Green Concrete Technology

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(Received on 01 September 2011 and accepted on 02 March 2012)

Abstract - **Aeopolymer concrete technology has the potential to reduce globally the carbon emission and lead to a sustainable development and growth of the concrete industry. The influence of alkaline activators on the strength and durability properties has been studied. Sodium Hydroxide is available in plenty and Potassium hydroxide is more alkaline than NaOH, both were added by the same amount (50% NaOH+50%KOH) as alkaline activators alongwith sodium silicate at varying temperatures in the preparation of geopolymer concrete. Fly ash was procured from a local thermal power station. Compression test, Split tensile test, Flexure test, Pull out test and durability test were performed. The results indicate that the combination of the above constituents at 80^{0}C has a positive impact on the strength and durability properties of geopolymer concrete. Rapid strength gain mechanism has been explained with SEM images.**

Keywords: **Geopolymer, Concrete, Fly Ash, Alkaline Solution, Compressive Strength**

1. GEOPOLYMER CONCRETE

The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere which leads to global warming conditions[19]. A need of present status is, should we build additional cement manufacturing plants or find alternative binder systems to make concrete?. On the other scenario huge quantity of fly ash are generated around the globe from thermal power plants and generally used as a filler material in low level areas. Alternative binder system with fly ash to produce concrete eliminating cement is called “Geopolymer Concrete” [7, 13].

Geopolymer is a type of amorphous alumino-hydroxide product that exhibits the ideal properties of rock-forming elements, i.e., hardness, chemical stability and longevity [1]. Geopolymer binders are used together with aggregates to produce geopolymer concretes which are ideal for building and repairing infrastructures and for precasting units, because they have very high early strength, their setting times can be controlled and they remain intact for very long time without any need for repair [2,3,15]. The properties of geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance. These high-alkali binders do not generate any alkali-aggregate reaction. The geopolymer binder is a low-CO_2 cementious material. It does not rely on the Calcination of limestone that generates CO_2. This technology can save up to 80% of CO_2 emissions caused by the cement and aggregate industries [4].

II. EXPERIMENTAL PROGRAM

In this work, low-calcium (ASTM Class F) [5, 6] fly ash-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods as in the case of OPC concrete in Applied Mechanics laboratory of S.V. National Institute of Technology, Surat. The silicon and the aluminium in the low-calcium fly ash react with an alkaline liquid that is a combination of sodium Hydroxide and Potassium Hydroxide solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials[8].

A. Materials

Geopolymer concrete can be manufactured by using the low-calcium (ASTM Class F) fly ash obtained from coal-burning power stations. Most of the fly ash available globally is low-calcium fly ash formed as a by-product of burning anthracite or bituminous coal [9, 10].

Commercial grade Potassium Hydroxide in pallets form (97% -100% purity) and Sodium Hydroxide solution (Na_2O=18.2%, SiO_2=36.7%, Water = 45.1%) were used as the alkali activators. The potassium Hydroxide pallets were dissolved in the required amount of water according to the desired molarity. Local clean river sand (fineness modulus of medium sand equal to 2.50) conforming to grading zone III of IS-383-1970 was used. Locally available well graded aggregates of normal size greater than 4.75 mm and less than 12mm were used. Note that the mass of water is the major component in both the alkaline solutions. For improving the workability of the concrete, a naphthalene sulphonate superplasticiser was used [11, 17].

B. Mixture Proportions

The different mixture proportions used to make the trial geopolymer concrete specimens in this study are given in Table I.

TABLE I MIXING PROPORTION

Ingredients	Unit	NaOH(50%)+ KOH(50%)	M25 Mix
Temperature	^{0}C	60, 80, 100	Room Temp.
Fly ash	kg/m^3	400	400 (Cement)
Fine Aggregates	kg/m^3	505	563
Coarse Aggregates			
10Dn	kg/m^3	442	493
20 Dn	kg/m^3	663	740
Alkaline solution/FA	-	0.5	0.5 W/C ratio
Hydroxide s /Sodium silicate	-	0.85	-
Sodium Hydro xide(NaOH)/Potassium Hydroxide (KOH)	-	1	-
Sodium Hydroxide solution	kg/m^3	46	-
Potassium hydroxide solution	kg/m^3	46	-
Sodium silicate solution	kg/m^3	108	-
Extra water	kg/m^3	-	200
Plasticizer	kg/m^3	8	8

III. TESTS CONDUCTED

a) Compression test.
b) Split tensile test.
c) Flexure test.
d) Pull out test.
e) Durability test.

A. *Compressive Strength*

Compressive strength test was carried out in concrete cubes of size 150x150x150mm using 1:1:2 mix with W/C ratio of 0.50. Specimens with ordinary Portland cement concrete (control) were removed from the mould after 24h and subjected to water curing for 1,7, 14 and 28 days. The geopolymer concrete specimens were prepared according to the method followed by Hardjito *et. al.* [2]. Geopolymer cubes of 12M were cast. During moulding, the cubes were mechanically vibrated. The specimens were wrapped by plastic sheet to prevent loss of moisture and placed in an oven. Since the process needs curing at high temperature, the specimens were cured at three different temperatures of 60^0 C, 80^{0}C and 100^{0}C for 24 h in the oven. They were then left at open air (room temperature 25^{0}C) in the laboratory until testing. Tests were carried out on triplicate specimens and average compressive strength values were recorded.

B. *Split Tensile Test*

Split tensile test was carried out as per ASTM C496-90. Concrete cylinders of size 150 mm diameter and 300 mm height were cast using 1:1:2 mix with W/C ratio of 0.50. Specimens with OPC and GPC at 12M were cast. During moulding, the cylinders were mechanically vibrated using a table vibrator. After 24h, the OPC specimens were removed from the mould and subjected to water curing for 1,7, 14 and 28 days. The GPC specimens were wrapped by plastic sheet to prevent the loss of moisture and placed for curing at 60^{0}C, 80^{0}C and 100^{0}C in the oven for 24h. They were then left at open air (room temperature 25^{0}C) in the laboratory until testing. Tests were carried out on triplicate specimens and average split tensile strength values were recorded.

C. *Flexure Test*

Central point loading was used for the determination of flexural strength of concrete. Specimens of size 100x100x500mm were casted using 1:1:2 mix with W/C of 0.50. During moulding, the beams were mechanically vibrated. Specimens with OPC and GPC at 12M were cast. After 24h, the OPC specimens were removed from the mould and subjected to water curing for 7, 14 and 28 days. The GPC specimens were wrapped by plastic sheet to prevent the loss of moisture and placed for curing at 60^{0}C, 80^{0}C and 100^{0}C in the oven for 24h. They were then left at open air (room temperature 25^{0}C) in the laboratory until testing. Loading was applied at the rate of 400kg/min. Tests were carried out on triplicate specimens and average flexural strength values were recorded.

D. *Pull Out Test*

Pull out test was carried out as per IS 2770-1967-Part-1. Cold twisted deformed bars of 12 mm diameter and 450mm long were used for steel-concrete bond strength determination. The rod was placed centrally along with helical reinforcement provided in the centre of the concrete cube of size 100x100x100 mm using a concrete mix of 1:1:2 with W/C ratio equal to 0.50. Specimens with OPC and GPC at 12M were cast. The bar is projected down for a distance of about 10mm from the bottom face of the cube as cast and projected upward from the top up to 300mm height in order to provide an adequate length to be gripped for application of load. During casting of concrete cubes, the moulds were mechanically vibrated. The OPC cubes were removed from the mould after 24h and then cured for 28 days with complete immersion in distilled water. The GPC cubes were wrapped by plastic sheet to prevent the loss of moisture and placed for curing at 60^{0}C, 80^{0}C and 100^{0}C in the oven for 24h.They were then left at open air (room temperature 25^{0}C) in the laboratory until testing.

After the curing period was over the steel-concrete bond strength was determined using Universal Testing Machine of capacity 60t. The bond strength was calculated from the load at which the slip was 0.25 mm. Tests were carried out in triplicate specimens and average bond strength values were obtained.

E. Durability Test

Salt resistance test was performed to determine the durability of samples. The 150x150x150 mm geopolymer concrete specimens were prepared and cured in saturated salt water. After curing for 28 days, the specimens were taken out to measure the initial weights, and then transferred to 3.5% solution of Sodium Chloride (NaCl) acid. The parameters investigated were the time and weight loss of fully immersed concrete specimens in the acid solution. The measurements of weight loss were performed at the age of 1, 7, 14, 21, 28 and 56 days. Three concrete specimens were tested for each data.

IV. Observations And Test Results

The tables and graphs of all the tests performed are given below. From the tables, it can be seen that the geopolymer concrete cured at 80^0C gives the best results. The values are much higher than OPC. Also, it can be seen that one day strength of GPC is much more than OPC on all the experiments performed because of curing at higher temperatures. Later on the strength increases at room temperature possibly because of polymerization process but the actual reason is not known. Also, at temperatures higher than 80^0C, the strength of all tests is not found to increase. Hence, 80^0C can be thought of as an optimum temperature for

Table II Compressive Strength

Days	Compressive strength (MPa) for 50%NaOH+50%KOH					
	M25	60^0	80^0	100^0	12M NaOH	12M KOH
1	4.92	26.84	31.14	29.9	20.14	23.1
7	25.36	34.74	37.22	36.12	31.05	33.16
14	28.42	42.38	48.86	44.08	35.38	39.12
28	30.33	50.42	55.26	52.18	39	42.44

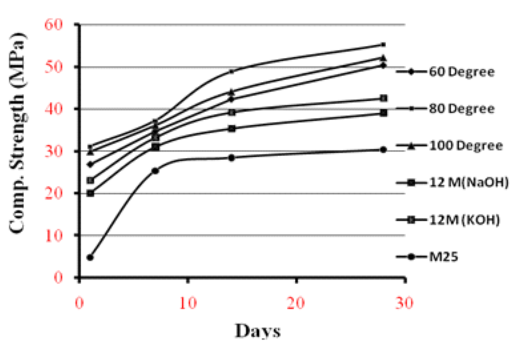

Fig. 1 Comp. strength of OPC and GPC

Table III Split Tensile Strength

Days	Split tensile strength (MPa) for 50%NaOH+50%KOH					
	M25	60^0	80^0	100^0	12M NaOH	12M KOH
1	0.66	2.7	3.89	3	2.04	2.38
7	2.62	3.82	4.8	4.22	3.22	3.5
14	3.14	4.68	5.76	4.96	4	4.48
28	3.6	5.4	6.48	6	4.08	4.8

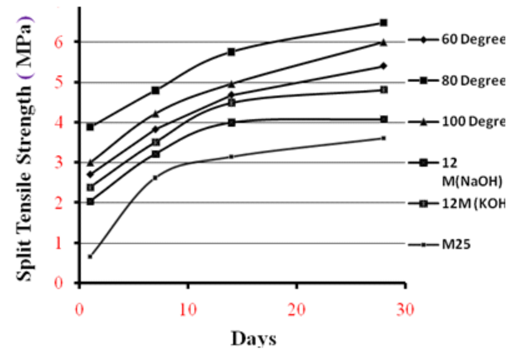

Fig. 2 Split tensile strength of OPC and GPC

Table IV Flexural Strength

Days	Flexural strength (MPa) for 50%NaOH+50%KOH					
	M25	60^0	80^0	100^0	12M NaOH	12M KOH
1	1.1	4.12	5.68	5.04	3.18	3.5
7	3.12	4.9	7	6.14	4	4.3
14	3.98	5.8	8.44	7.08	5.38	5.76
28	4.54	7.56	10.58	8.98	6	6.6

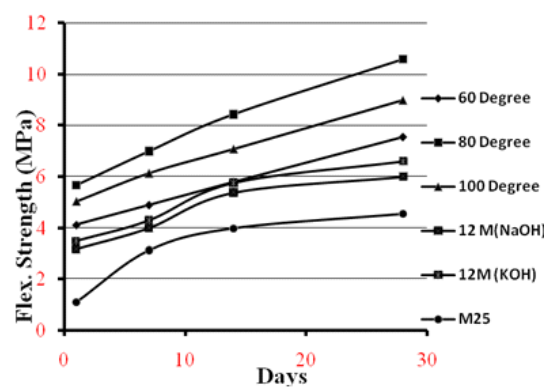

Fig. 3 Flexural strength of OPC and GPC

Table V Pull Out Strength

Days	Pull out strength (MPa) for 50%NaOH+50%KOH					
	M25	60^0	80^0	100^0	12M NaOH	12M KOH
1	2.08	8.03	9.0	8.41	6.92	7.14
7	5.62	9.11	10.96	9.99	8.6	8.74
14	7.8	11.07	12.12	11.8	10.52	10.78
28	8.9	13.78	16.24	14.84	11.0	11.34

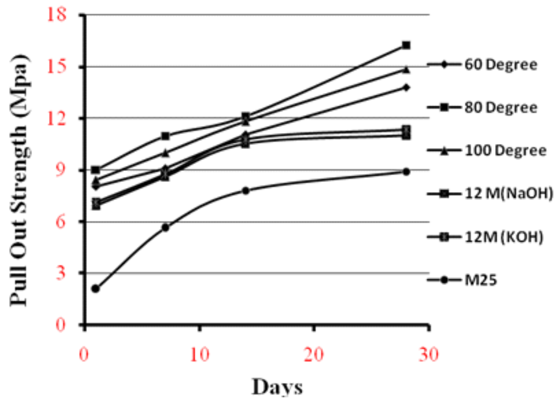

Fig. 4 Pull out strength of OPC and GPC

TABLE VI DURABILITY TEST

Days	Durability test (% Loss in weight) for 50%NaOH+50%KOH					
	M25	60^0	80^0	100^0	12M NaOH	12M KOH
1	0.84	0.07	0.07	0.07	0.30	0.09
7	1.68	0.29	0.27	0.29	0.44	0.33
14	3.21	0.50	0.48	0.55	0.64	0.59
28	4.84	0.55	0.52	0.54	0.82	0.78
56	5.66	0.84	0.60	0.76	0.92	0.88

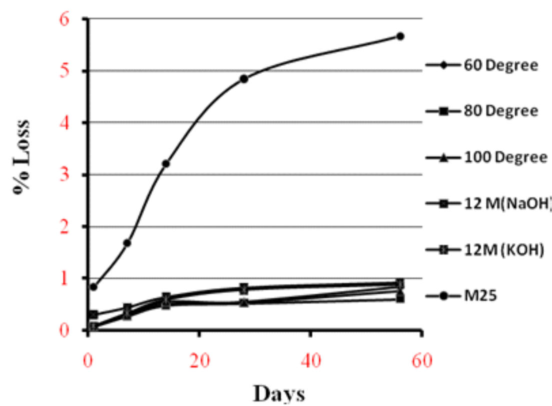

Fig. 5 % Loss in weight for OPC and GPC

V. SCANNING ELECTRON MICRO GRAPH IMAGES

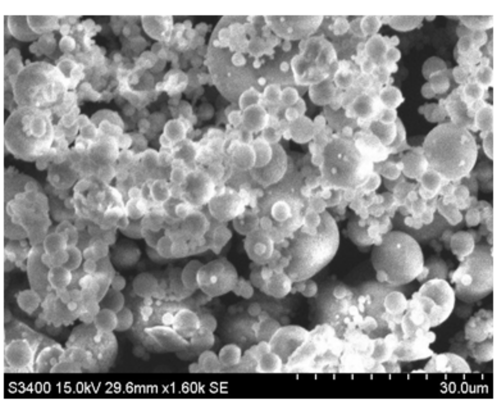

Fig. 6 Pulverized Fly Ash Powder

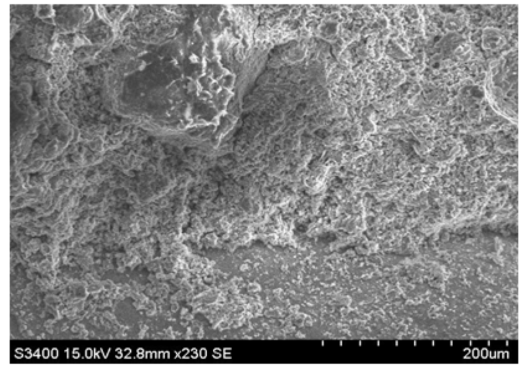

Fig. 7 Normal Concrete M25

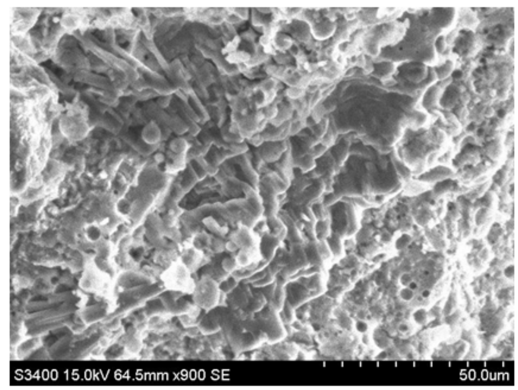

Fig 8 GPC OF NaOH (50%) +KOH (50%)

From Scanning Electron Micro-Graph images of GPC of NaOH(50%) + KOH(50%), the sharp peaks observed shows enhancement of rapid strength gain mechanism in Geopolymer Concrete.

VI. DISCUSSIONS ON EXPERIMENTAL WORK

1. Compressive strength of GPC increases over controlled concrete by 1.5 times (M-25 achieves M-45).
2. Split Tensile Strength of GPC increases over controlled concrete by 1.45 times.
3. Flexural Strength of GPC increases over controlled concrete by 1.6 times.
4. In Pull Out test, GPC increases over controlled concrete by 1.5 times.
5. In Durability test, there is decrease in weight loss by 10 times (At 56 days % loss in weight has reduced from 5.66% to 0.60%).
6. It has been observed that at 12 molarity of KOH, the gain in strength remains very moderate and the reason is at an ambient temperature of 60°C for 24 hours the polycondensation process has already completed and particle interface is also achieved.
7. The SEM images are also revalidating the polycondensation process of rapid strength gain mechanism in Geopolymer Concrete.

VII. Conclusion

Heat cured low calcium fly ash based geopolymer concrete offers several economic benefits over Portland Cement concrete. The price of one ton of fly ash is only a small fraction of the price of one ton of Portland cement. Therefore, after allowing for the price of alkaline liquids needed to make the geopolymer concrete, the price of fly ash-based geopolymer concrete is estimated to be about 10 to 30 % cheaper than that of Ordinary Portland cement concrete**.**

Rapid strength gain mechanism was explained with Scanning Electron Micrograph images**.** Low calcium fly ash based geopolymer concrete has excellent compressive strength and is suitable for structural applications.

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