Strength Performance Studies on Ambient Cured Silica fume based Geopolymer Concrete

Manjunath S. Sontakki[1], Prof. Swapnil B. Cholekar[2]

[1]M.Tech Student, Civil Engineering Department, KLE's Dr.M.S.S.C.E.T. Belagavi, Karnataka,India.
[2]Assistant professor, Civil Engineering Department, KLE's Dr.M.S.S.C.E.T. Belagavi, Karnataka,India.

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Abstract - Geopolymer Concrete (GPCs) is a new class of concrete based on an inorganic alumino-silicate binder system compared to the hydrated calcium silicate binder system of concrete. It possesses the advantages of rapid strength gain, elimination of water curing, good mechanical and durability properties and are eco-friendly and sustainable alternative to Ordinary Portland Cement (OPC) based concrete. In the construction industry mainly the production of Portland cement causes the emission of air pollutants which results in environmental pollution. This paper presents the details of the studies carried out on development of strength for various grades of geopolymer concrete with varying molarity. The alkaline liquids used in this study for the geopolymerization are sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). Different molarities of sodium hydroxide solution (10M and 12M) are taken to prepare different mixtures. The test specimens were 150 x 150 x 150 mm cubes, 150 x 200mm cylinders prepared and ambient temperature curing conditions. The geopolymer concrete specimens are tested for their compressive strength at the age of 7 and 28 days. GPC mix formulations with compressive strength ranging from 15 to 60MPa have been developed. Experimental investigations have been carried out on workability, the various mechanical properties of GPCs. The test results indicate that the combination of silica fume and ground granulated furnace slag (GGBS) can be used for development of geopolymer concrete.

Key Words: Geopolymer concrete, molarity, silica fume, GGBS, Quarry dust, Sodium hydroxide and Sodium silicate.

1. INTRODUCTION

Davidovits [1988] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (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. Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer concrete.

1.1 Source materials and alkaline liquid

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

1.2 The principal objective of the research were

1. The development of structural grade geopolymer concrete with different combinations of SILICA FUME and GGBS.

2. To study the influence Fluid/Binder ratio on geopolymer concrete. The fluid/binder ratios of geopolymer concrete mixes are (i) 0.75, (ii) 0.80, (iii) 0.85, (iv) 0.90.

3. To study the effect of concentration of alkaline activator solution in geopolymer concrete. The molar ratios considered are 10M and 12M Sodium Hydroxide Solutions are used.

2. SILICA FUME-BASED GEOPOLYMER CONCRETE

Geopolymer concrete is manufactured using source materials that are rich in silica and alumina. While the cement-based concrete utilizes the formation of calcium-silica hydrates (CSHs) for matrix formation and strength, geopolymers involve the chemical reaction of alumino-silicate oxides with alkali polysilicates yielding polymeric Si–O–Al bonds.

In this experimental work, silica fume is used as the source concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, silica fume-based geopolymer concrete, the aggregates occupy the largest volume, i.e. about 75-80% by mass.

Sodium-based activators were chosen because they were cheaper than Potassium-based activators. The sodium hydroxide was used, in flake or pellet form. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. The concentration of sodium hydroxide solution can vary in the range between 8 Molar and 16 Molar. The mass of water is the major component in both the alkaline solutions. In order to improve the workability, a melamine based super plasticizer has been added to the mixture.

2. MIX DESIGN PROCEDURE

The primary difference between Geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low –calcium fly ash reacts with the alkaline liquid to from the geopolymer paste that binds the loose coarse and fine aggregates and other unreacted materials to form the geopolymer concrete. As in the case of Portland cement concrete the coarse and fine aggregates occupy about 75% to 80% of the mass of Geopolymer concrete. This component of Geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete. The compressive strength and workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste.

TABLE I: Chemical composition silica fume

Characteristics	**SF (% weight)**
Silica	92
Iron oxide	1.6
Aluminium Oxide	<1
Calcium Oxide	<1
Magnesium Oxide	<1
Titanium Oxide	<1
Phosphorous	<1
Sulphates	0.1
Alkali Oxide	<1

TABLE 2: Properties of aggregates

Property	Coarse Aggregate	Fine Aggregate
Specific gravity	2.70	2.375
Water absorption	0.50%	0.9%
Fineness modulus	7.20	3.33
Bulk density(Kg/m3)	1690	1790
source	Crushed granite stone	Quarry dust

TABLE 3: Properties of sodium hydroxide Naoh

Molar mass	40 g/mol
Appearance	White solid
Density	2.1gr/cc
Melting point	318^0C

TABLE 4: Properties of sodium silicate solution

Specific gravity	1.56-1.66
Na_2O	15.5-16.5
SiO_2	31-33
Weight ratio	2
Molar ratio	2

2.1 Design mix of G 40.

Density of Concrete	2400 kg/m³
Take mass of combined aggregate	75% of mass of concrete 0.75 x 2400 1800 kg/m³ of concrete
Take fine aggregate to coarse aggregate ratio	1:2
Weight of fine aggregate 1800/3=	600 kg/m³ of concrete
Weight of coarse aggregate:600x2=	1200 kg/m³ of concrete
Take fluid/binder(f/b) ratio	0.8
Weight of binder + solution	2400-1800 = 600 kg/m³
Weight of binder only	(600 x 1)/1.6 =375 kg/m³
Weight of fluid	600-375 = 225 kg/m³
With Sodium hydroxide: sodium silicate as 1:2 Sodium Hydroxide solution	225/3 =75 kg/m³
Sodium silicate solution	75x2=150 kg/ m³
Proportion by Weight	375:600:1200 1 : 1.6 : 3.2 Where, 1 = Binder (Silica fume : GGBS) 1.6 = Fine Aggregate (Manufactured sand) 3.2 = Coarse Aggregate
Fluid/binder ratio (f/b)	0.8

2.2. Experimental program

The sodium hydroxide flakes were dissolved in distilled water to make a solution with a desired concentration at least one day prior to use. The fly ash and the aggregates were first mixed together in a pan mixer for about three minutes.

The sodium hydroxide and the sodium silicate solutions were mixed together with superplasticizer then added to the dry materials and mixed for about four minutes. The fresh concrete was cast into the molds immediately after mixing, in three layers and compacted with manual strokes and vibrating table.

Fig -1: Silica fume based fresh geopolymer concrete.

After casting, the specimens were cured at 60°C for 24 hours. And the specimens were cured at ambient temperature i.e. specimens were left to air for desires period.

For the designated grade of Geopolymer concrete mix about 4 mixture proportions were tested and optimized by taking the mix which is giving maximum compressive strength at 28 days under Ambient cured conditions.

TABLE 5: Compressive Strength test results on GPC

DAYS	AVERAGE STRENGTH OF 10M N/mm²	AVERAGE STRENGTH OF 12M N/mm²
DAY 3	30.13	36.9
DAY 7	40.22	45.10
DAY 28	45.62	53.77

TABLE 6: Compressive Strength test results on GPC

DAYS	FLUID/ BINDER RATIO	AVERAGE STRENGTH OF 10M N/mm²	AVERAGE STRENGTH OF 12M N/mm²
DAY 7	0.75	40.22	45.10
	0.80	33.12	36.07
	0.85	31.83	32.53
	0.90	28.14	30.63
DAY 28	0.75	45.62	53.77
	0.80	38.45	44.91
	0.85	36.08	39.71
	0.90	32.86	35.76
DAY 56	0.75	57.40	59.33
	0.80	46.42	50.06
	0.85	41.01	43.40
	0.90	37.43	40.26

3. RESULTS AND DISCUSSIONS

Based the Experimental investigations carried out on low, medium & high strength geopolymer concrete, the concluded data can be presented in the following form.

Compressive strength tests were performed at the age of, 7 and 28 days in accordance with IS: 516-1959 [14] under 2000KN Compression testing machine with uniform rate of load application for Geopolymer concrete mixes. It can be seen from the results that the compressive strength increases with increase in the silica fume content and decrease with increase in fluid/binder ratio for all ages. It is also observed that 80% of strength is achieved within 7 days. It is observed that the strength development of Geopolymer concrete is slow under ambient conditions and 100% strength achieved at 28 days only.

The Influence of alkaline liquid to silica fume ratios and molar concentrations of NaOH on the compressive strengths geopolymer concretes for G40 grade is shown in chart 2.

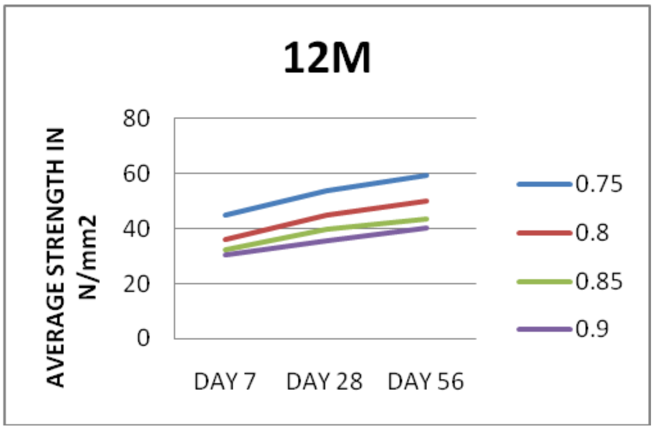

Chart -1: Variation of compressive strength with age of different fluid binder ratio.

- It is found that the strength of GPC decreases with the increase in fluid binder ratio at all ages.
- In the case of normal concrete, according to Abram's law, compressive strength decreases with increase in w/c ratio, other parameters being unchanged. In case of GPC similar trend is observed

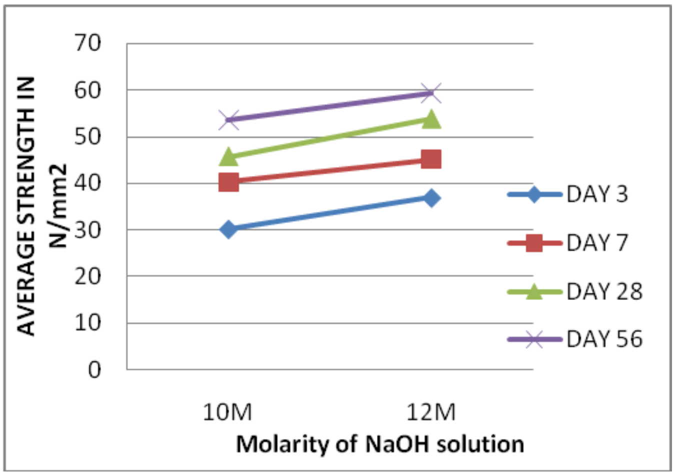

Chart -2: Variation of Compressive Strength with molarity of NaOH at different ages

- It is attributed to the fact that as molarity increases as more salts are available for Geopolymerisation reaction.
- It is found that the strength of Geopolymer concrete increases with the increase in molarity of sodium hydroxide solution used in synthesizing Geopolymer concrete.

4. CONCLUSIONS

- It is possible to develop the ambient cured GPC using Silica fume - GGBS (without thermal curing), without any conventional cement.
- The compressive strength of the geopolymer concrete is increased with the increasing concentration of NaOH. The geopolymer concretes produced with different combination of FA and GGBS are able to produce structural concretes of high grades (much more than M40MPa) by self curing mechanisms only.
- The GPC mixes were produced easily using equipment similar to those used for production of conventional cement concretes
- Apart from less energy intensiveness, the GPCs utilize the industrial wastes for producing the binding system in concrete. There are both environmental and economical benefits of using silica fume and GGBS.
- The influences of GGBS on strength of geopolymer concrete mixes were studied. It has been observed that the increasing the quantity of GGBS and Compressive strength of geopolymer increases. The measured compressive strength of geopolymer mix is in the range from 45 MPa to 60 MPa and maximum of 60 MPa for 30% GGBS.
- From the findings it has It is recommended to add Superplasticizers for high strength Geopolymer concretes, which is analogous to Conventional concrete of higher grades to secure required workability.

- For geopolymer concrete, as the molarity of sodium hydroxide solution increases, the compressive strength also increases.
- As the fluid binder ratio increases, the compressive strength of geopolymer concrete decreases.
- As the size of the specimen increases, the compressive strength seem to decrease slightly revealing the size effect in compressive strength.
- Quarry dust can be used as fine aggregate in place of river sand.
- From the findings it is clear that addition of GGBS more than 30% decreases the compressive strength.
- Thus, sustainable and eco-friendly concrete can be developed by synthesizing binders using industrial by products/marginal materials alternative to ordinary Portland cement (OPC) and by using quarry dust as fine aggregate rather than river sand.

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