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Investigation on Fly ash based geopolymer concrete for an alternative of Ordinary Portland Cement Concrete

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ABSTRACT

Current concerns about global warming, due to the buildup of greenhouse gases in our Atmosphere, have prompted the cement industry to investigate alternatives to ordinary Portland Cement (OPC). One ton of carbon dioxide is produced for every ton of OPC. A sustainable alternative to this OPC is low CO_2 producing Geopolymer concrete (GPC). Geopolymers produce no CO_2 in chemical reactions and less emitted carbon dioxide due to manufacturing techniques. Hence, GPC's have emerged as a promising alternative to conventional cement concrete in this scenario. Fly ash based Geopolymer concrete is a special type of concrete where in the C-S-H gel of cement is replaced by an inorganic polymer of alumino silicates as the binder to bind the loose aggregates and other un-reacted material together. The two main constituents of GPC are Fly ash and an alkaline activator solution (AAS) which is a combination of Sodium silicate and Sodium hydroxide. The role of AAS is to activate the geopolymeric source material and conduct the polymerization. This article discusses the detailed preparation method of Fly ash based Geopolymer concrete and comparison of GPC with Ordinary Portland Cement Concrete for their compressive strength is done. Resistance of these concretes to Acid and Sulphate environments is investigated. The results have shown that Geopolymer concrete has strengths comparable to that of cement concrete and has excellent resistance to acid and sulphate solutions.
Keywords: Geopolymer Concrete, Nominal Concrete, Fly Ash, Compressive Strength, Workability.

I. INTRODUCTION

Concrete usage around the world is second only to water. Concrete manufacturing involves consumptions of ingredients like cement, fine aggregates, coarse aggregates, water and admixtures. The utilization of concrete is increasing manifold due to developments and subsequent demand for infrastructure and construction activities. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacturing of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced.

On the other hand, there is abundant availability of fly ash, which is mostly regarded as a waste material and dumped in landfills. This extensive availability of fly ash around the world creates opportunity to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass is a significant development.

Coal-based thermal power plants have been a major source of power generation in India where about 57% of the total power obtained is from coal-based thermal power plants . Fly Ash is a by-product material being generated by thermal power plants from combustion of Pulverized coal. Presently, the annual production of Fly Ash in India is about 112 million tonnes with 65,000 acres of land being occupied by ash ponds and is expected to cross 225 million tonnes by the year 2017. Such a huge quantity does pose challenging problems, in the form of land usage, health hazards and environmental dangers, both in disposal as well as in utilization.

Thus, Fly Ash, which is considered as an industrial waste, if utilized to its maximum capacity in the construction industry, provides the benefits of reducing the Conventional cement, production of which generate Carbon di Oxide as well as saving precious land from becoming a landfill site. Hence, Fly Ash based Geopolymer concretes have been gaining popularity as an eco friendly construction material and studies are being conducted on its suitability as an alternative to the much popular Portland cement concrete.

II. AIM OF THE STUDY

The present study deals with the manufacture and the short-term properties of low-calcium fly ash-based Geopolymer concrete (GPC).

The aims of the study were:

1. To understand the manufacturing process of Fly-ash based Geopolymer concrete.
2. To ascertain it's suitability as an alternative to conventional cement concrete.
3. Comparative study of Geopolymer based and Portland cement based concretes in acid and sulphate environments.

III. FLY ASH BASED GEOPOLYMER CONCRETE

3.1. Geopolymer concrete

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 geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

3.2. Use Of Fly Ash In Concrete

One of the efforts to produce more environmentally friendly concrete is to reduce the use of OPC by partially replacing the amount of cement in concrete with by-products materials such as fly ash. As a cement replacement, fly ash plays the role of an artificial pozzolan, where its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (C-S-H) gel. The spherical shape of fly ash often helps to improve the workability of the fresh concrete, while its small particle size also plays as filler of voids in the concrete, hence to produce dense and durable concrete.

An important achievement in the use of fly ash in concrete is the development of high volume fly ash (HVFA) concrete that successfully replaces the use of OPC in concrete up to 60% and yet possesses excellent mechanical properties with enhanced durability performance. The HVFA technology has been put into practice, for example the construction of roads in India, which implemented 50% OPC replacement by the fly ash

3.3. Low-Calcium Fly Ash-Based Geopolymer Concrete

In this work, low-calcium (ASTM Class F) 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 presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in geopolymer concrete. The silicon and the aluminium in the low-calcium (ASTM Class F) Fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials.

3.4. Manufacturing Process Of Geopolymer Concrete

Concrete mixture design process is vast and generally based on performance criteria. The aggregates and the fly ash are mixed dry in a pan mixer for about 4 minutes.

At the end of this dry mixing, the activator solution (prepared one day prior to casting), the super plasticiser, and the extra water (if any) are mixed together, and then added to the solid particles and the mixing continued for another 3 to 5 minutes. The fresh concrete is expected to have a stiff consistency and was glossy in appearance. The fresh concrete mixture was then cast in moulds in three layers and vibrated for 10 seconds on a vibrating table.

The previous studies on Geopolymer concrete revealed that geopolymer concrete did not attain any strength at room temperature or by water curing. The Geopolymer concrete will harden at steam curing or hot air curing and the minimum curing period shall be 24 hours. After casting the specimens, they were kept in rest period in room temperature for 2 days. The term 'Rest Period' was coined to indicate the time taken from the completion of casting of test specimen to the start of curing at an elevated temperature. The geopolymer concrete was demoulded and then placed in an autoclave for steam curing for 24 hours at a temperature of 60^{o} C. The cubes were then allowed to cool in room temperature for 24 hours.

IV. MATERIALS USED

Concrete, is a homogeneous mixture of cement, fine aggregates and coarse aggregates. Concrete derives its strength in the presence of water through hydration of cement. The bonding strength of concrete mainly depends on the cement used and the compressive strength of concrete is derived from the coarse and fine aggregates used. In case of Geopolymers, the bonding strength is obtained from the polymerization reaction that occurs when fly ash reacts with the alkali activator solution and the compressive strength is derived from the aggregates as in the case of conventional concrete. In present experimental work the following ingredients are used

4.1. Cement

Ordinary Portland cement 53 grade is used for the present work. The specific gravity of cement was found out in the laboratory and is obtained as 2.54

4.2 Fly Ash

The fly ash used in the experimental work was low calcium fly ash (ASTM Class F) with specific gravity 2.0

4.3.Fine Aggregates

The fine aggregates used for making concrete are normally of the maximum size 4.75mm, 2.36mm,1.18mm 600 microns, 300 microns and 150 microns.

4.4. Coarse Aggregates

Coarse aggregates of nominal size 20mm and sub round in shape are used for the experimental work with specific gravity of 2.78.

4.5 Alkaline activator solution

A combination of Sodium Silicate and 10 Molar Sodium Hydroxide was used in the experimental work. They were mixed together one day prior to the day of casting in the ratio of NaOH: Na_2SiO_3 of 1: 2.5

Sodium Hydroxide, commercially available in pellet form, is white in colour and produces a colourless solution when dissolve in distilled water. Sodium silicate is available in the form of a thick viscous liquid and is colourless. The combined solution was also colourless and sticky in nature.

4.6 Super Plasticizer

Glenium based super plasticizer from local construction site was used in the experimental work. Super plasticizers are added to concrete to improve the flow characteristics without majorly altering their strengths.

4.7 Water

Distilled water for mixing chemicals and fresh potable water for the purpose of workable mix was used in the experimental work

V. COMPARATIVE STUDY ON ACID RESISTANCE

In this experimental work, Fly ash based geopolymer concrete cubes and conventional concrete (M30 Grade) cubes of size 150mm×150mm×150mm were cast. Now, geopolymer concrete cubes and conventional concrete cubes were cured for a period of 7 days in their respective curing conditions. After completion of curing process, compressive strengths of both conventional and geopolymer concrete cubes were tested. Later, concrete specimens were immersed in 5% of acidic solution of sulphuric acid for a period of 7, 14, 28days.

After completion of immersion period, concrete specimens were taken out and allowed for drying for a period of 1 day and the compressive strength of concrete cubes after acid immersion was determined by using U.T.M. and the obtained results were compared. Residual compressive strength and percentage strength loss of geopolymer and conventional concrete cubes after 7, 14 and 28days acid immersion have been studied for comparison

VI. COMPARATIVE STUDY ON SULPHATE RESISTANCE

Sulphates , when come in contact with concrete, reacts with its components and causes deterioration in its structure. It combines with the concrete paste and begins destroying the paste that holds the concrete together. As sulfate dries, new compounds are formed, often called ettringite.(calcium sulphate hydrate) These new crystals occupy empty space, and as they continue to form, they cause the paste to crack, further damaging the concrete. Hence, resistance to sulphate attack is a major property desired in concrete.

In this experimental work, Fly ash based geopolymer concrete cubes and conventional concrete (M30 Grade) cubes of size 150mm×150mm×150mm were cast. Now, geopolymer concrete cubes and conventional concrete cubes were cured for a period of 7 days in their respective curing conditions. After completion of curing process, compressive strengths of both conventional and geopolymer concrete cubes were tested. Later, concrete specimens were immersed in 5% of sulphate solution of SODIUM SULPHATE for a period of 7, 14, 28days.

After completion of immersion period, concrete specimens were taken out and allowed for drying for a period of 1 day and the compressive strength of concrete cubes after sulphate immersion was determined by using U.T.M. and the obtained results were compared. Residual compressive strength and percentage strength loss of geopolymer and conventional concrete cubes after 7, 14 and 28days sulphate immersion have been studied for comparison.

VII. MIX DESIGN

Mix design is carried out for M30 grade concrete as per IS 10262 -2009 for Nominal concrete and from past literature for Geopolymer concrete.

7.1 Mix Design For Nominal Concrete:

Step 1: Calculation of Target Mean Strength

In order that not more than the specific proportion of test results are likely to fall below the characteristic strength, the concrete mix has to be proportioned for higher target mean compressive strength f'_{ck} . The margin over characteristic strength is given by the following relation

$$f'_{ck} = f_{ck} + 1.65\ s$$

Where s = standard deviation

f_{ck} = Characteristic compressive strength at 28 days

f'_{ck} = Target mean compressive strength at 28 days

Standard deviation values for different grades of concrete are assumed from **table 1** of **IS 10262 – 2009**

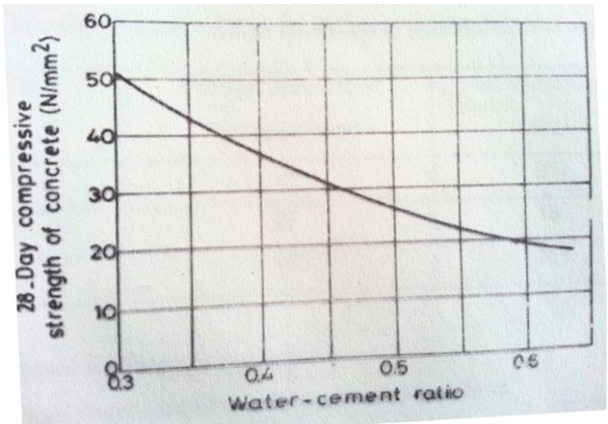
Table 1. Standard Deviation Values For Different Grades Of Concrete

Grade Of Concrete	**Assumed Standard Deviation (N/mm^2)**
M 10, M 15	3.5
M 20, M25	4.0
M 30, M 35, M 40, M45 and M 50	5.0

Step 2: Selection Of W/C Ratio

Water cement ratio is selected based on strength criteria and durability criteria from the following graph for plain concrete.

The obtained water cement ratio has to be checked against limiting water cement ratio as given in table 2 and the least o the two values has to be taken.



Graph 1. Graph showing W/C ratio against 28days compressive strength

Selection of water content depends on slump value, aggregate shape and size, admixtures and environmental conditions. Preliminarily, the water content is decided based on the size of aggregate from table 2 and then suitable corrections have to be applied based on the shape of aggregate, based on the slump value and presence of any admixtures.

Table2. Maximum Water Content For Different Nominal Size Of Aggregates

S.No.	Nominal Max Size Of Aggregate (mm)	Max Water Content (Kg)
1	10	208
2	20	186
3	40	165

Correction 1: Based On Shape Of Aggregate

The obtained water content has to be decreased as follows Sub angular: 10 litGravel with crushed part: 20 litRounded gravel: 25 lit

Correction 2: Based On Slump Value

The water content has to be increased in terms of 3% for every 25mm increase in slump.

Correction 3: Based On Admixtures

If there are any added admixtures, the water content has to be decreased as follows Water reducing admixtures : 5- 10% Super plasticizing admixtures: 20% and above

Step 3: Calculation Of Water Content

The average nominal size of aggregate taken is 20mm and the water content given in table 2 for 20mm aggregate is 186 litres. Since the size of aggregate, shape of aggregate and the slump value taken are in accordance with the specified conditions, no corrections were applied for water content.

Therefore water content obtained is 186 litres.

Step 4: Calculation Of Cement Content

The cement and supplementary cementations material per unit volume of concrete may be calculated from the free water-cement ratio and the quantity of water per unit volume of concrete.

Cement content = $\frac{\text{water content}}{\text{water}-\text{cement ratio}}$

Step 5: Calculation Of Fine Aggregate And Coarse Aggregate Contents

Aggregates of same nominal maximum size, type and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate per unit volume of total aggregate is used.

Correction 1:

Ratio changed at a rate of -/+ 0.01 for every +/- 0.05 change in W/C ratio.

Correction 2:

If concrete is applied through pumping or if concrete is used to work around congested steel, the volume of coarse aggregate is decreased by 10%.

Step 6: Mix Calculations

Volume of cement concrete=1m^3

Volume of cement=$\frac{\text{water of cement}}{\text{specific gravity of cement}}x\frac{1}{1000}$

$\frac{413.3}{2.54}$ x $\frac{1}{1000}$

=0.1627m^3

Volume of Water=0.186m^3

Total volume of aggregate

=1(0.16207+0.186)

= 0.6513 m^3

Volume of fine aggregate=0.37x0.6513

=0.241 m^3

Weight of aggregate= Volume of fine aggregate x Specific gravity of Volume of fine aggregate x1000

= 0.24 x2.54 x 1000

= 612.14 kg

Volume of Coarse aggregate=0.63 x 0.6513 = 0.41 m^3

Weight of Coarse aggregate=volume of Coarse aggregate x specific gravity of Coarse aggregate x1000

= 0.41 x2.78 x1000
=1139.8kg

Table 3. Volume Of Coarse Aggregate Per Unit Volume Of Total Aggregate For Different Zones Of Fine Aggregate

S. No.	Nominal Max Size Of Aggregate (mm)	Volume Of Coarse Aggregate Per Unit Volume Of Total Aggregate For Different Zones Of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zon e I
1	10	0.50	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

7.2 Mix Design For Geopolymer Concrete

The mix design of geopolymer concrete is based on Trial and Error method since there is no code provision for the mix design of geopolymer concrete as of now. Based on past literature and research on geopolymer concrete, suitable mix proportions were arrived at. An example is given below.

Assume that normal-density aggregates in SSD condition are to be used Unit-weight of concrete is 2400 kg/m^3.

Take the mass of combined aggregates as 77% of the mass of concrete. Therefore, Mass of combined aggregates = 0.77x2400=1848 kg/m^3.

The combined aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, let us assume that 30% of combined aggregates may comprise of sand to meet the requirements of standard grading curves.

Hence, the weight of fine aggregate = 0.3x 1848= 554 kg/m^3

The mass of low-calcium fly ash and the alkaline liquid together = (2400 – 1848) = 552 kg/m^3

Taking the alkaline liquid-to-fly ash ratio by mass as 0.35, the mass of fly ash = 552/ (1+0.35) = 408 kg/m^3.
The mass of alkaline liquid = 552 – 408
= 144 kg/m^3.
Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5;

Hence, the mass of sodium hydroxide solution = 144/ (1+2.5) = 41 kg/m^3

The mass of sodium silicate solution = 144 – 41 =103 kg/m^3.

Therefore, the trial mixture proportion is as follow: combined aggregates = 1848 kg/m3, low-calcium fly ash = 408 kg/m^3, sodium silicate solution = 103 kg /m^3, and sodium hydroxide solution = 41 kg/m^3 To manufacture the geopolymer concrete mixture, commercially available sodium silicate solution is taken. The sodium hydroxide solids (NaOH) with 97-98% purity is purchased from commercial sources, and mixed with distilled water to make a solution with a concentration of chosen molarity according to the mix desired

8.1. Cement Concrete Mix Design

Following are the site considerations used for the mix design for nominal concrete in our experimental work
Concrete Grade: M30
Type Of Cement : OPC 53
Type Of Aggregate : 20mm Sub rounded
Exposure Condition : Severe
Specific Gravity Of Cement : 2.54 g/cc
Specific Gravity of Fine Aggregate:2.54g/cc Specific Gravity of Coarse Aggregate:2.78 g/cc
Zone Provision : Zone II
Workability : 25 -50 mm (slump)

Step 1: Calculation Of Target Mean Strength

$\boldsymbol{f'_{ck} = f_{ck} + 1.65\ s}$

Where s = standard deviation
f_{ck} = Characteristic compressive strength at 28 days
f'_{ck} = Target mean compressive strength at 28 days
Standard deviation value for M30 grade concrete = 5.0 N/mm^2
Therefore f'_{ck} = 30 + 1.65 x 5.0
= 38.25 N/mm^2

Step 2: Selection Of W/C Ratio

From figure 1, W/C ratio obtained is 0.45 and the maximum W/C ratio for plain cement concrete for a severe exposure condition is 0.50

Hence W/C ratio of 0.45 is taken as a value satisfying both the conditions.

Step 3: Calculation Of Water Content

The average nominal size of aggregate taken is 20 mm and the water content given in table 2 for 20mm aggregate is 186 litres. Since the size of aggregate, shape of aggregate and the slump value taken are in accordance with the specified conditions, no corrections were applied for water content.

Therefore water content obtained is 186 litres.

Step 4: Calculation of Cement Content

Cement content = $\frac{\text{water content}}{\text{water−cement ratio}}$

$= \frac{186}{0.45}$

= 413.3 kg

The cement content obtained should be greater than the limiting cement content as given in durability criteria which is satisfactory for the above obtained value and the exposure conditions adopted.

Hence Cement content is 413.3 kg

Step 5: Volume of Fine Aggregates And Coarse Aggregates

Sieve analysis of fine aggregates taken for the experimental work conformed the fine aggregates into zone II and hence volume of coarse aggregate per unit volume of total aggregate obtained is 0.62 .

i.e., volume of CA per unit volume of TA

= 0.62 + (0.01 x 1)

= 0.63

Therefore, the volume of FA per unit volume of TA

=1-0.63 = 0.37

Step 6: Mix Calculations

Volume of cement concrete=1m^3

Volume of cement=$\frac{\text{water of cement}}{\text{specific gravity of cement}}x\frac{1}{1000}$

$\frac{413.3}{2.54}$ x $\frac{1}{1000}$

=0.1627m^3

Volume of Water=0.186m^3

Total volume of aggregate =

1-(0.16207+0.186)

= 0.6513m^3

Volume of fine aggregate=0.37x0.6513

=0.241 m^3

Weight of aggregate= Volume of fine aggregate x Specific gravity of Volume of fine aggregate x1000

= 0.24 x2.54 x 1000

=612.14 kg

Volume of Coarse aggregate=0.63 x 0.6513

=0.41 m^3

Weight of Coarse aggregate=volume of Coarse aggregate x specific gravity of Coarse aggregate x1000

= 0.41 x2.78 x1000

=1139.8kg

Table 4. Quantities of materials in cement concrete.

Material	Quantity
Cement (grade 53)	413.3Kg/m^3
Water	186 liters
Fine aggregate	612.14 kg/m^3
Coarse aggregate	1139.8Kg/m^3
Water: cement	0.45

The final mix proportions are cement: fine aggregate: coarse aggregate= **1: 1.48: 2.76**

Mould Specifications:

Size Of Cube =0.15 x 0.15 x 0.15

Volume Of Cube = 0.0033m^3

Number Of Cubes =27

8.2. Geopolymer Concrete Mix Design:

The optimum mix for Geopolymer concrete of M30 compressive strength was chosen as fly ash: fine aggregate: coarse aggregate of 1:1.5:3.3 with alkali liquid/ fly ash ratio of 0.35. The liquid was prepared by mixing Sodium silicate and Sodium hydroxide in the weight ratio of 2.5 and the Sodium Hydroxide chosen had a molarity of 10. A 10 molar solution of Geopolymer concrete has 314 grams of NaOH pellets in 1 kilogram of solution.

Table 5. Quantities of Geopolymer concrete ingredients.

Material	Quantity
Fly Ash	408 kg/m^3
Fine aggregate	612.00 kg/m^3
Coarse aggregate	1346.4 kg/m^3
Sodium Silicate solution	103 kg/m^3
SodiumHydroxide solution(10molar)	41 kg/m^3
Super Plasticizer	4 kg/m^3
Additional Water	20 kg/m^3

The final mix proportions are fly ash: fine aggregate: coarse aggregate= **1: 1.5: 3.3**

VIII. EXPERIMENTAL INVESTIGATIONS ON CONCRETE

Concrete cubes of sizes 150mm x 150mm x 150mm are casted by following the Mix design recommendations for both Cement concrete and Geopolymer concrete, cured in their respective conditions, and were tested for their 7days, 14days, 28days compressive strength by using the Compression Testing Machine. This test determines the peak load value that a specimen can withstand before failing. All tests were performed as per guidelines prescribed under IS: 516 - 1959

8.1 Test Results For Compressive Strength For M30 Grade Cement Concrete

The casted cubes were tested for their compressive strengths at 7days, 14days, 28days respectively and the results are tabulated as follows. Portland cement based concrete, which is the nominal mix, is designated as PCC and Geopolymer concrete is designated as GPC

Table 6. Test Results For Compressive Strength For M30 Grade cement concrete

Sample	Cement concrete 7 Days Testing		Cement concrete 14 Days Testing		Cement concrete 28 Days Testing	
	Peak Load (KN)	Peak Stress(MPa)	Peak Load (KN)	Peak Stress(MPa)	Peak Load (KN)	Peak Stress(MPa)
Sample 1	806.83	35.86	956.90	42.53	1098.00	48.40
Sample 2	810.44	36.02	950.80	42.26	987.75	43.90
Sample 3	806.30	35.84	913.70	40.61	1033.20	45.92
Average	807.90	35.91	940.46	41.8	1039.65	46.25

Table 7. Test Results For Compressive Strength For M30 Grade Geopolymer concrete

Sample	Geopolymer concrete 7 Days Testing		Geopolymer concrete 14 Days Testing		Geopolymer concrete 28 Days Testing	
	Peak Load (KN)	Peak Stress(MPa)	Peak Load (KN)	Peak Stress(MPa)	Peak Load (KN)	Peak Stress(MPa)
Sample 1	820.58	36.47	878.39	39.04	963.90	42.84
Sample 2	828.89	36.47	905.15	40.23	946.57	42.07
Sample 3	728.21	32.32	971.34	43.17	1017.92	45.24
Average	792.48	35.22	918.28	40.81	976.29	43.39

8.2.Comparative study on acid resistance (Acid Immersion)

Compressive strength of reference mixes:

Compressive strength of geopolymer concrete after 7 days of curing was 35.22 MPa ,after 14 days curing 40.81 MPa and after 28 days curing 43.39 Mpa.

Compressive strength of conventional concrete after 7 days of curing was 35.91Mpa ,after 14 days curing 40.81 MPa and after 28 days curing 46.25 Mpa.

Table 8. Test Results For 7 days Compressive Strength For M30 Grade concrete

Sample	Cement concrete 7 days acid testing		Geopolymer concrete 7 days acid testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	511.88	2.75	748.13	33.25
Sample2	569.02	5.29	677.48	30.11
Sample3	473.87	1.06	670.95	29.82
Average	518.26	3.03	698.87	31.06

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.91-23.03) ÷35.91×100 = **35.87%**

Percentage Loss In Compressive Strength in Geopolymer concrete= Loss in compressive strength ÷ initial compressive strength×100
= (35.22-31.06) ÷35.22 ×100 = **11.81%**

Table 9. Test Results For 14 days Compressive Strength For M30 Grade concrete

Sample	Cement concrete 14 days acid testing		Geopolymer concrete 14 days acid testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	525.2	23.37	636.96	28.31
Sample2	430.8	19.12	671.85	29.86
Sample3	461.2	20.49	650.91	28.93
Average	472.7	20.99	653.24	29.03

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.91-20.99) ÷ 35.91 × 100 **= 41.55%**

Percentage Loss In Compressive Strength in Geopolymer concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.22-29.03) ÷ 35.22 × 100 **= 17.57%**

Table 10. Test Results For 28 days Compressive Strength For M30 Grade

Sample	Cement concrete 28 days acid testing		Geopolymer concrete 28 days acid testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	382.26	16.99	597.59	26.56
Sample2	391.95	17.42	655.88	29.15
Sample3	418.47	18.60	562.94	25.02
Average	397.56	17.67	605.47	26.91

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.91-17.67) ÷ 35.91 × 100 **= 50.79%**

Percentage Loss In Compressive Strength in Cement concrete = Los in compressive strength ÷ initial compressive strength×100
= (35.91-31.57) ÷ 35.91 × 100 **= 12.09%**

Percentage Loss In Compressive Strength in Geopolymer concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.22-33.54) ÷35.22 ×100 = **4.80%**

8.3.Comparative study on sulphate resistance

Compressive strength of reference mixes:

Compressive strength of geopolymer concrete after 7 days of curing was 35.22 MPa ,after 14 days curing 40.81 MPa and after 28 days curing 43.39 Mpa.

Compressive strength of conventional concrete after 7 days of curing was 35.91Mpa ,after 14 days curing 40.81 MPa and after 28 days curing 46.25 Mpa.

Table:11 Test Results For 7 days Compressive Strength For M30 Grade

Sample	Cement concrete 7 days sulphate testing		Geopolymer concrete 7 days sulphate testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	746.33	33.17	763.18	33.92
Sample2	730.36	32.46	779.20	34.63
Sample3	772.22	34.32	760.73	33.81
Average	749.64	33.31	767.70	34.12

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.91-33.31) ÷ 35.91 × 100 **= 7.25%**
Percentage Loss In Compressive Strength in Geopolymer concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.22-34.12) ÷35.22 ×100 **= 3.12%**

Table 12. Test Results For 14 days Compressive Strength For M30 Grade

Sample	Cement concrete 14 days sulphate testing		Geopolymer concrete 14 days sulphate testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	761.3	33.85	740.47	32.91
Sample2	690.2	30.69	749.24	33.30
Sample3	679.7	30.22	774.26	34.41
Average	710.1	31.57	754.66	33.54

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.91-31.57) ÷ 35.91 × 100 **= 12.09%**

Percentage Loss In Compressive Strength in Geopolymer concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.22-33.54) ÷35.22 ×100 = **4.80%**

Table 13. Test Results For 28 days Compressive Strength For M30 Grade (sulphate testing)

Sample	Cement concrete 7 days sulphate testing		Geopolymer concrete 7 days sulphate testing	
	Peak load (KN)	Peak stress (MPa)	Peak load (KN)	Peak stress (MPa)
Sample1	651.9	28.95	692.14	30.76
Sample2	567.7	25.23	664.86	29.55
Sample3	600.8	26.71	746.10	33.16
Average	606.8	26.96	701.03	31.15

Percentage Loss In Compressive Strength in Cement concrete = Loss in compressive strength ÷ initial compressive strength×100
=(35.91-26.96) ÷ 35.91 × 100 **= 24.91%**
Percentage Loss In Compressive Strength in Geopolymer concrete = Loss in compressive strength ÷ initial compressive strength×100
= (35.22-31.15) ÷35.22 ×100 **= 11.53%**

IX. RESULTS AND DISCUSSION

9.1. Test Results On Fresh Concrete

Workability of the concrete mixes, both conventional and geopolymer has been measured using the Slump Cone Test. In both the cases, True Slump was observed and the mixes rendered sufficient workability

Table 14. Slump values for concrete mixes.

S.no	Types of concrete	Slump value
1	Cement concrete	37
2	Geopolymer concrete	40

9.2 Test Results On Hardened Concrete

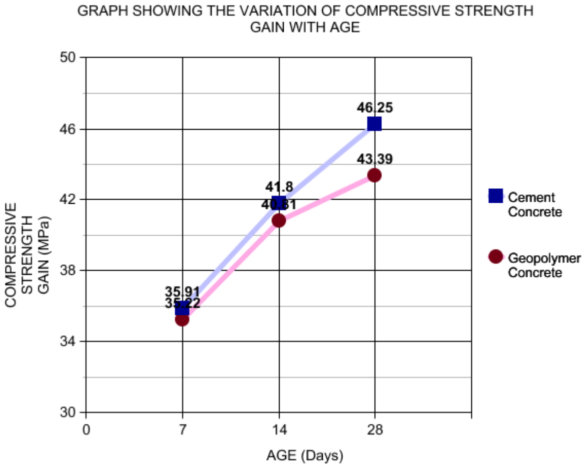
A total of 54 cube of cement concrete and Geopolymer Concrete were casted. After 7,14 and 28 days of strength gain, the cubes were immersed in 5% acid and sulphate solutions. Compressive strengths of both cement concrete and geopolymer concrete cubes after 7, 14 and 28 days of solution immersion were tested and compared for the loss in strength.

9.2.1 Comparison Of Compressive Strength Gain

Tests on cube compressive strength of Cement Concrete and Geopolymer Concrete have yielded the following results. Cement concrete cubes were cured by placing in a water curing tank and Geopolymer concrete cubes, after 24 hours of hot air curing, were left to air dry until the test date. Compressive strength of cubes was found as an average of three test cubes and the average value tabulated. Both mixes showed satisfactory performance and achieved the design compressive strength.

Table 15. Compressive strength gain with age of curing.

Age Of Curing (Days)	Cube Compressive Strength (MPa)	
	Cement Concrete	Geopolymer Concrete
7	35.91	35.22
14	41.80	40.81
28	46.25	43.39



Graph 2. The variation of compressive strength gain with age of curing.

9.2.2 Test Results On Acid Immersion Of Concrete

Hardened concrete cubes, after 7 days of curing in their respective conditions, were immersed in 5% Sulphuric Acid solution to test the resistance to acid attack. The average of three test cubes after 7, 14 and 28 days of immersion in acid solution were tabulated and compared.

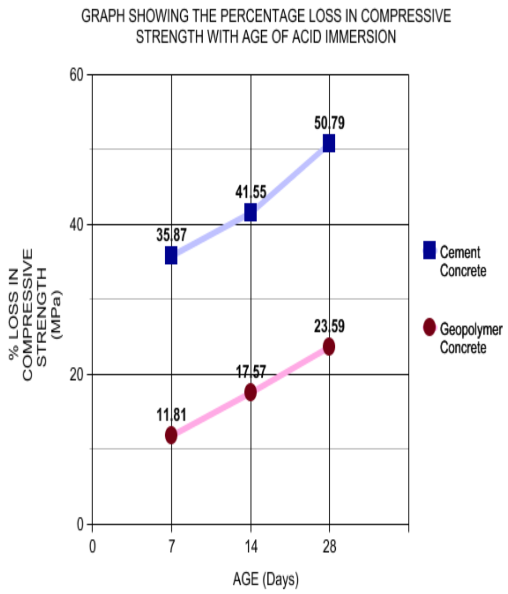
Table 16. Residual compressive strength after various ages of acid immersion.

Age Of Immersion (Days)	Cube Compressive Strength (MPa)	
	Cement Concrete	Geopolymer Concrete
7	26.99	31.06
14	20.99	29.03
28	17.67	26.91

The percentage loss in compressive strength was calculated by dividing the reduction in the compressive strength (from the initial compressive strength value of 7 days) with the initial value. These values give us accurate idea about the extent of resistance of these concretes in acidic environment.

Table 17. %Loss in compressive strength after acid immersion.

Age Of Immersion (Days)	%Loss In Compressive Strength	
	Cement Concrete	Geopolymer Concrete
7	35.87%	11.81%
14	41.55%	17.57%
28	50.79%	23.59%



Graph 3. Percentage loss in compressive strength with acid immersion.

9.2.3 Test Results On Sulphate Immersion Of Concrete

Hardened concrete cubes, after 7 days of curing in their respective conditions, were immersed in 5% Sodium Sulphate solution to test their resistance to sulphate attack. The average of three test cubes after 7, 14 and 28 days of immersion in sulphate solution were tabulated and compared.

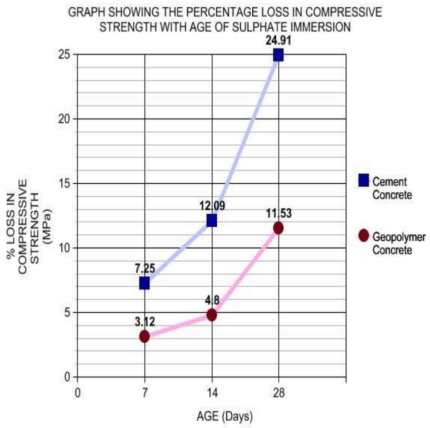
Table 18. Residual compressive strength after various ages of sulphate immersion.

Age Of Immersion (Days)	Cube Compressive Strength (MPa)	
	Cement Concrete	Geopolymer Concrete
7	33.31	34.12
14	31.57	33.54
28	26.96	31.15

The percentage loss in compressive strength was calculated by dividing the reduction in the compressive strength, from the initial compressive strength value of 7 days, with the initial value. These values give us accurate idea about the extent of resistance of these concretes in sulphate environment.

Table 19. %Loss in compressive strength after sulphate immersion

Age Of Immersion (Days)	%Loss In Compressive Strength	
	Cement Concrete	Geopolymer Concrete
7	7.25%	3.12%
14	12.09%	4.80%
28	24.91%	11.53%



Graph 4. Percentage loss in compressive strength with sulphate immersion.

X. CONCLUSION

From the results obtained in the Sulphuric acid and Sodium sulphate immersion tests, it can be seen that Geopolymer concrete had resisted acids and sulphates in a better way compared to Cement concrete. This property of Geopolymer concrete is attributed to the fact that Fly ash based GPC, having low contents of calcium, having a strong polymerization tends to be passive to aggressive environment. And also, since geopolymer concrete does not rely on lime like Portland cement concrete, it resists reactive chemicals in a better way.

The immersion of Portland cement based cubes in sulphuric acid attack leads to deposition of a white layer of gypsum crystals on the acid-exposed surface of the specimen. Whereas, geopolymer cement tested, unlike Portland cement, no gypsum deposition can be detected visually. Also, on visual inspection, one can observe that Cement concrete has seen erosion of its skin and the aggregates being exposed. This erosion was minimum in the case of Geopolymer concrete cubes.

This property of high resistance to sulphuric acid environment makes Geopolymer concrete an ideal choice for acid resistant coatings for installations in the chemical and sewage industry.

The immersion of cement concrete cubes in sulphate solution has lead to the formation of white stains on prolonged immersion. This degradation was absent in Geopolymer concrete owing to its low calcium content. This property of Geopolymer concrete is particularly beneficial in such conditions where the concrete is exposed to the risk of deterioration due to sulphate attack such as Foundations, piles, Basements and underground structures, Sewage and Water treatment plants, Chemical, Fertilizers and Sugar factories, Food processing industries and Petrochemical projects, Coastal works, Construction of building along the coastal area within 50 km from coast line.

XI. REFERENCES

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