



# Mechanical Performance Evaluation Of Fly Ash-Based Geopolymer Concrete And Conventional Concrete For Paver Blocks

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## ABSTRACT

This research delves into the potential of geopolymer concrete as an environmentally sustainable alternative to conventional concrete. By utilizing fly ash, an industrial byproduct, as a partial replacement for cement, this innovative approach significantly reduces carbon emissions and contributes to waste reduction. The study primarily focuses on optimizing the mix design, carefully considering factors such as the proportion of fly ash, water content, and aggregate grading to achieve optimal performance.

Compressive strength tests are conducted to compare the performance of geopolymer concrete with that of Ordinary Portland Cement (OPC) concrete at various time intervals. The results indicate that geopolymer concrete exhibits higher early strength, showcasing its potential for early application and rapid setting. This characteristic can be advantageous in time-sensitive projects.

Additionally, the research investigates the use of geopolymer concrete for paver blocks in low-traffic areas. The findings reveal that geopolymer concrete paver blocks display remarkable durability and cost-effectiveness in such scenarios. The enhanced durability of geopolymer concrete, when compared to OPC concrete, makes it a promising material for long-lasting infrastructure applications.

Overall, this study highlights the viability of geopolymer concrete as a sustainable and high-performance alternative to conventional concrete, with its potential to reduce greenhouse gas emissions, effectively utilize industrial waste, and offer superior mechanical properties for specific applications such as paver blocks.

Key Words: Geopolymer, Fly Ash, Concrete

## Introduction

As Pavers Blocks are pre-manufactured in the processing plant utilizing press/vibrating table framework before their genuine use. These are utilized in surface layer of pavements, urban and semi urban streets, town streets, lanes, foot paths, gardens, travelers holding up sheds, petrol filling stations, stages, industry, etc. Precast paver Blocks are perfect materials for asphalts and pathways alongside of the road where a great deal of face lift is being given owing from simple laying, better look, simple to fix and prepared to move after laying. Paver Blocks are practical as they don't break and these have 100% rescue an incentive if there should arise an occurrence of replacement. The term precast implies that the blocks are produced and solidified before laying and are brought to work site. The paver blocks are made in such a design, that these interlock with one another during laying to maintain structural strength.

## Type of Paving Blocks

1. Clay Paving Block
2. Concrete Paving Block

### Clay Paving Blocks

The blocks are generally in shape of rectangular or in customise shape. For this colour dye not be used it come in natural colour. Clay Paving Block is very difficult to cut. The Clay Paving Block mainly use in walls or pillars

### Concrete Paving Block

The Concrete blocks (paver blocks) were first presented in Holland. From last 5 decades the Shapes of the developed from non-interlocking shapes to interlocking shape now they are called as interlocking concrete paver blocks. Mass manufacturing is done at standard size make them interchangeable.

### Shapes and Classification of Paver Blocks as per [IRC SP 63-2004]

The paver blocks are classified into four categories which are described as under:

**Type A:** Type 'A' paver blocks are those which have vertical plain faces and do not have anykey -lock into each other.

**Type B:** Type 'B' paver blocks are those which have arched vertical faces and have key-lockinto each other.

**Type C:** Type 'C' paver blocks are those which have curved all faces and have key-lockalong the vertical faces.

**Type D:** Type D paver blocks are those which have 'L' and 'X' shapes and have key-lockalong the vertical faces.

### Use of Concrete in Paver Blocks

Concrete is a widely used construction material comprising cement, coarse aggregates, fine aggregates, water, and additives. However, the production of cement, particularly Portland cement, releases a significant amount of CO<sub>2</sub> into the atmosphere, contributing to climate change [Davidovits, 1994]. The demand for cement is increasing due to infrastructure development, exacerbating the environmental impact. To address this issue, a new technology called geopolymers has been developed. Geopolymer is an innovative solution that reduces CO<sub>2</sub> emissions. It involves replacing cement with materials like fly ash and alkaline solutions. This technology can reduce CO<sub>2</sub> emissions by up to 80% [Van Jaarsveld et al., 1997]. Geopolymer has different properties compared to conventional cement, including density and chemical composition. In geopolymer, water is released during the poly-condensation process to achieve the desired strength, unlike in cement concrete where water is essential for the hydration process. To facilitate the use of geopolymer concrete, a new design procedure has been developed [Mullick, 2005]. This procedure takes into account the specific characteristics and requirements of geopolymer materials. By adopting geopolymer technology, the environmental impact of cement production can be significantly reduced. The use of geopolymer concrete contributes to a substantial reduction in CO<sub>2</sub> emissions, preserving natural resources and promoting sustainable construction practices.

## Literature Review

### Introduction to Geopolymer

In 1978, the term "geopolymer" was coined by Davidovits to describe inorganic polymeric materials formed through the polymerization of waste materials such as fly ash and rice husk ash. Geopolymers consist of alkaline fluids, such as  $\text{Na}_2\text{SiO}_3$  and  $\text{NaOH}$  or  $\text{KOH}$ , and raw materials rich in Si and Al, such as clays or industrial waste materials. The manufacturing process of geopolymers involves polymerization, resulting in chemical changes.

Geopolymer concrete, introduced by Davidovits, utilizes mechanical waste materials like fly ash and alkaline activators. It possesses similar mechanical properties to Ordinary Portland Cement (OPC) concrete, including strength and stiffness. Geopolymer concrete requires lower curing temperatures and emits less  $\text{CO}_2$  compared to OPC. It achieves significant strength within a short time period, with approximately 70% of the ultimate compressive strength developed within the first 4 hours after mixing. The compressive strength of geopolymer concrete can be enhanced by using a higher concentration of activating agent, a higher activator-to-binder ratio by mass, and longer curing time. Geopolymer concrete also exhibits excellent resistance to acid environments, making it suitable for applications such as sewer pipes, dairy floors, and corrosive industrial settings.

### Experimental Requirements

#### Overview

Concrete is a widely used construction material due to its accessibility, versatility, and strength. It comprises constituents like cement, aggregates, sand, fly ash, water, and superplasticizers. The properties of concrete are influenced by the properties of its constituents, which can vary depending on their source. A trial mix design of General Purpose Cement (GPC) and Ordinary Portland Cement (OPC) is developed according to the standards of IS 456:2000. Testing and evaluation of the mixes involve assessing various physical and mechanical properties. Compressive strength tests are conducted on 150 mm cubes after 7, 14, and 28 days using a Compressive Testing Machine (CTM). The research aims to determine the strength and durability of concrete incorporating fly ash. Material used are described as under

Cement, the binding agent in concrete, is produced by grinding finely ground limestone, clay, and shales into a powder form. This powder is then burned in a furnace at high temperatures to obtain clinker, to which gypsum is added to produce cement. OPC is categorized into different grades, such as 33 grade, 43 grade, and 53 grade, based on their 28th-day strength. OPC 43 grade Ultratech cement conforming to IS:8112-1989 is used in the investigation.

Aggregates, the main component of concrete, are obtained from natural sources such as igneous, sedimentary, and metamorphic rocks. Coarse aggregates, occupying a large volume in the concrete mix, provide stability. Fine aggregates, like sand, are used to fill the voids between coarse aggregates. The properties of aggregates depend on the properties of the parent rocks. Properly shaped, clean, hard, and well-graded aggregates are preferred for concrete mixtures.

Water is an essential component in concrete, forming a paste with cement to bind the aggregates and sand. In geopolymer concrete, a chemical reaction occurs instead of forming a paste. The water used should have a neutral pH level. Admixtures, such as Sikament 2002 NS, are added to decrease water content and enhance strength. In this research, 2% of fly ash is used as an admixture.

Fly ash is a by-product of coal combustion in thermal power stations. It is collected from chimneys and stored on-site. Fly ash composition varies but generally contains silica, alumina, iron oxide, calcium oxide, and other elements. Alccofine, a highly reactive product, is used as a super pozzolanic material to reduce concrete permeability and water content, thereby improving compressive strength.

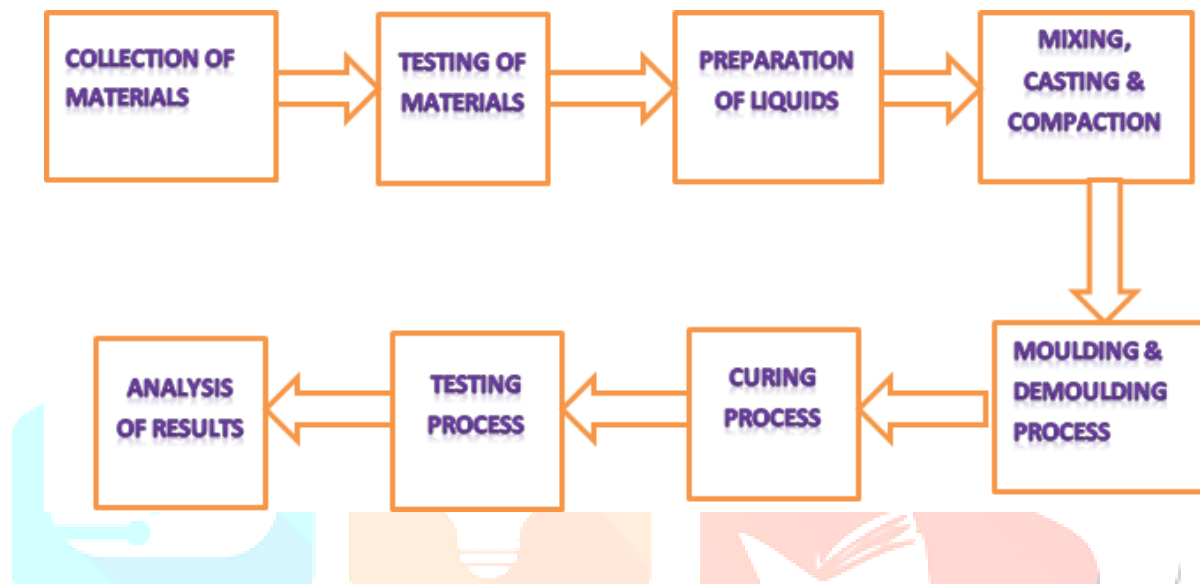
Sodium hydroxide and sodium silicate are used in geopolymer concrete. Sodium hydroxide pellets are utilized, and the properties include molar mass, appearance, density, melting point, boiling point, storage requirements, and the amount of heat produced. Sodium silicate, also known as liquid glass or water glass, is available in

liquid or gel form and has a ratio of sodium oxide to silica.

Overall, this research aims to calculate the strength and durability of concrete containing fly ash. Various tests are conducted to evaluate the properties of the constituents, including cement consistency, setting time, specific gravity, compressive strength, and sieve analysis of aggregates. The properties of admixtures, such as Sikament and Alccofine, are also considered.

### Experimental Works

This chapter deals with the Research Methodology and mix design of geopolymer concrete and mix design of conventional concrete. Their description as follows



The collection of materials for the study includes cement (UltraTech), coarse aggregates (20mm and 10mm), fine sand, fly ash, sodium hydroxide, sodium silicate, Alccofine, and superplasticizer. These materials are obtained from local suppliers and thermal power plants. The materials undergo testing to determine their physical properties. Cement, aggregates, and sand are tested in the University Test House. The testing procedures are explained in earlier chapters. Preparation of liquids involves dissolving sodium hydroxide pellets in distilled water to prepare a 12M concentration solution. The sodium hydroxide solution and sodium silicate solution are mixed at least 24 hours before use.

The mixing, casting, and compaction process involves mixing the dry mixture of fly ash and aggregates with the alkaline activator solution. The mixture is then mixed for 4 to 5 minutes until a uniform color is obtained. Extra water and superplasticizer are added if required. The fresh concrete is cast into molds and compacted using a tamping rod and plate vibrator. Curing of the specimens involves removing them from the molds after 24 hours and placing them in a curing tank or room at room temperature. The specimens are cleaned and tested after the curing period.

The concrete mix design for geopolymer concrete involves determining the target mean average strength, quantity of fly ash, quantity of alkaline activators, total solids in the alkaline solution, water quantity, additional water content, wet density, and quantities of fine and coarse aggregates. The proportions of materials are calculated based on the mix design requirements. For conventional concrete, the mix design involves determining the target average strength, water/cement ratio, water content, cement content, and quantities of fine and coarse aggregates.

### Results and Discussion

In order to accomplish the goal of investigation of waste utilization, an experimental program was derived in which 100% fly ash with alkaline activators solution is fully replaced with cement to determine the best proportion of materials that can provide the enhanced properties. The experimental program included the following:

Testing the material's properties utilized in making the concrete. Design of mixes of controlled and replaced concrete by making trials. Cubical specimen of size 15cm with each face were tested for compressive strength and durability of concrete.

### Compressive Strength Test Results

Compressive strength test gives a thought regarding all the attributes and characteristics of concrete. By doing this test we realize that the cubes are properly filled or not. The compressive strength of the cubes is calculated by using the equations.

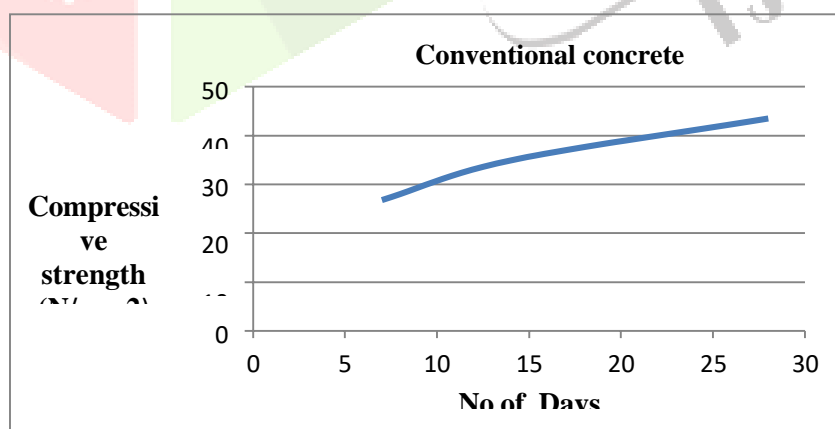
**Compressive strength = Compressive-Load (KN) / Area of cross section (mm<sup>2</sup>)**

For the testing of the compressive strength, geopolymer and conventional concrete cubes of size 150mm with each face were prepared. After preparing the cubes, they were left for curing i.e. conventional concrete cubes in the water and geopolymer concrete cubes in the room itself at 27<sup>0</sup> C for the 28th days.

The cubes were tested at the age of 7<sup>th</sup>, 14<sup>th</sup>, 28<sup>th</sup> days. While testing the conventional concrete cubes are taken out from water for 30 minutes so that there outer surface water is removed otherwise it create problem in testing. According to IS: 516-1959, load was applied continuously until the failure of the cubes take place. The photograph showing the testing of cubes under CTM is provided below.

Mix Designation	Compressive Strength (N/mm <sup>2</sup> ) 7 <sup>th</sup> Day	Compressive Strength (N/mm <sup>2</sup> ) 14 <sup>th</sup> Day	Compressive Strength (N/mm <sup>2</sup> ) 28 <sup>th</sup> Day
GPC	27.58	36.52	41.4
CC	26.85	34.94	43.5

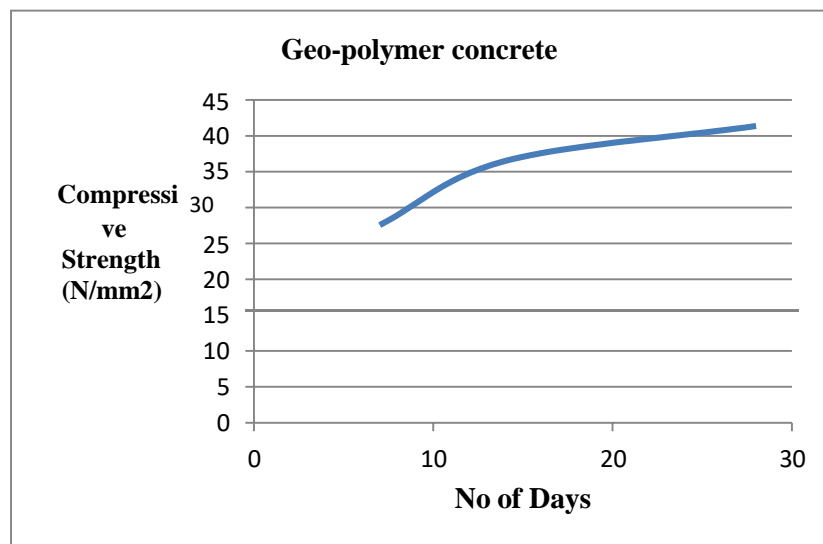
**Compressive strength test results of GPC & OPC**



**Graph 1- Compressive strength graph of Conventional Concrete**

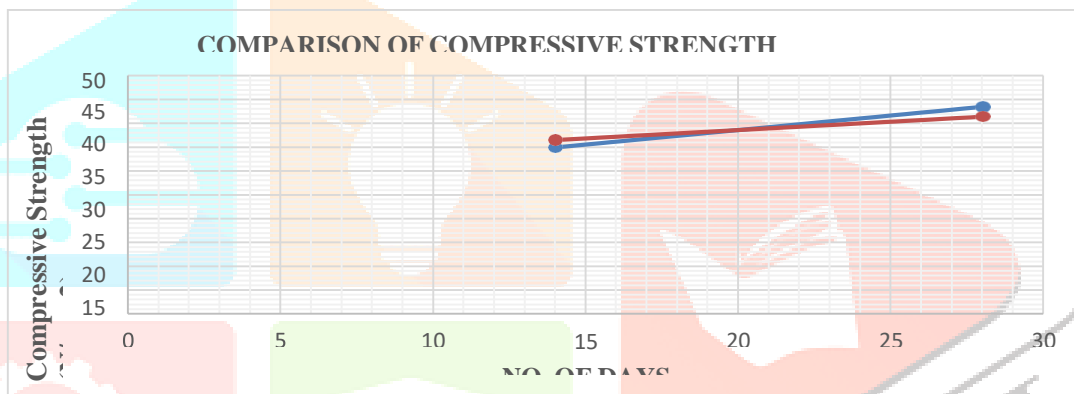
**Graph 1:** represents the compressive strength of conventional concrete which are done at different days under the CTM. At 7 days it gains 26.85 N/mm<sup>2</sup>, 34.94 N/mm<sup>2</sup> & 43.5.N/mm<sup>2</sup>





**Graph 2 Compressive strength graph of Geopolymer Concrete**

**Graph 2:** represents the compressive strength of conventional concrete which are done at different days under the CTM. At 7 days it gains 27.58 N/mm<sup>2</sup>, 34.52 N/mm<sup>2</sup> and 41.4 N/mm<sup>2</sup>.



**Graph 3 – Comparison of compressive strength of geopolymer and conventional concrete**

**Graph 3:** represents the comparison of compressive strength of geopolymer concrete and conventional concrete. In this study we have done the compressive strength test under the CTM and find some results, at 7 and 14th the compressive strength of geopolymer concrete is higher than the conventional concrete but at 28th days the compressive strength of geopolymer concrete is slightly less as shown in the graph. The red line shows geopolymer concrete strength and the blue line shows conventional concrete strength.

#### **Durability test Results**

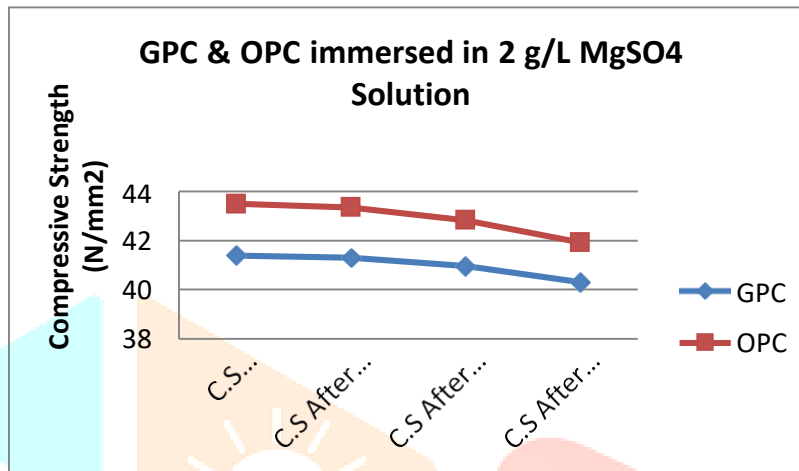
Durability tests are conducted to check durability of concrete that will work good in every environment exposure. Since concrete is not completely resistant to acids so its durability during acid rains and repeated fluids overflow is not expected to be satisfactory. When the attack of fluid is near or below that of pH 4.5, this is a severe situation. In that case cement concrete breaks down and starts to wear out. To test the durability of our new geopolymer concrete we immerse the OPC and GPC in different concentrations of chloride (Sodium Chloride) solution and Sulphate (Magnesium Sulphate) solutions and noted down readings for 7, 14 and 28th days respectively.

**A) Sulphate resistance Test:** For this test, the magnesium sulphate (MgSO<sub>4</sub>) solution are prepared at concentration i.e. 2g/L and 4g/L. The geopolymer concrete and conventional concrete specimen are immersed in the solution for the 28th days only. The results of different concentration are shown in the tables and graphs:

i) Compressive strength when concentration of MgSO<sub>4</sub> is 2g/L

Sample Name	Compressive Strength (N/mm <sup>2</sup> ) before immersion into Solution	Compressive Strength (N/mm <sup>2</sup> ) after immersion for 7 <sup>th</sup> Days	Compressive Strength (N/mm <sup>2</sup> ) after immersion for 14 <sup>th</sup> Days	Compressive strength (N/mm <sup>2</sup> ) after immersion for 28 <sup>th</sup> Days
GPC	41.4	41.30	40.97	40.31
OPC	43.5	43.36	42.83	41.93

Compressive strength when concentration of MgSO<sub>4</sub> is 2g/L on different days

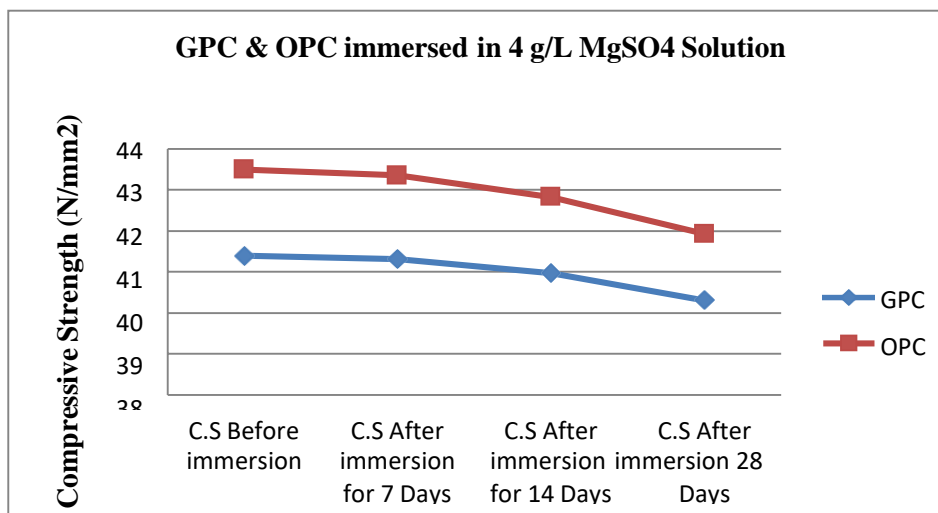


Graph 4 Compressive Strength graph of GPC & OPC immersed in 2 g/L MgSO<sub>4</sub> Solution

ii) Compressive strength when concentration of MgSO<sub>4</sub> is 4g/L

Sample Name	Compressive Strength (N/mm <sup>2</sup> ) before immersion into Solution	Compressive Strength (N/mm <sup>2</sup> ) after immersion for 7 Days	Compressive strength (N/mm <sup>2</sup> ) after immersion for 14Days	Compressive strength (N/mm <sup>2</sup> ) after immersion for 28th Days
GPC	41.4	41.27	40.77	40.03
OPC	43.5	43.28	42.63	41.60

Compressive strength when concentration of MgSO<sub>4</sub> is 4g/L on different days



Graph 5- Compressive Strength graph of GPC & OPC immersed in 4 g/L MgSO<sub>4</sub> Solution

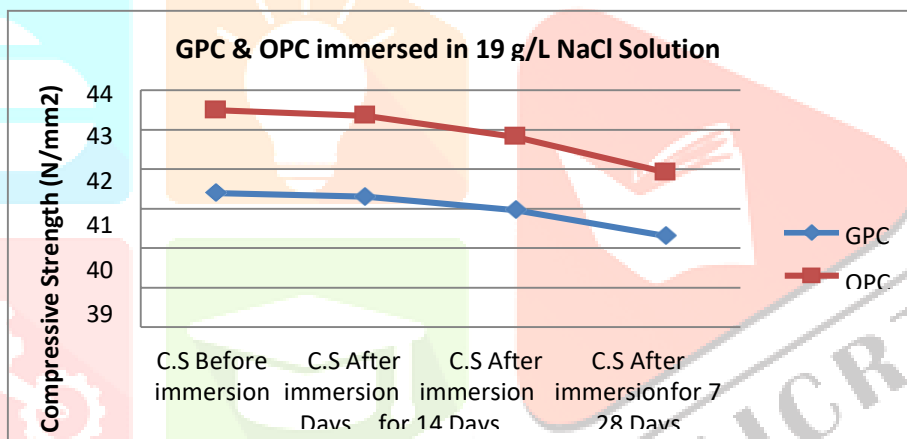
B) The compressive strength of geopolymer concrete remains relatively stable over time, while conventional Portland cement concrete experiences a decrease in strength when exposed to  $MgSO_4$  solution. This is due to the reaction between magnesium ions and the calcium silicate hydrate (C-S-H) bonds formed during cement hydration. The reaction forms magnesium-silicate-hydrate (M-S-H), which does not contribute to concrete strength and results in a loss of strength in the presence of  $MgSO_4$ .

C) **Chloride resistance test:** For this test, the sodium chloride (NaCl) solution are prepared at concentration i.e. 19g/L and 38g/L. The geopolymer concrete and conventional concrete specimen are immersed in the solution for the 28th days only. The results of different concentration are shown in the tables and graphs:

i) Compressive strength when concentration of NaCl is 19g/L

Sample Name	Compressive Strength ( $N/mm^2$ ) before immersion into Solution	Compressive strength ( $N/mm^2$ ) after immersion for 7 Days	Compressive strength ( $N/mm^2$ ) after immersion for 14 Days	Compressive strength ( $N/mm^2$ ) after immersion for 28th Days
GPC	41.4	41.23	40.69	39.89
OPC	43.5	43.19	42.49	41.53

Compressive strength when concentration of NaCl is 19g/L on different days



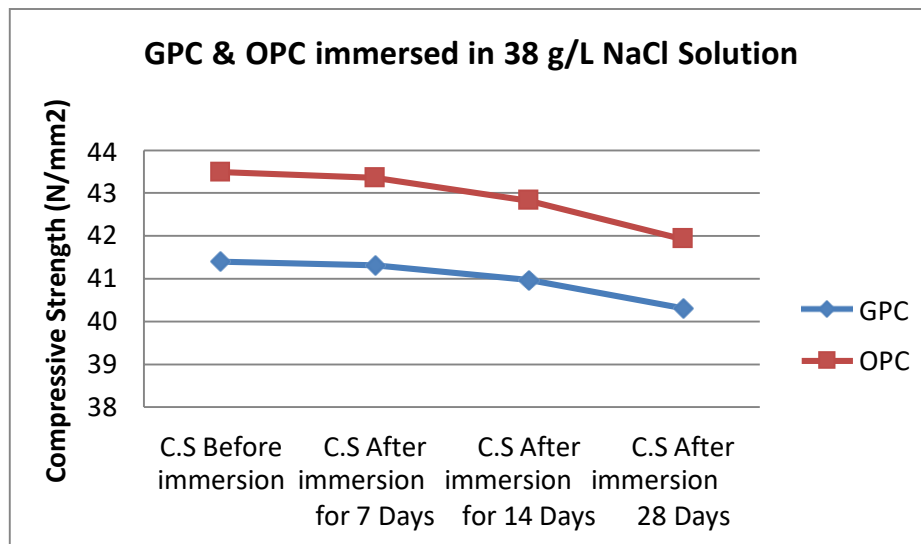
Graph 6- Compressive Strength graph of GPC & OPC immersed in 19 g/L NaCl Solution

ii) Compressive strength when concentration of NaCl is 38 g/L

Sample Name	Compressive Strength ( $N/mm^2$ ) before immersion into Solution	Compressive strength ( $N/mm^2$ ) after immersion for 7 Days	Compressive strength ( $N/mm^2$ ) after immersion for 14 Days	Compressive strength ( $N/mm^2$ ) after immersion for 28th Days
GPC	41.4	41.19	40.53	39.62
OPC	43.5	43.10	42.25	41.16



## Compressive strength when concentration of NaCl is 38g/L on different days



**Graph 7- Compressive Strength graph of GPC & OPC immersed in 38 g/L NaCl Solution**

The evaluation of chloride penetration was performed to assess the depth of concrete deterioration caused by chloride ions. By plotting the number of days on the x-axis and compressive strength on the y-axis, we compared the performance of geopolymer concrete and conventional Portland cement concrete. It was observed that the compressive strength of geopolymer concrete remained relatively stable over time, with minor changes. In contrast, ordinary Portland cement concrete exhibited a decrease in compressive strength over the same time period. This can be attributed to the weakening of Si-Al bonds in the concrete caused by the presence of large pores when immersed in NaCl solution for 28 days. The geopolymer concrete had a higher chloride concentration, as the absence of C3A in the fly ash prevented the formation of a chloride binding mechanism that would have minimized strength loss.

### Conclusions

Geopolymer concrete exhibits higher compressive strength than conventional concrete at 7 days, but lower strength at 28 days. This is due to the polymerization process and differences in curing methods. Geopolymer concrete reduces CO<sub>2</sub> emissions and is an eco-friendly alternative to Ordinary Portland Cement. Ambient curing saves water, and workability can be improved with admixtures. Geopolymer concrete shows superior durability, lower density, and efficient utilization of fly ash. It has potential for use in paver blocks and non-traffic areas. Overall, geopolymer concrete offers early high strength, environmental advantages, and diverse construction applications.

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