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Experimental Study on Flyash Based Geopolymer Concrete Blended with GGBS and Phosphogypsum after Exposure to Elevated Temperatures

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Abstract : Geopolymer is an inorganic alumino-hydroxide polymer synthesized form predominantly silicon and aluminum materials of geological origin and by product materials such as Flyash. In this paper an attempt was made to study the compressive strength properties of Flyash based Geopolymer Concrete blended with GGBS and Phosphogypsum which was exposed to higher temperatures of 200^0C and 300 ^{0}C.

This experiment consists of Flyash blended with 5 different percentages of GGBS and 5 different percentages of Phosphogypsum. 10 Molar Sodium Hydroxide and Sodium Silicate solution is used as alkaline activator. These Geopolymer samples were cured at 60 ^{0}C for 24 hours and these samples are sintered at four and six hours after 28 days at above mentioned temperatures. These samples are tested for compressive strength due to thermal changes. The results showed that Geopolymer exhibits lesser strength after temperature exposure.

1. Introduction

Concrete is most widely used construction material after water. Ordinary PortlandCement is generally used as most important binder to prepare concrete. Some of the main disadvantages of OPC are still not easy to overcome. Two major drawbacks of OPC sustainability are, the contribution of OPC production worldwide to the greenhouse gas[1] emission is to be about 5-7% of the total greenhouse gas emission in to the earth's atmosphere. Cement is energy intensive building material after steel and aluminum. Therefore it is necessary to overcome these disadvantages and find an alternate material to cement.Geopolymer concrete binder can become good alternate for cement.

Silicon (Si) and the Aluminum (Al) in a source material of natural origin or in by-product materials such as Flyash or Rice husk ashcould be used to react withAlkaline liquid to produce binders. The chemical reaction in present case is polymerization process so this is a "Geopolymer". Geopolymer concrete is a concrete which does not use any Portland cement in its production. Geopolymer concrete is being widely studied and can become a good substitute to ordinary Portland cement concrete.

2. Liteature Review

Joseph Davidovits (1984) proposed that the source material which is rich in Silica (Si) and Aluminum (Al) when reacted with alkaline solution through process of geopolymerisation results in a binding material. Geopolymer can thus be viewed as mineral polymers due to geosynthesis or geochemistry.

Lee etal (2004)have experimented and reported the micro structure and the bonding strength of the interface between natural siliceous aggregates and Flyash based Geopolymers. It was found that when the alkali activating solution that contained no or little soluble silicates, the compressive strength of Geopolymer binders, mortars and concretes were considerably weaker than alkali activated solution with high dosage of soluble silicates. The occurrence of soluble silicates in the original activating solution was also effective in reducing alkali saturation in the concrete pore solutioneven when high alkali concentrated solution was used.

Hardijito and Ranjan (2005) observed that higher is the concentration of sodium hydroxide (molar) higher compressive strength is achieved and higher is the ratio of sodium silicate to sodium hydroxide solutions by mass, achieved higher compressive strength of Geopolymer concrete, and alsoThey found that the increase in curing temperature in the range of 30^0C to 90 ^{0}C will increase the compressive strength. They handled the Geopolymer concrete up totwo hourswithout any sign of setting or degradation.

Hardijito (2005) reported that curing temperature plays an important role in geopolymerisation reaction and concluded that higher the curing temperature higher will be thespeed of geopolymerisation process, which ultimately speed up the hardening of Geopolymer mortar.

Raijiwala etal (2011) evaluated that the compressive strength of GPCimproved over OPC by 1.5 times (M-25 achieves M-45), split tensile strength of GPC improved over OPC by 1.45 times and flexural strength of GPC improved over OPC by 1.6 times.

Md Mustafa Al Bakri (2011) inhis conclusions said that Flyash porous Geopolymer Concrete displayed increase in the strength after temperature exposure of 1000 ^{0}C. This credited to the boost in combination of polymerization reaction and sintering at elevated temperature. The Flyash to activator ratio was important with regard to strength and sintering temperature of Geopolymer concrete.

3. Experimental Programme

In the present experimental program Flyash based Geopolymer concrete specimens blended with GGBS and Phosphogypsum are subjected to temperatures of 200 ^{0}C and 300 ^{0}C under sustained duration of 4 hours and 6 hours after 28 days of sun curing[4] and were tested for compressive strength.

3.1 materials Used

Flyash, GGBS, Phosphogypsum, NAOH pellets, Sodium Silicate solution, Coarse Aggregate, Fine Aggregate, Super Plasticizer and Water.

3.1.1 Flyash

Flyash used in the experiment was obtained from Rayalaseema thermal power plant (RTPP), near Mudhanur which was finely grained residue resulting from the combustion of ground or powdered coal. The specific gravity of Flyash is 2.1.

3.1.2 Aggregates

Locally available clean river sand was used as Fine Aggregate in the study which was having fineness modulus as 2.22, specific gravity as 2.67 and conforming to grading zone-II as per IS 383-1970. Coarse Aggregate used is locally available crushed granite of maximum size 20mm and specific gravity of Coarse Aggregate is 2.62.

3.1.3 Alkaline liquid

Commercially available Sodium Silicate Solution with water content as 56.6% and100% pure Sodium Hydroxide pellets are used for creating alkaline activator.

3.1.4 Water

Fresh water available in the laboratory free from inorganic materials was used for mixing and curing purpose.

3.1.5 Super plasticizer

The super plasticizer used in this experiment is Naphthalene Sulphate based super plasticizer. It is manufactured by MYK SCHOMBURG, Hyderabad. MYK Savemix SP200 compiles with IS: 9103:1999 and has specific gravity of 1.24.

3.1.6 GGBS and Phosphogypsum

GGBS and Phosphogypsum are the mineral admixtures used for partial replacement of Flyash. The specific gravity of GGBS and Phosphogypsum are 2.9 and 2.35 respectively.

3.2 Mix Design of Concrete

From the previous literatures we came to know that the average density of Flyash based Geopolymer concreteis same as OPC i.e. 2400kg/m^3. So in our mixdesign[12] all the materials required for 1$m^3$of Concrete are as follows

1. Total aggregates shall be taken as 77% of entire mix by mass = 1848kg/m^3.
2. Coarse aggregates shall be taken as 70% of total aggregates = 1294kg/m^3.
3. 20mm aggregates are 70% i.e. 906kg/$m^3$and 10mm aggregates are 30% i.e. 388kg/m^3.
4. Fine aggregates shall be taken as 30% of total aggregates = 554kg/m^3.
5. Alkaline liquid to Flyash ratio shall be taken as 0.4 and combined mass of alkaline liquid andFlyash =552kg/m^3.
6. Mass of Flyash = 394.3kg/m^3 and alkaline liquid =157.7kg/m^3.
7. Sodium Silicate solution to Sodium Hydroxide solution ratio shall be taken as 2.5.
8. Sodium Hydroxide solution =45.06 kg/m^3 &Sodium Silicate Solution 112.64kg/m^3.
9. Super Plasticizer is 3% of Flyash by mass = 11.829kg/m^3.

In our investigation we are using 10M sodium hydroxide solution that means we should dissolve 40gm of NaOH in every 100ml of distilled water[7].

Table 1 : Geopolymer Concrete Mix Proportions

Materials	Flyash	Fine aggregate	Coarse aggregate
For 1m^3	394.3 kg	554 kg	1294 kg
Mix proportion	1	1.405	3.28

3.3 Mixing, Curing and Testing of Geopolymer Concrete

Geopolymer concrete can be prepared by using the conventional methods employed to in the production of Portland cement concrete. In the laboratory, the aggregates and Flyash were first mixed dry for about three minutes. The aggregates were placed in plastic buckets at SSD condition. The alkaline liquid which was prepared one day in advance is mixed with super plasticizer. The alkaline solution was then added to dry materials and mixing is usually continued up to four more minutes. The fresh concrete could be easily workable up totwo hours without any sign of degradation.Now place the mix in the moulds in three layers and compact each layer 25 times with tamping rod and place the moulds in vibrating machine to get proper degree of compaction. Smoothen the top surface of mould and cover the moulds with iron plate and keep the moulds in oven at 60 ^{0}Cfor one day, and after this period the cubes are removed from moulds and left for sun curing for 28 days. Now these specimens are subjected to sustained temperatures of 200 ^{0}C and 300 ^{0}C for a period of 4 hours and 6 hours at each temperature and then allowed to cool for 2 hours and tested for compressive strength in the laboratory.

Table 2: Residual compressive strengths of Geopolymer concrete specimens blended with GGBS when subjected to 200 ^{0}C temperature

%Replacement of Flyash with GGBS	Compressive strength (N/mm^2)		
	Ambient temperature	200 ^{0}C for 4 hours	200 ^{0}C for 6 hours
0	44	42	40
2.5	45	43	41
5	48	46	44
7.5	50	48	46
10	53	50	47

Table 3: Residual compressive strength of Geopolymer concrete specimens blended with GGBS when subjected to 300^o C temperature

%Replacement of Flyash with GGBS	Compressive strength (N/mm^2)		
	Ambient temperature	300 ^{0}C for 4 hours	300 ^{0}C for 6 hours
0	44	40	38
2.5	45	41	39
5	48	43	40
7.5	50	45	42
10	53	47	44

Table 4: Residual compressive strengths of Geopolymer concrete specimens blended with Phosphogypsum when subjected to 200 ^{0}C temperature

%Replacement of Flyash with Phosphogypsum	Compressive strength (N/mm^2)		
	Ambient temperature	200 ^{0}C for 4 hours	200 ^{0}C for 6 hours
0	44	42	40
2.5	45	44	42
5	47	47	44
7.5	49	48	45
10	52	43	41

Table 5: Residual compressive strengths of Geopolymer concrete specimens blended with Phosphogypsum when subjected to 300 ^{0}C temperature

%Replacement of Flyash with Phosphogypsum	Compressive strength (N/mm^2)		
	Ambient temperature	300 ^{0}C for 4 hours	300 ^{0}C for 6hours
0	44	40	38
2.5	45	41	40
5	47	44	41
7.5	49	46	43
10	52	41	39

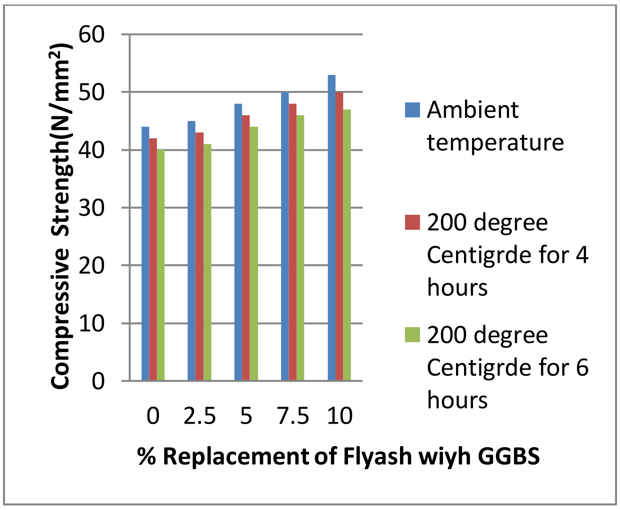

Fig-1 Variation of compressive strength of Flyash based GPC blended with different percentages of GGBS for different durations at 200 ^{0}C

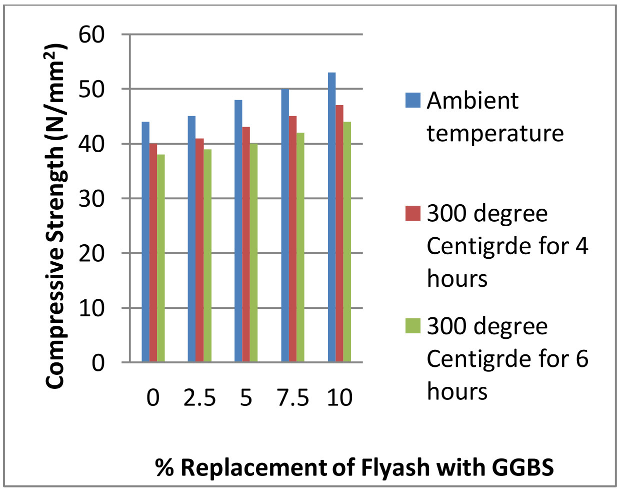

Fig-2 Variation of compressive strength of Flyash based GPC blended with different percentages of GGBS for different durations at 300 ^{0}C

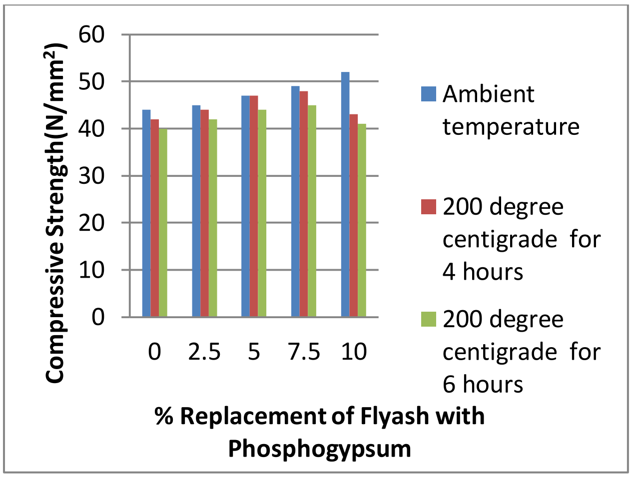

Fig-3 Variation of compressive strength of Flyash based GPC blended with different percentages of Phosphogypsum for different durations at 200 ^{0}C

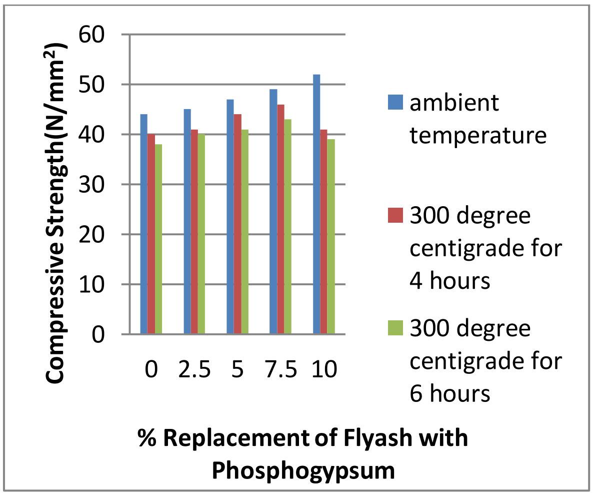

Fig-4 Variation of compressive strength of Flyash based GPC blended with different percentages of Phosphogypsum for different durations at 300 ^{0}C

4. Discussion of Results

On physical examination the cubes subjected to high temperatures slightly turned into red dishcolour and micro cracks began to appear at 300 ^{0}C for both durations of 4 and 6 hours. The colour change was light pink for the specimens subjected to 200^{0}Ctemperature.

With the mineral admixtures GGBS and Phosphogypsum, maximum compressive strength was achieved at 10% replacement of Flyash with GGBS after 28 days which was left for sun curing, and even when these specimens are subjected to higher temperatures of 200^{0}C and 300 ^{0}C gave good results when compared to Phosphogypsum.

Flyash based Geopolymer Concrete blended with the mineral admixture Phosphogypsum exhibited increase in the compressive strength with increase in content of Phosphogypsum at ambient temperature, but after 7.5% replacement when the cubes are subjected to elevated temperatures[5] for different durations, there is decrease in the compressive strength which was found from the preceding values.

For the same alkaline liquid to Flyash ratio of 0.4, and all the parameters such as NaOH concentration, Flyashetc kept as constant the Workability of the mixes with different percentage replacements of mineral admixtures showed a variation in which increase in percentage of mineral admixture increases the Workability of the mix for both GGBS and Phosphogypsum.

5. Conclusions

1. Colour of Geopolymer concrete specimens blended with GGBS and Phosphogypsum gradually changed from grey to reddish as exposure temperature or duration is increased.
2. Loss in weight was considerable from 200 to 300 ^{0}C as and when temperature rises.
3. The reduction in compressive strengths was not of larger magnitude for increase in duration at a particular temperature.
4. Higher the percentage replacement of Flyash with Phosphogypsumhigher is the loss in compressive strength.
5. Flyash based Geopolymer concrete blended with GGBS and Phosphogypsum when subjected to temperatures of 300 ^{0}C developed micro cracks in them.
6. Geopolymer concrete based on Flyash cannot be considered as complete replacement of cement, but it can minimize the complete dependence of cement.
7. Geopolymer concrete imperatively needs further research and can be one of the best replacements to cement, in the near future.

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