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Strength Behaviour of Fly-Ash Based Geopolymer Concrete

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Abstract
Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with a caustic activator. Commonly, waste materials such as fly ash or slag from iron and metal products are used, which helps lead to a cleaner environment. Geopolymer concrete does not require heat to make it and it does not produce carbon dioxide. Standard Portland cement-based concrete requires both heat and carbon dioxide.The present study on the development of Geopolymer concrete by using industrial by-products such as fly ash as a substitute for OPC to manufacture concrete. The basic properties include workability of fresh concrete, compressive and tensile strength in the hardened state, and their resistance to acid attack when immersed in 10% sulphuric acid solution in a laboratory for different curing ages.

Keywords: *Compressive strength; Spilling Tensile Strength; Fly ash; Geopolymer concrete, acid attack.*

1.0 Introduction

The production of Portland cement, the main component of making concrete, contributes a 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. Therefore, the introduction of a novel binder called 'geopolymer' by Davidovits promises a good prospect for application in the concrete industry as an alternative binder to Portland cement. In terms of reducing global warming, geopolymer technology could reduce the CO2 emission to the atmosphere caused by cement and aggregates industries by 80%.In 1978, Davidovits introduced the word 'GEOPOLYMER' to describe an alternative cementitious material that has ceramic-like properties. As oppose to OPC, the manufacturer of fly ash-ground granulated blast furnace slag (GGBS) based geopolymer does not consume high levels of energy, as fly ash and slag are already an industrial by-product. This geopolymer technology has the potential to reduce emissions by 80%. Because high temperature calcining is not required. These also exhibit ceramic-like properties with superior resistance to fire at elevated temperatures. Geo-polymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions. Fly ash, which is available abundantly worldwide from coal-burning operations, is excellent alumino-silicate source material.

2. Literature Review

In 1978, Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and aluminum in source materials of the geological origin or by-product materials such as fly ash and rice husk ash. He termed these binders as geopolymers. Palomo et al (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. In this scheme, the main contents to be activated are silicon and calcium in the blast furnace slag. The main binder produced is a C-S-H gel, as the result of the hydration process.
In 2001, when this research began, several publications were available describinggeopolymer pastes and geopolymer coating materials (Davidovits 1991; Davidovits1994; Davidovits et al. 1994; Balaguru, et al. 1997; van Jaarsveld, et al. 1997; Balaguru 1998; van Jaarsveld et al. 1998; Davidovits 1999; Kurtz et al. 1999; Palomo et al. 1999; Barbosa et al. 2000). However, very little was available in the published literature regarding the use of geopolymer technology to make low-calcium(ASTM Class F) fly ash-based geopolymer concrete. This research was therefore dedicated to the development, manufacture, and engineering properties of the fresh and hardened low-calcium (ASTM Class F) fly ash-based geopolymer concrete.

3. Methodology

3.1 General
In recent years due to the accumulation of large quantities of fly ash as an industrial by-product, caused plenty of environmental hazards. Recognizing the need for utilization of fly ash to produce concrete, to save nature, and also due to some technical and economical reasons studies have been carried out previously on the usage of fly ash to produce concrete by completely replacing the cement. Hence our project is mainly concerned with making and testing low-calcium Class-F fly ash-based geopolymer concrete to know its basic properties.

3.1.1 Fly Ash: Fly ash used in this study was low-calcium (ASTM Class F) dry fly ash collected from Mettur Thermal Power Station, Mettur, Tamilnadu.

3.1.2 Cement: Ordinary Portland cement of 53 grade [Birla Super Plus] confirming to IS: 12269-2013 has been used. The results of the physical properties of the cement and the requirements as per IS 12269-2013.

3.1.3 Fine aggregate: Good river sand in absence of any earthy matter and organic matter. Particles are angular in shape passing 4.75mm and retaining on a 150-micron standard sieve. It confirmed the requirements of Indian Standard Specification (IS: 383).

Fig 3.1:-Slump of Fresh Geopolymer and OPC Concrete

3.1.4 Coarse aggregates: The maximum size of aggregate is generally limited to 20mm well-graded cubical or rounded aggregate is desirable. Aggregates should be of uniform quality concerning shape and grading. It confirmed the requirements of the Indian Standard Specification (IS:383).

3.1.5 Alkaline Liquid: The alkaline liquid used was a combination of sodium silicate solution and sodium-hydroxide solution along with a calculated amount of water, prepared at least one day before it is being used.
Sodium Hydroxide & Sodium Silicate Solution: The solid Sodium Hydroxide in the form of flakes or pellets of 98% purity is dissolved in a calculated amount of water to make the desired concentration of NaOH solution and also sodium silicate solution used.

3.1.6 Sulphuric Acid: Lab grade concentrates sulphuric acid solution of 98% purity is used. 100ml of concentrated $H_2SO_4$is diluted with 900ml to make 10% H_2SO_4solution, which is used to study the acid resistance behavior of both geopolymer concrete and ordinary Portland cement concrete **3.1.7 Water:** Clean potable Tap water was used for mixing and curing of concrete specimens.

3.2 Mix Design: Based on the limited past research on geopolymer pastes available in the literature review and the experience gained during the preliminary experimental work, the following ranges were selected for the constituents of the mixtures.

- Coarse & fine aggregate together were taken as 77% of the entire mixture by mass.
- Fine aggregate was taken as 30% of total aggregate by mass.
- From the past literature, the average density of fly-ash-based geopolymer concrete is taken similar to OPC concrete.i,e 2400kg/m3
- The ratio of alkaline liquid to fly ash 0.4
- The ratio of sodium silicate to sodium hydroxide was fixed as 2.5
- The concentration of NaOH is varied as 8M & 16M.
- The ratio of Total water to total geopolymer solid is 0.3

3.3 Manufacture of geopolymer concrete Test Specimens

3.3.1 Preparation of Alkaline Solution:

To prepare sodium hydroxide solution of **Z** molarity (**Z** M), (**Z** x 40 that is, molarity x molecular weight) of sodium hydroxide flakes was dissolved in a half-liter of water and then water is added to make it 1 liter. To make 8M NaOH Solution 320g & 16M NaOH Solution 640g of sodium hydroxide flakes was dissolved in half a liter of water and then water is added to make it 1 liter.

3.3.2 Manufacture of Fresh Concrete and Casting:

The solid constituents of the fly ash-based geopolymer & OPC-based concrete, that is the aggregates and the flyash, were dry mixed for about three minutes. After dry mixing, an alkaline solution was added to the dry mix and wet mixing was done for 4 to 5 min**.** Before the fresh concrete was cast into the molds, the slump value of the fresh concrete wasmeasured. As reported by fig 3.1

3.3.3 Curing of Test Specimens: After casting the specimens, they were kept in a rest period for two days, and then they were demoulded. The term 'Rest Period' was coined to indicate the time taken from the completion of the casting of test specimens to the start of curing. In this study curing of a specimen is done only in ambient condition (i,e. in lab temperature).reported by fig 3.2

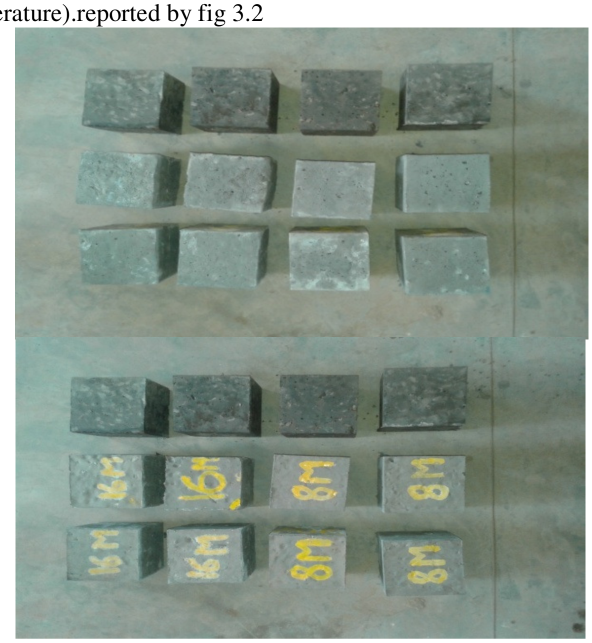

Fig 3.2: GPC & OPC Specimen in Rest Period and Curing

3.4 Compressive Strength Test: Both geopolymer concrete and ordinary portland cement concrete cubes of size 150×150×150mm is tested for their compressive strength at the 7^{th}, 14^{th}, and 28^{th} day of the curing period. The rated loading is fixed to 10 tonnes/min or 4.44 Mpa/min.

3.5 Split tensile strength test: Both geopolymer concrete and ordinary portland cement concrete cylinders of dimension 150mm in diameter and 300mm in height is tested for their tensile strength by adopting indirect tensile strength test method at 7^{th}, 14^{th}, and 28^{th} day of the curing period

3.6 Acid Resistance Test: In the present study both geopolymer concrete and ordinary portland cement concrete cubes specimen of size 150mm×150mm×150mm, after 28 Days of curing were immersed in a 10% Sulphuric Acid Solution. These specimens were tested for their mass change and residual compressive strength on the 7^{th} and 14^{th} day of immersion. A minimum of 3 specimens is tested at a specific immersion period.

4.0 RESULTS AND DISCUSSION

4.1. Introduction

In this Chapter, the test results are presented and discussed. The test results cover the effect of age on the compressive strength, split tensile strength, and resistance to the acid attack of both geopolymer concrete and ordinary Portland cement concrete.

Table 4.1: Test results of basic Materials.

Materials	Tests conducted	Results obtained	Requirement as per Code
Cement	Specific gravity	3.10	3.15
	Standard consistency (%)	30	-
	Initial setting time (min)	45	Not less than 30
	Final setting time (min)	385	Not more than 600
	Fineness (%)	2.20	Not more than 10
	Compressive strength at 7-days (MPa) 28-days (MPa)	 33.00 53.00	 33 53
Fine aggregate	Specific gravity	2.65	Not more than 2.75
	Bulk density (Kg/m^3)	1630	Not more than 1650
	Water absorption (%)	1.01	Not more than 2
	Fineness Modulus (%)	2.78	Not more than 3.2
Coarse aggregate	Specific gravity	2.67	Not more than 2.85
	Bulk density (Kg/m^3)	1590	Not more than 1650
	Fineness Modulus (%)	6.24	Not more than 8
	Water absorption (%)	0.806	Not more than 0.6%

4.2 Fresh Properties of Concrete: -

In the present study slump value of the fresh concrete was measured fly ash-based geopolymer 8M is 40.65mm, 16M is 40 mm of slump value & OPC based concrete is 15mm of slump value

4.3 Hardened property results:-The following Tables give the test results of OPC &GPC, Compressive strength, and Spiting tensile strength reported by Table 4.2 & 4.3

4.3.1 Compressive strength results:- The following are the tables that give the Compressive strength results of OPC& GPC for 7, 14, and 28 days.

Table 4.2: Compressive strength results of 7, 14, and 28 days

Mix Proportions	Compressive Strength (MPa)		
	7 days	14 days	28 days
OPC Mix	30.10	36.10	38.40
GPC-8M NaOH	25	27.95	32.20
GPC-16M NaOH	22	28.10	34.15

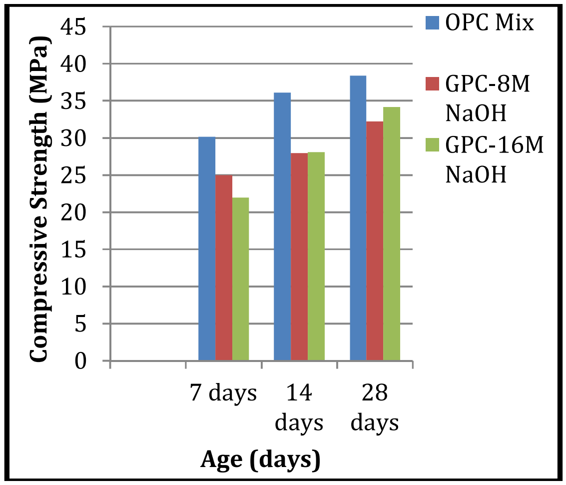

Fig 4.1:- A Graph of Compressive Strength verse curing period

Observation:-From Table 4.2 & Fig 4.1 it is clear that the compressive strength of geopolymer concrete increases with the increase in age of curing, similarly to that of ordinary portland cement concrete. Also, the strength of geopolymer concrete has seen to be increased with the increase in molar concentration of sodium hydroxide solution used, as shown in the graph, due to the increased rate of reaction. The increased reaction rate increases the dissolution of silicon and aluminum atoms from the fly-ash due to the action of Hydroxide ions. But the compressive strength of ordinary Portland cement concrete is found to be much higher than the geopolymer concrete prepared with both the concentrations of NaOH solution.

Table 4.3:Splitting tensile strength of 7, 14, and 28 days

Mix Proportions	**Splitting tensile strength (MPa)**		
	7days	**14 days**	**28 days**
OPC Mix	4.80	5.95	6.25
GPC-8M NaOH	3.860	4.20	4.95
GPC-16M NaOH	4.05	4.40	5.10

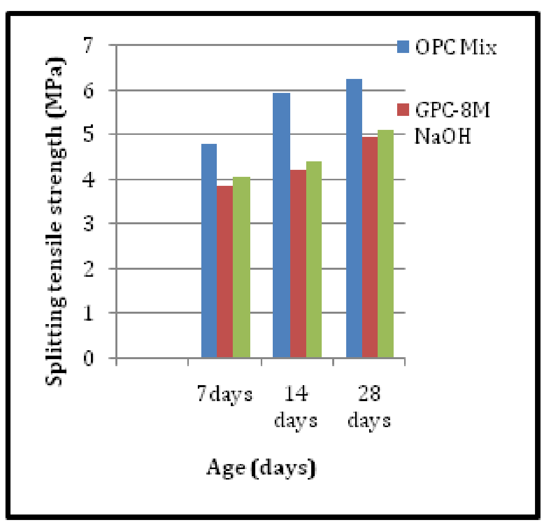

Fig 4.2:- A Graph of Splitting Strength verse age curing period

Observation: - From table 4.3 & Fig 4.2 it is clear that the tensile strength of geopolymer concrete increases with the increase in age of curing, similarly to that of ordinary Portland cement concrete. And the split tensile strength behavior of geopolymer concrete is as same as the compressive strength behavior which increases with the increase in molar concentration of NaOH solution

4.4 Acid Resistance Test: In the present study both geopolymer concrete and ordinary Portland cement concrete Change in mass due to acid attack and Residual compressive strength after acid attack on GPC

Table 4.4: Change in mass due to acid attack on GPC, prepared with 8M, 16M NaOH solution, and OPC

Mix Proportions	**Average of Change in Mass (%)**		
	7 days	**14 days**	**28 days**
OPC Mix	16.10	22.90	40.65
GPC-8M NaOH	2.25	3.15	3.80
GPC-16M NaOH	2.625	3.75	4.50

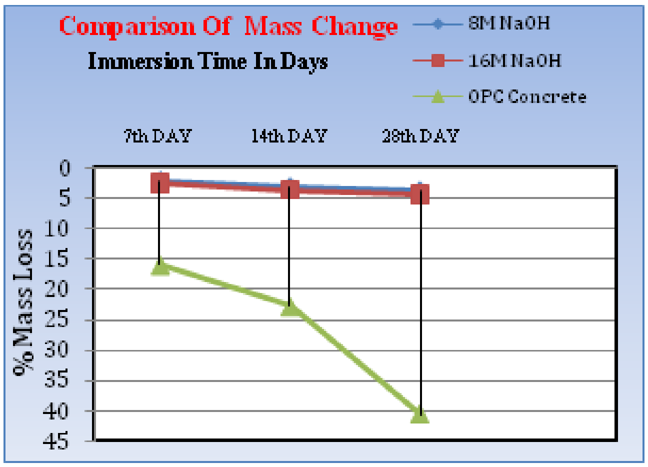

Fig 4.3:- Comparison of Change in Mass Due to Acid Attack

Observation:- From table 4.4 & fig 4.3 we can say that the resistance of geopolymer concrete for an acid attack is greater than that of ordinary portland cement concrete. The change in mass after the 7^{th}, 14^{th}, and 28^{th} day of immersion in 10% sulphuric acid solution is found to less in the case of geopolymer concrete and it is comparatively very high in ordinary portland cement concrete. This is maybe due to the attack of sulfate (SO_4^{2-}) ion on calcium hydroxide [$Ca(OH)_2$] which is freely available, to form calcium sulfate [$CaSO_4$]. The calcium sulfate formed further reacts with the calcium-aluminate phase to form calcium sulphoaluminate, which on crystallization can cause expansion and disruption of concrete. Also sulphuric acid attacks on C-S-H gel, due to which the bond in the concrete matrix decreases and all the cement compounds are eventually broken down and leaches away showing considerable deterioration. [2] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

Table 4.5: Residual compressive strength after acid attack on GPC prepared with 8M,16M NaOH solution

Mix Proportions	**Average of Change in Mass (%)**		
	7 days	**14 days**	**28 days**
GPC-8M NaOH	9.65	9.15	8.95
GPC-16M NaOH	19.10	18.10	17.90

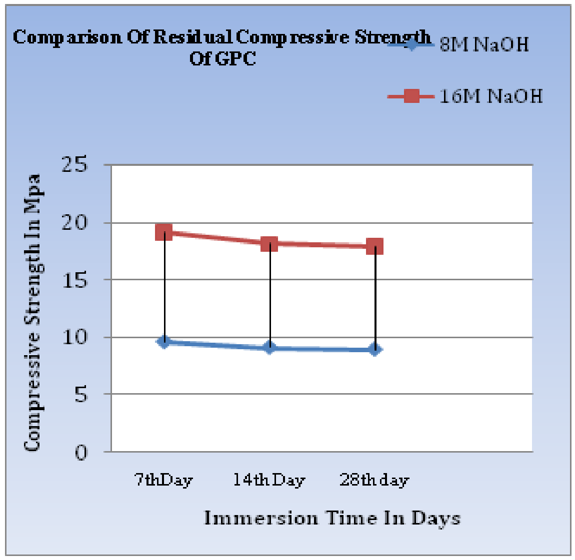

Fig 4.4:-Comparison of Residual Compressive Strength of acid Attack

Observation: - From table 4.5 & fig 4.4 we can say that Since, in ordinary portland cement concrete, the whole structure deteriorates it is not possible to determine its residual compressive strength. But, in the case of geopolymer concrete, since the deterioration level is less, the residual compressive strength is found out. Although the change in mass of geopolymer concrete prepared with 16M NaOH is more than that of prepared with 8M NaOH, the former still has high strength than the latter. This shows that change in mass due to acid attack has very little influence on the bond strength of geopolymer concrete.

5.0 CONCLUSIONS

Based on the laboratory investigation the following important conclusions have arrived.

- Workability of geopolymer concrete prepared with both the concentrations of NaOH has the slump value around 39mm to 41mm. and that of ordinary portland cement is around 15mm. from this, it is clear that the workability of geopolymer concrete is more when compared to the workability of ordinary portland cement concrete for the same mix proportion.
- It is observed that conventional concrete compressive strength and splitting tensile strength are more than 8M and 16M geo-polymer concrete.
- The resistance of geopolymer concrete to 10% H_2SO_4 solution is higher than the Ordinary portland cement concrete. The change in mass of geopolymer concrete is about 3.8% which is prepared with 8M NaOH. And about 4.5% for geopolymer concrete prepared with 16M NaOH. But coming to ordinary portland cement concrete it is about 41%.
- Coming to residual compressive strength it is highly impossible to determine the residual compressive strength of deteriorated ordinary portland cement concrete. Since the deterioration level is less in geopolymer concrete, residual compressive strength is determined and the difference between the strength of both geopolymers concretes prepared with 8M and 16M NaOH solution is as same as the strength observed when studied under compressive strength test. But the value of residual compressive strength obtained is less when compared to strength obtained under normal compressive strength test.

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