Durability of Fly ash based Geopolymer Concrete using Alkaline Solutions (NaOH and Na_2SiO_3)

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ABSTRACT

This study presents an investigation into the durability of geopolymer concrete manufactured using class F fly ash and alkaline activators (NaOH and Na_2SiO_3) when exposed to sulphate and acidic environment and comparison was made with normal Ordinary Portland Cement (OPC) concrete. In total four tests were conducted to determine acid and sulphate resistance of geopolymer concrete. The tests involved immersion for a period of 30 to 60 days into 5% solution of sodium sulphate, 5% solution of magnesium sulphate, 5% solution of sulphuric acid and 5% solution of phosphoric acid. The evolution of weight loss and compressive strength loss were studied.

The most significant degradation of compressive strength and weight were determined in acid solution. The least strength changes and weight loss were found in the sulphate solution. The OPC concrete more deteriorated in acid as well as in sulphate solution in compared with geopolymer concrete, thus geopolymer concrete is more durable than the OPC concrete.

Keywords: Durability, Acid resistance, Sulphate resistance, Fly ash, Alkaline activators.

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INTRODUCTION

Concrete is the most versatile material of construction the world over. It is man made material. Concrete is the material of choice for a variety of applications such as housing, bridges, highway pavements, industrial structures, water-carrying and retaining structures, etc. The credit for this achievement goes to well-known advantages of concrete such as easy availability of ingredients, adequate engineering properties for a variety of structural applications, adaptability, versatility, relative low cost, etc. Moreover, concrete has an excellent ecological profile compared with other materials of construction.

Geopolymer concrete

Geopolymer concrete, known also as resin concrete, is a constructional composite, a variation of concrete, in which traditional binder - cement, has been fully replaced with fly ash, red mud, fibres etc (synthetic resin). With a hardening agent and filler: mixture of sand-and-gravel and quartz powder. Binder of polymer concrete is crucial for improved strength in relation to ordinary concrete, and particularly for chemical resistance.

Geopolymer is a combined product of aluminium and silicon. It is produced by geochemistry process. Fly ash based geopolymers use fly ash as the material which acts as source of silicon and aluminium for reaction by an alkali to make silicon and aluminium atoms to form geopolymer paste. When fly ash based geopolymer acts as a binder material, fly ash takes part in the reaction to form alumino-silicate binder. It binds components such as aggregate together to form geopolymer concrete. From various works it has been found that in any geopolymer concrete aggregates occupy 75-80% by mass.

The schematic formation of geopolymer material has vividly been shown by Davidovits (1994), Van Jarsveld et al (1997): -

- n(Si_2O_5, Al_2O_2) + 2nSiO_2+4nH_2O + NaOH or KOH ➡ Na^+, K^{++} n$(OH)_3$-Si-O-Al—O-Si $(OH)_3$ (Si-Al materials) $(OH)_2$ (Geopolymer precursor) ------------- (1)
- n$(OH)_3$-Si-O-Al—Si-$(OH)_3$+NaOH or KOH ➡ (Na^+, K^+) (-Si-O-Al—O-Si-O-) + 4nH_2O $(OH)_2$ O-O-O (Geopolymer backbone) ------------ (2)

Durability

Durability is defined as the capability of concrete to resist weathering action, chemical attack, abrasion or any other process of deterioration while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance.

Factor influencing durability

The factors influencing durability include:

- The environment
- The cover to embedded steel
- The type and quality of constituent material
- The cement content and water binder ratio of concrete
- Workmanship to obtain full compaction and efficient curing
- The shape and size of member.

Types of durability tests

- There are following types of durability tests:
- Rapid chloride penetration test (RCPT)
- Oxygen penetration test
- Resistance to rapid freezing and thawing test
- Acid resistance test
- Sulphate resistance test
- Saturated water absorption test

In this study acid resistance and sulphate resistance tests are applied on the geopolymer concrete and OPC concrete.

Fly ash

Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by flue gases and collected by electrostatic precipitator.

ASTM classifies fly ash into two classes:

- Class-F: Fly ash normally produced by burning anthracite or bituminous coal, usually has less than 5% CaO. Class F fly ash has pozzolanic properties only.
- Class-C: Fly ash normally produced by burning lignite or sub-bituminous coal, usually has CaO content in excess of 10%. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

OBJECTIVES

1. To study research papers related to durability of Geopolymer concrete, OPC concrete and fiber concrete and durability testing of concrete.
2. To prepare Geopolymer concrete specimens using fly ash and alkaline solution (NaOH and Na_2SiO_3) and OPC concrete specimens.
3. To determine acid resistance of Geopolymer concrete and OPC concrete specimens.
4. To determine sulphate resistance of Geopolymer concrete and OPC concrete specimens.
5. To compare durability of Geopolymer concrete and OPC concrete.
6.

MATERIAL AND EXPERIMENTAL STUDY

Material used for Geopolymer concrete

The materials used for preparation of Geopolymer Concrete in the laboratory were coarse aggregates (10mm-20mm), fine aggregates, Fly ash, Sodium Hydroxide, Sodium Silicate**.**

Aggregate

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium to form compound materials. By volume, aggregate generally accounts for about 70 to 80 percent of portland cement concrete and about 70 to 75 percent of Geopolymer concrete. A good quality, well graded coarse aggregate size 20mm, 10mm and 6mm were used in preparation of all test specimens. Fine river sand with the fineness of modulus of 2.28 was used as a fine aggregate.

Fly ash

Fly ash is a by-product obtained during the combustion of coal in Thermal Power Plants. Fly ash used in this study was low-calcium (ASTM Class F). The chemical composition of the Fly ash is given in table. The Specific gravity of Fly Ash is founded 2.26.

Table 1: Chemical Composition of Fly Ash

S.NO.	Constituents	Percentage
1	Cao	03.68
2	Silica content SiO_2	60.27
3	Al_2O_3	25.46
4	Fe_2O_3	06.02
5	Loss of Ignition	01.10

6	Magnesium Oxide	00.29
7	Available Alkalies	02.64
8	SO_3	00.12
9	Chloride	00.01

Alkaline liquid

The alkaline liquid used in geopoiymer concrete, Is a combination of sodium silicate solution and sodium hydroxide solution. The pellets which are made up of sodium hydroxide having 98% purity and it are dissolved in water to make a required concentration solution. In the present study the molarity of NaOH solution is kept 14M for all specimens. The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use to prepare the alkaline liquid.

Cement

The cement used in this study was an Ordinary Portland Cement (OPC) 43 grade (Ultratech cement). Cement was purchased from local supplier. Cement was used in making OPC concrete for comparing with geopolymer concrete.

Manufacturing of Geopolymer concrete

The source material Fly ash, sand and Aggregates are mixed together as conventional concrete is mixed. The alkaline solution is mixed in the dry materials and required water is added. The fresh concrete was cast into the moulds immediately after mixing.

After casting, the test specimens were kept for heat-cured at 60^{o}C for 24 hours. After the curing period, the test specimens were left in the moulds for at least six hours in order to avoid a drastic change in the environmental conditions. After demoulding, the specimens were left to air-dry in the laboratory until the day of test.

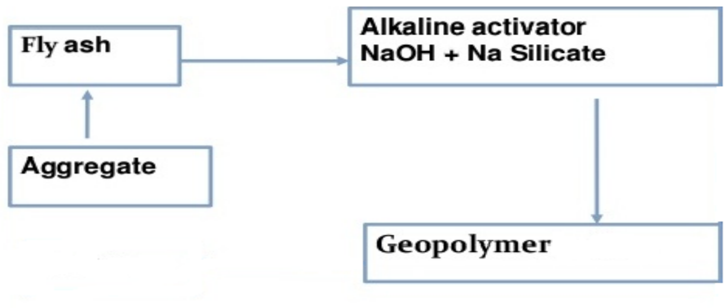


Figure 1: Manufacturing of geopolymer concrete

Mix Proportion

Table 2 Mix proportion of Geopolymer concrete

Mix	Ratio (FA:Sand:CA)	Alkaline to Fly Ash Ratio	Sodium Hydroxide to Sodium Silicate Ratio
M-40	1:1.35:3.00	0.6	2.5

Table 3 Mix proportion of OPC concrete

Mix	Ratio (Cement:Sand:CA)	Water to Cement Ratio
M-40	1:1.3:3.05	0.4

Durability test

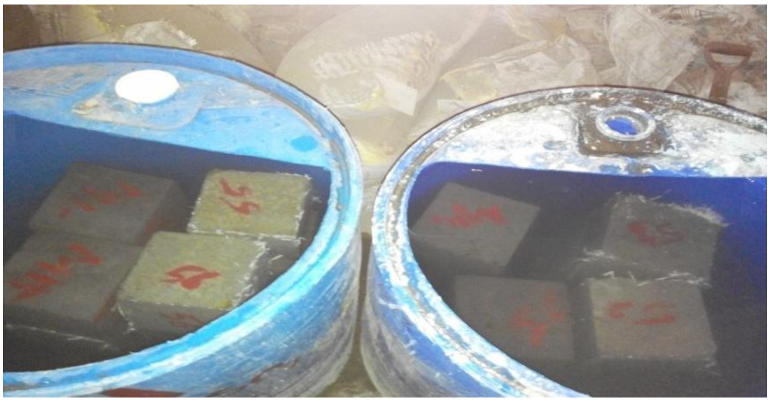
Acid resistance

Acid resistance was tested on 15×15×15 cm size cube specimens made of geopolymer concrete. The cube specimens were weighed and immersed in 5% solution of sulphuric acid and 5% solution of phosphoric acid for 30 and 60 days respectively. Then the specimens were taken out from the acid solutions and the surfaces of specimens were cleaned and the weight and compressive strength of specimens were found out and thus the average loss of weight and compressive strength were calculated.

Photograph 1: Cubes immersed into acid Solutions

Sulphate resistance

The sulphate attack testing procedure was conducted on 150×150×150 mm size cube specimens of geopolymer concrete. Then, they were cured in 5% sodium sulphate solution and 5% magnesium sulphate solution for 30 and 60 days respectively. This type of testing represent an accelerated testing procedure, which indicates the performance of particular concrete mixes to sulphate attack on geopolymer concrete. The degree of sulphate attack was evaluated by measuring the weight losses and compressive strength loss of the specimens at 30 and 60 days respectively.



Photograph 2: Cubes immersed into Sulphate Solutions

For comparison purpose, these test were also performed on same grade of OPC concrete. But for this test on OPC concrete the specimen cubes were first cured for 28 days and then sulphate resistance test was performed with the same procedure as mentioned above.

RESULTS

Resistance to acid attack

Weight loss

Table 4 Weight loss (in %) due to 5% solution of H_2SO_4

No. of Days	OPC concrete (%)	Geopolymer concrete (%)
0 Day	0	0
30 Days	3.50	2.35
60 Days	6.76	3.36

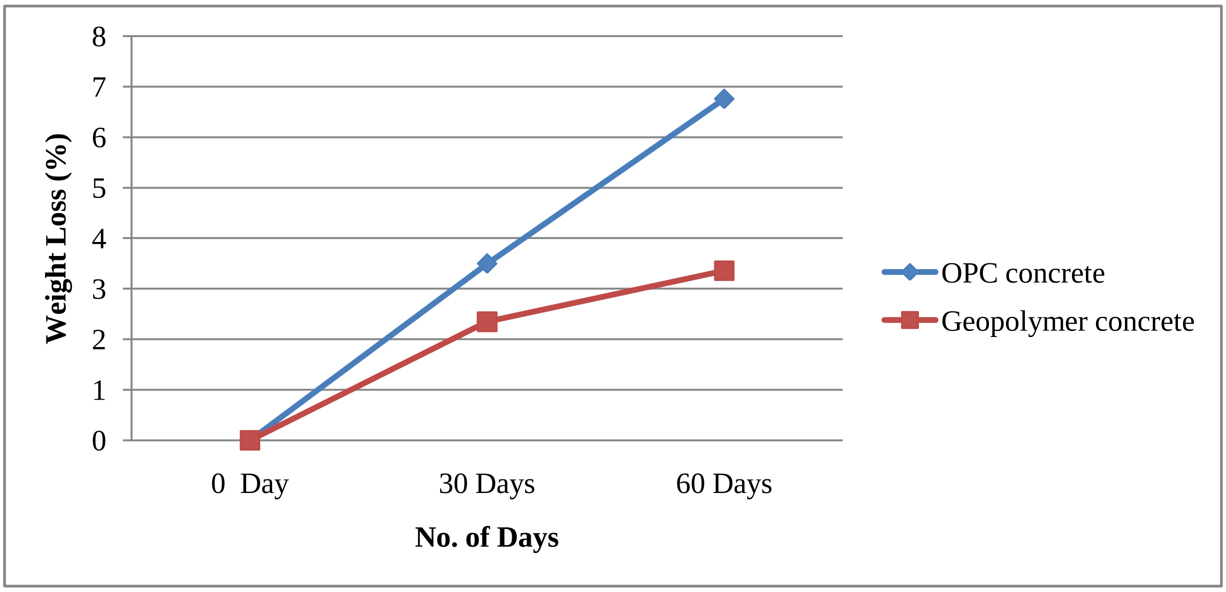


Figure 1: Comparison of Weight loss (in %) of M40 OPC Concrete with Geopolymer Concrete due to 5% solution of H_2SO_4

Table 5 Weight loss (in %) due to 5% solution of H_3PO_4

No. of Days	OPC concrete (%)	Geopolymer concrete (%)
0 Day	0	0
30 Days	2.49	1.78
60 Days	3.99	2.02

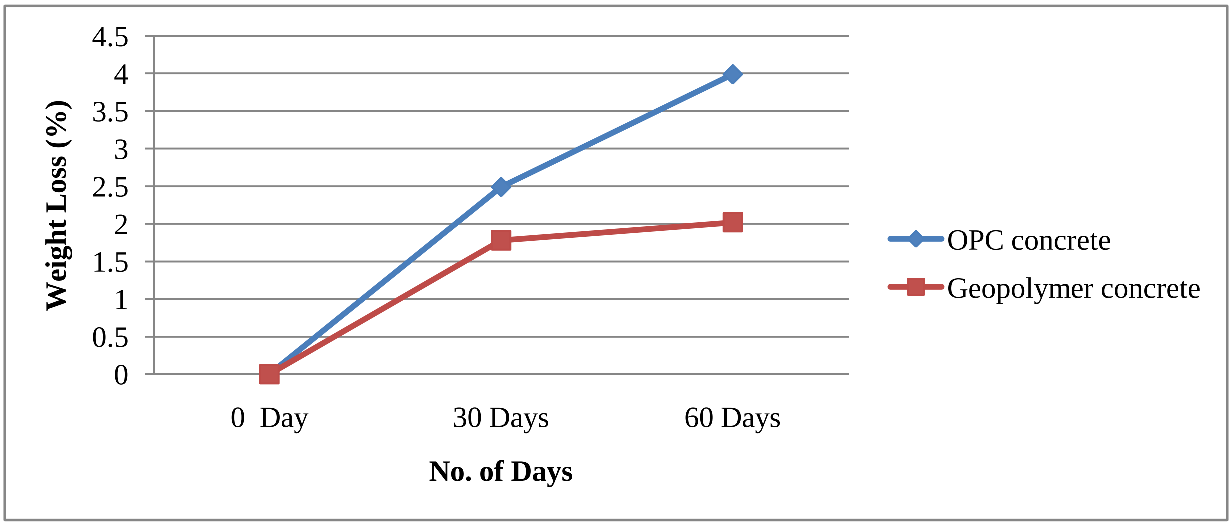


Figure 2: Comparison of Weight loss (in %) of M40 OPC Concrete with Geopolymer Concrete due to 5% solution of H_3PO_4

Photograph 3: Specimen cubes after acid attack

Compressive strength

Table 6: Compressive strength of concrete due to 5% solution of H_2SO_4 (N/mm^2)

No. of Days	OPC concrete (N/mm^2)	Geopolymer concrete (N/mm^2)
0 Day	39.43	39.57
30 Days	32.88	34.78
60 Days	30.66	31.85

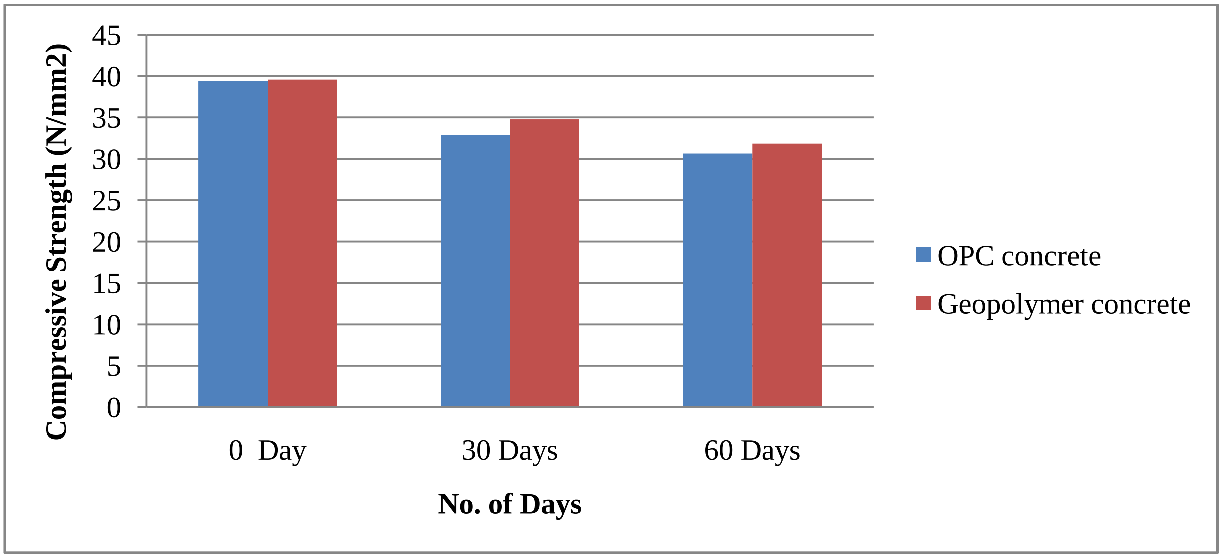


Figure 3: Comparison of Compressive strength of M40 OPC concrete with Geopolymer concrete due to 5% solution of H_2SO_4 (N/mm^2)

Table 7: Compressive strength of concrete due to 5% solution of H_3PO_4 (N/mm^2)

No. of Days	OPC concrete (N/mm^2)	Geopolymer concrete (N/mm^2)
0 Day	39.43	39.57
30 Days	34.66	36.85
60 Days	31.77	32.42

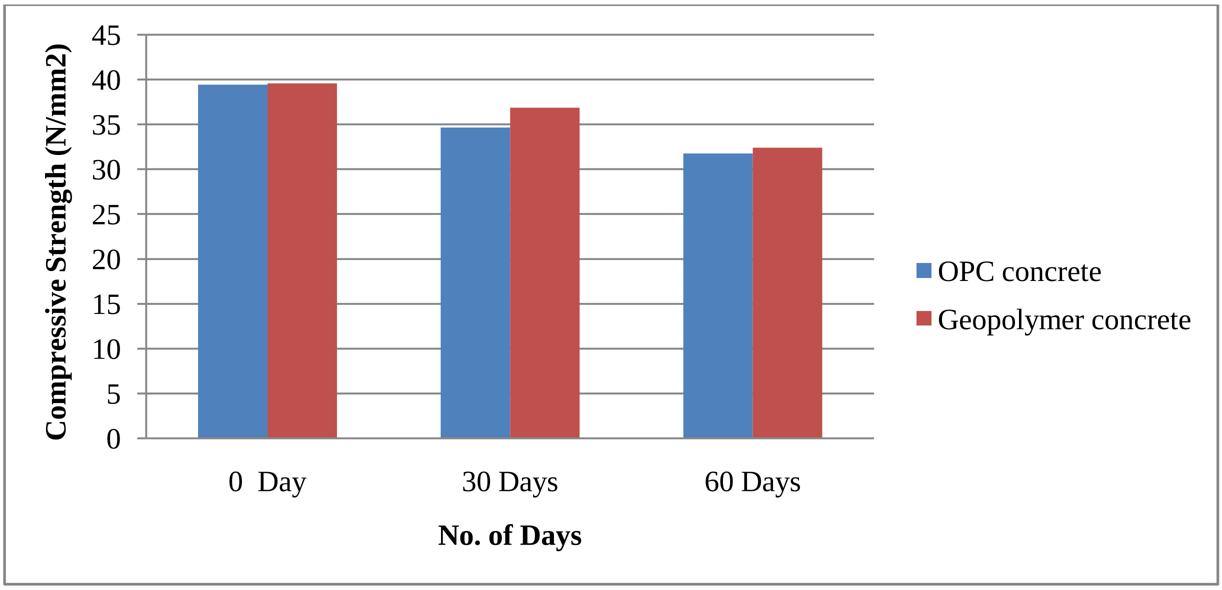


Figure 4: Comparison of Compressive strength of M40 OPC concrete with Geopolymer concrete due to 5% solution of H_3PO_4 (N/mm^2)

Resistance to sulphate attack

Weight loss

Table 8: Weight loss (in %) due to Na_2SO_4

No. of Days	OPC concrete (%)	Geopolymer concrete (%)
0 Day	0	0
30 Days	1.00	0.77
60 Days	1.50	1.24

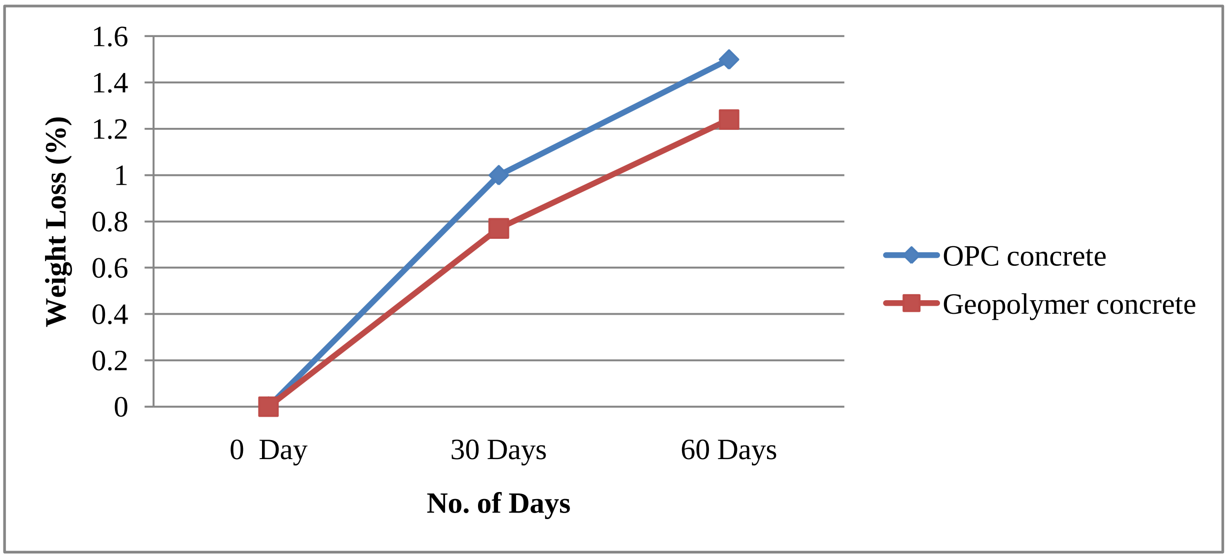


Figure 5: Comparison of Weight loss (in %) of M40 OPC Concrete with Geopolymer Concrete due to 5% solution of Na_2SO_4

Table 9 Weight loss (in %) due to 5% solution of $MgSO_4$

No. of Days	OPC concrete (%)	Geopolymer concrete (%)
0 Day	0	0
30 Days	0.70	0.34
60 Days	1.25	0.79

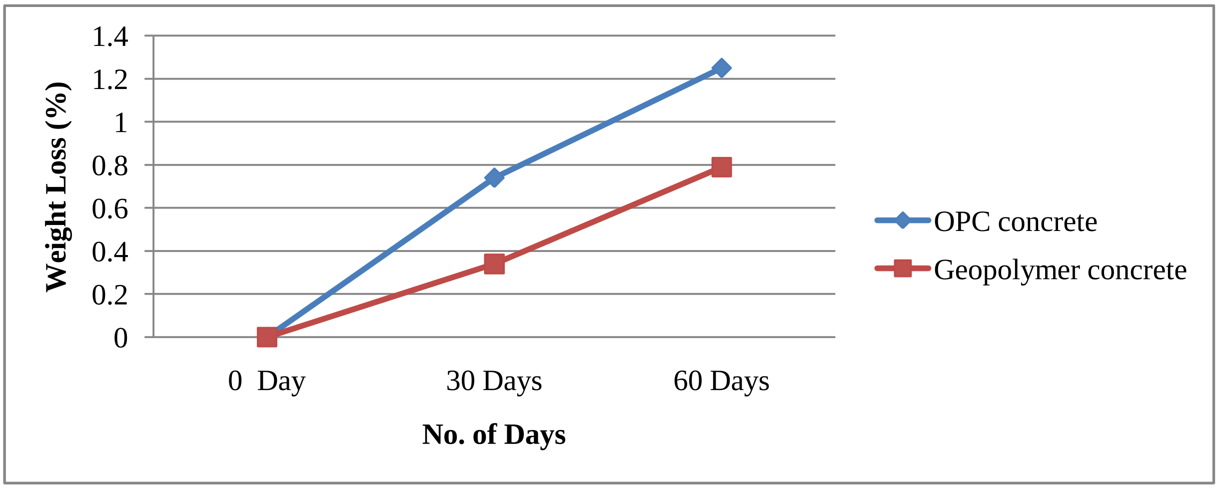


Figure 6: Comparison of Weight loss (in %) of M40 OPC Concrete with Geopolymer Concrete due to 5% solution of $MgSO_4$

Photograph 4: Specimen cubes after sulphate attack

Compressive strength

Table 10: Compressive strength of concrete due to 5% solution of Na_2SO_4 (N/mm^2)

No. of Days	OPC concrete (N/mm^2)	Geopolymer concrete (N/mm^2)
0 Day	39.43	39.57
30 Days	36.44	37.65
60 Days	34.45	34.77

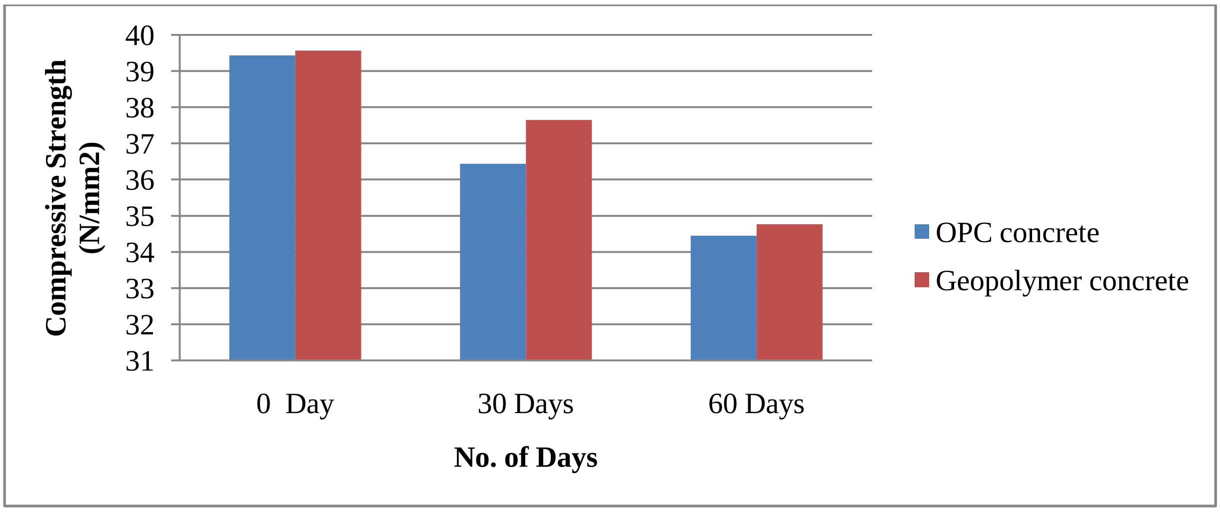


Figure 7: Comparison of Compressive strength of M40 OPC concrete with Geopolymer concrete due to 5% solution of Na_2SO_4 (N/mm^2)

Table 11: Compressive strength of concrete due to 5% solution of $MgSO_4$ (N/mm^2)

No. of Days	OPC concrete (N/mm^2)	Geopolymer concrete (N/mm^2)
0 Day	39.43	39.57
30 Days	36.88	37.45
60 Days	35.15	36.05

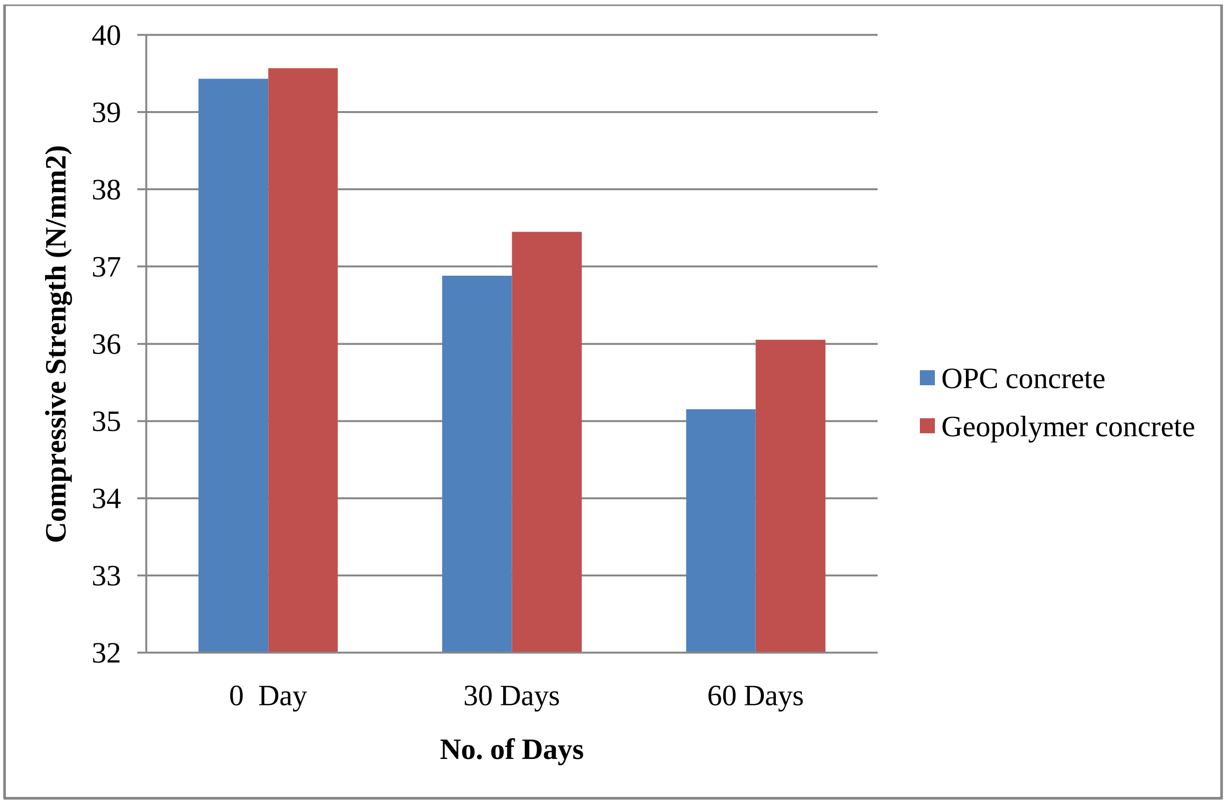


Figure 8: Comparison of Compressive strength of M40 OPC concrete with Geopolymer concrete due to 5% solution of $MgSO_4$ (N/mm^2)

4.3 WEIGHT LOSS

The following weight loss (%) of OPC concrete was observed more than geopolymer concrete.

Table 12: Weight loss

Solutions	30 days	60 days
Acid solutions		
5% H_2SO_4 solution	1.15%	3.4%
5% H_3PO_4 solution	0.71%	1.97%
Sulphate solutions		
5% Na_2SO_4 solution	0.23%	0.26%
5% $MgSO_4$ solution	0.36%	0.46%

4.4 COMPRESSIVE STRENGTH

The following compressive strength loss (%) of OPC concrete was observed more than geopolymer concrete.

Table 13: Compressive strength

Solutions	30 days	60 days
Acid solutions		
5% H_2SO_4 solution	4.51%	2.74%
5% H_3PO_4 solution	5.22%	1.36%
Sulphate solutions		
5% Na_2SO_4 solution	3%	2.89%
5% $MgSO_4$ solution	1.11%	0.92%

DISCUSSIONS

Fly ash based Geopolymer Concrete possesses the improved qualities to be used widely for any construction purpose. Geopolymer mixed concrete develops a glossy surface that can give a good appearance if used in constructing floors and walls. Fly ash based Geopolymer Concrete more resistant against abrasion and cracking. Since fly ash is only a byproduct material found from industrial waste, cost of such Geopolymer Concrete is less than or at most equal to OPC Concrete which uses expensive cement as binder material. Use of fly ash geopolymer also helps in rapid development of strength and so it can be used in underwater structures where early strength and rapid setting is necessary. Geopolymer Concrete based on fly ash gain a very high compressive strength in the first few hours of alkali activation (60-70 MPa after 24 hours). Its resistance against sulphate and acid attack makes it suitable to be used for construction in abrasive soils where ground water contains considerable amount of sulphate salts. Also fly ash based Geopolymer Concrete possesses improved rheological properties. Both static and dynamic viscosity is high when fly ash is used. So it also helps in easy transportation and handling of Geopolymer Concrete with the use of low water-cement ratio and less vibration. But it should also be remembered at the same time that fly ash is an industrial waste and mostly inhomogeneous. The inhomogeneity means that proper care should be taken in respect of quantity of mixing and methods while working with fly ash Geopolymer Concrete.

CONCLUSION

1 OPC Concrete specimens has found 1.15% and 3.4% more weight loss than the Geopolymer Concrete specimens, when they are immersed into 5% acidic (H_2SO_4) solution for 30 and 60 days respectively.
2 OPC Concrete specimens has found 4.51% and 2.74% more compressive strength loss than the Geopolymer Concrete specimens, when they are immersed into 5% acidic (H_2SO_4) solution for 30 and 60 days respectively.
3 OPC Concrete specimens has found 0.71% and 1.97% more weight loss than the Geopolymer Concrete specimens, when they are immersed into 5% acidic (H_3PO_4) solution for 30 and 60 days respectively.
4 OPC Concrete specimens has found 5.22% and 1.36% more compressive strength loss than the Geopolymer Concrete specimens, when they are immersed into 5% acidic (H_3PO_4) solution for 30 and 60 days respectively.
5 OPC Concrete specimens has found 0.23% and 0.26% more weight loss than the Geopolymer Concrete specimens, when they are immersed into 5% sulphate (Na_2SO_4) solution for 30 and 60 days respectively.
6 OPC Concrete specimens has found 3% and 1.36% more compressive strength loss than the Geopolymer Concrete specimens, when they are immersed into 5% sulphate (Na_2SO_4) solution for 30 and 60 days respectively.
7 OPC Concrete specimens has found 0.36% and 0.46% more weight loss than the Geopolymer Concrete specimens, when they are immersed into 5% sulphate ($MgSO_4$) solution for 30 and 60 days respectively.
8 OPC Concrete specimens has found 1.11% and 0.92% more compressive strength loss than the Geopolymer Concrete specimens, when they are immersed into 5% sulphate ($MgSO_4$) solution for 30 and 60 days respectively.
9 The results obtained and the observations made in this study show that OPC Concrete has suffered more deterioration in acidic as well as sulphate solution as compare to Geopolymer Concrete thus Geopolymer Concrete is more durable than OPC Concrete.

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