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EVALUATION AND DEVELOPMENT OF GEOPOLYMER PERVIOUS CONCRETE PAVEMENT REINFORCED WITH GEOGRID

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ABSTRACT

The construction industry is increasingly exploring sustainable materials to reduce the environmental impact associated with conventional Portland cement. This study investigates the development of geopolymer pervious concrete pavement reinforced with geogrid, using Ground Granulated Blast Furnace Slag (GGBS) as the primary binder. Sodium hydroxide (NaOH) and sodium silicate are used as alkaline activators to promote geopolymerisation. The interconnected void structure of pervious concrete allows water infiltration and is intended to reduce surface runoff, while geogrid is incorporated to provide reinforcement within the pavement slab.The experimental programme considers NaOH molarities of 10 M and 12 M, activator-to-binder ratios of 0.35 and 0.45, a sodium silicate-to-sodium hydroxide ratio of 1.5:1, and two curing conditions: room temperature and 100°C. Slab specimens measuring 457.2 mm × 304.8 mm × 101.6 mm were prepared. The experimental investigation evaluated compressive strength, flexural strength and water infiltration performance.

The compressive-strength values ranged from 15.14 to 18.23 MPa for the 10 M series and from 16.11 to 17.58 MPa for the 12 M series. The maximum compressive strength of 18.23 MPa was obtained with 10 M NaOH, an A/B ratio of 0.45 and curing at 100°C. The flexural-strength values ranged from 1.29 to approximately 2.50 MPa for the 10 M series and from 1.859 to 2.054 MPa for the 12 M series. The maximum flexural strength was approximately 2.50 MPa for the 10 M, A/B = 0.45 mixtures. The calculated infiltration rates ranged from approximately 15,078 to 16,852 mm/h across the eight tested combinations, based on the adopted calculation method and test parameters.

The findings demonstrate that the selected activator-to-binder ratio, NaOH molarity and curing condition influence the mechanical and infiltration performance of the developed geopolymer pervious concrete. The study presents the experimental performance of geogrid-containing pavement slabs; further comparison with unreinforced control specimens is required to quantify the independent contribution of geogrid reinforcement.

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Keywords: Geopolymer concrete, Pervious concrete, GGBS, Geogrid reinforcement, Sodium hydroxide, Sodium silicate, Compressive strength, Flexural strength, Infiltration rate, Sustainable pavement, Alkali-activated concrete

I. INTRODUCTION

The construction industry is increasingly adopting sustainable materials to reduce the environmental impact of conventional cement production. Geopolymer concrete, produced using industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and alkaline activators (sodium hydroxide and sodium silicate), offers a potential alternative to ordinary Portland cement concrete.

Pervious concrete contains interconnected voids that facilitate water infiltration and reduce surface runoff. However, its high porosity can reduce mechanical strength. This study investigates the development of GGBS-based geopolymer pervious concrete pavement reinforced with geogrid to evaluate its mechanical and infiltration performance

The experimental programme considers NaOH concentrations of 10 M and 12 M, activator-to-binder ratios of 0.35 and 0.45, and room-temperature and 100°C curing. Compressive strength, flexural strength and water infiltration are evaluated to assess the material's suitability for low-traffic applications such as footpaths, parking areas and cycle tracks.

II. RESEARCH GAP, AIM AND OBJECTIVES

2.1 Research Gap

The supplied literature discusses geopolymer concrete, pervious concrete, GGBS-based binders, and geogrid reinforcement. However, the combined use of a GGBS-based geopolymer binder, an interconnected pervious structure, and geogrid reinforcement requires further experimental evaluation. In particular, the relationship between activator-to-binder ratio, NaOH molarity, curing condition, mechanical strength, and permeability needs to be assessed together.

2.2 Proposed Novelty

The project investigates a GGBS-based geopolymer pervious concrete pavement system reinforced with geogrid. The experimental variables include NaOH molarity, activator-to-binder ratio, and curing condition. The study evaluates compressive and flexural strength and identifies permeability as an essential hydraulic performance parameter.

III. OBJECTIVES

- To prepare GGBS-based geopolymer pervious concrete using varying NaOH molarities and curing conditions of room temperature and 100°C, with geogrid reinforcement.

- To evaluate the compressive strength of the prepared geopolymer pervious concrete specimens.
- To evaluate the flexural strength of geopolymer pervious concrete pavement slabs reinforced with geogrid.
- To investigate the permeability of the developed geopolymer pervious concrete.

IV. MATERIALS AND EXPERIMENTAL METHODOLOGY

4.1 Materials

Table 1: Materials used and their function

Material	Function in the project
Ground Granulated Blast Furnace Slag (GGBS)	Primary aluminosilicate-rich source material used to form the geopolymer binder.
Sodium hydroxide (NaOH)	Alkaline activator used to promote dissolution of reactive constituents in GGBS.
Sodium silicate (Na_2SiO_3)	Alkaline activator used with NaOH to form the activating solution.
Coarse aggregate	Forms the granular skeleton and interconnected void structure of pervious concrete.
Geogrid	Polymeric grid reinforcement incorporated to investigate load distribution and flexural behaviour.
Water	Used in solution preparation and as required by the adopted mixing procedure.

4.2 Design Parameters

The pervious-concrete design framework in the supplied report refers to IRC:44-2017 and lightly compacted pervious concrete. The project modifies the binder system by using GGBS and alkaline activators instead of treating a conventional cement mix design as a complete geopolymer design method.

Table 2: Design parameters

Parameter	Adopted value
Type of concrete	Geopolymer pervious concrete
Maximum nominal aggregate size	10 mm
Target void content	24%
Paste volume	18%
Coarse aggregate content	1566 kg/m³
Main binder	GGBS
Alkaline activators	Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3)
Sodium silicate-to-sodium hydroxide ratio	1.5

4.3 Experimental Variables

Table 3: Experimental variables

Variable	Levels considered
NaOH molarity	10 M and 12 M
Activator-to-binder ratio	0.35 and 0.45
Curing condition	Room temperature and 100°C
SS/SH ratio	1.5

4.4 Methodology Flow

1. Preliminary literature survey and identification of project requirements.
2. Procurement and characterisation of GGBS, coarse aggregate, alkaline activators, and geogrid.
3. Selection of mix proportions and preparation of alkaline activator solutions.
4. Mixing of GGBS, aggregates, and activator solution to obtain a uniform coating of aggregate particles.
5. Placement of the mixture in slab moulds and positioning of geogrid reinforcement.
6. Compaction, finishing, and identification of specimens.
7. Curing under the selected conditions.
8. Testing for compressive strength, flexural strength, and water permeability.
9. Recording, calculation, comparison, and interpretation of results.

4.5 Preparation of Alkaline Activator

Sodium hydroxide solution is prepared at the selected molarity and allowed to cool before use. Sodium silicate is then combined with the sodium hydroxide solution at the selected SS/SH ratio of 1.5. The project report considers 10 M and 12 M NaOH solutions. Preparation and handling of NaOH require suitable laboratory supervision, personal protective equipment, and safe handling procedures.

4.6 Material Testing

The supplied report identifies material characterisation as part of the methodology. Specific gravity and water absorption of the natural aggregate are relevant inputs for pervious geopolymer concrete mix proportioning. The exact measured aggregate test values should be inserted from the original laboratory observation sheets if they are to be reported.

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V. MIX DESIGN AND SPECIMEN PREPARATION

5.1 Experimental Mix Series

The design-of-experiments arrangement varies activator-to-binder ratio, NaOH molarity, and curing condition while maintaining an SS/SH ratio of 1.5. The quantities below reproduce the values in the supplied report. The unit notation for the sodium silicate and sodium hydroxide quantity columns is reproduced as reported; the entries shown as 1.166 should be checked against the original batch records before final submission.

Table 4: Experimental mix series

Series	Curing	A/B	SS/SH	NaOH (M)	GGBS (kg)	Aggregate (kg)	SS quantity (g)	SH quantity (g)
TMGG11	100°C	0.35	1.5	10	4.32	22.17	907	242
TMGG12	Room temp.	0.35	1.5	10	4.32	22.17	907	242
TMGG21	100°C	0.35	1.5	12	4.32	22.17	907	290.4
TMGG22	Room temp.	0.35	1.5	12	4.32	22.17	907	290.4
TMGG41	100°C	0.45	1.5	10	4.32	22.17	1166	653.2
TMGG42	Room temp.	0.45	1.5	10	4.32	22.17	1166	653.2
TMGG51	100°C	0.45	1.5	12	4.32	22.17	1166	783.84
TMGG52	Room temp.	0.45	1.5	12	4.32	22.17	1166	783.84

5.2 Slab Dimensions

Table 5: Slab dimensions

Parameter	Dimension
Length	450 mm
Width	300 mm
Depth	100 mm
Support span used in flexural calculation	370 mm
Nominal slab volume	0.0135 m^3

5.3 Casting and Curing Procedure

1. Clean the moulds and apply a suitable mould-release agent.
2. Weigh the GGBS, coarse aggregate, sodium silicate, and sodium hydroxide solution according to the selected experimental series.
3. Combine the alkaline activators and mix with GGBS as per the adopted mixing sequence.

4. Add the coarse aggregate and mix until the binder paste coats the aggregate particles uniformly without excessively filling the interconnected voids.
5. Place the fresh mixture into the slab mould in layers and compact using the adopted light-compaction procedure.
6. Position the geogrid in the specified location within the slab, ensuring consistent placement between specimens.
7. Finish and label each specimen with its mix identification, molarity, activator ratio, and curing condition.
8. Allow specimens to set and then cure under the selected condition: room temperature or 100°C.
9. After curing, prepare the specimens for the relevant mechanical and hydraulic tests.

VI. EXPERIMENTAL TESTING

6.1 Compressive Strength Test

Compressive strength testing was conducted using a Compression Testing Machine (CTM). The specimen is placed centrally between the loading platens and load is applied until failure or the specified endpoint. The maximum load is recorded and compressive strength is calculated by dividing the failure load by the loaded area.

Compressive strength (MPa) = Maximum load (N) / Loaded area (mm^2)

6.2 Flexural Strength Test

Flexural testing was carried out on slab specimens using a Universal Testing Machine (UTM). The reported slab dimensions are 450 mm × 300 mm × 100 mm, with a support span of 370 mm. The maximum load is recorded and used to calculate flexural strength according to the adopted loading arrangement and formula.

For a rectangular beam under centre-point loading, the commonly used expression is: $f_r = 3PL / (2bd^2)$, where P is the maximum load, L is the span, b is the specimen width, and d is the depth. The exact formula must match the actual loading arrangement used in the laboratory.

6.3 Water Permeability Test

The infiltration performance of geopolymer pervious concrete slabs reinforced with geogrid was evaluated by measuring the time required for 5 litres of water to infiltrate through the specimen. The infiltration rate was calculated using the adopted formula:

$$I = K M / (D^2 t)$$

where (K) is the adopted constant, (M) is the mass of water, (D) is the test diameter and (t) is the infiltration time.

The calculated infiltration rates ranged from 15,077.85 to 16,851.71 mm/h under the different mix and curing conditions. The highest rate was observed for A/B = 0.35 with 12 M NaOH under 100°C curing and A/B = 0.45 with 10 M NaOH under room-temperature curing.

6.4 Testing Precautions

- Measure specimen dimensions accurately before testing.
- Place the specimen centrally and ensure proper alignment of the loading arrangement.
- Record the maximum load and test conditions carefully.
- Use consistent specimen preparation, compaction, curing, and loading procedures for comparative testing.
- Document failure patterns and water-infiltration observations.

VII. RESULTS AND DISCUSSION

7.1 Compressive Strength Results – NaOH

Table 6: Compressive strength results

A/B ratio	Curing temperature	NaOH molarity	Compressive strength (MPa)
0.35	100°C	10 M	15.63
0.35	Room temperature	10 M	15.14
0.45	100°C	10 M	18.23
0.45	Room temperature	10 M	18.07
0.35	100°C	12 M	17.58
0.35	Room temperature	12 M	16.11
0.45	100°C	12 M	17.09
0.45	Room temperature	12 M	16.60

For the 10 M series, the highest compressive strength of 18.23 MPa was obtained at an activator-to-binder (A/B) ratio of 0.45 under 100°C curing, while the corresponding room-temperature specimen recorded 18.07 MPa. At an A/B ratio of 0.35, the compressive strengths were 15.63 MPa and 15.14 MPa under 100°C and room-temperature curing, respectively. In the 12 M series, the maximum reported compressive strength was 17.58 MPa at an A/B ratio of 0.35 under 100°C curing. Unlike the 10 M series, the 12 M results did not show a consistent increase in strength with increasing activator-to-binder ratio, indicating that compressive strength is influenced by the combined effects of activator content, NaOH molarity, and curing conditions.

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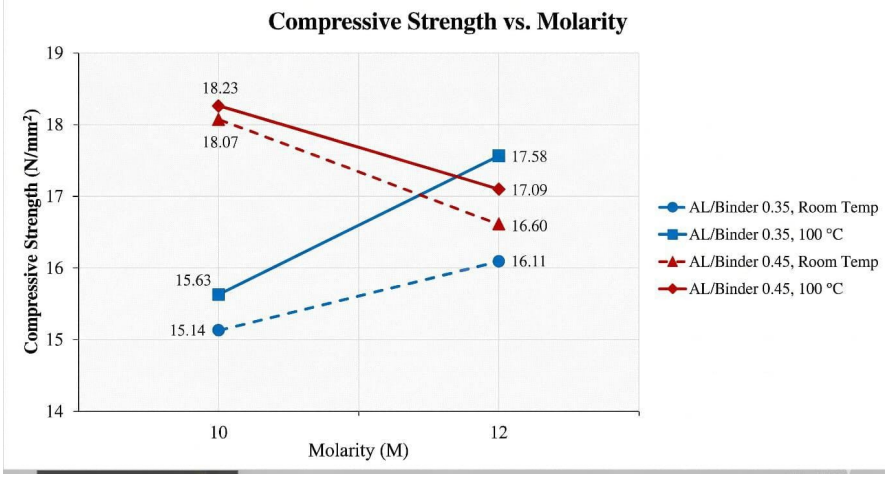


Figure 1: Compressive strength results

7.2 Flexural Strength Results – NaOH

Table 7: Flexural strength results

A/B ratio	Curing temperature	NaOH molarity	Flexural strength (MPa)
0.35	100°C	10 M	2.035
0.35	Room temperature	10 M	1.290
0.45	100°C	10 M	3.885
0.45	Room temperature	10 M	2.500
0.35	100°C	12 M	1.905
0.35	Room temperature	12 M	1.859
0.45	100°C	12 M	1.956
0.45	Room temperature	12 M	2.054
0.35	100°C	12 M	1.905

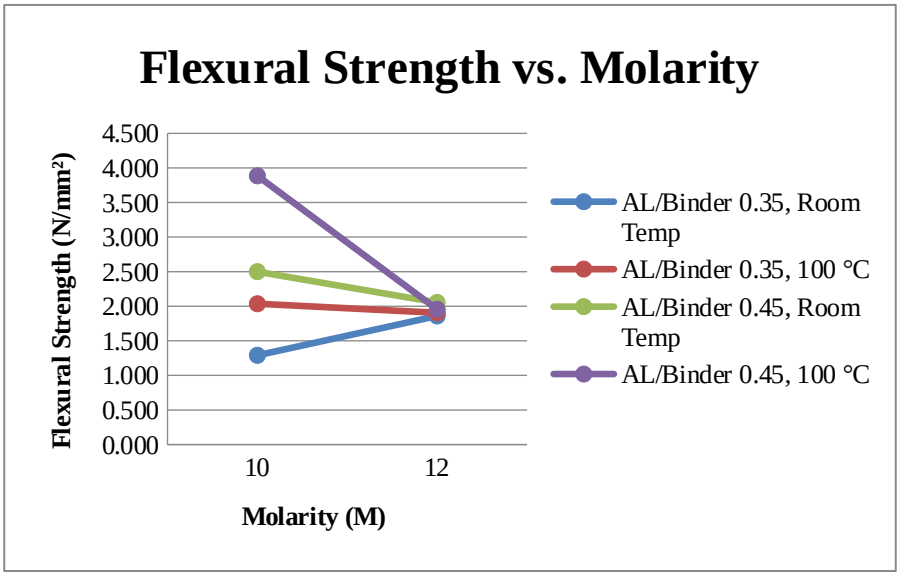


Figure 2: Flexural strength results

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The highest reported flexural strength in the 10 M series was 3.885 MPa at an A/B ratio of 0.45 and 100°C curing. At the same A/B ratio under room-temperature curing, the reported value was 2.500 MPa. The flexural results vary with the combined effects of binder coating, aggregate interlocking, compaction, pore distribution, and curing condition. In the 12 M series, the highest reported flexural strength was 2.054 MPa at an A/B ratio of 0.45 under room-temperature curing. The values are relatively close, and no single curing condition produced the highest flexural strength for every mixture.

7.3 Permeability Test Results

Table 8: Infiltration rate results

Test condition	10 M (mm/h)	12 M (mm/h)
A/B 0.35 – Room temp. (25°C)	15485.35811	16031.28847
A/B 0.35 – 100°C	15915.50694	16851.71324
A/B 0.45 – Room temp. (25°C)	16851.71324	16370.23571
A/B 0.45 – 100°C	15077.84868	15740.61126

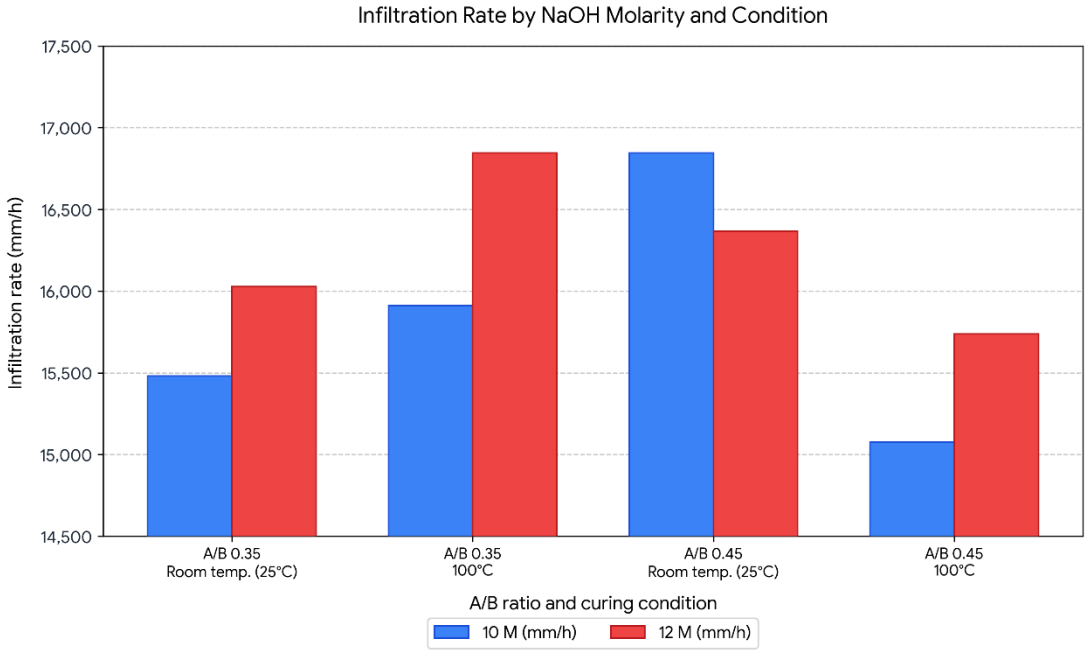


Figure 3: Infiltration rate results

The experimental results indicate that the infiltration rate of geopolymer pervious concrete is influenced by NaOH molarity, activator-to-binder ratio, and curing temperature. The highest infiltration rate of 16,851.71 mm/h was obtained for both A/B 0.35 with 12 M NaOH under 100°C curing and A/B 0.45 with 10 M NaOH at room temperature. The lowest value of 15,077.85 mm/h was observed for A/B 0.45 with 10 M NaOH under 100°C curing. Overall, the results show that the developed geopolymer pervious concrete has good water infiltration capacity, indicating its potential application in sustainable pavement systems and groundwater recharge.

7.4 Discussion

The experimental observations show that compressive and flexural strengths are affected by NaOH molarity, activator-to-binder ratio, and curing condition. The 100°C curing condition produced higher compressive strength than room-temperature curing for the corresponding 10 M and 12 M comparisons shown in the tables. However, the flexural-strength response was not uniform: the 10 M series recorded higher flexural values under 100°C curing, while the highest 12 M flexural value occurred under room-temperature curing.

The effect of activator-to-binder ratio also varied with molarity and test type. A higher ratio produced the highest compressive strength in the 10 M series, whereas the highest compressive strength in the 12 M series occurred at the lower ratio of 0.35.

The geogrid is intended to distribute tensile stresses and help control crack propagation. However, its independent contribution cannot be quantified from the supplied results unless comparable unreinforced specimens are tested under the same mix proportions, curing conditions, specimen dimensions, and loading arrangements. Similarly, the balance between strength and drainage cannot be fully assessed until numerical permeability results are recorded.

VIII. LIMITATIONS OF THE PRESENT STUDY

- The supplied report does not provide a complete numerical permeability dataset; therefore, hydraulic performance cannot be quantified here.
- The experimental series described in the result tables cover 10 M and 12 M NaOH. Although 14 M is mentioned in one discussion of the DOE plan, no 14 M result table was supplied and it is not included in the reported results.
- The sodium silicate and sodium hydroxide quantity entries for the A/B = 0.45 series include values whose units or decimal notation require verification against the original batch records.
- The available data do not establish a complete reinforced-versus-unreinforced comparison; consequently, the independent effect of geogrid cannot be isolated.
- Replicate variability and statistical uncertainty are not reported in the supplied result tables.
- Long-term durability, abrasion resistance, chemical resistance, clogging behaviour, and field performance are outside the reported experimental results.

IX. CONCLUSIONS

This study investigated the development of GGBS-based geopolymer pervious concrete pavement reinforced with geogrid using sodium hydroxide and sodium silicate as alkaline

activators. The experimental variables included NaOH concentrations of 10 M and 12 M, activator-to-binder ratios of 0.35 and 0.45, and room-temperature and 100°C curing conditions.

The maximum compressive strength of 18.23 MPa was achieved with 10 M NaOH, an A/B ratio of 0.45 and 100°C curing. The maximum flexural strength was approximately 2.50 MPa for the 10 M mixture with an A/B ratio of 0.45.

The results show that NaOH concentration, activator-to-binder ratio and curing conditions influence the mechanical performance of geopolymer pervious concrete. Geogrid was incorporated to provide reinforcement and improve load distribution and crack control. The infiltration test results ranged from 15,077.85 to 16,851.71 mm/h under the different mix and curing conditions.

The developed material demonstrates potential for use in low-traffic pavement applications such as footpaths, parking areas and cycle tracks.

X. FUTURE SCOPE

- Conduct repeated permeability tests and determine the coefficient of permeability and infiltration capacity.
- Prepare matched reinforced and unreinforced specimens to quantify the contribution of geogrid to flexural strength, crack resistance, and load-carrying behaviour.
- Verify all batch quantities, activator masses, and units, particularly for the A/B = 0.45 mixtures.
- Investigate additional NaOH molarities and activator-to-binder ratios to identify a balanced combination of strength and permeability.
- Study durability through abrasion resistance, acid and sulphate exposure, wetting–drying cycles, and clogging tests.
- Measure water absorption, interconnected void content, and total porosity to relate pore structure to strength and drainage.
- Use SEM, XRD, or FTIR to investigate geopolymer reaction products and the binder–aggregate interface.
- Construct trial pavement sections and monitor drainage, cracking, settlement, and surface wear under field conditions.

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