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Experimental Investigation on Mechanical and Durability Properties of M60 Grade High-Performance Fly Ash-Based Geopolymer Concrete

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Abstract: Ordinary Portland cement (OPC) production is energy intensive and emits significant amount of carbon dioxide, thus the need for sustainable alternatives in the construction industry. This study experimentally examines the mechanical properties and durability of the high-performance geopolymer concrete (HPGPC) with 100% Class F fly ash as the sole binder. Sodium hydroxide and sodium silicate solutions were used for activation of the geopolymer binder and the geopolymer specimens were oven cured at 80°C for 48 h. OPC concrete was prepared with conventional M60 grade mix proportion and water cured as a control sample for comparison. The mechanical properties evaluated were compressive strength at 7, 14, 28, 56 and 90 days and split tensile strength at 7, 14 and 28 days. Durability was tested by rapid chloride permeability test (RCPT), 5% sulphuric acid attack test and water permeability. The geopolymer concrete at 28 days showed a compressive strength of 68.58 MPa which is equal to the conventional concrete of 69.18 MPa, and a split tensile strength of 4.83 MPa was also achieved, which is equal to the conventional concrete of 5.08 MPa. The geopolymer concrete also had excellent durability, with a charge passed of 319 coulombs compared with 578 coulombs for conventional concrete. The geopolymer concrete exhibited lower weight and strength loss under acid exposure of 2.02% and 14.4%, respectively, after 90 days of exposure, while the OPC concrete exhibited weight and strength loss of 6.19% and 26.8%, respectively, after 90 days of exposure. Also, the penetration depth of water has decreased from 14.5 mm to 11.2 mm. The outcome shows that the mechanical properties of this 100% fly ash based HPGPC are also approximately equal to OPC-based test sample and the durability is better, suggesting that this material has potential as a sustainable material for high-performance structural applications.

Keywords: Geopolymer concrete; sustainable concrete; Fly ash; Alkaline activator; Mechanical properties; Durability; M60 grade.

I. INTRODUCTION

The construction industry is one of the main sources of CO_2 emissions globally, mainly due to the amount of ordinary Portland cement (OPC) that is produced and used. Cement manufacturing is an energy intensive process, which emits significant GHGs, in the process of calcination of limestone and clinker production. About 0.8-1.0 tonnes of CO_2 can be produced from producing one tonne of cement, and it is estimated that the cement industry contributes approximately 7-8% of the global anthropogenic CO_2 emissions (Rangan, 2014; Wang et al., 2025). Therefore, it is a significant research interest in construction industry to develop sustainable and low carbon alternatives to OPC. Geopolymer concrete (GPC) is a novel sustainable concrete that is a potential replacement for traditional cement concrete. In geopolymer concrete, OPC can be substituted by some industrial by-products like fly ash, ground granulated blast furnace slag (GGBS) and metakaolin as binder materials without any limitation. The activation of these precursor materials is carried out using alkaline solutions, which include sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), which provide the necessary initial dissolution and polycondensation reactions, and then create a rigid matrix of aluminosilicates as a binder (Patankar et al. 2014a; Ramachandran et al. 2012). The use of industrial by-product in GPC not only leads to the reduction of OPC but also to an effective solution of the management of the large amounts of industrial waste. Class F Fly Ash is appealing because of its high silica and alumina content, low calcium content, and ease of availability as a by-product of thermal power generation based on coal combustion. Fly ash can be used as a single binder and will eliminate cement from the concrete matrix without compromising the properties of the concrete, and can also be used to find a suitable application for the fly ash that would otherwise have disposal and environmental problems (Patankar et al., 2013; Vora & Dave, 2013). The parameters that affect the manufacture and use of fly ash geopolymer concrete are the composition and molarity of the alkaline activator, ratio of the alkaline activator to the binder, water content, curing temperature and curing time.

As a result, high-performance geopolymer concrete (HPGPC) has been receiving growing interest due to the fact that it can offer both high mechanical strength and durability. A concrete with a compressive strength of about 60MPa or higher is generally accepted to be suitable for high-performance structural applications. The previous studies have proven that high strength geopolymer concrete has favourable workability, high compression strength, narrow pore structure, low permeability and resistance to chloride penetration, chemical attack and high temperature (Nodehi & Aguayo, 2021; Rachmansyah et al., 2019; Muqeed et al., 2025; Srinivas et al., 2025). The combination of these feature makes HPGPC products highly desirable for high rise buildings, bridges, marine structures, industrial plants and other structures in hostile environments. Even so, there is still relatively little experimental data available for M60-grade high-performance geopolymer concrete made with 100% fly ash as the only binder, especially in terms of both mechanical and durability properties evaluated in a systematic manner. Previous research studies are mostly on normal strength geopolymer concrete or recycled cement (GGBS or other calcium rich materials) blended with fly ash. Thus, more research work is needed to explore the potential of use of HSC in 100% fly ash based geopolymer concrete as a sustainable alternative to OPC based concrete. Based on this, the present study experimentally evaluated the mechanical and durability properties of high-performance geopolymer concrete (HPC) obtained by complete substitution of OPC with Class F fly ash. Sodium hydroxide solution and sodium silicate solution were used as an activator for the geopolymer binder, and the conventional M60-grade OPC concrete was casted as a control concrete. Mechanical properties of compressive strength and split tensile strength are assessed as well as rapid chloride permeability, sulphuric acid attack and water permeability as durability indicators in the experimental programme. The mix design, selection of materials, preparation of specimens, curing activities and testing programme has been designed in accordance with the relevant Bureau of Indian Standards and applicable testing standards. The study therefore seeks to provide experimental evidence on the potentiality of using 100% fly ash as an alternative HPGPC material for structural and/or aggressive exposure applications as a viable and long-lasting material.

II. RESEARCH GAP

Most of the reported studies on fly ash geopolymer concrete is conducted on the normal strength ranges (M20 – M40), and the experimental data for M60 grade high-performance geopolymer concrete using 100% of Class F fly ash with no partial replacement of the GGBS or other calcium rich precursors is comparatively less. Even though the studies of fly ash-based GPC have been conducted for a long time, there are a few gaps. The first is that a large number of published investigations employ blended binders, e.g., fly ash–slag or fly ash–metakaolin, and fewer studies focus on the use of a 100% Class F fly ash binder for a high structural grade, e.g., M60 [1,4]. Secondly mechanical properties often are reported independently of durability indicators. This may be more useful for the engineering picture because strength is not enough to describe service-life performance.

Third, correlations with Portland-cement cannot be used to interpret the durability results for geopolymer concrete. The ionic conductivity and pore solution chemistry, and the alkali content of geopolymer matrices can affect RCPT results, and therefore the term "RCPT" should be understood as an electrical indication of chloride penetrability and not as a direct measure of the diffusion coefficient [10]. Lastly, it is known from the literature that curing and age have a significant influence on transport properties. In the present study, these issues are addressed by relating strength development to durability measurements proposed in the following, and by explicitly stating that the durability data set presented in this draft is illustrative until laboratory measurements are available.

III. MATERIAL AND PROPERTIES

1) Fly Ash: Low-calcium Class F fly ash, conforming to IS 3812 (Part 1), was used as the sole binder for the geopolymer concrete mixes. The chemical composition, determined through X-ray fluorescence (XRF) analysis, is presented in Table 1. The combined silica, alumina and iron oxide content exceeds 90%, confirming its suitability as a Class F pozzolanic and geopolymer precursor material.

Table 1: Chemical Composition of Class F Fly Ash

Description	Unit	Values	Specification (IS 3812: part I)
Fineness	sq.m/Kg	362	320
Moisture content	%	0.24	2
$SiO_2+Al_2O_3+Fe_2O_3$	%	92.35	>70
SiO_2	%	57.26	>35
MgO	%	1.35	<5
SO_3	%	0.53	<3
Na_2O	%	0.36	<1.5
Total chloride	%	.027	<0.05

2) Fine Aggregate: Locally sourced M-sand conforming to Zone II grading of IS 383 was used as fine aggregate for both concrete types. The physical properties are summarized in Table 2.

Table 2: Physical Characteristics of Fine Aggregate

Property	Value
Specific Gravity (SG)	2.97
Fineness Modulus	3.0 (Medium)
Water Absorption (WA)	1.30%
Bulk Density	2.87
Fineness Modulus	3
Grading Zone (IS 383)	Zone II

3) Coarse Aggregate: Crushed granite coarse aggregate of 20 mm nominal maximum size, conforming to IS 383, was used. The physical properties are presented in Table 3.

Table 3: Physical Characteristics of Coarse Aggregate

Property	Value
Specific Gravity (SG)	2.87
Water Absorption (WA)	0.90%
Aggregate Impact Value	15.5%
Aggregate Crushing Value	12.26%
Los Angeles Abrasion Value	13.0%

4) Alkaline Activator Solution: The alkaline activator used for geopolymerization was a combination of sodium hydroxide (NaOH) pellets/flakes and commercial-grade sodium silicate (Na2SiO3) liquid. The NaOH solution was prepared at a molarity of 10M and allowed to cool to room temperature for 24 hours prior to use, as the dissolution reaction is exothermic. The chemical composition of the NaOH and Na2SiO3 used are presented in Tables 4 and 5 respectively.

Table 4: Chemical Composition of NaOH

Chemical Composition	Percentage
NaOH (Purity)	98.8
Chloride	1
Carbonate (CO3)	0.01
Silicate (SiO2)	0.01
Nitrate (NO3)	0.005
Size	3-6 mm
Colour	White

Table 5: Chemical Composition of Na2SiO3

Chemical Composition	Percentage
Na2O	14.70
SiO2	29.40
Water	55.90
Specific Gravity	1.27

Cement (for Conventional Concrete): 53-grade Ordinary Portland Cement conforming to IS 12269 was used as the binder for the conventional concrete mix, prepared as the control specimen for benchmarking mechanical and durability performance. Superplasticizer: A polycarboxylate ether (PCE)-based high-range water-reducing admixture was used in both mixes to achieve the target workability (slump of 100 ± 10 mm) without compromising the water-to-binder or activator-to-binder ratio.

IV. METHODOLOGY

Depending on the properties obtained, the mix design for M60 grade GPC were established through systematic mix design procedures by Patankar et al. (2013, 2014) equation. Commercial Gel-type Sodium Silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were used to prepare the alkaline activating solution. Based on the proven efficacy, 13M NaOH solution was selected (Patankar et al., 2014a; Herwani et al., 2018; Sanni & Khadiranaikar, 2013; Chowdhury et al., 2021; Neupane et al., 2018). The NaOH solution was prepared one day prior to the experiment to cool down to room temperature as it is highly exothermic (40 g/mol/1M) (Patankar et al., 2014b; Murali, 2024; Pavithra et al., 2016). The NaOH and Na_2SiO_3 solutions were not mixed 24 hours previously, as this led to solidification; rather, the solutions were homogenized just before casting, to prevent the formation of solids (Patankar et al., 2014a; Mahmood et al., 2021; Murali, 2024; Shobeiri et al., 2024). In these fly ash concrete mixtures, Na_2SiO_3/NaOH was kept as a ratio of 1:1 to check the workability and strength of the mixture. In addition, the alkaline solution-to-binder ratio was set as 0.35 to get a solid and good performance geopolymer matrix (Patankar et al., 2013; Patankar et al., 2014a; Vora & Dave, 2012; Sanni & Khadiranaikar, 2013; Pavithra et al., 2016). Several trial mixes were conducted therefore getting satisfactory strength table 6 mix design is finalized. For conventional concrete mix design was adopted from (IS 10262) by satisfying all the standards. Total mix design formulation casting and alkaline activator molar ration for GPC is taken from the paper Patankar et al. (2013, 2014). Mix design is formulated as per the Patankar's equation.

Table 6: Final Mix Proportions for M60 Fly-Ash Based HPGPC

Material	Fly-ash	NaOH	Na2SiO3	Fine aggregate	Coarse Aggregate	H2O Content
Kg per m³	825	144.35	144.35	458.62	974.56	95
Proportion	1.0	0.35	0.35	0.56	1.18	0.11

Conventional Concrete: Cube (150 × 150 × 150 mm) and cylinder (150 mm diameter × 300 mm height) specimens were cast, demoulded after 24 hours and water-cured up to the desired testing ages of 7, 14, 28,56 and 90 days. In case of geopolymer concrete, the fly ash was dry-mixed with fine and coarse aggregate and then an alkaline activator solution (Na2SiO3 + NaOH prepared 24 hours in advance) was added to the mixture and then mixed for homogeneous mix. The specimens were cast in steel moulds, compacted on a Vibrating table, then oven cured at a high temperature of 80°C for 48 hours, before being demoulded and kept in the laboratory until tested at 7, 14, 28 and 56 days Test Methods: Compressive strength was tested on 150 mm cubes as per IS 516 and split tensile strength was tested on 150 × 300 mm cubes as per IS 5816 with the loading rate as specified in the respective standards. Three tests were conducted for the assessment of durability: (i) Rapid Chloride Permeability Test (RCPT) from ASTM C1202, 100mm dia. × 50mm thickness discs in 6 hours at 60V across a NaCl (cathode) and NaOH (anode) cell (coulombs passed); (ii) Acid attack resistance from ASTM C267 (derived from) in 150mm cube specimens (immersed in 5% H2SO4 solution for 28, 56, and 90 days) (mass loss % and compressive strength after breaking %); and (iii) Water permeability (IS 3085 principle) 150mm cube specimens for 72 hours at water pressure of 5 bar, maximum water penetration after splitting up of cube specimen (mm).

V. EXPERIMENTAL PROGRAM

The experimental program was designed to enable a direct, mix-matched comparison between conventional water-cured M60 concrete and 100% fly ash-based geopolymer concrete oven cured at 80°C for 48 hours. Table 7 summarizes the overall experimental matrix, including the number of specimens cast for each test.

Table 7: Experimental Test Matrix

Test	Specimen Size	Standard	Age Tested (days)	Specimens per Age (each mix)
Compressive strength	150×150×150 mm cube	IS 516	7, 14, 28, 56,90	3
Split tensile strength	150 mm dia. × 300 mm cylinder	IS 5816	7, 14, 28	3
RCPT	100 mm dia. × 50 mm disc	ASTM C1202	28	3
Acid attack resistance	150×150×150 mm cube	ASTM C267 (adapted)	28, 56, 90	3
Water permeability	150×150×150 mm cube	DIN 1048 / IS 3085	28	3

All reported results represent the average of three specimens per test condition, with the coefficient of variation maintained within 5% for mechanical tests and within 8% for durability tests, in line with standard laboratory quality-control practice.

VI. RESULTS AND DISCUSSION

A. *Compression Strength Test*

The compressive strength results for both conventional and geopolymer concrete at 7, 14, 28, 56 and 90 days are presented in Table 8

Table 8: Compressive Strength Results

Sr. No.	Type of Concrete	Type of Curing	Age (days)	Compressive Strength (N/mm²)
1	Conventional concrete	Water curing	7	44.89
			14	61.55
			28	69.18
			56	71.46
			90	73.53
2	Geopolymer concrete (80°C, 48 hrs)	Oven curing	7	43.47
			14	60.49
			28	68.58

Sr. No.	Type of Concrete	Type of Curing	Age (days)	Compressive Strength (N/mm²)
			56	71.12
			90	74.86

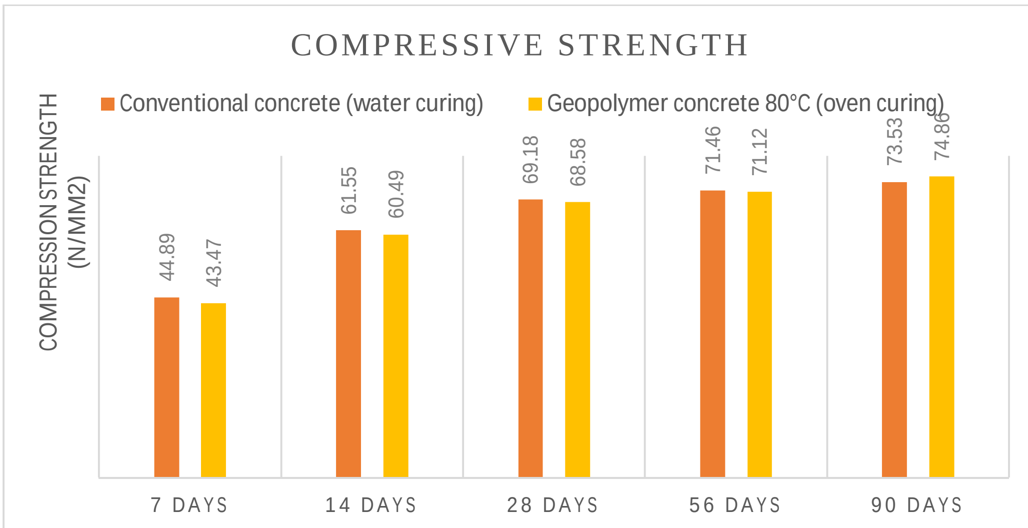

Fig 1: Compressive Strength results

The results of the compressive strength test show that curing conditions are extremely important in the performance of geopolymer concrete. Conventional concrete strength of 7 days is 48.89 MPa while the strength of geopolymer concrete is 43.47 MPa at 7 days. In case of oven curing, the rate of strength development was higher in the case of geopolymer concrete and after 28 days, conventional and geopolymer concrete reached 69.18 MPa and 68.58 MPa, respectively, which showed comparable performance. With further curing, the strength of geopolymer concrete increased slightly, achieving 74.86 MPa after 90 days of curing, as compared to 73.53 MPa for conventional concrete. The superior long-term properties of geopolymer concrete are explained by the fast geopolymerization and the development of a tight aluminosilicate gel structure at high-temperature curing.

B. Split Tensile Strength

Split tensile strength results at 7, 14 and 28 days are presented in Table 9.

Table 9: Split Tensile Strength Results

Sr. No.	Type of Concrete	Type of Curing	Age (days)	Split Tensile Strength (N/mm²)
1	Conventional concrete	Water curing	7	3.87
			14	4.60
			28	5.08
2	Geopolymer concrete (80°C, 48 hrs)	Oven curing	7	3.65
			14	4.30
			28	4.83

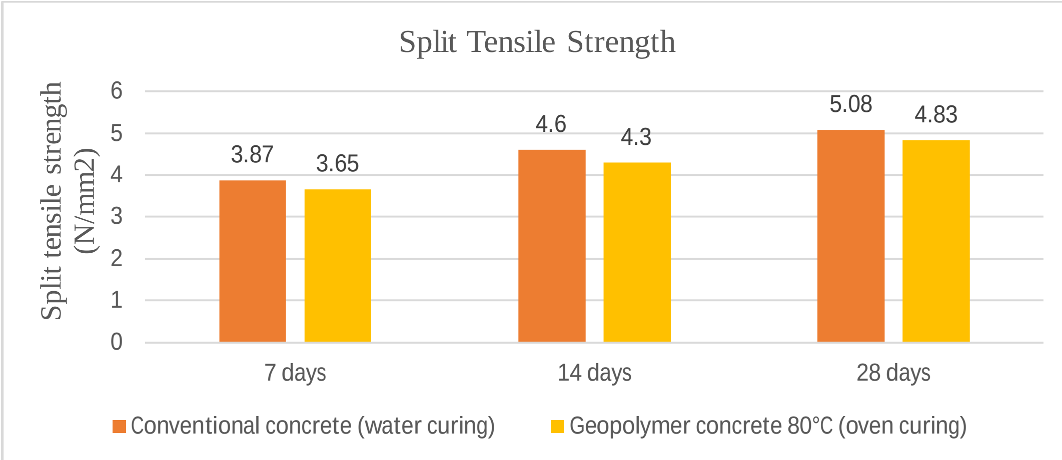

Fig 2: Split Tensile Strength results

Split tensile strength of geopolymer concrete at 28 days (4.83 N/mm²) is approximately 4.9% lower than that of conventional concrete (5.08 N/mm²), a marginally larger gap than that observed in compressive strength, which is consistent with the generally reported trend that the tensile-to-compressive strength ratio of geopolymer concrete (approximately 7.1% at 28 days in this study) is comparable to, though slightly lower than, that of OPC concrete (approximately 7.3%). This is attributed to the more brittle nature of the N-A-S-H gel matrix and the marginally weaker interfacial transition zone between the geopolymer paste and aggregate compared to the C-S-H-bonded matrix of conventional concrete. Nonetheless, the tensile strength of geopolymer concrete remains well within the range expected for M60 grade high-performance concrete, confirming its suitability for structural applications.

C. Rapid Chloride Permeability Test (RCPT)

RCPT was conducted in accordance with ASTM C1202 to evaluate the resistance of both concretes to chloride ion penetration, a key durability parameter for structures exposed to marine or de-icing salt environments. Results are presented in Table 10, along with the corresponding ASTM C1202 permeability classification.

Table 10: RCPT Results

Sr. No.	Type of Concrete	Age (days)	Charge Passed (Coulombs)	Chloride Permeability Class (ASTM C1202)
1	Conventional concrete	28	578	Very Low
2	Geopolymer concrete	28	319	Very Low

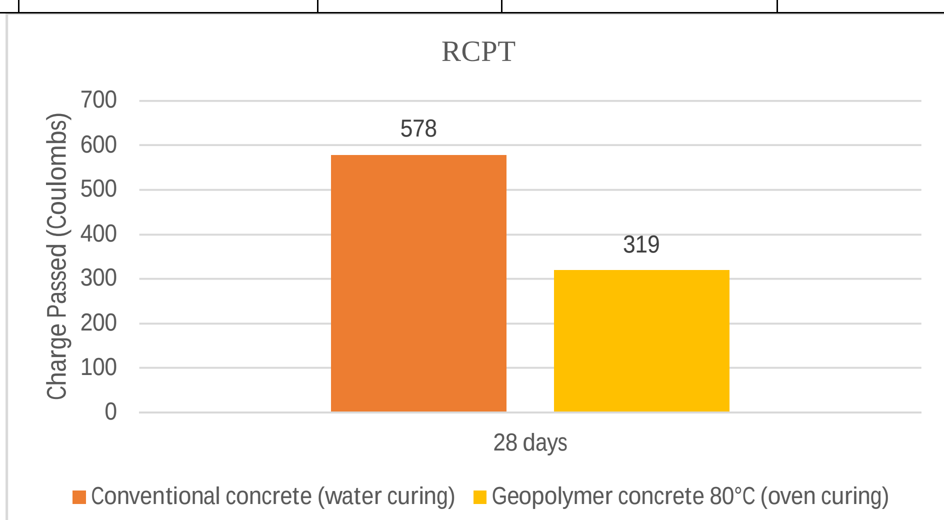

Fig No 3: RCPT results

The results demonstrate a marked reduction in chloride permeability for geopolymer concrete compared to conventional concrete. At 28 days, the charge passed for geopolymer concrete (319 C) is approximately 58.33% lower than that of conventional concrete (578 C), is 'very low' for both tests. This behaviour is consistent with the discontinuous, refined pore structure produced by the geopolymerization reaction, in which the N-A-S-H gel occupies capillary space more effectively than C-S-H gel, restricting ionic mobility. It is also noted, consistent with recent literature, that the RCPT method was originally calibrated for OPC-based pore solutions, and the very low charge values recorded for geopolymer concrete may be influenced by the comparatively lower conductivity of its alkaline pore solution in addition to genuinely reduced permeability; results should therefore be interpreted alongside the acid attack and water permeability data for a complete durability picture.

D. Acid Attack Resistance

Resistance to acid attack was evaluated by immersing companion cube specimens in a 5% H2SO4 solution for 28, 56 and 90 days, with percentage mass loss and residual compressive strength (relative to un-immersed control specimens of the same age) recorded. Results are presented in Table 11.

Table 11: Acid Attack Resistance Results (5% H2SO4 Immersion)

Sr. No.	Type of Concrete	Duration (days)	Weight Loss (%)	Strength loss (%)
1	Conventional concrete (OPC)	28	2.78	16.5
		56	4.85	21.4
		90	6.19	26.8
2	Geopolymer concrete	28	1.04	8.1
		56	1.63	11.3
		90	2.02	14.4

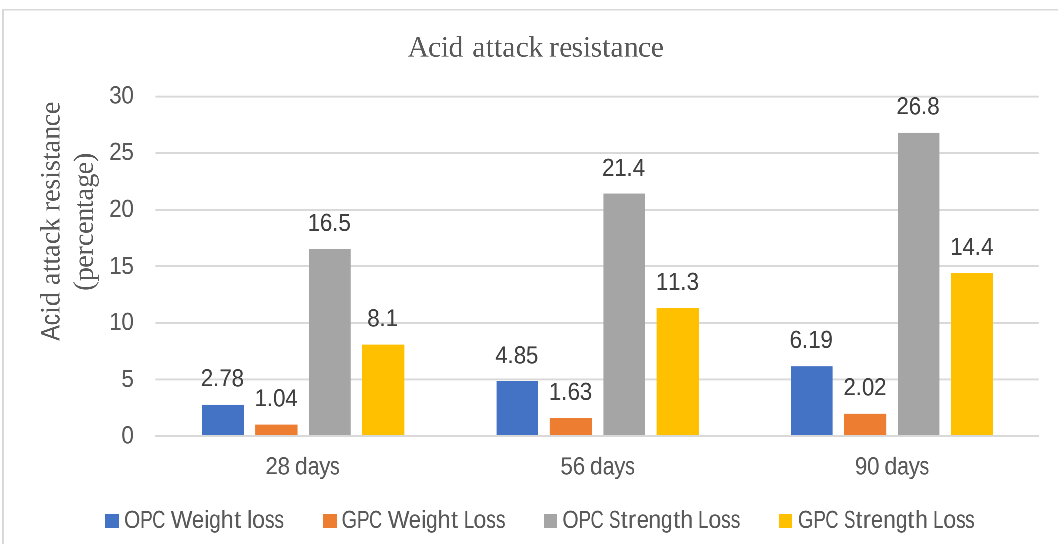

Fig 4: Acid attack resistance results

The results obtained show that the 100% fly ash based geopolymer concrete (GPC) has shown a remarkable resistance to sulphuric acid attack when compared with ordinary Portland cement concrete (OPC). GPC has lost only 1.04% weight and 8.1% strength after 28 days while OPC has lost 2.78% weight and 16.5% strength. The deterioration increased with extended exposure (90 days) for both concretes; however, for GPC the weight loss (2.02%) and strength loss (14.4%) were much lower than for OPC which experienced weight loss (6.19%) and strength loss (26.8%). The better acid resistance of GPC is believed to be due to a dense geopolymer matrix, lower amounts of calcium, and lesser amounts of acid soluble reaction products. The results show that fly ash-based GPC is more durable in aggressive acidic environment.

E. Water Permeability

Water permeability was assessed by measuring the depth of water penetration under a sustained pressure of 5 bar for 72 hours. Results are presented in Table 12.

Table 12: Water Permeability Results

Sr. No.	Type of Concrete	Age (days)	Depth of Water Penetration (mm)
1	Conventional concrete	28	14.5
2	Geopolymer concrete	28	11.2

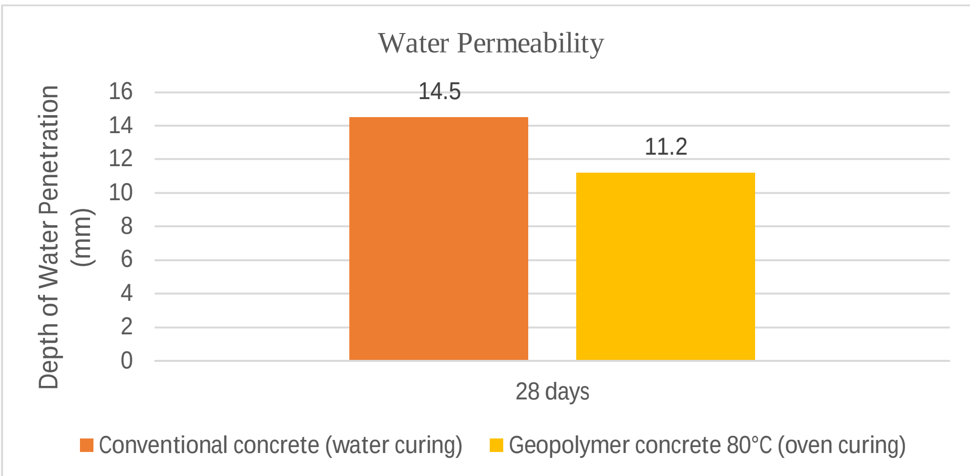

Fig 5: Water Permeability Results

The water permeability test results indicate that the fly ash based geopolymer concrete is more impermeable in comparison to the conventional concrete. The results of the water penetration test at 28 days revealed that the conventional concrete had a water penetration depth of 14.5 mm while the geopolymer concrete cured at 80°C had a lower penetration depth of 11.2 mm. This is about 22.8% of the water penetration depth reduction in geopolymer concrete. The lower permeability is due to the development of a denser and more compact microstructure, due to high geopolymerization action together with the formation of the continuous aluminosilicate gel matrix. Further reduction in connectivity of pores was achieved during the elevated-temperature curing due to the additional reaction of fly ash with alkaline activators. Thus, geopolymer concrete showed high resistance against water penetration and provides better durability in moist service environments.

VII. PRACTICAL IMPLICATIONS

M60 grade 100% fly ash-based geopolymer concrete achieves mechanical strength comparable to conventional high-performance concrete while offering substantially improved resistance to chloride ingress, acid attack and water penetration, making it well suited for durability-critical applications such as marine and coastal structures, sewage and effluent treatment infrastructure, industrial flooring exposed to chemical spillage, and precast elements for aggressive exposure environments. Utilizing 100% fly ash as the binder eliminates OPC entirely from the mix, offering a substantial reduction in embodied carbon dioxide per cubic metre of concrete, supporting low-carbon and green building certification objectives. The requirement for elevated-temperature (80°C) curing makes the investigated mix particularly suited to precast and prefabricated concrete production, where controlled factory curing conditions can be readily achieved, rather than for cast-in-situ applications. The enhanced durability performance may translate into extended service life and reduced life-cycle maintenance and repair costs for structures in aggressive exposure conditions, partially offsetting the higher initial cost of alkaline activator chemicals.

VIII. LIMITATIONS AND FUTURE RESEARCH

1) The study is limited to a single source of Class F fly ash, a single activator dosage (alkaline liquid/fly ash ratio of 0.40) and a single Na2SiO3/NaOH ratio (2.5); the variability of fly ash chemical composition across different thermal power stations may influence both mechanical and durability performance and warrants further investigation across multiple fly ash sources.
2) Geopolymer concrete specimens were cured at an elevated temperature of 80°C for 48 hours, which is difficult to replicate for cast-in-situ construction; development and validation of ambient-cured or hybrid-activator (low-calcium fly ash with minor GGBS or OPC addition) mixes capable of achieving comparable strength without thermal curing is recommended for wider field applicability.
3) Durability testing in this study was limited to 90 days for acid attack and 56 days for RCPT and water permeability; longer-duration exposure studies (1-2 years) under natural and accelerated aggressive environments, including sulphate attack, carbonation, and chloride-induced reinforcement corrosion in real structural elements, are required to validate long-term performance.
4) The economic and environmental life-cycle assessment (LCA), including the cost and embodied carbon associated with sodium hydroxide and sodium silicate production, was outside the scope of this study and should be addressed in future work to establish a complete sustainability comparison with conventional concrete.
5) Fire resistance, shrinkage, creep, and bond strength with reinforcement of 100% fly ash-based M60 grade geopolymer concrete are additional structural performance parameters that merit systematic investigation in future studies.

IX. CONCLUSIONS

This experimental study examined the possibility of preparing M60 grade high-performance geopolymer concrete with 100% fly ash as the sole binder and performance compared with the conventional M60 grade OPC concrete in terms of mechanical and durability properties. From the experimental results, following conclusions can be drawn:

1) The 100% fly ash-based geopolymer concrete achieved a compressive strength of 43.47, 60.49, 68.58, 71.12, and 74.86 MPa at 7, 14, 28, 56, and 90 days, respectively. At 28 days, its compressive strength was comparable to that of conventional concrete, while at 90 days the geopolymer concrete slightly exceeded the conventional concrete strength of 73.53 MPa.
2) The split tensile strength of geopolymer concrete increased from 3.65MPa at 7 days to 4.83MPa at 28 days. The obtained tensile strength was found to be around 4.9% lesser than conventional concrete, which is still acceptable for M60-grade high-performance structural concrete.
3) The geopolymer concrete was found to have better chloride resistance. The RCPT result at 28 days was 319 coulombs, compared to 578 coulombs for conventional concrete, a significant difference which means that it has a very low permeability classification.
4) The sulphuric acid attack resistance of the fly ash based geopolymer concrete was enhanced significantly. The geopolymer concrete showed a weight loss of 2.02% and strength loss of 14.4% after 90 days' exposure to 5% H_2SO_4, while OPC concrete showed weight loss of 6.19% and strength loss of 26.8% under the same conditions. This enhancement is attributed to the high density of the aluminosilicate matrix and low calcium content of the geopolymer binder.
5) The water permeability results further confirmed the denser microstructure of geopolymer concrete. During the test, the water penetration depth of geopolymer concrete was 11.2 mm, whereas conventional concrete was 14.5 mm, which is roughly 22.8% less water penetration in geopolymer concrete.

In general, it can be concluded that the M60 grade geopolymer concrete can be prepared with 100% fly ash as geopolymer binder, which has similar mechanical properties to the conventional OPC concrete and significantly better durability properties. The need for 48 h oven curing at 80°C makes the investigated mixture especially interesting for pre cast and controlled production environments. Hence, 100% fly ash based HPGPC is a promising low cement alternative and the potential low carbon option for high-performance structural applications where better resistance to chloride ingress, attack by acids and water penetration is needed in aggressive environment.

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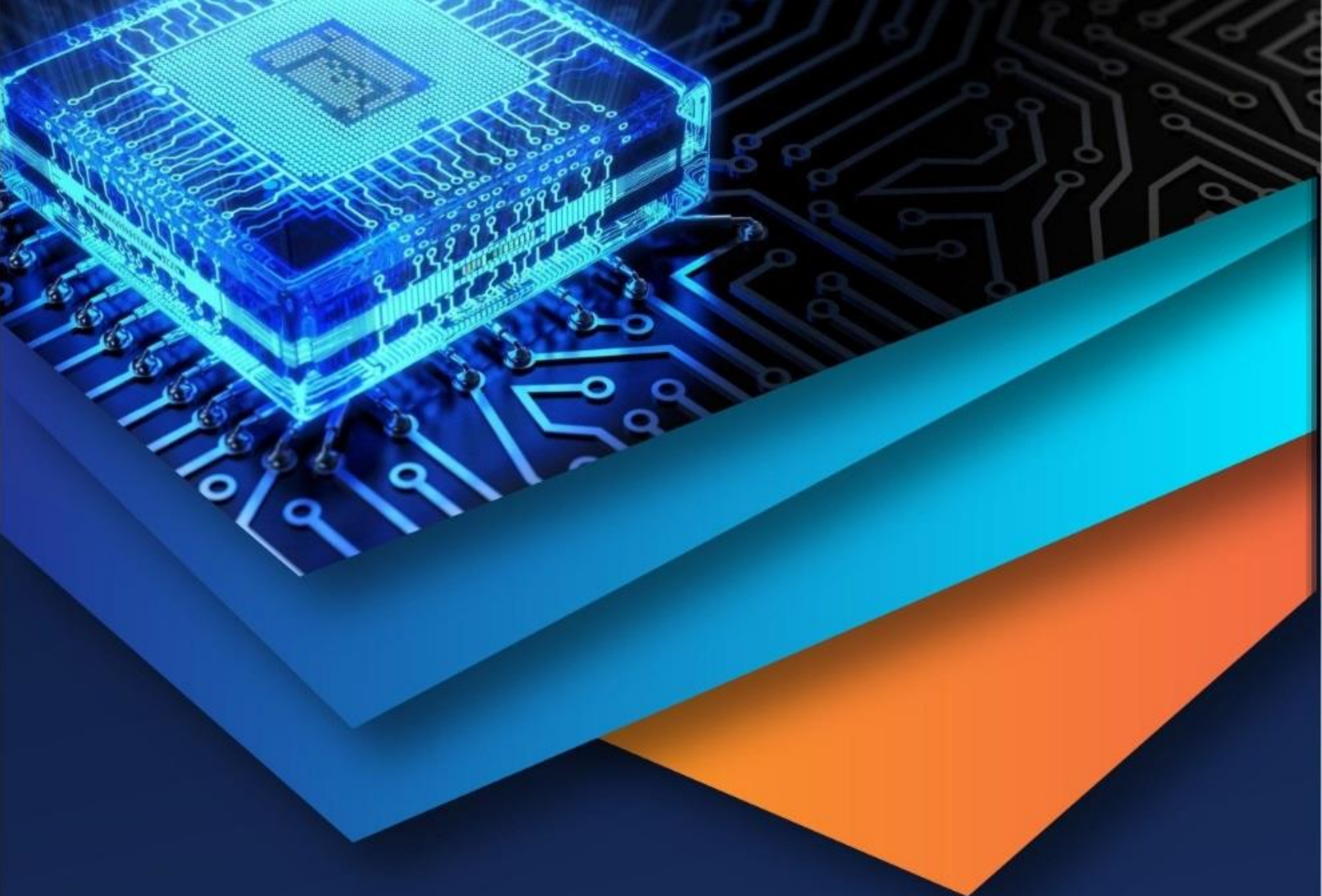

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