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Compressive Strength and Leaching Studies of Fly Ash and GGBS based M30 grade Geopolymer Concrete in Ambient Curing Conditions

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Abstract: *As environmental concerns intensify, geopolymer concrete (GPC) is emerging as a sustainable alternative. The cement industry is responsible for approximately 8% of global CO_2 emissions, largely due to its energy-intensive production processes and reliance on limestone calcinations, which generates significant greenhouse gases. Beyond CO_2, cement production also releases pollutants like sulphur dioxide and nitrogen oxides, adversely impacting human health and the environment. The industry's mineral requirements contribute to ecological degradation and habitat destruction. Utilizing industrial by-products like fly ash and ground granulated blast-furnace slag (GGBS), GPC can reduce CO_2 emissions by 80-90% compared to traditional cement. This paper, presents the leaching impact on the compressive strength of M30-grade geopolymer concrete. Multiple fly ash/GGBS ratios (100/0, 90/10, 70/30, and 60/40) were tested in ambient curing conditions to find the optimum ratio of geopolymer concrete. Static leaching tests were conducted over 28 days, with compressive strength assessments. Results indicate that GPC with 60/40 Fly ash/ GGBS ratio gives the optimum compressive strength. 28 days Leaching test showed a negative effect on compressive strength due to leaching of sodium silicate into water.*

***Index Terms** - Geopolymer concrete (GPC), Ambient Curing, fly ash, GGBS, Compressive Strength, Leaching behavior.*

1. INTRODUCTION :

The energy-intensive processes used in the cement industry account for about 8% of global CO_2 emissions, making it a significant contributor to the problem. Both the fuel needed for manufacture and the chemical conversion of limestone into clinker, the main binding agent in cement, are responsible for these emissions. The health of the surrounding communities and employees may be adversely affected by the additional dangerous pollutants that this industry releases, such as sulphur dioxide, nitrogen oxides, and particulate matter. Additionally, environmental deterioration, such as habitat loss and soil erosion, is caused by the need for raw materials like sand for the production of cement, [1]. And also in recent years, there has been concern about the environmental impact of industrial byproducts such as fly ash and ground granulated blast furnace slag (GGBS). These materials contribute to environmental damage since they are frequently disposed of in landfills. Because of their size and possible environmental risks, fly ash—a byproduct of burning coal in power plants and GGBS-a byproduct of making steel, both pose serious waste management problems. However, because it can lower CO_2 emissions and save these byproducts from ending up in landfills, using these ingredients to make concrete offers a sustainable substitute for conventional Portland cement, [2]. As the cement industry's emissions rise, there is an increasing need to adopt low-carbon alternatives. In order to meet decarbonization targets, the CO_2 emissions from the worldwide building sector, which have lately reached record highs, must be reduced. We run the risk of escalating the effects of climate change and raising the carbon intensity of construction if present trends continue. A hopeful way ahead is provided by innovations such as geopolymer concrete, which can use fly ash and GGBS to reduce emissions by up to 90% when compared to ordinary cement and minimize the environmental impact, [3].

2. CONCEPT OF GEOPOLYMER CONCRETE

Joseph Davidovits originally used the term "geopolymer" in 1979 and proposed the idea that material's high in Si-Al may be utilized as binder by causing them to react with alkaline liquids. Geopolymers are inorganic polymers that are lightweight [4]. After dissolving in an alkaline activating solution, the Si-Al-rich compounds polymerize into molecular chains and take on the function of a binder. "A process that involves a significant fast chemical reaction between alkaline liquids and Si-Al rich minerals that result in a three-dimensional polymeric chain and ring structure" is the definition of polymerization. The three primary phases of geopolymerization are as follows:

- Dissolution: Silica (SiO_2) and alumina (AlO_3) are released into the solution as the alkaline activator breaks down the alumina silicate source.
- Hydrolysis: Reactive monomers and oligomers are created when the liberated silica and alumina go through hydrolysis.
- Polymerization: As water evaporates or is consumed in the reaction, these monomers combine to form a cross-linked, gel-like structure (Si-O-Al linkages), which solidifies into a matrix.
- Development of Hardness and Strength: As the geopolymer network grows, it binds aggregates (such sand or gravel) and becomes stronger, producing concrete that has better mechanical and thermal qualities than conventional portland cement.
- In the chemical process of geopolymer concrete, aluminosilicate components (such fly ash, metakaolin, or slag) dissolve and polymerize when an alkaline activator is present. Similar to the chemistry of zeolites, the procedure creates a three-dimensional polymeric network with Si-O-Al links.
  1. Dissolution: $Al_2O_3 . SiO_2 + 2OH^- \rightarrow Al(OH)_4^- + Si(OH)_4$.
  2. Polymerization: $nSi(OH)_4 + mAl(OH)_4^- \rightarrow (\text{-Si-O-Al-O-})n + (H_2O)$.
  3. Hardening & Condensation: $(\text{-Si-O-Al-O-})n + (H_2O) \rightarrow$ Geopolymer network + H_2O

2.1 Leaching of geopolymer concrete

Leaching in geopolymer concrete (GPC) is the process where water or other fluids percolate through the concrete, causing the dissolution and removal of its constituent materials. This process can significantly affect the mechanical and durability properties of GPC over time. Leaching primarily involves the migration of alkaline elements such as Sodium silicate [5] and other ions from the concrete matrix into surrounding environments. The primary concerns associated with leaching are the potential loss of strength and the durability of the geopolymer concrete. As water interacts with the GPC, it can cause the dissolution of the geopolymer binder, leading to a reduction in the material's structural integrity. This research highlights the importance of understanding leaching behavior in geopolymer concrete made with fly ash and ground granulated blast furnace slag (GGBS).The primary chemical reaction responsible for this involves the breakdown of weakly bound alkali ions and partially unreacted materials. Key chemical reactions in leaching are as follows:

- Leaching of Alkali Ions (Na^+ or K^+):

When geopolymer cubes are exposed to water, alkali cations (such as Na^+ or K^+) from the alkaline activators used in the geopolymerization process may leach out into the water. The reaction can be represented as: \

1. $M + H_2O \rightarrow M(aq) + OH^-$

where M^+ represents sodium (Na^+) or potassium (K^+) ions. These ions are weakly bound in the geopolymer structure and are more susceptible to leaching when exposed to water.

- Dissolution of Silica and Alumina:

Some unreacted or loosely bonded silica (SiO_2) and alumina (Al_2O_3) in the geopolymer matrix may dissolve in water, though this is generally a slower process. The dissolution reactions can be simplified as:

2. $\text{Si-O-Si} + H_2O \rightarrow Si(OH)_4$
3. $\text{Si-O-Al} + H_2O \rightarrow Al(OH)_4^- + Si(OH)_4$

This leads to a slow degradation of the geopolymer matrix over time, particularly if the water is acidic or contains aggressive ions (e.g., chloride or sulphate).

➤ Formation of White Efflorescence:

Leached alkali ions (Na^+ or K^+) can react with carbon dioxide (CO_2) in the atmosphere or water to form carbonates, which may appear as white deposits on the surface of the geopolymer:

4. $2Na^+ + CO_2 + H_2O \rightarrow Na_2CO_3 + H_2O$

These carbonates can form a layer of efflorescence on the geopolymer cubes, which may be an indication of leaching.

3. OBJECTIVES OF PRESENT STUDY

The main objective of the research was to find an alternative to Portland cement in order to make the construction industry eco-friendly.

1. The purpose of this pilot project is to examine the effect of ambient curing on the Compressive strength.
2. To develop a suitable mixture proportion of M30 grade of geopolymer concrete based on fly ash and GGBS as source materials.
3. To determine which ratio (100/0, 90/10, 70/30, 60/40) of fly ash/GGBS gives the optimum strength cured in ambient conditions for 60 days.
4. To study the Leaching behavior of geopolymer concrete cubes cured under ambient curing for 60 days through Static Leaching Test.
5. Measuring the pH of leachate and comparing the concentration of leached substance from day 1 to 28 days.
6. Establishing the correlation between compressive strength of concrete under ambient curing and how leaching of sodium silicate causes the concrete to lose strength. The immediate potential source materials are fly ash and GGBS and hence all the research work is done concerning these source materials only.

4. MATERIALS

4.1 Source materials

Fly Ash

In this study we made use of Class F fly ash which is low lime Fly ash, sourced from NTPC Ramagundam, Telangana. When hard, old, bituminous coal is burned, Class F flyash is created. Class F flyash has less than 10% lime concentration and is pozzolanic in nature. In the presence of water, this kind of flyash typically requires binding material such as OPC. Low calcium flyash is considered since it provides better control over the geopolymerization process, leading to higher long-term strength and high alkali content in fly ash can increase the risk of alkali leaching into the environment and also it may interfere with the polymerization process and alter the microstructure [6]. Low alkali fly ash reduces this risk, making the concrete more environmentally friendly [7]. The chemical and physical characteristics were within IS 3812 bounds and are listed in Table 1 & 2. (2013, IS 3812).

Table 1: Main oxides of fly ash

Oxides and Other properties	**Proportion in %**
Na_2o	0.89
M_gO	1.33
Al_2O_3	22.52
SiO_2	46.78
P_2O_5	0.17
SO_3	0.90
K_2O	4.09
CaO	2.24
TiO_2	1.05
MnO	0.05
Fe_2O_3	9.15
BaO	0.10
LOI	3.57

Table 2: Physical properties of fly ash

Physical properties	Proportions
Fineness (m^2/kg)	1.84
Specific Gravity	8%

Ground Granulated Blast Furnace Slag (GGBS)

We used GGBS in different ratios to fly ash since fly ash is less reactive than other alumina-silicate sources like GGBS, this means without elevated temperature the geopolymer process is slower and at ambient temperature, FA based geopolymers may take longer to achieve significant strength. GGBS achieves early strength. Due to presence of calcium in GGBS facilitates formation of C-A-S-H gel which contributes to rapid hardening and improved mechanical properties. Since we aimed to prepare geopolymer concrete under ambient curing conditions, GGBS is also considered to facilitate ambient curing [8]. GGBS was acquired from a manufacturing company named JSW Cements Limited, Hyderabad. Table 3 and 4 (IS 12089, 1987) lists the physical characteristics and chemical composition, both of which fell within the specified bounds in IS 12089. The test findings were provided by the producer of GGBS.

Table 3: Main oxides of GGBS

Oxides and Other properties	Proportion
Na_2o	1.05
M_gO	6.94
Al_2O_3	11.23
SiO_2	29.38
P_2O_5	0.00
SO_3	1.76
K_2O	0.93
CaO	43.72
TiO_2	0.67
MnO	0.51
Fe_2O_3	0.36
BaO	0.12
LOI	2.40

Table 4: Physical properties of GGBS

Physical properties	Proportions
Fineness (m^2/kg)	386
Specific Gravity	2.9

4.2 Coarse and fine aggregates

For this study, coarse aggregates of nominal sizes 10mm and 20mm were used obtained from local market, along with yellampally river sand as fine aggregate. The physical properties and sieve analysis of the coarse and fine aggregates were conducted, with details provided in table 5.

Table 5: Physical properties of aggregates used in the mix

Properties	10mm coarse aggregate	20mm coarse aggregate	Fine aggregate
Specific Gravity	2.88	2.89	2.55
Water Absorption	1.53%	1.02%	1.06%

4.3 Alkaline solution

Sodium hydroxide

For this study, Sodium hydroxide, (NaOH) flakes were purchased in Grasim Industries Limited (IS 252). NaOH solution with concentration 30% by weight i.e. (Molarity = 10M) was prepared by dissolving NaOH in portable tap water. The chemical composition of the NaOH flakes, provided by the distributor, is listed in table 6.

Table 6: Physical and Chemical composition of NaOH flakes

Parameters	Specifications
Purity %	99
NaOH, % by mass as such, Min	47.0
Chloride (CI), % by mass	0.015
Sodium Carbonate (CO_3), % by mass	0.20
Silicates (SiO_2), % by mass	0.01
Sulphate (SO_4), % by mass	0.015
Iron (Fe), ppm	10
Copper (Cu), ppm	1
Manganese (Mn), ppm	0.5
$NaCIO_3$, ppm	40
Matter insoluble in water, % by mass	0.025
NaOH, % by mass on dry basis	99.50
Specific Gravity	0.7- 0.8 gm/cc at 25˚ C
Appearance and Odor	Solid, White flakes, odorless
Solubility in water	100 % soluble

Figure 1: NaOH flakes

Figure 2: NaOH

Sodium Silicate

Na_2SiO_3 solution was obtained from NTPC Ramagundam, Telangana. To keep it from drying out and solidifying, it was covered with a thick gel. Sodium silicate as a solution have molar ratio of SiO_2/Na_2O is 2.055. The chemical composition of the Na2SiO3 solution is listed in table 7.

Table 7: Chemical Composition of Na_2SiO_3 solution

Chemical Composition	Percentage
Na_2O	14.70
SiO_2	29.40
Water	55.90
Specific gravity	1.27

Figure 3: Na_2SiO_3 solution

Figure 4: Mixing of NaOH & Na_2SiO_3 solution

Water

The aggregates were washed and the solution was made using tap water. Since super plasticizer was not used, some water was also added to the source materials while they were being mixed to make the mixture more workable.

5. MIX DESIGN

Based on the literature and laboratory trials, the following procedure was adopted to determine material proportions. The goal was to develop a geopolymer concrete mixture with an average compressive strength of 30 N/mm². Chemical activators were added in the mixes according to the alkali dosage (M+) and the alkali modulus (AM). Here M+ is the mass ratio of sodium oxide (Na_2O) in the activating solution (i.e., Na_2O from NaOH solution + Na_2O from sodium silicate solution) to the binder dry mass. The mass ratio of Na_2O to SiO_2 in alkali solutions is known as the alkali modulus (AM) [9].

The following dosages were selected for this study: M+ = 10 [10] and AM = 1.25. These values provided satisfactory strength and setting time while potentially reducing production costs and environmental impacts, based on the preliminary study, [11]. For the present investigation, ratios of fly ash/GGBS were varied as 100/0, 90/10, 70/30, 60/40. The water/solids (w/s) ratio is defined as the mass ratio of water in the system (activating solutions + added water) to the solids (precursors + alkali solids). Aggregates used included natural sand and quarried basalt in two sizes: 5-10mm and 10-20mm. The aggregate proportions were 40% sand (Yellampally river sand) and 50% of the total coarse aggregate volume. The water/solid ratio did not account for the water that the aggregate absorbed. Table 8 provides the mix proportions.

Table 8: Trial Mix proportions for 1m3 of geopolymer concrete equivalent to M30 grade for 10M NaOH solution

Final Ingredients of GPC for M30 grade concrete	Quantities in (kg/m3)
M+ (Molarity)	10
AM (Alkali modulus)	1.25
W/S (Water to solid ratio)	44.12
Paste Volume (%)	33.33
Sodium Silicate Na_2SiO_3 (kg/m3)	128.57
Sodium Hydroxide NaOH (kg/m3)	20.57

Water Content (kg/m3)	130.57
Fly Ash	240.00
Ground granulated Blast Furnace Slag (GGBS)	160.00
Fine Aggregate	635.87
Coarse Aggregate (5-10mm)	538.24
Coarse Aggregate (10-20mm)	538.24

Note: Water Content of aggregates and Fly ash during mixing to be verified and to be adjusted during mix preparation at site.

6. EXPERIMENTAL INVESTIGATION

For the current study, the trial mix is determined as outlined in Table-8.

- A rotating drum concrete mixer with an 80-liter capacity is used to dry mix the aggregates, fly ash, and GGBS for approximately three minutes after they have been prepared in saturated surface dry condition.
- Because the reaction is exothermic, the liquid portion of the mixture Na_2SiO_3 and NaOH solutions is mixed three to five hours in advance to ensure thorough mixing and cooling.
- The liquid and dry aggregate mixture is wet mixed for an additional four minutes.
- In most cases, the wet mix is cohesive. The traditional slump test is used to determine the workability of the fresh concrete.
- The prepared concrete mixture with various fly ash/ GGBS ratios is casted in cubes of 150 x 150 x 150mm and vibrated using a hand vibrator.
- Immediately after casting, the samples were left for curing in room temperature.
- The 150 x 150 x 150 mm cubes are taken out of the moulds after the curing period is over. At the designated age, the specimens are subsequently tested in a 2000 kN capacity CTM in compliance with the applicable Indian requirements.

6.1 Procedure for static leaching test of geopolymer concrete

- The geopolymer cubes with 60/40 fly ash /GGBS ratio are considered for static leaching test.
- Geopolymer cubes (150x150x150 mm) were prepared and cured for 60 days under ambient conditions to ensure adequate strength.
- Water was chosen as the leaching solution and the cubes were then immersed in water in closed containers, with three cubes per container, ensuring complete submersion for a leaching period of 28 days maintaining required room temperature.
- IONIX pH meter was used to record the pH values. The pH meter was calibrated using standard buffer solutions to ensure accurate readings.
- The pH electrode was rinsed with deionised water before and after each measurement and the electrode is immersed in the water sample, ensuring it is fully submerged and allowed the reading to stabilize and recorded the pH value.
- The pH value is recorded immediately after immersion and 24 hours after immersion.
- Measurements are conducted at regular intervals to monitor changes in pH over time, by replacing the water for every 24 hours for 28 days.

7. RESULTS AND DISCUSSIONS

Geopolymer concrete cubes were tested on the 7^{th}, 14^{th}, 28^{th} and 60^{th} day, for geopolymer concrete M30 grade with different Flyash/GGBS ratios. These results were then compared to the compressive strength outcomes of geopolymer concrete cubes after leaching test.

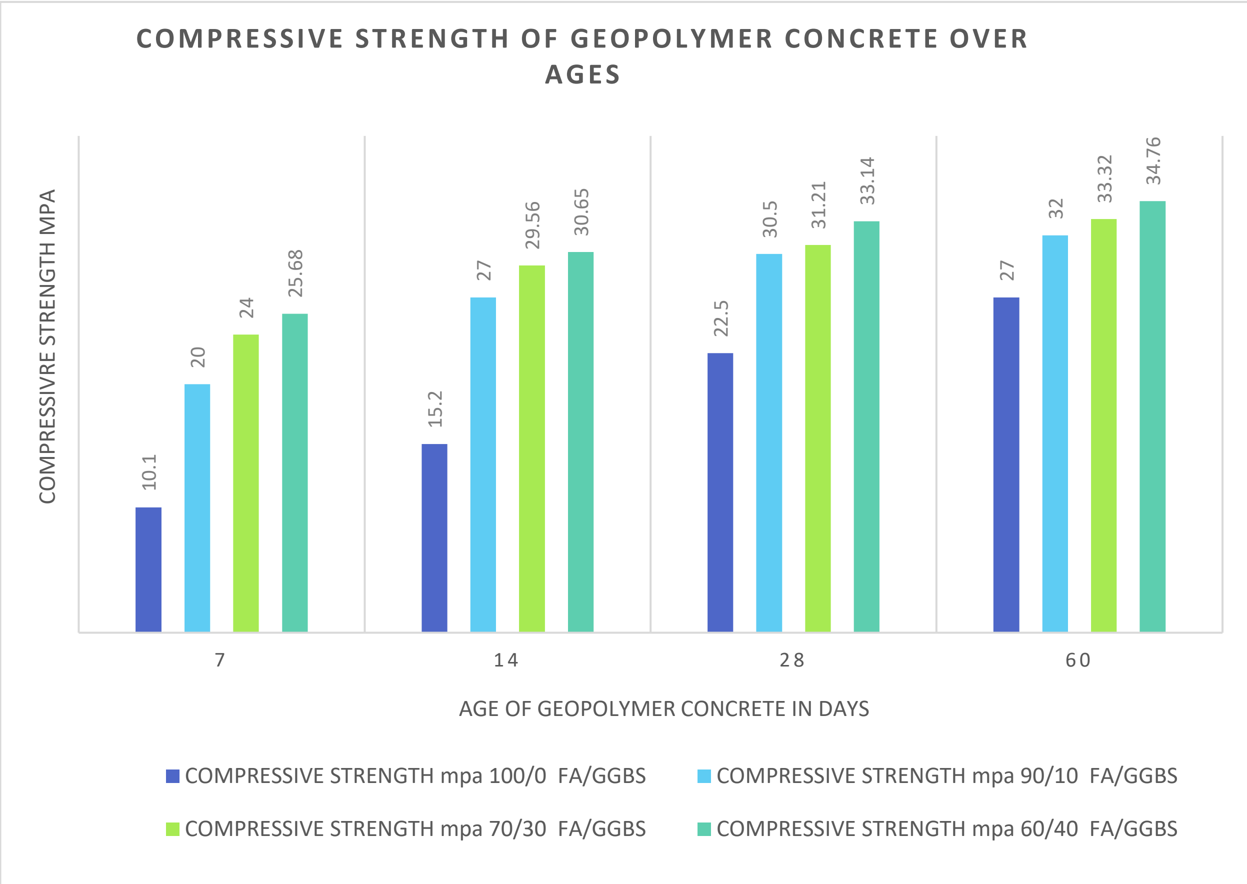
- As shown in figure-1, it is evident that the compressive strength of geopolymer concrete increases with both curing time and the inclusion of Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement for fly ash (FA).
- The 60/40 FA/GGBS mix achieves the highest strength at all ages, reaching 34.76 MPa at 60 days, indicating that GGBS significantly enhances the geopolymerization process due to its higher calcium content, which promotes faster setting and strength gain under ambient curing conditions.

- In comparison, the 100/0 FA/GGBS mix, which contains no GGBS, exhibits the lowest compressive strength at each time interval. This is likely due to fly ash being less reactive at ambient temperatures, as it relies more on heat curing for activation. Therefore, the 60/40 FA/GGBS mix is the optimum ratio, as it provides a balance between sufficient reactivity and enhanced strength gain over time, making it a suitable choice for applications where early and long-term strength is desired without the need for elevated curing temperatures.

Table 9: Compressive strength test of M30 grade geopolymer concrete cured under ambient conditions

Age of geopolymer concrete in days	Compressive Strength in N/mm^2			
	100/0 FA/GGBS	90/10 FA/GGBS	70/30 FA/GGBS	60/40 FA/GGBS
7	10.1	20	24	25.68
14	15.2	27	29.56	30.65
28	22.5	30.5	31.21	33.14
60	27	32	33.32	34.76

Graph 1: Comparison between compressive strength of M30 grade geopolymer concrete for different Fly ash/GGBS ratios



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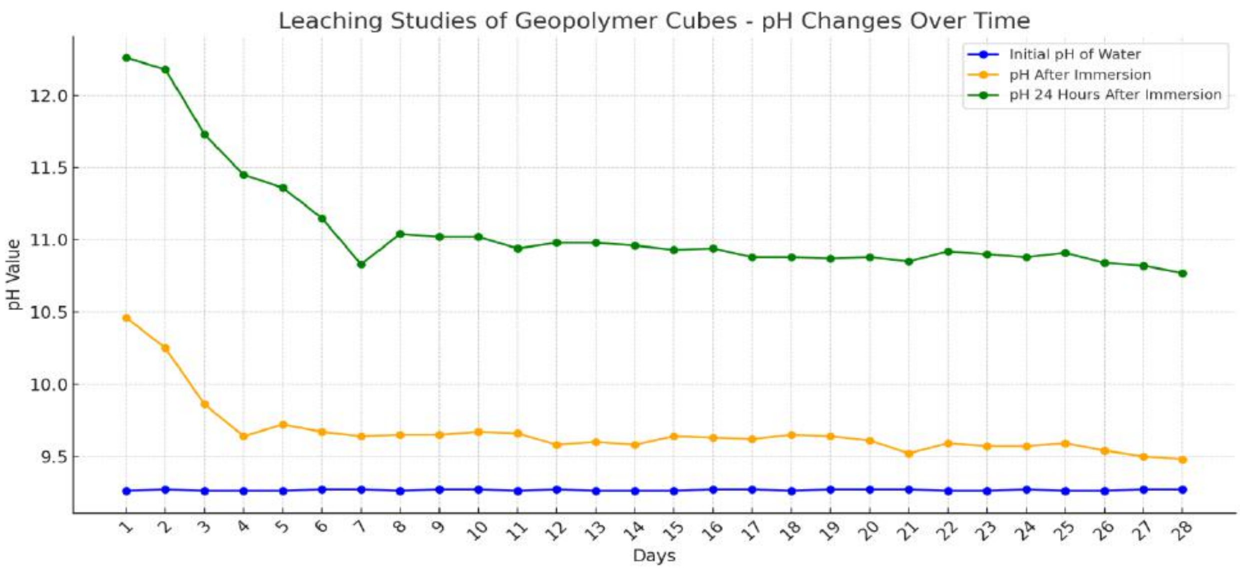
Graph 2: Change of pH over time due to leaching of GPC.



- Graph 2 illustrates the pH changes over time in the leaching study of geopolymer cubes. The orange line shows the pH immediately after immersion, which decreases gradually from around 10.5 to below 9.6, indicating a slight leaching effect. This suggests that the leachable alkaline content diminishes as the concrete matures. The green line represents the pH 24 hours after immersion, which starts around 12.26 and gradually decreases, stabilizing near 10.8 after 28 days. This suggests that while leaching reduces over time, it does not completely stop within the 28-day period.

Table 10: pH values of 60/40 fly ash/GGBS geopolymer cubes during leaching studies.

	LEACHING STUDIES OF GEOPOLYMER CUBES								
NO OF SETS	PH VALUES								
A set consists of 3 geopolymer cubes of size 150*150*150mm	PH value of water	PH of water after immersion of geopolymer cubes				PH of water 24hrs after immersion of geopolymer cubes			
		SET 1	SET 2	SET 03	SET 04	SET 01	SET 02	SET 03	SET 04
DAY 1-7 SET 01	9.26	10.46	10.54	10.57	10.5	12.26	12.16	12.14	12.29
	9.27	10.25	10.29	10.52	10.3	12.18	12.09	12.17	12.21
	9.26	9.86	9.78	10	10.09	11.73	11.62	11.74	11.89
	9.26	9.64	9.71	9.7	9.71	11.45	11.37	11.29	11.32
	9.26	9.72	9.7	9.74	9.68	11.36	11.21	11.23	11.21
	9.27	9.67	9.68	9.7	9.64	11.15	11.18	11.13	11.19
	9.27	9.64	9.66	9.61	9.61	10.83	11.07	11.06	11.14
DAY 8-14 SET 02	9.26		9.65	9.6	9.59		11.04	11.06	11.11
	9.27		9.65	9.54	9.63		11.02	11.02	11.08
	9.27		9.67	9.52	9.61		11.02	10.98	11.06
	9.26		9.66	9.5	9.54		10.94	10.97	11.04
	9.27		9.58	9.59	9.56		10.98	10.96	11.04
	9.26		9.6	9.62	9.64		10.98	10.94	11
	9.26		9.58	9.6	9.62		10.96	10.96	11.02
DAY 15-21 SET 03	9.26			9.64	9.6			10.93	11.1
	9.27			9.63	9.92			10.94	11.02
	9.27			9.62	9.69			10.88	11.02

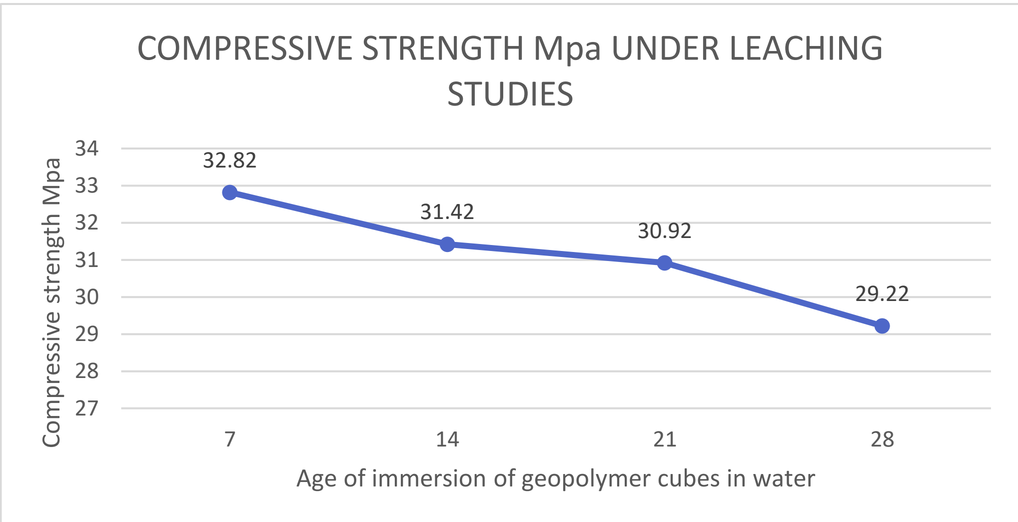
	9.26			9.65	9.68			10.88	10.86
	9.27			9.64	9.65			10.87	10.98
	9.27			9.61	9.64			10.88	10.98
	9.27			9.52	9.54			10.85	10.94
DAY 22-28 SET 04	9.26				9.59				10.92
	9.26				9.57				10.9
	9.27				9.57				10.88
	9.26				9.59				10.91
	9.26				9.54				10.84
	9.27				9.5				10.82
	9.27				9.48				10.77

Note: pH value of water is 9.26-9.27

Table 11: Compressive strength test of 60/40 fly ash/GGBS geopolymer concrete cubes immersed in water.

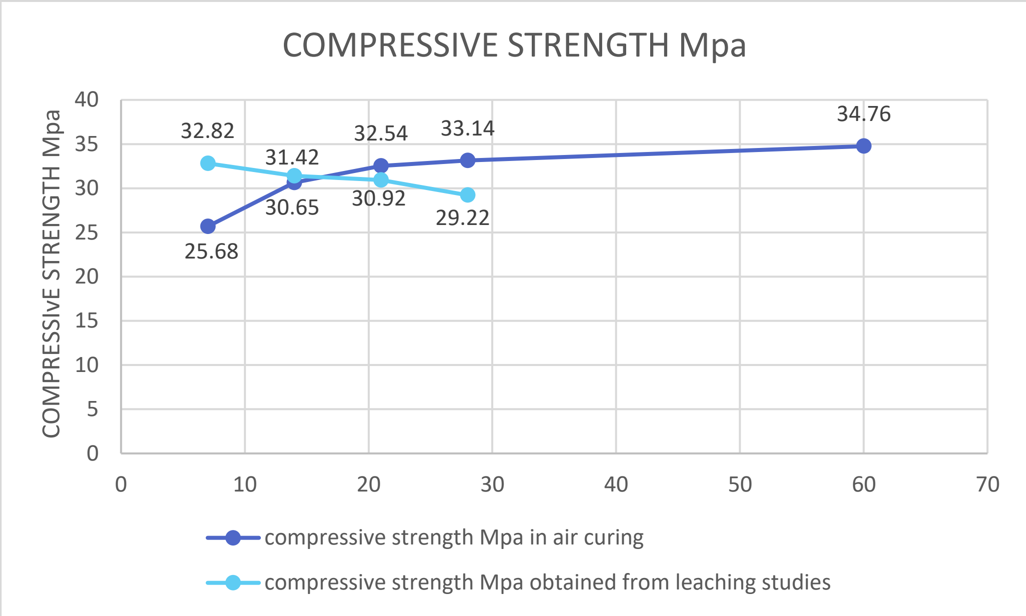
Age of geopolymer cubes immersed in water.	Compressive strength Mpa
7	32.82
14	31.42
21	30.92
28	29.22

Graph 3: Variation of compressive strength over time when immersed in water.



- Graph 3 illustrates a steady decline in the compressive strength of geopolymer cubes as they undergo immersion in water over a 28-day period, highlighting the impact of leaching on material durability. The reduction in compressive strength over time is indicative of sodium silicate leaching from the GPC matrix. Sodium silicate is a key component in geopolymerization, providing binding strength and stability. When it leaches out during immersion, the matrix weakens as sodium silicate contributes to the structural integrity of the geopolymer network. Loss of sodium silicate also results in a reduction in binding efficiency, leading to lower compressive strength.

Graph 4: Comparison between compressive strength of geopolymer cubes cured in ambient condition vs immersed in water over time.



- Graph 4 compares the compressive strength of geopolymer cubes under air curing v/s leaching conditions over a period of up to 28 days. The air-cured samples show a consistent upward compressive strength, indicating continuous strength gain with time but the leaching-affected samples display decreasing compressive strength after the 7th day. This suggests that leaching negatively impacts the strength of geopolymer concrete. Table 12, initially shows the compressive strength is 32.82 MPa on 7th day, with a 5.58% strength loss. After 28 days, the strength falls to 29.22 MPa, with the percentage loss reaching 15.93%. These results indicate a continuous reduction in compressive strength over time.

Table 12: Percentage loss of compressive strength of geopolymer concrete due to leaching effect

Age of immersion of geopolymer cubes in water	Compressive strength Mpa	Percentage loss of strength %
7	32.82	5.58
14	31.42	9.60
21	30.92	11.04
28	29.22	15.93

Note: Percentage loss was calculated taking strength gained by the geopolymer concrete under ambient curing for 60 days as base value i.e. 34.76 Mpa.

Figure 5: Geoloymer concrete mix

Figure 6: Casting of GPC in moulds

Figure 7: Testing of GPC cubes in CTM

Figure 8: GPC cubes immersed in water

Figure 9: Change of color of water due to leaching of Sodium silicate

Figure 10: GPC cubes after compression test.

8. CONCLUSIONS

From the experimental tests the following conclusions are drawn:

1. The compressive strength of ambient cured concrete increases as the age of geo-polymer concrete increases from 7 days, 14 days, 28 days and 60 days for 100/0, 90/10, 70/30, 60/40 FA/GGBS ratios.
2. The 60/40 FA/GGBS mix is the optimum ratio, as it provides a balance between sufficient reactivity and enhanced strength gain over time, making it a suitable choice for applications where early and long-term strength is desired without the need for elevated curing temperatures.
3. There is compressive strength reduction ranging from 5.58% to 15.93% for geopolymer concrete cubes immersed to water and the strength reduction may be due to leaching out of sodium silicate when immersed in water.
4. The leached Sodium silicate measured using pH meter has shown the gradual decrease in release of leachate but it does not completely within the 28 day period. The average reduction of Ph value after 28 days is 15.93%.

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