Experimental Work on Alkali Activated Concrete

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Abstract— In the present investigation, strength development in ambient cured geo-polymer concrete using industrial by-products for sustainable development is studied. The materials considered are Fly Ash, Ground Granulated Blast Furnace Slag (GGBFS). Geo-polymer concrete is prepared without using any conventional cement. The experimental program involves casting of geopolymer concrete cubes and testing the same at different ages for compressive strength. The different parameters considered in the study are, the molarity of alkaline activator and the proportion of binder components. The results reveal that the geopolymer concrete develops the strength even at ambient conditions without any conventional curing. Strength increases with an increase in the quantity of GGBFS. It can be concluded that geopolymer concrete can emerge as an ecofriendly sustainable construction material with properties similar to OPC.

Key words: Geopolymer concrete (GPC), Molarity (M), Alkaline activator solution(AAS), liquid to binder ratio(L/B), Fly ash(FL), slag or GGBFS(SL)

I. INTRODUCTION

With the gradual growth of a global effort to reduce greenhouse gas emissions, a large section of the concrete industry has growing interest in minimizing the use of ordinary Portland cement (OPC). This is because it is estimated that the production of 1 t of OPC requires about 2.8 t of raw materials, such as limestone and coal, and releases about 0.7 t of carbon dioxide (CO2) to the earth's atmosphere from the decarbonation of lime in the kiln. As a result, since the late 1980s, toward the reduction of the use of OPC, various investigations have been conducted in several fields to develop a cementless alkali-activated (AA) ground granulated blast furnace slag binder together with a fly ash–based geopolymer binder. As pointed out by Shi et al. (2006), AA fly ash-slag binders will gradually attract a great deal of interest because of their extensive advantages of lower carbon emissions and energy cost, higher-strength development, and better durability than with OPC concrete. In particular, AA fly ash- slag concrete can effectively be applied to precast concrete products because of its quick setting and high strength development at an early age.

The amorphous to crystalline reaction products resulting from the synthesis of alkali alumino- silicates activated by high alkaline solution is generically known as "Geo-Polymer" or ''Inorganic polymer concrete''.

II. LITERATURE REVIEW

Geopolymers are inorganic polymeric materials, firstly developed by Joseph Davidovits in 1970s. Geopolymerization involves a chemical reaction between alumino-silicate oxides and alkali metal silicate solutions under highly alkaline conditions yielding amorphous to semi-crystalline three-dimensional polymeric structures, which consist of Si–O–Al bonds. The geopolymerization reaction is exothermic and takes place under atmospheric pressure at temperatures below 100 ◦C. Despite of the intense research on the geopolymerization of different aluminosilicate materials and the development of a wide range of geopolymeric materials that have been carried out, the exact mechanism that takes place during geopolymerization is not fully understood.

The most proposed mechanisms for the geopolymerization includes the following four stages that proceed in parallel and thus, it is impossible to be distinguished: (i) dissolution of Si and Al from the solid aluminosilicate materials in the strongly alkaline aqueous solution, (ii) formation of oligomers species (geopolymers precursors) consisting of polymeric bonds of Si–O–Si and/or Si–O–Al type, (iii) polycondensation of the oligomers to form a three-dimensional aluminosilicate framework (geopolymeric framework) and (iv) bonding of the undissolved solid particles into the geopolymeric framework and hardening of the whole system into a final solid polymeric structure.

Geopolymers possess excellent physico-chemical and mechanical properties, including low density, micro-porosity or nano-porosity, negligible shrinkage, high strength, thermal stability, high surface hardness, fire and chemical resistance. Due to these properties, they are viewed as alternative materials for certain industrial applications in the areas of construction, transportation, road building, aerospace, mining and metallurgy. Certain industrial wastes, such as coal-fired fly ash, blast furnace slag and mine tailings contain sufficient amounts of reactive alumina and silica, in order to be used as source materials for the geopolymerization process. Therefore, geopolymerization can be considered as an economically viable technology for the transformation of industrial wastes and/or by-products of aluminosilicate composition into attractive construction materials. This potential application of geopolymerization gained increasing attention during the last decades, creating a new field for research and technological development.

III. EXPERIMENTAL WORK

A. *Materials*

In the present study, the materials used are Class F Fly Ash from Raichur Thermal Power Station, Raichur; Ground Granular Blast Furnace Slag from J S W Steel, Bellary, Karnataka; Sodium Hydroxide (flakes 97-98 % purity) and Sodium Silicate (liquid form) both commercial grades; Tap water was used to prepare alkaline solution. Table 1 gives the properties of these materials. The alkaline activator used in this study is a combination of sodium hydroxide and sodium silicate in certain specified ratio. The fluid shall be prepared at least one day prior to use.

Binder	Sp. Gravity	Fineness m2/kg	LOI	Al2O3	Fe2O3	SiO2	MgO	SO3	Na2O	Chlorides	CaO
Fly ash	2.4	1134.1	0.90	31.23	1.50	61.12	0.75	0.53	1.35	0.06	3.2
GGBFS	2.9	416.0	0.19	13.24	0.65	37.21	8.46	2.23	---	0.003	37.2

Table 1: Properties of binders (%)

Locally available river sand having fineness modulus 2.22, specific gravity 2.4 and conforming to grading zone-III as per I.S: 383 - 1970. Coarse aggregate is of angular shaped crushed granite with maximum size 20mm and its fineness modulus and specific gravity are 7.17 and 2.89 respectively.

B. Mix Proportions

In this investigation, to study the strength properties of geopolymer concrete, firstly 3 different specimens were prepared with 3 different molarities of AA solution (8M, 12M&16M) are as presented in Table 1. Next 10 different specimens were prepared by replacing of fly ash with slag and the 10 different specimens are presented in Table 2.

Specimen / Materials kg/m^3	GPC 8M	GPC 12M	GPC 16M
Coarse aggregate	1295	1295	1295
Fine aggregate	555	555	555
Fly ash	184	184	184
GGBFS	184	184	184
NaOH solution	53	53	53
Molarity NaOH	8M	12M	16M
Na2SiO3 solution	131	131	131
Temperature C	Ambient	Ambient	Ambient
Curing period days	1,3,7,14,21,28	1,3,7,14,21,28	1,3,7,14,21,28
Liquid/binder	0.50	0.50	0.50
Age of specimens	1,3,7,14,21,28	1,3,7,14,21,28	1,3,7,14,21,28
Extra water	18.4 (5%)	18.4 (5%)	18.4 (5%)
Super plasticizer	7.36 (2%)	7.36 (2%)	7.36 (2%)

Table 1: Mix proportions

Materials / Binder content	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	Fly ash kg/m^3	GGBFS kg/m^3	NaOH solution kg/m^3	Na2SiO3 solution kg/m^3	Curing & testing period in days	L/B ratio	EW&SP % of binder
100FA:0SL	1295	555	0	368	53(8M)	131	3,7	0.5	5%&2%
90FA:10SL	1295	555	36.8	331.2	53(8M)	131	3,7	0.5	5%&2%
80FA:20SL	1295	555	73.6	294.4	53(8M)	131	3,7	0.5	5%&2%
7OFA:30SL	1295	555	110.4	257.6	53(8M)	131	3,7	0.5	5%&2%
60FA:40SL	1295	555	147.2	220.8	53(8M)	131	3,7	0.5	5%&2%
50FA:50SL	1295	555	184	184	53(8M)	131	3,7	0.5	5%&2%
40FA:60SL	1295	555	220.8	147.2	53(8M)	131	3,7	0.5	5%&2%
30FA:70SL	1295	555	257.6	110.4	53(8M)	131	3,7	0.5	5%&2%
20FA:80SL	1295	555	294.4	73.6	53(8M)	131	3,7	0.5	5%&2%
10FA:90SL	1295	555	331.2	36.8	53(8M)	131	3,7	0.5	5%&2%
0FA:100SL	1295	555	368	0	53(8M)	131	3,7	0.5	5%&2%

Table 2: Mix proportions

C. Mixing, Curing, and Testing

Geo-polymer concrete specimens were prepared using the same method as for OPC concrete. coarse and fine aggregates are mixed with the binder component of pre-determined proportion. Then the activator solution of specified fluid binder ratio is added and mixed to get a homogeneous and uniform mix. This concrete is filled into 150 mm cubes and compacted manually. It is interesting to note that the specimens could be de-moulded within about 2 hours of drying in ambient conditions after casting. The demoulded specimens were left in room temperature until tested without any special curing regime. The specimens were tested as per IS 516:1959 and strengths were calculated for 1, 3, 7, 14, 21 and 28 days and the results were tabled.

D. Fresh GPC

The fresh Geopolymer concrete can be handled up to 80 min with slump up to 200mm.

IV. TEST RESULTS AND DISCUSSIONS

In this section, strength development of ambient cured geo-polymer concrete is discussed with reference to the factors considered at the selected levels. Experimental results are presented in the form of few representative graphs facilitating the discussions.

Age of specimen in days	8M GPC specimen (Nmm^2)	12M GPC specimen (N/mm^2)	16M GPC specimen (N/mm^2)
1	29	26	27
3	42	42	39
7	52	56	54
14	61	60	63
21	68	64	65
28	69.1	64.2	69

Table 3: Variation of Compressive Strength with Ages and Molarities.

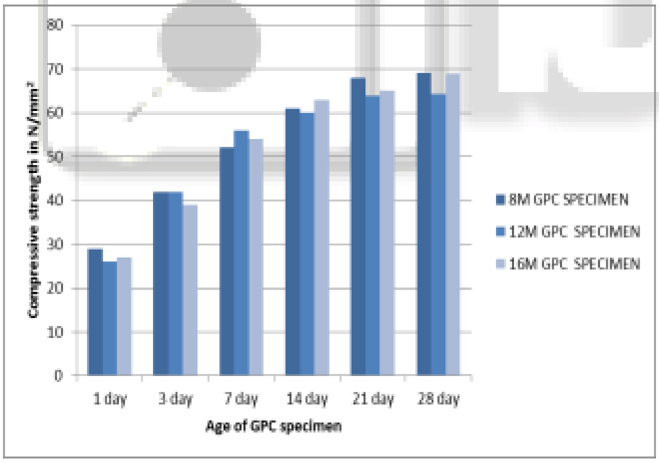

Fig. 1: Variation of Compressive Strength with Ages and Molarities.

Figure 1 represents the variation of compressive strength of ambient cured GPC specimen, prepared by using different molar alkali activator solution (8M, 12M&16M) tested at the ages of 1, 3, 7,14,21,28 days. It is clear that maximum strength development takes place during 7 to 14 days and 60% strength is gained during 3 days, 90% during14 days & rest during 28 days. Increasing molarities does not have significant effect on the strength gains of GPC specimen, although marginal increase in strength is observed. Maximum strength gained by GPC specimen at the age of 28 days is nearly 70MPa irrespective of molarities of GPC specimen. Hence 8M AAS is sufficient and economical for preparing GPC, as strength gains are same as 12M and 16M at all ages of GPC specimen, further cost reduces with less molar AAS.

Fly ash(FA)/ GGBS(SL) ratio	3 day compressive strength N/mm^2	7 day compressive strength N/mm^2
100FA:0SL	0	15.55
90FA:10SL	16.88	41
80FA:20SL	20	45
7OFA:30SL	27	48
60FA:40SL	31	49
50FA:50SL	30	48.8
40FA:60SL	32	51
30FA:70SL	37	53
20FA:80SL	40	59
10FA:90SL	45	65
0FA:100SL	44	70

Table 4: Variation of Compressive Strength with Various Binder Proportion

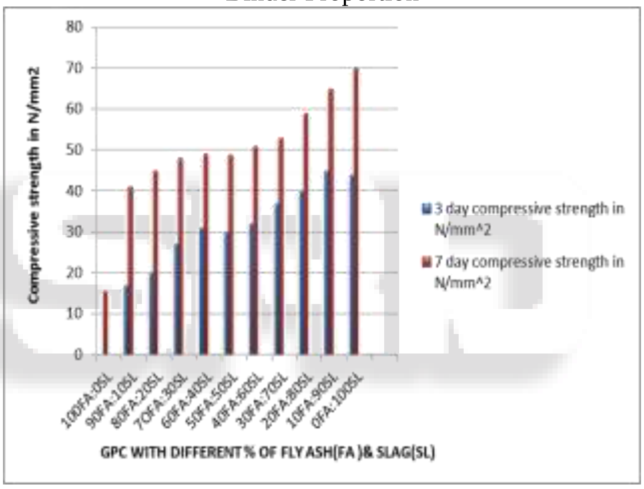

Fig. 2: Variation of Compressive Strength with Various Binder Proportion

Figure 2 represents that 100% slag (SL) based GPC specimen gives high strength of nearly 45MPa and 70MPa compressive strengths respectively at 3 day and 7 day for ambient cured GPC specimen, however setting time was short. It is observed that strength development is slow for higher percentage fly ash based GPC specimen because it requires elevated temperature as reaction accelerator for fast strength development of GPC, oven curing or steam curing can adopted for elevated temperature curing and also there is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength, if minimum 10% of fly ash is replaced by GGBS. Hence, It is suitable to use a combination of 60FA:40SL or 50FA:50SL to produce GPC as it gave desired workability and sufficient strength about 50MPa at 7 day for ambient cured GPC specimen.

V. CONCLUSIONS

1) Maximum strength gained by GPC specimen at the age of 28 days is nearly 70MPa and strength development of GPC specimen is very fast than OPC with 90% strength gained during14 days.

2) 8M AAS is sufficient and economical for preparing GPC, as strength gains are almost same as 12M and 16M at all ages of GPC specimen, further cost reduces with less molar AAS.
3) There is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength, if minimum 10% of fly ash is replaced by GGBS.
4) It is observed that strength development is slow for higher percentage fly ash based GPC specimen because it requires elevated temperature as reaction accelerator for fast strength development of GPC, oven curing or steam curing can adopted for elevated temperature curing.
5) It is clear that 100% slag (SL) based GPC specimen gives high strength of nearly 45MPa and 70MPa compressive strength at 3 day and 7 day respectively for ambient cured GPC specimen.
6) It is suitable to use a combination of 60FA:40SL or 50FA:50SL to produce GPC as it gave desired workability and sufficient strength about 50MPa at 7 day for ambient cured GPC specimen.

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