Effect of Replacement of Slag on the Mechanical Properties of Flyash Based Geopolymer Concrete

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***Abstract*— Efforts are underway throughout the world to develop an eco-friendly construction materials, which will minimize the utility of fast deteriorating natural resources and also to reduce the emission of green house gases. In this regard, Geopolymer plays a vital role and many researchers examined the various facets of its feasibility as a binder material. Ground Granulated Blast Furnace Slag (GGBS) has been included in the Fly Ash (FA) based Geopolymer Concrete (GPC) to modify the geopolymerisation reaction of FA. In this paper, the influence of the various proportions of GGBS (0-100%) on Fly Ash based GPC; the effect of the amount of Alkaline Activated Solution (AAS) in the mixture of GPC on their compressive strength is studied under ambient temperature conditions. From the experimental results, it was observed that the compressive strength of the GPC is increased with the increase in the percentage of GGBS and also with the increase in the amount of the sodium silicate solution in which the concentration of sodium hydroxide in the aqueous solution is fixed at a constant value of 10M.**

Keyword-Geopolymer, Slag, Flyash, Alkaline solution

I. Introduction

Concrete is a broadly used construction material and the construction industry exploit the natural resources greatly [5]. Ordinary Portland Cement (OPC) plays a vital function in the production of concrete and the manufacturing of cement involves burning of huge quantities of fuel and breakdown of limestone, which results in large emission of Carbon dioxide to the atmosphere [9]. In manufacturing one ton of cement, one ton of carbon dioxide is released to the atmosphere [2]. Due to these environmental issues, attempts were made to reduce the use of Portland cement [4]. Cement is used as a binder which can be replaced by the use of source material containing high amount of Silicon (Si) and Aluminium (Al) to react with an alkaline liquid or a by-product materials like flyash and rice husk ash [1] and the chemical reaction is of polymerisation process and the binders were termed as Geopolymers. The curing temperature or the temperature at which the initial reaction takes place plays a vital role in the development of strength and can be achieved by curing it above ambient temperature [6][7][11]. The strength was improved at a curing temperature of 50 – 80^{o}C rather than at room temperature [3]. The setting time of GPC decreases with increases in curing temperature [8]. The polymerisation reaction becomes very rapid with increase in curing temperature and the concrete can gain strength of 70% within 3-4 hours of curing and the higher early strength was achieved when curing at 65^{o}C and there was no significant increase in the strength after 28 days [2]. The aggregate not prepared to saturated-surface-dry condition were found to produce Geopolymer with high strength and good workability. The flexural behaviour of GPC beams were studied and reported that the conventional reinforced concrete theory can be used for GPC beams under flexure study for the computation of moment capacity, deflection and crack width within reasonable limits [10].

II. MATERIALS USED

A. Flyash and Ground Granulated Blast Furnace Slag

Low calcium fly ash (Class F) is one of the deposits produced in the burning of coal. In this work, Class F fly ash was used which was collected from Ennore Thermal Power Station, Chennai. Generally, Class F fly ash provides good pozzolanic activity and it contains less than 10% of lime (CaO). Ground Granulated Blast Furnace Slag (GGBS) is the by-product of iron which was collected from JSW Steel Limited, Salem. The properties of Flyash and GGBS are presented in Table I.

TABLE I
Physical Properties of Flyash and GGBS

Materials	Specific Gravity	Fineness Modulus
Flyash	2.20	2.73
GGBS	2.90	3.75

B. *Alkaline Liquid*

Alkaline Activated Solution (AAS) used here was a mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) and their properties are given in Table II. Sodium hydroxide was available in flakes form, dissolved in distilled water to get solution with required Molarity. More amount of heat was generated during the mixing of water with NaOH flakes. For this reason, NaOH solution was prepared one day before the casting of Geopolymer Concrete during which it undergoes some exothermic process thus results in the reduction of heat. Sodium silicate solution is then mixed with the NaOH solution prior to batching.

TABLE III
Properties of Sodium Hydroxide and Sodium Silicate

Sodium Hydroxide		Sodium Silicate	
Appearance	Flakes	Appearance	Clear less viscous liquid
Sodium Hydroxide	99.51 (% by mass)	Sp. Gravity	1.35
Sodium Carbonate	0.35 (% by mass)	Mg_2O	9 %
Chlorides	0.05 (% by mass)	SiO_2	28 %
Sulphates	0.005 (% by mass)	Solids	35 to 40 %
Silicates	0.004 (% by mass)		
Iron	8 ppm		

C. *Aggregates*

Local aggregates comprising 20mm, 14mm and 10mm size coarse aggregates of crushed granite-type aggregates and fine aggregates (fine sand) in saturated surface dry condition were used. Their properties are presented in Table III.

TABLE IIIII
Properties of Aggregates

Materials	Specific Gravity	Fineness Modulus
Coarse Aggregates	2.62	2.72
Fine aggregates	2.75	2.97

D. *Superplasticizer*

In order to reduce the low workability problem and rapid setting time of geopolymer concrete, chemical admixture was added. Gelenium B233 was used in this study to improve the workability of concrete. It was added after mixing the source materials and aggregates. Their properties from the manufacturers are listed in Table IV.

TABLE IV
Properties of Superplasticizer

Aspect	Light Brown Liquid
Relative Density	1.08±0.01 at 25°C
pH	≥ 6
Chloride ion content	< 0.2 %

III. EXPERIMENTAL PROGRAM

A. *Mix Proportioning*

Unlike Ordinary Portland Cement (OPC), GPCs are a new construction material and therefore does not have a standard mix design procedure. Therefore, the mixes were formulated by the mix design procedure followed for OPC as per IS 10262-2009 for a characteristic compressive strength of 40 MPa at the end of 28 days. The ratio of AAS to binder was varied with different proportions to obtain a satisfactory workability range (Slump of 100mm to 160mm) and was found to be 0.55 as optimum, which was adopted for the entire mixes. The proportions and compositions of GPC and AAS were varied and are listed in Table V. The mixes were prepared for a different replacement level of flyash with GGBS for ratio of AAS to binder as 1.0 and 1.5. For all the mixes, the concentration of NaOH was kept constant at 10M and the rate of superplasticizer was also kept constant as 2%. In the entire mix, no extra water has been added. It has been noted from the mixing, the workability of the concrete reduces with the increase in the mixing time.

B. *Preparation of test Specimens*

The mixture was casted in 150mm size cube specimens to study their compressive strength and compaction has been done by using table vibration. The specimens were kept in the mould for 24h which were then de-moulded and kept for curing under ambient temperature condition.

TABLE V
Design Mix Proportions

Mix Ratio = 1 : 1.08 : 3.44

Mix No.	**NaOH Concentration**	**Ratio of AAS**	**Replacement of Flyash with GGBS in %**
GPC01	10 M	1.00	0
GPC02			20
GPC03			40
GPC04			60
GPC05			80
GPC06			100
GPC07		1.50	0
GPC08			20
GPC09			40
GPC10			60
GPC11			80
GPC12			100

C. *Results and Discussions*

The workability of the mixes were determined by using Slump cone test and their corresponding compressive strength was found out by testing under Compression Testing Machine of 3000kN capacity and their results are shown in Table VI and their variations are plotted in Fig. 1. From the test results, it has been observed that the slump value increases with the increase in the GGBS content. The compressive strength of the specimens was tested for 7 and 28 days curing to determine their early age and characteristic strength at 28 days. It has been noted that the strength at 7 days is about 70% and it is getting increased with the increase in the GGBS content and this was found to be getting reduced for 100% slag content. The addition of superplasticizer with 2% of the binder has showed no impact on the strength, but shows a considerable increase in the workability of the concrete.

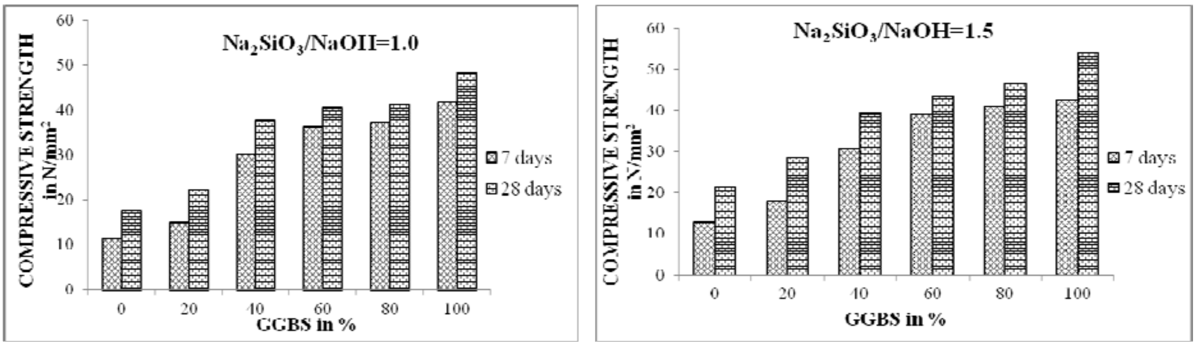

Fig. 1. Variation of Compressive strength of Geopolymer Concrete

TABLE VI
Slump and Compressive strength results of Geopolymer Concrete

Mix No.	Slump in mm	Compressive strength in N/mm^2	
		7 Days	28 Days
GPC01	100	11.22	17.57
GPC02	115	14.92	22.23
GPC03	120	30.17	37.61
GPC04	140	36.12	40.56
GPC05	150	37.10	41.23
GPC06	150	41.63	48.31
GPC07	110	12.64	21.35
GPC08	120	17.91	28.69
GPC09	140	30.70	39.46
GPC10	160	39.13	43.48
GPC11	160	40.92	46.44
GPC12	160	42.49	53.87

IV. CONCLUSION

From the experimental investigations, the following findings are drawn:

1. With the elimination of the use of Portlant Cement, the emission of CO_2 has been greatly reduced which results in the reduction of Environmental pollution.
2. The workability of Geopolymer concrete depends on the mixing time of concrete and is getting reduced with the increase in the mixing time. It also increases with the increase in the content of the slag.
3. The chemical admixture Glenium B233 has been added to reduce the effect of low workability and rapid setting time of Geopolymer concrete. This inclusion does not show any impact on the compressive strength but shows a considerable increase in the workability of the concrete.
4. The specimens have been cured in ambient temperature condition rather than accelerated curing to check the suitability of Geopolymer concrete for cast-in-situ conditions.
5. The 7 days strength was found to be 70% of its 28 day strength and this percentage is getting increased with the increase in the slag content and found to be getting reduced for 100% slag content. The 28 days strength shows higher strength compared with OPC. This shows that the Geopolymer concrete can be considered as a best alternative for Cement Concrete.

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