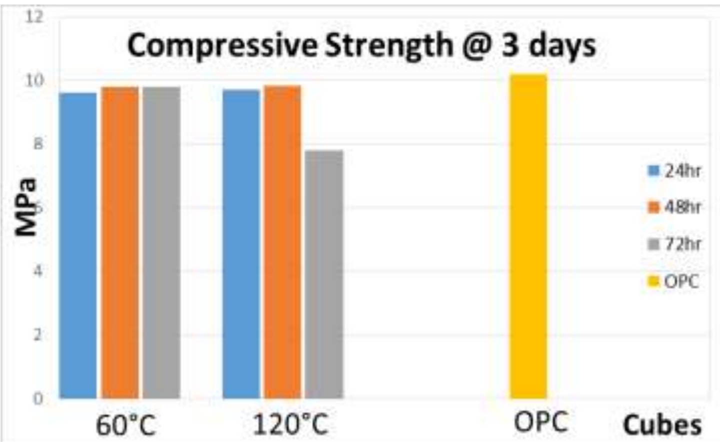

Fig 1 Average Compressive Strength of geopolymer concrete and OPC concrete after 3 days

From figure 2, It was found that the compressive strength of fly ash based geopolymer concrete show an increase of 25% when kept at 60°C for 24hr as well as at 48 hr, 22.78% when kept at 60°C for 72hr as compared to OPC based normal concrete cured in water. The compressive strength of fly ash based geopolymer concrete show an increase of 25% when kept at 120°C for 24 hr and an increase of 33.33% when kept at 120°C for 48 hr as compared to OPC based normal concrete. The compressive strength of fly ash based geopolymer concrete show an increase of 6.67% in compressive strength when kept at 120°C for 48hr as compared to cubes kept at 60°C for 48 hr. The cubes kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

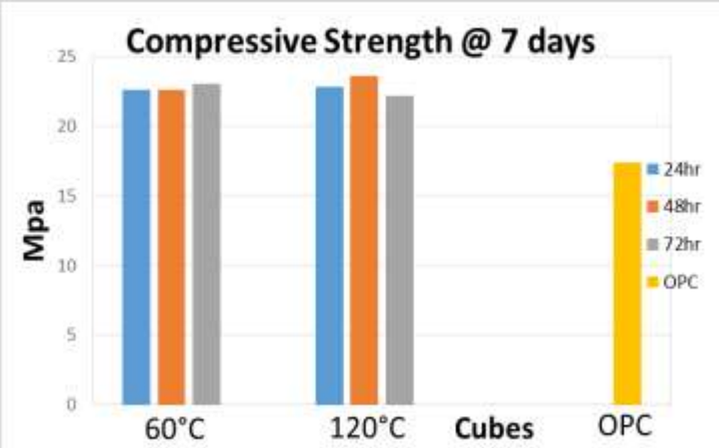

Fig 2 Average Compressive Strength of geopolymer concrete and OPC concrete after 7 days

From figure 3, It was observed that the compressive strength of fly ash based geopolymer concrete show an increase of 3.84% when kept at 60°C for 24hr, 5.76% when kept at 60°C for 48hr and 72hr as compared to OPC based normal concete cured in water at 28 days. The compressive strength of fly ash based geopolymer concrete show an increase of 11.53% when kept at 120°C for 24 hr and an increase of 15.38% when kept at 120°C for 48 hr as compared to OPC based normal concrete at 28 days. The compressive strength of fly ash based geopolymer concrete show an increase of 9.09% in compressive strength when kept at 120°C for 48hr as compared to cubes kept at 60°C for 48 hr. The cubes kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

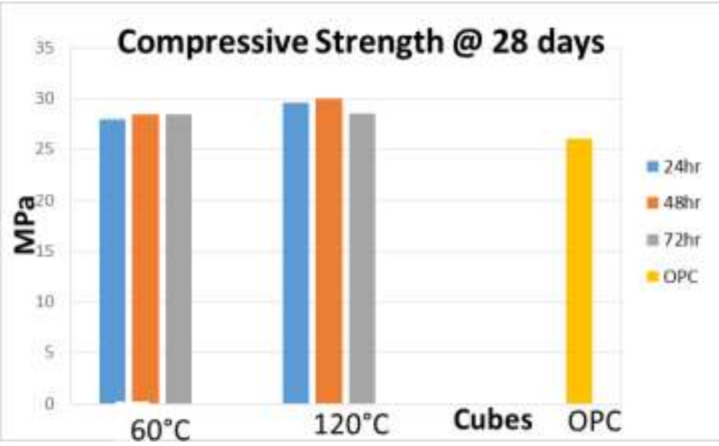

Fig 3 Average Compressive Strength of geopolymer concrete and OPC concrete after 28 days

The variation of split tensile strength (3, 7 & 28 days) with varying curing temperature (60^oC and 120^oC) and curing time (24, 48 and 72 hrs) for geopolymer (fly ash based) and normal concrete (OPC based) are shown in figure 4, 5 & 6. From figure-4, It was found that the split tensile strength of fly ash based geopolymer concrete cured at elevated temperature for 24 hr, 48hr , 72 hr at 60°C and for 24hr, 48hr at 120°C is less thansplit tensile strength of 1.8 Mpa of OPC based normal concrete cured in water at 3 days. The cylinders kept at 60°C show an increase of 2% in split tensile strength when cured for 72 hr w.r.t 48 hr of curing. Specimens kept at 120°C show an increase of 0.62% in split tensile strength when cured for 48 hr w.r.t 24 hr of curing. The cylinders kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

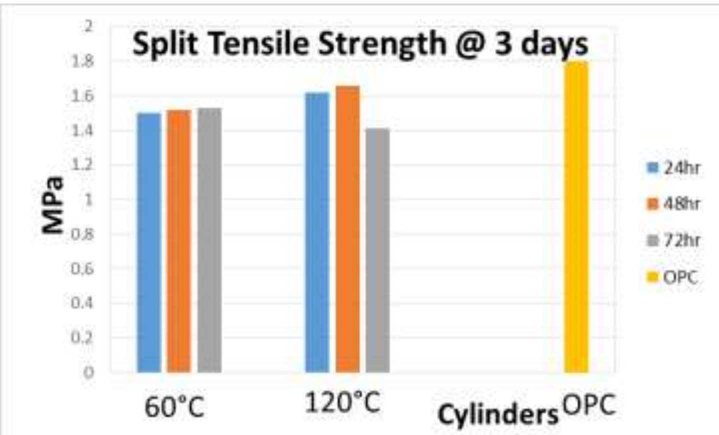

Fig 4 Average Split Tensile Strength of geopolymer concrete and OPC concrete after 3 days

From figure-5, It was observed that the split tensile strength of fly ash based geopolymer concrete show an increase of 2.32% when kept at 60°C for 24hr, 4.65% when kept at 60°C for 72hras compared to OPC based normal concrete cured in water at 7 days. The split tensile strength of fly ash based geopolymer concrete show an increase of 2.32% when kept at 120°C for 24 hr and an increase of 6.97% when kept at 120°C for 48 hr as compared to OPC based normal concrete cured in water at 7 days. The split tensile strength of fly ash based geopolymer concrete show an increase of 2.22% when kept at 120°C for 48hr as compared to cylinders kept at 60°C for 48 hr. The cylinders kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

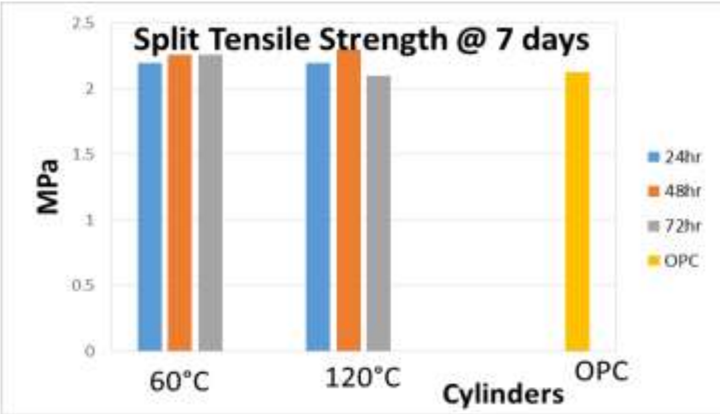

Fig 5 Average Split Tensile Strength of geopolymer concrete and OPC concrete after 7 days

From figure-6, It was found that the split tensile strength of fly ash based geopolymer concrete cured for 24 hr and kept at 60°C as well as 120°C is less than the split tensile strength of OPC based ordinary concrete at 28 days. The specimens kept at 60°C for 48 hr show an increase in 2.96% in spilt tensile strength as compared to OPC based normal concrete. The split tensile strength of fly ash based geopolymer concrete show an increase of 3.70% when kept at 60°C for 72hr as well as at 48 hr of curing at 120°C at 28 days. The cylinders kept at 120°C for 72 hr show initiaion of cracks in the oven itself.

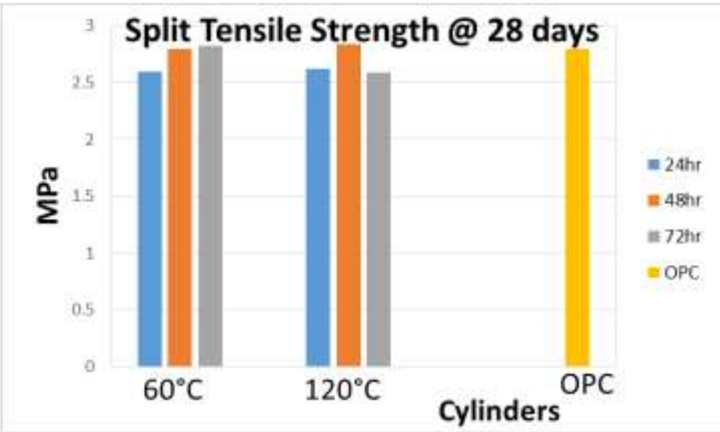

Fig 6 Average Split Tensile Strength of geopolymer concrete and OPC concrete after 28 days

IV. CONCLUSIONS

The following conclusions are drawn based on the experimental work conducted in this investigation:

i. It is observed that, the rate of gain of Compressive strength under optimized curing condition of Geopolymer concrete at 3 and 7 days is 23.72% and 13.33% more than the conventional concrete made up of OPC.

ii. It is also observed that, Compressive strength of Geopolymer concreteat optimized curing condition is 13.33% more than that of conventional concrete made up of OPC.

iii. It is also observed that rate of gain of compressive strength increases by an average 5% at 7 and 28 days with increasing temperature of curing.

iv. The split tensile strength of geo polymer concrete at optimized curing condition is 4.93% more than that of concrete made of OPC.

v. Due to rapid strength gain property permits Geopolymer concrete to be applied in areas where a fast and reliable fix is required such as on highways.

vi. Geopolymer concrete is economical as compared to normal concrete.

vii. Sodium silicate should be kept in air tight container.

viii Solutions should be mixed 24h prior to casting of specimen because it takes time for the polymerization process to begin.

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