EXPERIMENTAL INVESTIGATION OF STRENGTH AND CHARACTERISTICS OF GEOPOLYMER CONCRETE BY USING FLYASH AND QUARRY DUST

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Abstract

Ordinary Portland cement production is the second only to the automobile as the major generator of carbon dioxide, which polluted the atmosphere. In addition to that large amount energy was also consumed for the cement production. Hence, it is inevitable to fine an alternative material to the existing most expensive, most resource consuming Portland cement. Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. Fly ash, a byproduct of coal obtained from the thermal power plant is plenty available worldwide. Fly ash is rich in silica and alumina reacted with alkaline solution produced alumina silicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of Ordinary Portland Cement. This work briefly reviews the constituents of geopolymer concrete, its strength and potential applications. Due to growing environmental concerns of the cement industry alternative cement technologies have become an area of increasing interest. One such thing is “GEOPOLYMER CONCRETE”. It utilizes an alternate material including fly ash as binding material in place of cement. This fly ash reacts with alkaline solution NaOH and sodium silicate (Na2sio3) to form a gel which binds fine and coarse aggregates. Since geopolymer concrete is an emerging field, the guide lines from the bureau of Indian standards are yet to be formulated. An attempt has been made to find out an optimum mix for geopolymer concrete. Concrete cubes of size 150*150*150 mm were prepared. The compressive strength was found out at 7 days and 28 days.. When compared with conventional concrete or any other concrete method it is more advantageous, economical and eco friendly.

Keywords— Fly Ash, Geopolymer Concrete, Sodium Hydroxide (NaOH), Sodium Silicate (Na2sio3).

INTRODUCTION

The production of Portland cement, a main component of making concrete, contributes significant amount of greenhouse gas, because the production of one ton of Portland cement also releases about one ton of carbon dioxide gas into the atmosphere [1]. Therefore, the introduction of a novel binder called ‘geopolymer’ by Davidovits [2,3] promises a good prospect for application in the concrete industry as an alternative binder to Portland cement. In terms of reducing global warming, the geopolymer technology could reduce the CO2 emission to the atmosphere caused by cement and aggregates industries by 80% [4].

Inspired by this novel technology and the fact that fly ash is a waste material abundantly available, an attempt has been made to develop an alternative concrete binder by applying the geopolymer technology and utilising fly ash as the source material to produce the Fly Ash-Based Geopolymer Concrete. Hardjito, et. al. [5] introduced the early work on fly ash-based geopolymer concrete dealing with the manufacturing process and the effect of curing period, curing temperature and the age of concrete on the compressive strength of fly ash-based geopolymer concrete.

Moreover, the effect of alkaline ratio and the ratio of alkaline to water was also studied. More research results on the factors affecting the compressive strength and other properties of fresh and hardened fly ash-based geopolymer concrete were also reported [6-9]. Attempts to apply this material as a structural material have been carried out by studying the behaviour and strength of reinforced fly ash-based geopolymer concrete beams and columns [10,11] This paper presents the study on fly ash-based geopolymer concrete, focused on its creep behaviour, an important long-term property of concrete as a structure material.

GEOPOLMER MATERIAL

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymers could reduce the CO2 emission caused due to cement industries (Shankar H.Sanni and Khadiranaikar R.B 2012) The development of geopolymer concrete is an important step towards the production of environmentally friendly concrete (Hardijito et al.2005) Geopolymerization involves a chemical reaction between various alumino silicate materials with alkali metal silicates under strongly alkaline conditions yielding polymer – Si-O-Al-O- bonds, which lead to geopolymers by polycondestation

The schematic formation of geopolymer material can be shown as described by Equations as (A) and (B)

n(Si2O5,Al2O2)+2nSiO2+4nH2O+NaOH or KOH $\rightarrow$ Na+,K+ + n(OH)3-Si-O-Al^{-} -O-Si-(OH)3 (A)
(Si-Al materials) (OH)2
(Geopolymer precursor)

$\rightarrow$

(Equation 1)

n(OH)3-Si-O-Al- -O-Si-(OH)3+ NaOH or KOH (Na+,K+)-(-Si-O-Al- -O-Si-O-) +4H2O (B)

(OH)2 O O O

(Geopolymer backbone)

(Equation 2)

………Eq as (A) and (B) (Panias.D and Giannopoulou.I 2004)

To date the exact mechanism of setting and hardening of geopolymer material is not clear. However, most proposed mechanism consist of the chemical reaction may comprise the following steps.

- Dissolution of Si-Al atoms from the source material through the action of hydroxide ions.

- Transportation or orientation or condensation of precursor ions into monomers.

- Setting or polycondestion/ polymerization of monomers into polymeric structures. However, these three steps can overlap with each other and occur simultaneously thus making it difficult to isolate and examine each of them separately (Chanh Van Nguyen et al 2008)

FLY ASH-BASED GEOPOLYMER CONCRETE

Geopolymer concrete is manufactured using source materials that are rich in silica and alumina. While the cement-based concrete utilises 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 [14,15]. In geopolymer concrete, the silica and the alumina present in the source materials are first induced by alkaline activators to form a gel. This geopolymer gel binds the loose aggregates and other inert materials in the mixture to form the geopolymer concrete. In this experimental work, fly ash is used as the source material to make geopolymer paste as the binder, to produce concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, in fly ash-based geopolymer concrete, the aggregates occupy the largest volume, i.e. about 75-80% by mass. The silicon and the aluminium in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions.

MIXTURE PROPORTIONS

Geopolymer concrete in this study utilised the low calcium (class F) fly ash from Collie Power Station, Western Australia as the source material. Table 1 shows the chemical composition of the fly ash as determined by X-Ray Fluorescence (XRF) analysis. It can be seen from Table 1, the silicon and aluminium oxides constitute about 80% of the fly ash and the Si- to-Al ratio is about two. Particle size analysis is presented in Fig. 1. Graph A shows the percentage of the volume passing and Graph B shows the percentage volume for certain sizes

Aggregates, comprising 20 mm, 14 mm and 7 mm coarse aggregates and fine aggregate in saturated surface dry conditions, were used. The coarse aggregates were crushed granite-type aggregates and the fine aggregate was fine sand.

The alkaline activator was a combination of analytical grade sodium hydroxide (NaOH) in flake form with 98% purity dissolved in water and sodium silicate (Na_2O = 14.7%, SiO_2 = 29.4%, and water = 55.9% by mass solution).

In order to improve the workability, a high range water-reducing admixture with a dosage of 1.5% by mass of the fly ash was added to the mixture.

Table. Chemical composition of fly ash (% by mass)

Chemical composition	% by mass
SiO_2	47.80
Al_2O_3	24.40
Fe_2O_3	17.20
CaO	2.42
Na_2O	0.31
K_2O	0.55
TiO_2	1.328
MgO	1.19
P_2O_5	2.00
SO_3	0.29
Cr	0.01
MnO	0.12
Loss on ignition	1.10

Two types of mixture were used to make fly ash- based geopolymer concrete as shown in Table

Table. Mixture Proportions for Fly Ash-Based Geopolymer Concrete Mass (kg/m3)

Mix Proportions Value	Constituents density (kg/m3)
Coarse aggregate	1294
Fine aggregate	554
Fly ash	408
Sodium silicate	103
Sodium hydroxide	41
Super plasticizer	6.12

MATERIALS

General

In this chapter varies materials and method of conducting the test was discussed in detail and detailed methodology of the work was presented.

Materials Used

- Fly ash
- Chemicals
  - -Sodium hydroxide
  - -Sodium silicate
- Superplasticizer
- Aggregates
  - - Fine aggregate
  - - Coarse aggregate
- Quarry dust

Fly Ash

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geopolymer concrete due to its role in the geopolymerization process. A pozzolana is a material that exhibits cementitious properties when combined with calcium hydroxide. Fly ash is the main by product created from the combustion of coal in coal-fired power plants. There are two "classes" of fly ash, Class F and Class C. Each class of fly ash has its own unique properties.

Alkaline Liquid

A combination of alkaline silicate solution and alkaline hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

Chemicals

In this project chemicals are the very important constituents. Sodium Silicate and Sodium Hydroxide liquid are obtained commercially from local suppliers.

Sodium Hydroxide

The sodium hydroxide solids were of a laboratory grade in pellets form with 99% purity, obtained from local suppliers. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets (a small, rounded, compressed mass of a substance of sodium hydroxide)in water. The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per liter of the solution, where 40 is the molecular weight of sodium hydroxide.

Sodium Silicate

Sodium silicate solution (water glass) obtained from local suppliers was used. The chemical composition of the sodium silicate solution was Na_2O=8%, SiO_2=28%, and water 64%

by mass. The mixture of sodium silicate solution and sodium hydroxide solution forms the alkaline liquid.

Mechanical action of Superplasticizer

Superplasticizers are water reducers which are capable of reducing water contents by about 30 percent. However it is to be noted that full efficiency of superplasticizer can be got only when it is added to a mix that has an initial slump of 20 to 30mm. Addition of superplasticizer to stiff concrete mix reduces its water reducing efficiency. Depending on the solid content of the mixture, a dosage of 1 to 3 percent by weight of cement is advisable. In this present investigation, a superplasticizer namely CONPLAST SP 430 has been used for obtaining workable concrete at low w/c ratio. CONPLAST SP 430 is based upon NSF condensates used for this study. The mechanism consists of very large molecules (colloidal size) which dissolve in water to produce ions with high negative charge (anions).

Aggregates

The aggregates are the main components of the concrete which greatly varies the strength, density and other properties of the concrete. Different types of aggregates used are discussed below.

Fine Aggregate

The fine aggregate used in the project was locally supplied and conformed to grading zone II as per IS: 383:1970. It was first sieved through 4.75mm sieve to remove any particles greater than 4.75mm. Properties of the fine aggregate are tabulated below in Table 2.

Table. Properties of fine aggregates

S.No	Characteristics	Values
1.	Type	Uncrushed
2.	Specific gravity	2.54
3.	Bulk Density	1668 kg/m3
4.	Fineness modulus	2.76
5.	Grading zone	Zone II

Coarse Aggregate

Locally available coarse aggregate having the maximum size of (10 - 20mm) were used in this project. Properties of the coarse aggregate are tabulated in Table 4.

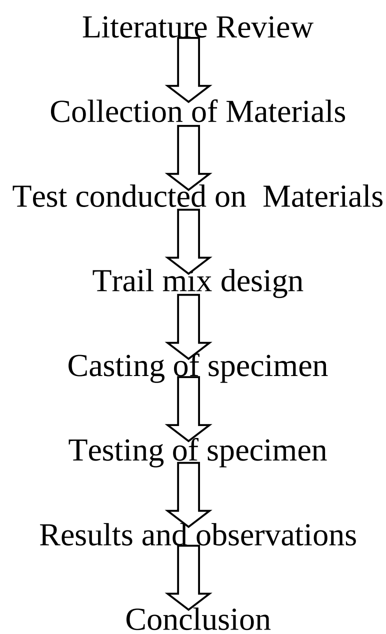
Table. Properties of Coarse aggregates

S.No	Characteristics	Values
1.	Type	Crushed
2.	Specific gravity	2.6
3.	Bulk Density	1765 kg/m3
4.	Fineness modulus	6.45
5.	Maximum size	20mm

METHODOLOGY

The methodology explains about the step by step procedure that is going to be done in the project. The methodology is explained in the following figure.

Fig -1: Methodology Of Geopolymer Concrete



MANUFACTURE

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 and the extra water and 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. After casting, the specimens were cured at 60°C for 24 hours. Two types of curing were applied, dry curing and steam curing. For dry curing, the specimens were cured in an oven and for steam curing the specimens were cured in the steam curing chamber. After curing, the specimens were left to air-dry in the laboratory for the next six days until testing on the 7th day.

EXPERIMENTAL WORK

In the present experimental work, low-calcium (Class F)8 dry fly ash obtained from the silos at a local power station was used as the base material. The chemical composition of the fly ash, as determined by x-ray fluorescence (XRF) analysis, is given in Table 1. Analytical grade sodium hydroxide in flake form and sodium silicate solutions were used as the alkaline activators. To avoid the effect of unknown contaminants in the mixing water, the sodium hydroxide flakes were dissolved in distilled water. The activator solution was prepared at least one day prior to its use. To improve the workability of fresh concrete, a commercially available naphthalene-based high-range water-reducing admixture was used. Four types of locally available aggregates, that is, 20, 14, and 7 mm aggregate, and fine sand, in saturated surface dry condition, were mixed together. The grading of this combined aggregate had a fineness modulus of 5.0. The aggregates and the fly ash were mixed dry in a pan mixer for 3 min. The alkaline solutions and the high-range water-reducing admixture were mixed together, then added to the solid particles and mixed for another 3 to 5 min. The fresh concrete had a stiff consistency and was glossy in appearance. The mixture was cast in 100 x 200 mm cylinder steel molds in three layers. Each layer received 60 manual strokes and vibrated for 10 s on a vibrating table. Five cylinders were prepared for each test variable. Immediately after casting, the samples were covered by a film to avoid the loss of water due to evaporation during curing at an elevated temperature. After being left in room temperature for 30 to 60 min, specimens were cured in an oven at a specified temperature for a period of time in accordance with the test variables selected. At the end of the curing period, the 100 x 200 mm test cylinders were removed from the molds and kept in the plastic bag for 6 h to avoid a drastic change of the environ- mental conditions. The specimens were then left to air dry at room temperature until loaded in compression at the specified age in a universal test machine. Before testing, the specimens were weighed to determine the density of the material. The loading rate and other test procedures used were in accordance with the details specified in the relevant Australian Standard for testing OPC concrete.12 Numerous trial mixtures of geopolymer concrete were made and tested in the laboratory. The data collected from these studies indicated that the salient parameters affecting the compressive strength of geopolymer concrete are as listed below:

• Silicon oxide (SiO2)-to-aluminum oxide (Al2O3) ratio by mass of the source material (fly ash); this ratio should preferably be in the range of 2.0 to 3.5 to make good concrete (Table 1);

• Activator liquids-to-source material (fly ash) ratio by mass;

• Concentration of sodium hydroxide (NaOH) liquid mea- sured in terms of Molarity (M), in the range of 8 to 16 M;

• Sodium silicate-to-sodium hydroxide liquid ratio by mass; the effect of this parameter depends on the com- position of the sodium silicate solution;

• Curing temperature in the range of 30 to 90 °C;

• Curing time in the range of 6 to 96 h; and

• Water content in the mixture. It must be noted that only the binder (which usually occupy approximately 20 to 25% of the total mass) is different in geopolymer concrete when compared to OPC concrete. Therefore, the effects of properties and grading of aggregates were not investigated in this study.

RESULTS & DISCUSSIONS

The various strength test that are to be done listed as below.

- Compressive strength
- Split tensile strength
- Flexural strength

TEST SPECIMENS

The test specimens for compressive strength test were made of cubes having a size of 150mm x 150mm x 150mm cast iron steel moulds were used. For each mix proportion three numbers of cubes were cast and tested at the age of 7 days and 28 days. The test specimens for split tensile strength test were made of cylinders having a size of 100mm diameter and 300mm high cast iron moulds were used. For each mix proportion three numbers of cylinders were cast and tested at 28 days. The test specimens for Flexural strength test were made of prism having a size of 500mm x 100mm x 100mm cast iron steel moulds were used. For each mix proportion three numbers of prisms were cast and tested at the age of 28 days.

Table shows the Details of test specimen

S.NO	NAME OF TEST	SIZE OF SPECIMEN (mm)	NO. OF SPECIMEN
1.	Compressive Strength	150 x 150 x 150	36
2.	Split tensile test	150 x 300	18
3.	Flexural strength test	500 x 100 x 100	18

	Total	72

COMPRESSIVE STRENGTH TEST

The variation of compressive strength at the age of 7th and 28th days for geopolymer concrete were given below in Table. From the test results, it was observed that the maximum compressive strength was obtained.

Age of specimen in days	Compressive strength in N/mm^2			Average compressive strength in N/mm^2
	Trial 1	Trial 2	Trial 3	
7 days	27.15	26.75	27.25	27.05
14 days	40.55	40.45	40.65	40.55
28 days	44.65	44.55	44.75	44.65

SPLIT TENSILE STRENGTH

The variation of split tensile strength at the age of 28th days for geopolymer concrete were given below. It was observed that the maximum split tensile strength was obtained.

Age of specimen in days	Tensile strength in N/mm^2			Average Tensile strength in N/mm^2
	Trial 1	Trial 2	Trial 3	
7 days	3.93	4.01	3.95	3.97
14 days	4.19	4.16	4.12	4.18
28 days	4.35	4.37	4.30	4.33

Flexural Strength

The results of flexural strength of concrete at the age of 3 days are presented. The values in flexural strength at the age of 3 days with 100% replacement of cement with flyash and 50%

replacement of sand were plotted. From the test results, it was observed the values are similar to that of conventional concrete.Three point loading is applied in the beam.

Table. Flexural strength values

Age of Age of specimen in days	Flexural strength in N/mm^2			Average Flexural strength in N/mm^2
	Trial 1	Trial 2	Trial 3	
7 days	3.2	3.1	3.3	3.15
14 days	4.5	4.25	4.6	4.45
28 days	4.6	4.75	4.5	4.67

Suggestions For Future Work

- Studies can be made on its durability property and to improve its workability characteristics.
- Fiber reinforced Geopolymer composites may be considered a solution to improve flexural strength and fracture toughness.
- Since there is demand for natural sand, the fine aggregate shall be replaced partially by quarry dust.
- Different structural elements like Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Columns, Reinforced Beam Column joints shall be cast for the above mentioned concentrations of Sodium Hydroxide solution and curing conditions and tested.

CONCLUSION

Geopolymer concrete has excellent properties within both acid and salt environments comparing to Portland cement, the production of geopolymer have a relative higher strength, excellent vol. stability, better durability. The increase in percentage of fine aggregates and coarse aggregates increase the compressive strength upto optimum level.This may be due to high bonding between the aggregates and alkaline solution. As the curing temperature in the range of 60º to 90ºC increases, the compressive strength of fly ash based geopolymer concrete also increases. With proper design and construction process, Geopolymer concrete can be used in reinforced concrete beams and columns. As the cost of geopolymer concrete is less as compare to “OPC”, we can use G.C for roadembankment construction, college’s path way, etc. Using geopolymer concrete we can produce more durable infrastructure capable of design life measure in hundred of years. It can also protect aquifers and surface bodies of fresh water via the elimination of fly ash from disposal sites.

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