

Experimental Investigation to Enhance the Strength and Access the Permeability of Geopolymer Permeable Concrete Using Variable Head Method

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Abstract:

This research aims to conduct comprehensive assessment of engineering attributes of Geopolymer permeable concrete. This investigation is to development of Geopolymer permeable concrete using mineral admixtures (Metakaolin (MK), GGBS and fly ash) as raw material and Sodium hydroxide (NaOH) and Sodium silicate solution (Na_2SiO_3) as activator. the activator solution to binder ratio is fixed at 0.4 ($\text{AL/B} = 0.4$). With a focus on systematically varying key parameters and incorporating different aggregate sizes (10mm&12mm). The primary objectives encompass enhancing compressive strength in Permeable concrete structures, and conducting a comprehensive analysis of the material performance characteristics. Utilizing a Geopolymer binder consisting of MK, Fly ash, GGBS (60:20:20-Trial 1 & 40:20:40- Trial 2), Sodium hydroxide to Sodium silicate solution ratio is 2.5($\text{NaOH}/\text{Na}_2\text{SiO}_3=2.5$) with molarity of 10. The purpose of this research is to study the compressive strength test and water permeability test.

Keywords: Geopolymer, MK, GGBS, fly ash, Sodium hydroxide (NaOH) and Sodium silicate solution (Na_2SiO_3)

1. INTRODUCTION

Geopolymer permeable concrete presents an innovative and sustainable approach to construction materials. With an increasing focus on environmental conservation and resource efficiency, Geopolymer concrete has gained attention for its potential to reduce carbon emissions and utilize industrial by-products. Permeable concrete is one of the most extensively used materials in the concrete industry for storm water management, pollution control, noise reduction, and sustainable design This study aims to conduct comprehensive assessment of engineering attributes of Geopolymer permeable concrete by systematically varying key parameters. Through a comprehensive analysis of factors such as mix proportions, curing conditions, and aggregate types, this research seeks to enhance our understanding of how these variations influence the structural and permeability characteristics of gap graded concrete.

2. PROBLEM STATEMENT

Industrial by-products such as fly ash, GGBS, and MK often go underutilized and contribute to environmental pollution when improperly disposed of. Despite their potential as supplementary cementitious or aggregate materials, there is limited research on integrating such by-products into sustainable concrete mixes, particularly in the context of geopolymer concrete. In this context, there is a pressing need to explore alternative materials and technologies that not only reduce the environmental footprint of concrete but also utilize industrial waste efficiently. The feasibility and effectiveness of MK as a replacement for traditional fine aggregates in geopolymer concrete remain largely unassessed. This project seeks to address this gap by performing a detailed investigation into the engineering properties of MK based geopolymer concrete. The aim is to determine whether this combination can serve as a sustainable, high-performance material suitable for structural and non-structural applications in the construction industry.

3. SIGNIFICANCE OF THE STUDY

The construction industry is a major consumer of natural resources and a significant contributor to global carbon emissions. As the demand for infrastructure continues to grow, there is an urgent need to adopt sustainable materials and methods to reduce environmental impact. This study addresses that need by exploring an innovative alternative in the form of MK-based geopolymer concrete.

Sustainable Material Utilization: MK, an industrial by-product, has the potential to replace conventional fine aggregates, thus reducing the over-reliance on natural river sand and minimizing ecological degradation.

Carbon Footprint Reduction: Geopolymer concrete does not rely on Ordinary Portland Cement, which is a major source of CO₂ emissions. Its use promotes environmentally friendly construction practices.

Waste Management and Resource Efficiency: By incorporating MK, this study contributes to effective solid waste management, offering a practical solution for industrial waste reutilization.

Improved Durability and Performance: Geopolymer concrete is known for its excellent durability and resistance to aggressive environmental conditions. Investigating its performance with MK may reveal enhanced or cost-effective engineering properties.

Economic Benefits: Utilizing industrial by-products may lead to cost reductions in concrete production, making it economically viable for large-scale applications.

Academic and Industrial Relevance: The findings of this study can serve as a reference for future research and also provide practical insights for engineers and decision-makers in the construction industry aiming for sustainability.

4. GEOPOLYMER CONCRETE

Geopolymer concrete represents a transformative shift in construction materials science, offering an innovative and sustainable alternative to Ordinary Portland Cement (OPC) based concrete. It is synthesized through the polymerization of aluminosilicate rich materials in the presence of alkaline activator solutions, forming a binder with strong molecular chains and enhanced durability. The term "geopolymer" was introduced by Joseph Davidovits in 1978, who proposed that certain aluminosilicate materials, when activated with alkaline liquids, undergo a polymerization reaction to form inorganic polymers. These polymers are comprised of repeating units of Si-O-Al bonds, which create a rigid and stable three-dimensional network.

5. CHARACTERIZATION OF MATERIALS

The performance and durability of geopolymer gap-graded concrete are highly dependent on the physical and chemical characteristics of its constituent materials. Hence, a comprehensive characterization of each material used is essential to ensure quality and consistency in mix design and concrete behavior.

Specific Gravity of binders

Name of the binder	Obtained value	Recommended Value
MK	2.88	2.80 to 3.00
Fly Ash	2.13	2.10 to 2.60
Ground Granulated Blast Furnace Slag (GGBS)	2.32	2.80 to 3.00

Table 5.1 Specific gravity of binders

Testing for Coarse aggregate

Name of the test	Obtained value		Recommended Value
	10mm	12mm	
Water Absorption	0.9 %	0.8 %	Max water absorption limit for coarse aggregates in any climatic condition should not be more than 2%
Impact value test	20.92%	21.23%	<10% Exceptionally strong 10- 20% Strong 10-30% Satisfactorily for road surface <35% Weak for road surfacing
Specific Gravity	2.83	2.82	The specific gravity of aggregates normally used in construction ranges from about 2.5 to 3.0 with an average value of about 2.68

Table 5.2 Testing of Coarse aggregate

6. MIX PROPORTIONS

Sl. no	Mix ID	No. of Specimen	Coarse Aggregate	MK content (Kg/m ³)	Fly ash content (Kg/m ³)	GGBS content (Kg/m ³)	Alkaline Liquid
1	PGCM1	12	87.221	17.08	4.92	5.50	11.030
2	PGCM2	12	87.221	11.39	9.97	5.50	10.746

Table 6.1 Mix Proportions

7. PREPARATION OF ALKALINE ACTIVATOR SOLUTION

To prepare the alkaline solution, sodium hydroxide is first diluted with distilled water based on the required molarity, typically 12 molarity, where one litre of water is mixed with 480g of NaOH. Following dilution, a minimum of thirty minutes is allotted before mixing sodium silicate with the diluted sodium hydroxide solution, adhering to the prescribed mix design.

The resulting combination of sodium hydroxide solution and sodium silicate constitutes the alkaline solution.

8. CASTING AND CURING



Fig 8.1 Geopolymer Concrete sample Specimen



Fig 8.2 Ambient Curing

9. SAMPLE PREPARATION

S.No	Concrete	7days	14 days	Total
1.	Trial 1 (60% AF + 20% FA+ 20% GGBS)			
	Cube	6	6	12
	Cylinder	6	6	12
2.	Trial 2 (40% AF +40% FA+ 20% GGBS)			
	Cube	6	6	12
	Cylinder	6	6	12

Table 10.1 Sample preparation

IV.RESULTS AND DISCUSSION

4.1 Compressive Strength



Compressive Strength (N/mm^2) = P/A

Where,

P = Cube failure load (N)

A = Specimen cross-sectional area (mm^2)

Trial - 1 (MK: FA: GGBS) (60: 20: 20) 10mm aggregate

Mix	No of days	Load (N)	Stress (N/mm ²)	Average Stress (N/mm ²)
PGCM1	7	360×10^3	16	16.41
PGCM2	7	380×10^3	16.80	
PGCM3	7	370×10^3	16.44	
PGCM1	14	460×10^3	20.4	20.5
PGCM2	14	450×10^3	20	
PGCM3	14	480×10^3	21.3	

Table 4.1 Compressive Strength of Trial – 1 (10mm)

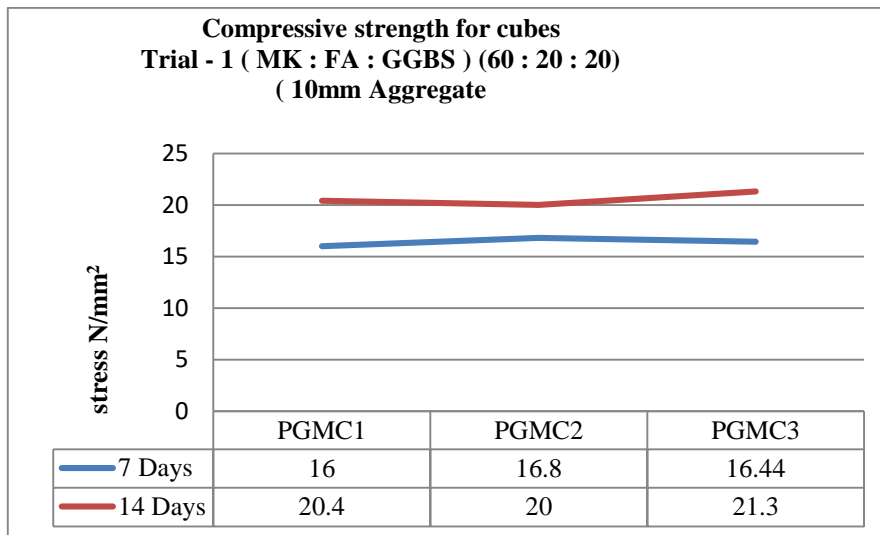


Fig 4.1 Compressive Strength of Trial – 1 (10mm)

Trial - 1 (MK: FA: GGBS) (60: 20: 20) 12mm aggregate

Mix	No of days	Load (N)	Stress (N/mm ²)	Average Stress (N/mm ²)
PGCM1	7	600×10^3	26.6	25.5
PGCM2	7	480×10^3	21.3	
PGCM3	7	640×10^3	28.4	
PGCM1	14	670×10^3	29.7	28.4
PGCM2	14	660×10^3	29.3	
PGCM3	14	590×10^3	26.2	

Table 4.2 Compressive Strength of Trial – 1 (12mm)

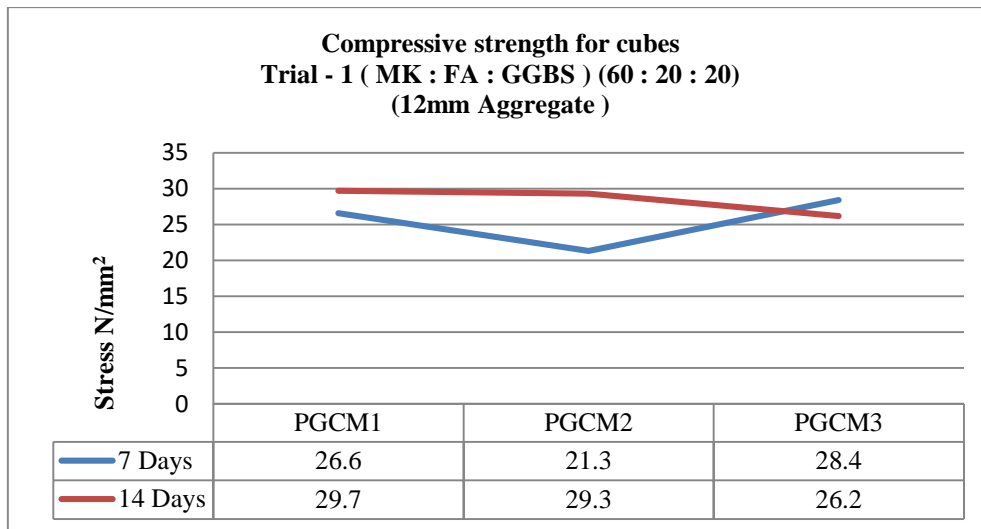


Fig 4.2 Compressive Strength of Trial – 1 (12mm)

Trial - 2 (MK: FA: GGBS) (40: 40: 20) 10mm aggregate

Mix	No of days	Load (N)	Stress (N/mm ²)	Average Stress (N/mm ²)
PGCM1	7	165 x 10 ³	7.33	7.6
PGCM2	7	180 x 10 ³	8	
PGCM3	7	170 x 10 ³	7.55	
PGCM1	14	270 x 10 ³	12	11.2
PGCM2	14	250 x 10 ³	11.1	
PGCM3	14	240 x 10 ³	10.6	

Table 4.3 Compressive Strength of Trial – 2 (10mm)

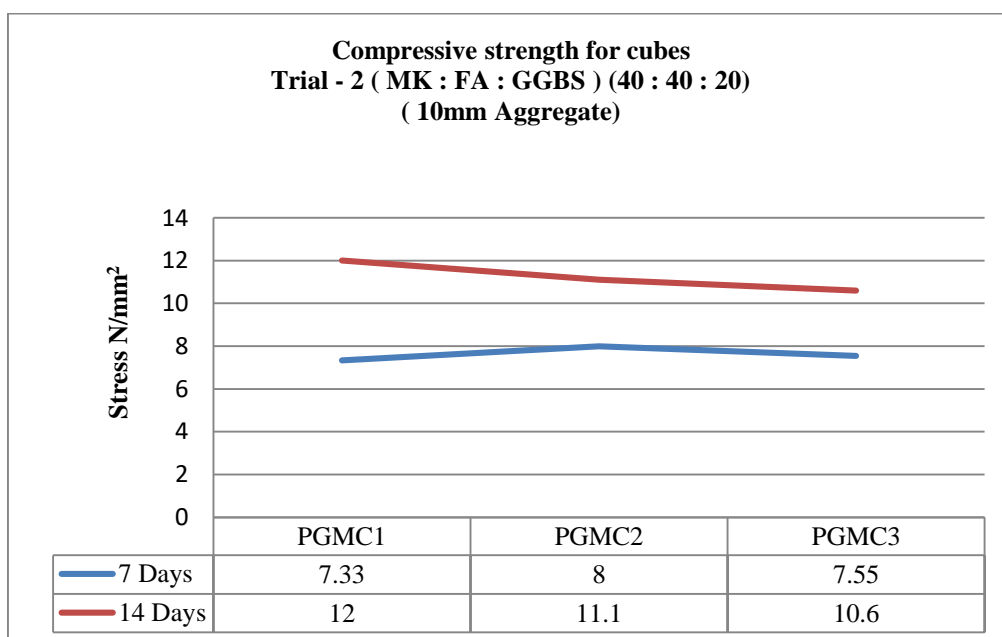


Fig 4.3 Compressive Strength of Trial – 2 (10mm)

Trial - 2 (MK: FA: GGBS) (40: 40: 20) 12mm aggregate

Mix	No of days	Load (N)	Stress (N/mm ²)	Average Stress (N/mm ²)
PGCM1	7	100 x 10 ³	4.44	4.7
PGCM2	7	100 x 10 ³	4.44	
PGCM3	7	120 x 10 ³	5.33	
PGCM1	14	230 x 10 ³	10.22	10.2
PGCM2	14	220 x 10 ³	9.77	
PGCM3	14	240 x 10 ³	10.66	

Table 4.4 Compressive Strength of Trial – 2 (12mm)

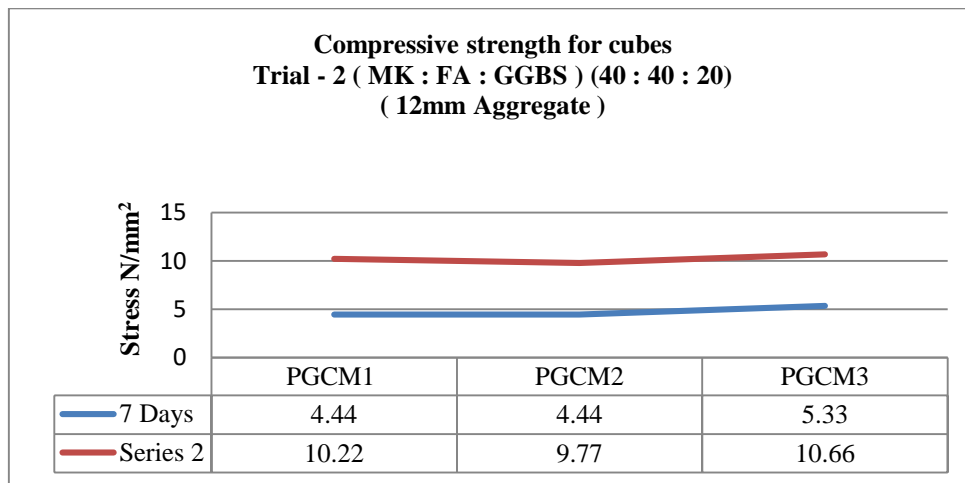


Fig 4.4 Compressive Strength of Trial – 2 (12mm)

4.2 Permeability test



$$\text{Permeability (k)} = \frac{La}{At} \ln \frac{H_f}{H_i}$$

Where,

K = Coefficient of permeability

L = Length of the soil specimen

a = Cross-sectional area of the standpipe

A = Cross-sectional area of the soil specimen

T = Time interval during which the head drops H_i to H_f

H_i = Initial head

H_f = Final head

SL. NO	Mix ID	Length of the Cylinder (cm)	Initial Head (cm)	Final head (cm)	Time (sec)	Coefficient of permeability (mm\ sec)
1	PGCM1 trial -1 (10mm)	20	5	35	32.8	11.8
		20	5	35	35.3	10.23
		20	5	35	35.2	10.8
2	PGCM1 trial -2 (10mm)	20	5	35	36.3	10.70
		20	5	35	37.52	10.31
		20	5	35	39.7	9.72

Table 4.5 Permeability of 10 mm Aggregate

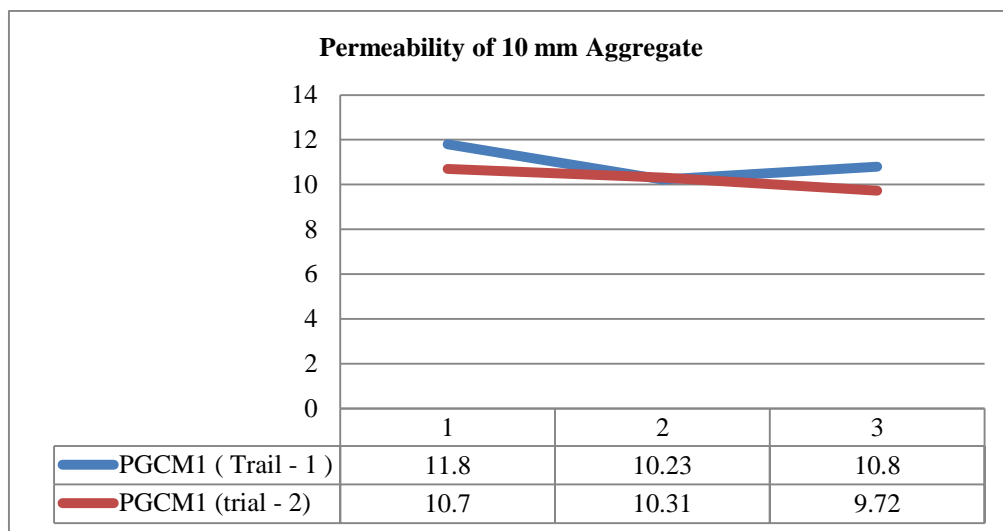


Fig 4.5 Permeability of 10 mm Aggregate

Sl. NO	Mix ID	Length of the Cylinder (cm)	Initial Head (cm)	Final head (cm)	Time (sec)	Coefficient of permeability (mm\ sec)
1	PGCM1 trial -1 (12mm)	20	5	35	42.5	9.14
		20	5	35	41.5	9.34
		20	5	35	45.3	8.56
2	PGCM1 trial -2 (12mm)	20	5	35	46.3	8.36
		20	5	35	45.3	8.56
		20	5	35	43.2	8.95

Table 4.6 Permeability of 12 mm Aggregate

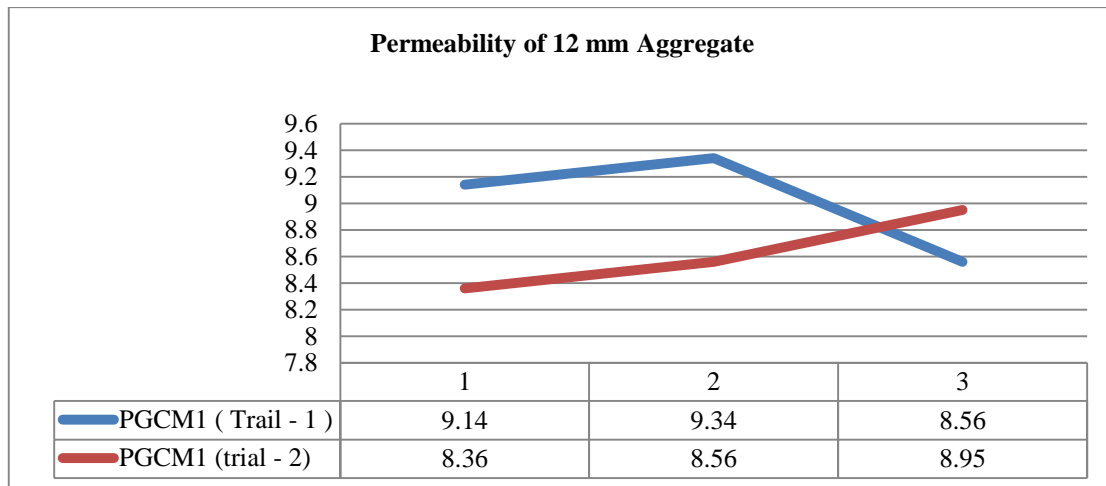


Fig 7.6 Permeability of 12 mm Aggregate

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CONCLUSION

- This investigation assesses the characteristics of geo polymer permeable concrete produced from utilization of waste materials as geo polymeric binder.
- Compressive strength of geo polymer permeable concrete varies between 16MPa to 25.4 MPa for 10 mm and 12mm aggregate respectively.
- Compressive strength enhanced by the use of increment in 60% of NK in geo polymeric binder.
- Permeability of geo polymer permeable concrete varies between 9.72 to 11.8 mm/sec and 8.36 to 9.34 mm/sec for 10 mm and 12mm aggregate respectively.
- The voids of geo polymer permeable concrete decreases with increase in using 12mm aggregate and 60% of MK.
- Based on the strength attainment in the geo polymer permeable concrete, it satisfied the requirements of pavements as low traffic area.

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