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Effect of Duration and Temperature of Curing on Compressive Strength of Geopolymer Concrete

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Abstract— Production of cement releases CO_2 in the atmosphere, which is one of cause of global warming. Also, in India more than 100 million tons of fly ash is produced annually. Out of this, only 17 – 20% is utilized either in concrete or in stabilization of soil. Most of the fly ash is disposed off as a waste material that coves several hectors of valuable land. So, efforts are needed to make concrete more environmental friendly by using fly ash which helps in reduce global warming as well as fly ash disposal problem. This paper presents the study of effect of duration and temperature curing on compressive strength of fly ash based of geopolymer concrete. Geopolymer concrete is manufactured by replacing cement fully with processed low calcium fly ash which is chemically activated by alkaline solutions like sodium silicate and sodium hydroxide. Cubes of size 150mmX150mmX150mm were made at solution to fly ash ratio of 0.35 with 16 Mole concentrated sodium hydroxide solution. All the specimens were cured in oven at 60^0C, 90^0C and 120^0C for 6, 12, 16, 20 and 24 hour's duration. Test results show that the compressive strength increases with increase in duration and temperature of oven curing.

Index Terms—**Fly ash, Geopolymer concrete, Heat-cured, Compressive Strength.**

I. INTRODUCTION

Every year the production of Portland cement is increasing with the increasing demand of construction industries. Worldwide annual increase in production of Portland cement is 3%. Therefore, the rate of carbon dioxide release to the atmosphere during the production of Portland cement is also increasing. Also, Portland cement is one the most energy-intensive construction materials, after aluminium and steel [1].

Fly ash, the finely divided residue that results from the combustion of ground or powdered coal in thermal power station is available abundantly all over the world. In India more than 100 million tons of fly ash is produced annually. Out of this, only 17 – 20% is utilized either in concrete or in stabilization of soil. Most of the fly ash is disposed off as a waste material that coves several hectors of valuable land [2]. There are environmental benefits in reducing the use of Portland cement in concrete, and using a by-product material, such as fly ash as a substitute. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete. The concrete made with such industrial waste is eco-friendly and so it is called as "Green concrete". As a relatively new material, extensive studies are still needed to explore this type of concrete as a construction material. In the present investigation effect of temperature Curing and its duration on compressive strength of fly ash based geopolymer concrete were studied.

II. PREVIOUS RESEARCH

V.M. Malhotra [2] uses the fly ash in 1930 as a workability-improving admixture. Later on its application increases as people are aware about pozzolanic reactivity of fly ash. It is used in the manufacture of Portland Pozzolana Cement (P.P.C.), partial replacement of cement and workability-improving admixture in concrete. But its utilization is limited to 20% throughout the world. An important achievement in this regard is the development of high volume fly ash (HVFA) concrete that utilizes up to 60 percent of fly ash, and yet possesses excellent mechanical properties with enhanced durability performance.

Davidovits introduced the term 'geopolymer' in 1978 to represent the mineral polymers resulting from geochemistry [4]. Geopolymers are a class of inorganic polymer formed by the reaction between the alkaline solution, silica and alumina present in source material. The hardened material has an amorphous 3-dimensional structure similar to that of an aluminosilicate glass. However unlike a glass these materials are formed at low temperature and as a result can incorporate an aggregate skeleton and a reinforcing system if required, during the forming process. The most common activator is a mixture of water, sodium hydroxide and sodium silicate but other alkali metal systems or mixtures of different alkalis can be used.

Djwantoro Hardjito and etal. [5, 6] studied the influence of curing temperature, curing time and alkaline solution-to-fly ash ratio on the compressive strength. It was reported that both the curing temperature and the curing time influenced the compressive strength. The authors confirmed that the temperature and curing time significantly improves the compressive strength, although the increase in strength may not be significant for curing at more than 60^0C. In addition, the compressive strength decreases when the water-to-geopolymer solids ratio by mass increased. The drying shrinkage strains of fly ash based geopolymer concretes were found to be significant.

The chemical reaction of the geopolymer gel is due to substantial fast polymerization process at certain elevated temperature (30^0C-90^0C); the compressive strength does not vary with the age of concrete by considering following parameters,

1. Silicon oxide-to-aluminium oxide ratio by mass of the source material should preferably in the range of 2.0 to 3.5 to make good concrete.

2. Activator liquids-to-source material ratio by mass should be in the range of 0.25 to 0.40.

3. Concentration of sodium hydroxide in terms of molarity in the range of 8 to 16 M.

4. Sodium silicate-to-sodium hydroxide liquid ratio by mass in the range of 0.40 to 2.5.

5. Curing temperature in the range of 30^0C to 90^0C.

6. Curing time in the range of 6 to 48 hours.

7. Water content in the mixture.

Most of the literature available on this material deals with geopolymer pastes. Past studies on the properties and the behavior of fly ash-based geopolymer concrete are extremely limited.

III. PRELIMINARY INVESTIGATION

Following parameters were fixed on the basis of various trial mix tests conducted by various authors [7, 8, 9, 10, 11];

Fixed Parameters

- Percentage replacement of cement by fly ash: 100%
- Sodium silicate-to-sodium hydroxide ratio: 1.0
- Solution-to-fly ash ratio: 0.35
- Concentration of Na_2O and SiO_2 in sodium silicate solution: Na_2O - 16.37%, SiO_2 – 34.35%, and H_2O - 49.28%.
- Concentration of sodium hydroxide solution: 16 Mole.
- Type of curing: Oven Heat Curing
- Fineness of fly ash: 500 m^2/kg
- Water to Geopolymer binder ratio: 0.30

Variable Parameters

- Temperature: 60, 90, and 120°C
- Duration of Curing: 6, 12, 16, 20 and 24 hours.

IV. EXPERIMENTAL INVESTIGATION

In the present investigation, a low calcium Processed fly ash was used as a source material procured from coal based National thermal power station, Eklahare, Nashik. Physical and chemical properties of fly ash are given in Table-1 and 2.Basalt coarse aggregate of nominal maximum size 20mm and 12.5mm in 65: 35 proportion and locally available river sand are used as fine aggregate. Table-3 shows the physical property of aggregates.A 16 mole concentrated NaOH solution was prepared by laboratory grade NaOH flakes and sodium silicate Na_2O = 16.45%, SiO_2 = 34.35%, H_2O = 49.20%. Geopolymer concrete cubes were cast using nominal mix 1:1.5:3 with water-to-geopolymer binder ratio of 0.30. The procedure of mixing and casting geopolymer cube is similar to cement concrete cubes as per IS 516. After 24 hours of casting, all cubes were demoulded and cured at 60^0C, 90^0C and 120^0C, for each period of 6, 12, 16, 20 and 24 hours in an oven. After specified period of curing, oven is switched off and allowed the cubes to cool up to room temperature then specimens were removed from oven and tested for compressive strength at the age of 3 days of casting.

Table 1 Physical Properties of Processed Fly Ash

Specification	Unit	Processed fly ash	Specification as per IS 3812-1981
Fineness- Specific Surface by Blaine's Permeability Method	m^2/kg	500	320
ROS 25 micron sieve	%	5.0	-
ROS 45 micron sieve	%	-	34
Loss on ignition, (max)	%	2.5	5.0
Water requirement, (max)	%	95	-
Moisture content, (max)	%	0.5	2.0
Soundness by autoclave (max)	%	0.05	0.2
28 days strength (min),%	%	80	80
Lime reactivity (min),	N/mm^2	6.0	4.5

Table 2 Chemical Properties Of Processed Fly Ash.

Specification	Unit	Processed fly ash	Specification as per IS 3812-1981
$Sio2+Al_2O_3+Fe_2O_3$, min	%	70	70
Sio_2 , min	%	35	3.5
Cao , max	%	10.0	-
Reactive silica, min	%	20	20
MgO , max	%	4.0	5.0
So_3 , max	%	2.0	3.0
Na_2O , max	%	1.5	1.5
Total chlorides, max	%	0.05	0.05

Table 3 Properties of Coarse Aggregate and Fine Aggregate.

Sr. No.	Particulars/ Properties of Materials	CA-I	CA-II	SAND
1	Type	Crushed	Crushed	Natural
2	Shape	Angular	Angular	Spherical
3	Maximum size	20mm	12.5mm	4.75mm
4	Specific gravity	2.73	2.38	2.565
5	Water absorption	0.716%	1.24%	1.87%
6	Crushing value	12.19%	15.11%	---
7	Impact value	9.86%	10.76%	---
8	Silt content	---	---	1.46%

Table 4. Effect of Duration and Temperature on Compressive Strength Of Geopolymer Concrete Using Fly Ash.

Cube Identification Mark	Duration of curing in Hours	Temperature in ^{0}C	Avg. Compressive Strength In N/mm^2	Remark
1	2	3	4	5
CPF1	6	60	39.26	Oven Cured and tested at the age of 3 days of casting
CPF2		90	44.89	
CPF3		120	56.44	
CPF4	12	60	42.67	
CPF5		90	46.81	
CPF6		120	57.92	
CPF7	16	60	44.89	
CPF8		90	49.48	
CPF9		120	58.52	
CPF10	20	60	45.48	
CPF11		90	50.07	
CPF12		120	59.70	
CPF13	24	60	46.52	
CPF14		90	53.33	
CPF15		120	60.29	

V. RESULT AND DISCUSSION

Table - 4 shows the effect of duration of heating and its temperature on strength of geopolymer concrete using fly ash as source material. In this table, 1st column shows identification mark of cube. CPF means the cubes of processed fly ash. 2nd column shows the duration of curing of cubes in oven. 3rd column shows the different temperatures of curing, 4th column shows the average compressive strength obtained on compression testing machine.

Figure 1 shows the effect of duration of oven heating on compressive strength of fly ash based geopolymer concrete with all other test variables were held constant. It is observed that for the same temperature of curing, compressive strength increases in with increase in duration of heating. At 60^{0}C and 90^0 C, the rate of gain of strength is constant up to 16 hours of duration. But beyond that strength increases with reduced rate but at 120^{0}C rate of gain of strength constant for all period of heating. It is also observed that geopolymer concrete attend more strength at just 6 hours of heating at 120^{0}C which is more than 80% of strength achieved after 24 hours.

Figure 2 shows the effect of temperature of oven curing on compressive strength of geopolymer concrete with all other test variables were held constant. It is observed that, for the same duration of curing, compressive strength increases with increase in temperature of heating. For 24 hours of duration of curing, the rate of gain of strength is constantly increasing linearly. There is considerably small difference in 16 hours and 24 hours of curing. Hence, we can achieve more than 60 MPa compressive strength within 24 hours of curing at 120^{0}C.

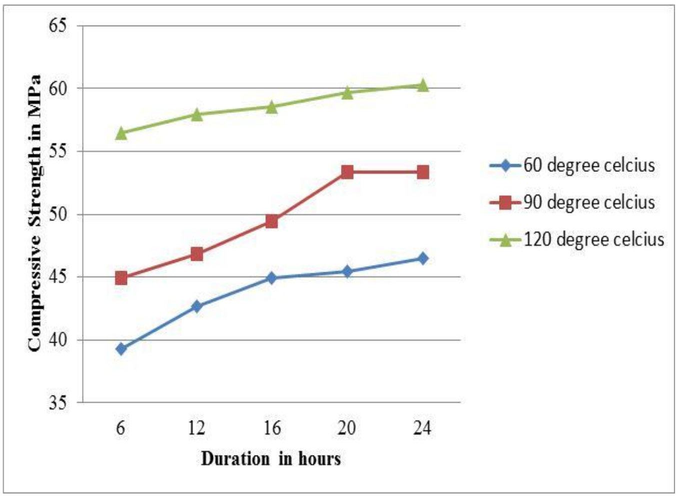

Fig. 1 Effect of Duration Of Oven Heating On Compressive Strength Of Geopolymer Concrete.

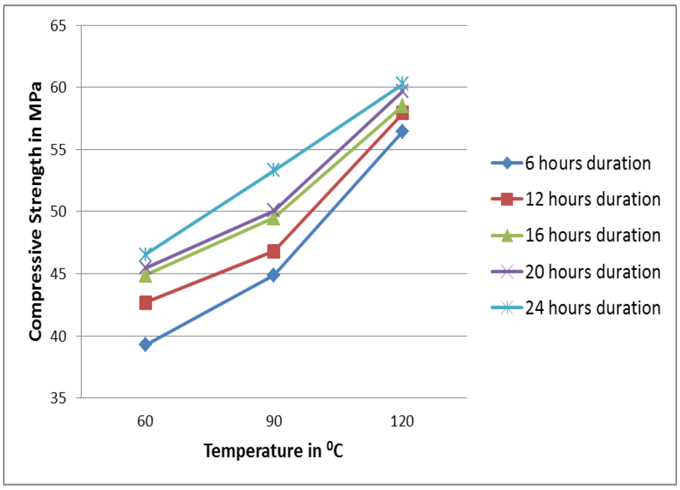

Fig. 2 Effect of Temperature of Curing On Compressive Strength of Geopolymer Concrete.

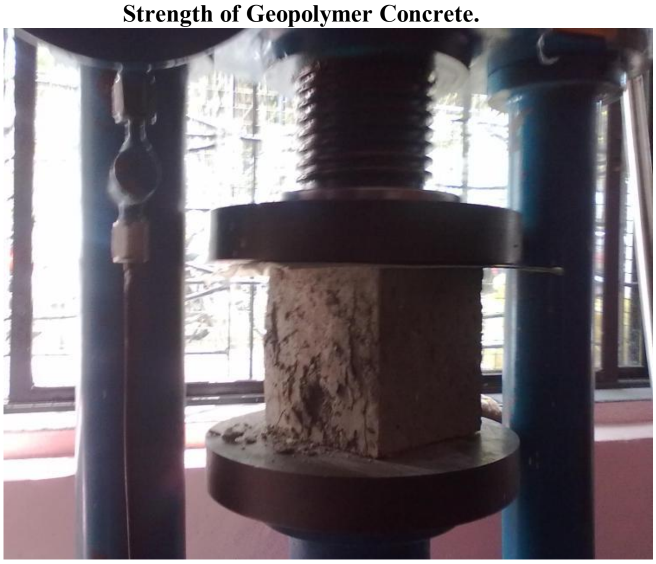

Fig. 3 Failure Pattern Of Fly Ash Based Geopolymer Concrete Cube In Compression Test.

VI. Conclusion

This paper presented the effect of temperature and its duration on the development of geopolymer concrete under oven heating. Based on the experimental work, following conclusions are drawn;

- Curing temperature and its duration are also important in the activation of geopolymer concrete. Curing time, in the range of 6 to 24 hours, produces higher compressive strength. However, the increase in strength beyond 20 hours is not significant.
- The rate of gain of strength is slow at 60°C compared to strength at 120°C. However, the compressive strength beyond 120°C is not significant.
- The difference between compressive strength of geopolymer concrete 16 to 20 hours is not much significant. So, it should be minimizes to 16 hours for saving of consumption of energy.
- More than 60 MPa strength can be achieved by fly ash based geopolymer concrete in just 24 hours of curing.

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