Research Paper Engineering

Study of Strength Parameters and durability of Fly ash based Geopolymer Concrete

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ABSTRACT

This paper present to study the effects of several factors on the properties of fly ash based geopolymer concrete on the compressive strength. In this preliminary experimental work different parameters were used such as Ratio of Alkine liquid to fly ash 0.40 ,0.45 and 0.50, ratio of NaOH to sodium silicate (Na_2SiO_3) 2.0 and 2.5, molarities of sodium hydroxide(NaOH) 10M ,12M, 14M and 16M, Curing temperature Ambient Temperature, 60^0C, 90^0C and 120^0C, Addition of Superplasticiser. A mix Proportion based on the result of preliminary investigation is to be developed for geopolymer concrete. Two concrete mixes is to be worked out: GPC Mix-1 Fly ash concrete and OPC Mix-2 Concrete Mix having OPC equivalent to amount of Cementitious Material used in GPC Mix-1. Compression test, Split tensile test, Pull out test and durability test were performed.

KEYWORDS Geopolymer, concrete, fly ash, alkaline solution, Compressive strength.

1: Introduction

Concrete is one of the most widely used construction materials. The demand of concrete is increasing day by day for satisfying the need of development of infrastructure facilities. The production of Portland cement not only consumes the significant amount of natural resources but also liberates a considerable amount of carbon dioxide (CO_2) and other greenhouse gases. The disposal of waste material as well as industrial by-product like fly ash is a worldwide problem and a large part of it is disposed in landfills. There is urgent need to find an alternate to Portland cement in order to make the construction industry eco-friendly. Fly ash based geopolymer concrete is a new material that does not need the presence of Portland cement as binder. By using the fly ash based geopolymer concrete reducing the two environments related issues i.e. the high amount of CO_2 released to the atmosphere during production of OPC and Utilization of Fly ash.

2: Geopolymer

Davidovits (1988, 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice-husk ash to produce binders Because the chemical reaction that takes place in this case is a Polymerization process, he coined the term 'Geopolymer' to represent these binders

3: Experimental Work

3.1 Materials:

3.1.1 Fly ash:

In the present experimental work, low -calcium class F processed Fly ash was collected and brought from Dirk India private limited under the name of the product POZZOCRETE 60. Physical properties and chemical compositions of the fly ash is shown in table 3.1 below and is provided by Company.

3.1.2 Alkaline liquid:

Alkaline solution plays most important role in geopolymerization process. The alkaline liquid used was a combination of sodium silicate and sodium hydroxide solution. Sodium solutions are chosen because they are cheaper than potassium based solutions. Commercial grade sodium hydroxide (NaOH) in flakes form with 97%-98% purity. NaOH and Na_2SiO_3 solution was purchased from a local supplier Desai chemicals Ahmedabad, Gujarat. Sodium hydroxide solution is prepared by dissolving the flakes in water. The activator solution was prepared at least one day prior to its use.

3.1.3 Aggregates:

Locally available 10mm and 20 mm crushed aggregates have been used as Coarse aggregates. Locally available clean river sand is used as fine aggregates .Both coarse and fine aggregates were in saturated - surface-dry (SSD) condition.

3.1.4 Super Plasticizer:

To improve the workability of the fresh geopolymer concrete, water reducing naphthalene based superplasticiser was used in all of the geopolymer mixes.

3.1.5 Mixture Proportion:

The different mixture proportions used to make the trial geopolymer concrete specimens in this study given in table 1.

Table -01 [Geopolymer Concrete Mix]

GPC Mix.	Fly Ash	C.A.	F. A.	NaOH	Na_2Sio_3	Alkal./Fly. Ratio	Molarity	Curing Temp.	Extra Water	Super Plasticizer
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3		M	°C	Kg.	Kg.
1	412	1185	639	47	118	0.40	14	90	42	4.2
2	397	1185	639	47	118	0.45	14	90	40	4.0
3	384	1185	639	47	118	0.50	14	90	39	3.9
4	412	1185	639	55	110	0.40	14	90	42	4.2
5	412	1185	639	47	118	0.40	14	90	42	4.2

6	412	1185	639	47	118	0.40	14	90	42	4.2
7	412	1185	639	47	118	0.40	14	60	42	4.2
8	412	1185	639	47	118	0.40	14	120	42	4.2
9	412	1185	639	47	118	0.40	14	Ambient	42	4.2
10	412	1185	639	47	118	0.40	10	90	42	4.2
11	412	1185	639	47	118	0.40	12	90	42	4.2
12	412	1185	639	47	118	0.40	16	90	42	4.2
13	412	1185	639	47	118	0.40	16	90	42	8.5
14	412	1185	639	47	118	0.40	16	90	42	12.5
15	412	1185	639	47	118	0.40	16	90	42	16.5

3.1.4 Mixing, Casting and curing of Concrete

The conventional method used in the making of normal concrete was adopted to prepare geopolymer concrete. Mixing of all the materials have been done in the laboratory at room temperature. First, the Fine aggregate, coarse aggregate and fly ash are mixed together in concrete mixture. The mixing is allowed to continue for about 3 to 4 minutes. The alkaline solution which was prepared one day before is added with additional water in the mix. The liquid component and superplasticiser was added to the dry material. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in colour.

The fresh concrete was cast and compacted in the moulds of cubes 150mm x 150mm x 150mm. for compressivetest, 100mm X 100mm X 100mm for Durability test, and 150mm X 300mm cylinder for split tensile test. Each cube specimen was cast in three layers by compacting manually as well as by using vibrating table. After casting, the specimens were kept in lab for hardening process for next 24 hours. The test specimens were demoulded after 24 hours of casting.

4. Test Results and discussion

4.1. Ratio of alkaline liquid to fly ash

Three concrete mixes Mix-1, Mix-2 and Mix-3with the alkaline liquid to fly ash ratio 0.40, 0.45 and 0.50 have been cast using the Ingredients as given in Table 1.

The effect of alkaline liquid to fly ash ratio by mass on compressive strength of concrete at age 3 days has been evaluated by comparing results of mixes.

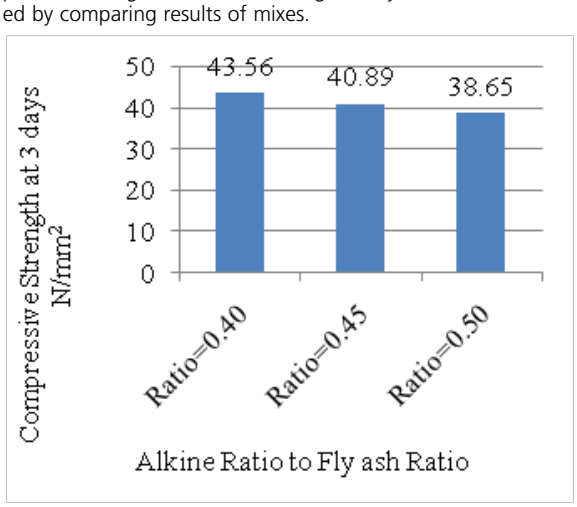

Figure 1

The results are presented in Fig.1. It has been observed that the alkaline liquid to fly ash ratio increases compressive strength decreases. The Alk. to Fly ash ratio by mass, ratio 0.40 gives higher results as compared to ratio 0.45 & 0.50 of GPC. Decrease in compressive strength of geopolymer concrete is because of increases in water in the preparation of alkaline liquid. This behavior is similar to normal concrete as water to cement ratio increases compressive strength decreases.

4.2 Ratio of sodium silicate solution to sodium hydroxide solution

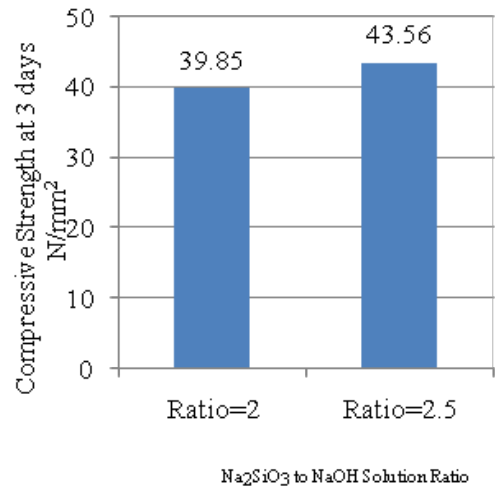

Figure 2

Two concrete mixes Mix-4 and Mix-5 with the Ratio of Sodium Silicate Solution to Sodium Hydroxide Solution by mass have been cast using the Ingredients as given in Table 1.

The results are presented in Figure 2. Higher Compressive strength has been observed in Ratio 2.5as compared to that of Ratio 2.0

4.3 Curing Temperature

Four concrete mixes Mix-6, 7, 8 and Mix-9 with the temperature Ambient Temperature, 60°C, 90°C & 120°C have been cast using the Ingredients as given in Table 1. The test specimens of mix -6, mix -7, & mix-8 have been heat cured in the oven for 24 hours

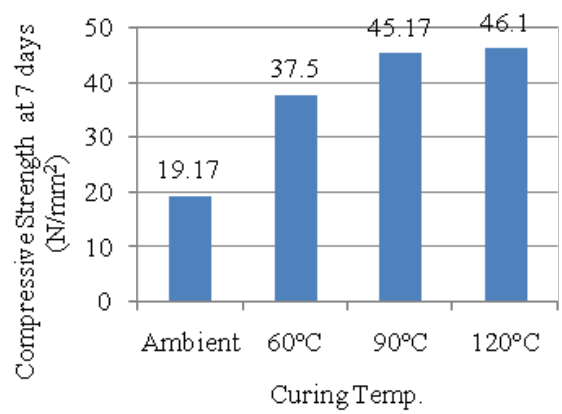

Figure 3

Higher is the compressive strength of fly ash based geo-polymer concrete, as the curing temperature in the range of Ambient Temperature to 120°C increases. Increase in curing temperature beyond 90°C has yielded into minor increment in the compressive strength for the concrete. Oven cured specimen gives higher compressive strength than the ambient temperature.

4. 4 Concentration of Sodium Hydroxide Solution

Concrete mixes 6, 10, 11 and 12 have been cast using the Ingredients as given in Table 1.

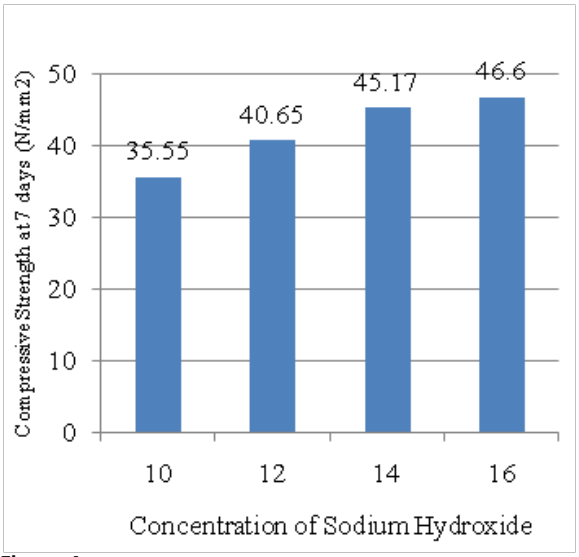

Figure 4

It has been observed that, increase the Concentration of sodium Hydroxide (NaOH) solution gives better results in terms of compressive strength of geopolymer concrete. Increase in Compressive strength beyond 14M has yielded into minor increment

4.5 Addition of Superplasticiser

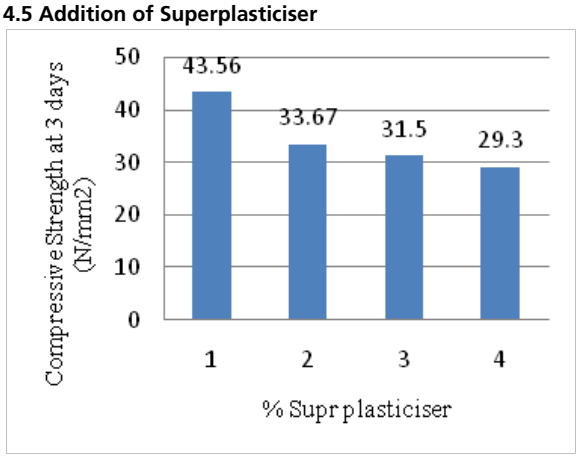

Figure 5

The result is presented in figure 5. Concrete mix 1 with 1% dosage of superplasticiser has been achived higher compressive strength as compared to the concrete mixes 13, 14 and 15 respectively.

5.0 Mechanical and Durability Properties

Based on these results of preliminary investigation, two concrete mix proportions are worked out for studying the mechanical properties and durability properties. GPC Mix contains fly ash based geopolymer concrete. The concrete mix is OPC mix . The cementious material used in concrete mix-1 and OPC used in concrete mix-2 are kept equal. Mixture proportion used in GPC mix and OPC mix in table 2.

Table 2. Mix Proportions For GPC & OPC (kg/m^3)

Sr. No.	Ingredients	GPC Mix-1	OPC Mix-2
1	Fly Ash	412	
2	Cement	_	412
3	Coarse Aggregate	1185	1185
4	Fine. Aggregate	639	639
5	NaOH	47	-
6	Na_2Sio_3	118	_
7	Alkaline./Fly. Ratio	0.40	_
8	Molarity	14M	_
9	Curing Temp.	90°C	
10	Extra Water	41.20	165
11	Super Plasticizer	1%	1%

5.1 Test: Compression test, Split tensile test, Pull out test and durability test.

5.1.1 Compressive Strength:

The compressive strength at an age 3, 7, 14 and 28 days has been observed for concrete GPC Mix -1 & OPC Mix -2 is given in Table 3. The results given in Table 3.

Table 3. Compressive strength of concrete mixes

Sr. No	Mix	Curing days	Average Compressive Strength (N/mm^2)
1	GPC Mix-1	3	43.65
		7	46.90
		14	49.75
		28	52.25
2	OPC Mix -2	3	29.50
		7	40.75
		14	43.65
		28	46.50

5.1.2 Split Tensile Strength:

The split tensile strength at an age 28 days has been evaluated for concrete GPC mix -1 and GPC mix-2 are reported in Table 4. Average split tensile strength of 3 cylinders (150mmx300mm) for all concrete mixes are given in Table 4.

Table 4. Split Tensile strength of concrete mixes

Sr. No	Mix	Curing days	Average Split Tensile Strength (N/mm^2)
1	GPC Mix-1	28	4.10
2	OPC Mix -2	28	3.95

5.1.3 Pull out strength:

The Pull out strength at an age 28 days has been evaluated for concrete GPC mix -1 and GPC mix-2 are reported in Table 5.

Table 5 Pull out strength of concrete mixes

Sr. No.	Mix	Curing days	Pull out Strength
1	GPC Mix-1	28	10.25
2	OPC Mix -2	28	7.80

5.2 Durability test

These are the tests which are performing to check the condition of geopolymer concrete in Sulphate, acidic and salty environmental.

The test has been observed based on change in mass, and change in compressive strength after the exposure of 28 days.

Specimen of concrete mix has been heat cured at 90^0C for 24 hours. The specimens were immersed in 5 % sodium sulfate solution, 2% Sulphuric acid solution and 3.5 % NaCl solution after curing for 28 days.

Table 6. For Durability Properties of concrete mixes

	Mix	Days of exposure	Weight (kg)	Change in mass %	Compressive strength (N/mm^2)	Change in Compressive strength (%)	Concentration of Solution
Sulphate Resistance Test	GPC Mix-1	0	8.34	0.0	52.32	100.0	5 % sodium sulfate solution
		28	8.51	2.04	50.65 (3.19%)	96.81	
Acid Resistance Test	GPC Mix-1	0	8.32	0.0	51.85	100.0	2 % acid solution
		28	8.48	1.92	49.15 (5.20%)	94.80	
Salt Resistance Test	GPC Mix-1	0	8.30	0.0	51.60	100.0	3.5 % NaCl
		28	8.46	1.80	49.90 (3.29%)	96.71	

6. Conclusions:

- Higher compressive strength is observed for concrete GPC Mix-1 as compared to that of concrete OPC Mix-2 respectively.
- Higher split tensile strength for concrete GPC mix-1 has been observed as compared to that for concrete OPC mix-2, respectively.
- Higher Pull out strength for concrete GPC mix-1 has been observed as compared to that for concrete OPC mix- 2, respectively.
- The test results demonstrate that oven cured fly ash based geopolymer concrete have an excellent resistance to sulfate attack, Salt attack and acid attack.
- Compared to oven cured and ambient temperature cured, oven cured specimens gives higher compressive strength at 7 days but ambient temperature curing is convenient for practical conditions.
- Minor increase in the mass of concrete specimens of mix has been observed due to the absorption of the sulfate, acid & salt for concrete mixes 1.
- Geopolymer concrete has excellent properties within Sulphate, acid and salt environments. Comparing to Portland cement, the production of geopolymer has a relative higher strength.
- GPC gives better durability because GPC has less CaO content Compare to OPC.(rangan 2006)
- It can be said that the geopolymer concrete is good alternative of construction material of from both strength and durability considerations.
- The reduced CO_2 emissions of GPC make them a good alternative to OPC.

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