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A Comparative Exploration of Pervious Concrete by Partially Replacing Cement with Silica Fume and GGBS

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Abstract:

Pervious concrete is called as no fines concrete or porous concrete which has high porosity and used for concrete flatworks operation that allows water from rush and reducing the runoff water from a site and allowing ground water storage .To study and estimate the permeability of the concrete pavement and to do the experimental procedure on porous concrete by use of GGBS and SILICA FUME and to assay the significance and benefits of using permeable concrete pavements. We have taken different forms of percentages for the partial replacement of cement by GGBS and SILICA FUME i.e., GGBS – 10% , 20% and SILICA FUME – 10%,20%. The test is being conducted for the concrete such as Compressive strength test, porosity, and slump cone test is done for the various samples.

1. INTRODUCTION

Concrete stands as the world's top manufactured substance because it uses Portland cement but its production leads to 8% of global CO_2 emissions while being the primary man-made material in use today. The use of silica fume derived from silicon metal waste products along with ground granulated blast furnace slag obtained from steel production provides sustainable cement substitution which helps reduce environmental waste and achieve lower carbon emissions. These supplementary cementitious materials (SCMs) redirect industrial waste and improve concrete properties and protect the environment at the same time. Pervious concrete benefits from these replacements because traditional cement production generates considerable CO_2 emissions. The use of silica fume together with GGBS leads to better concrete mechanics and environmental sustainability as demonstrated by research that supports worldwide emissions reduction goals. Pozzolanic substances are now extensively studied for eco-friendly concrete production because researchers recognize their importance in green construction and infrastructure development. The combination of silica fume and GGBS functions to cut cement consumption yet simultaneously strengthens concrete properties. The tiny particles of silica fume enhance concrete compressive strength and reduce permeability while GGBS strengthens concrete over time and protects it from chemical damage. Construction activities benefiting storm water management can achieve environmental friendliness alongside maintaining structural integrity through the adoption of pervious concrete containing these materials. The industry transformation helps achieve worldwide sustainable requirements through reduced carbon dioxide output while also decreasing landfilled waste and enhancing circular economic practices. Future progress in sustainable construction requires continuous research for alternative materials which will help decrease the environmental harm caused by traditional cement-based concrete.

2. IMPORTANCE OF THE STUDY

This research on pervious concrete which incorporates silica fume and GGBS as partial cement replacements stands vital because it solves current environmental and structural needs in construction. The research supports sustainable development by continuing to use industrial by-products silica fume and GGBS thus decreasing cement production CO_2 emissions while minimizing waste management issues. The combination of silica fume and GGBS with pervious

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concrete leads to improved mechanical characteristics as well as durability characteristics which enables its use for sustainable applications in pavements and storm water control systems. The research describes a usable approach to strike a balance between environmental advantages and structural performance which leads to sustainable and durable infrastructure construction.

3. METHODOLOGY

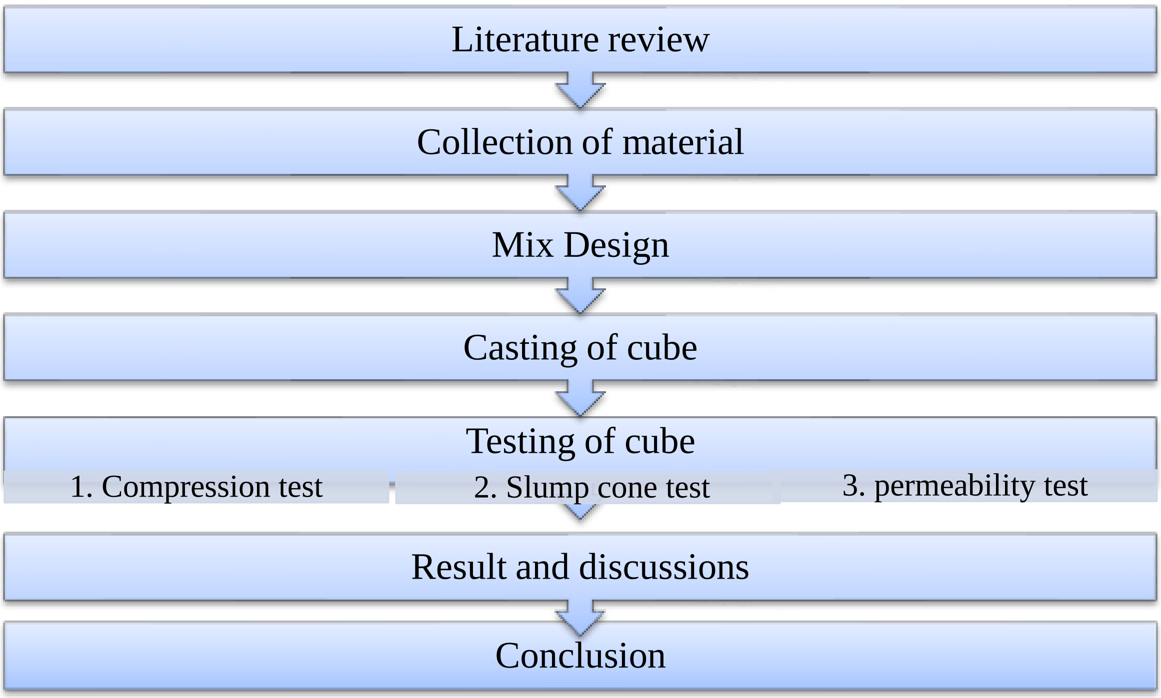


Fig.no. 1 Flow chart of research

4. MATERIALS USED

4.1 Cement

Type of cements used for this project is OPC (ordinary Portland cement) of grade satisfied as per the IS: 12269 -1987.

4.2 Water

The water used for experiments was potable water conforming as per IS: 456-2000.

4.3 Coarse aggregate

Coarse aggregate has been used for this study conforming to IS: 383-1970 is used, Maximum size of aggregate used is 20mm with specific gravity of 2.707.

4.4 Fine aggregate

Fine aggregate is used only for the normal concrete. In the investigation fine aggregate is manufactured sand from quarry is used, are as per IS: 383-1997.

4.5 Silica fume

Silica fume, also known as micro silica, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete which is added as the partial replacement of PPC cement in pervious concrete. The Specific gravity of silica fume is 2.2. It consists of 0.1 to 1 micron sized fine, smooth spherical particles with fineness conforming to ASTM C1240 – 1999 standards.

4.6 Ground granulated blast furnace slag (GGBS)

GGBS means the ground granulated blast furnace slag is a by-product of the manufacturing of pig iron. Iron ore, coke and lime stone are fed in to the furnace and the resulting molten slag floats above the molten iron at a temperature of about 1500°C to 1600°C. The quenching optimises the cementitious properties and produces granules similar to coarse sand. This 'granulated' slag is then dried and ground to a fine powder.The fine slag powder close to the chemical composition of Portland cement which is added as the partial replacement of PPC cement in pervious concrete.

4.7. Comptonization between the properties of Cement, Silica fume and GGBS :

Property	Cement	Silica Fume	GGBS
Color	Grayish-white	Light gray to dark gray	Light gray to off-white
Particle size	Finely ground powder	0.1 to 0.2 μm	10-45 μm
Specific Gravity	3.1-3.3	2.2-2.3	2.8-3.0
Strength	Develops strength over time through hydration reaction	Increases compressive strength and improves flexural and tensile strength	Strength gain is slower but exceeds ordinary Portland cement (OPC) over time .Improves bond with aggregates.
Setting time	Variable	Setting times decrease as the silica fume content increases.	Very slow setting, depends on its replacement level with cement and curing conditions.
Chemical composition	Calcium silicates, calcium aluminates, calcium alumino ferrites	Silicon Dioxide (SiO_2) 85–98%, Small amounts of Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O.	Calcium oxide, silicon dioxide, aluminum oxide, magnesium oxide, iron oxide

Table 1: Comptonization between the properties of Cement, Silica fume and GGBS

5. TEST METHODS

The compressive strength of pervious concrete was determined after 28 days. The porosity and water permeability coefficients of pervious concrete were tested using rectangular specimens 150x 150- x 150 mm, and the reported values are the average of three specimens. The pervious concrete porosity was calculated by taking the difference between the weight of specimens oven dried and saturated by submerging under water [30]. The total porosity, ϕ (m^3/m^3 in %) can be determined by two methods Assuming no isolated pores in the sample, the ϕ was calculated using Eq. (1):

$$\phi_T = (1 - \frac{}{G_s \rho_{ww}}) \times 100 \qquad (1)$$

where ρ_d is the dry density (kg/cm^3), G_s is the specific gravity, and ρ_w is the density of water (kg/cm^3).
If according to a water displacement method [34,35], the ϕ can be calculated using Eq. (2):

$$\phi_T = (1 - \frac{M_d - M_{sub}}{V_T \rho_{ww}}) \times 100 \qquad (2)$$

where M_d is the mass of a dry sample (kg), M_{sub} is the mass of a specimen under water (kg), and V_T is the volume of specimen (cm^3)

The effective porosity, ϕ_{eff} (m^3/m^3 in %), represents the open (connected) pores of the sample [36,37] and can be determined by using Eq. (3):

$$\phi_{eff} = (1 - \frac{M_{suf} - M_{sub}}{V_T \rho_{ww}}) \times 100 \qquad (3)$$

where M_{suf} is the saturated surface dried weight of a specimen (kg).

6. RESULTS AND DISCUSSION

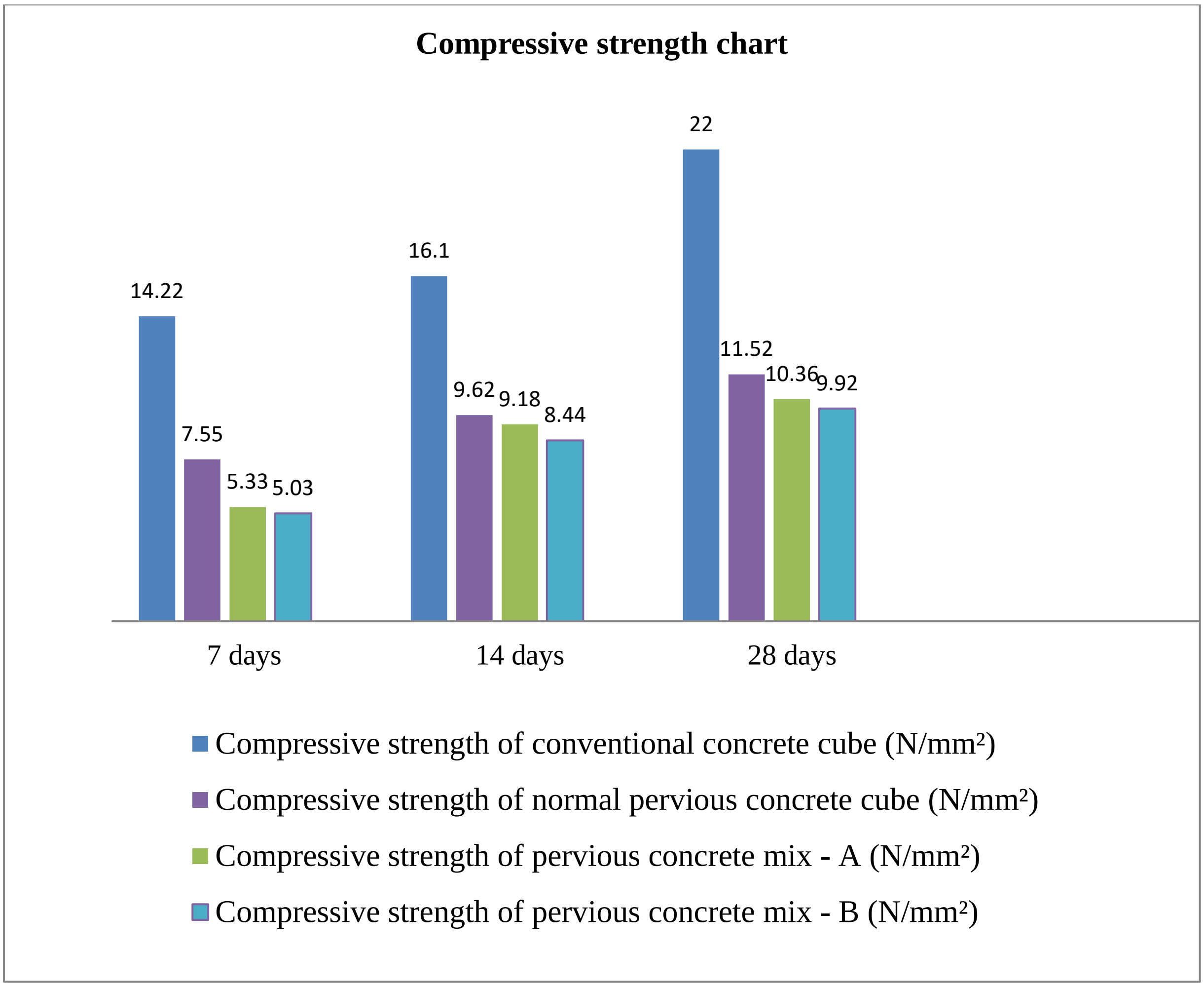
6.1 Density, porosity and Compressive Strength

The results of density, porosity and Compressive Strength tests of pervious concrete are shown in Table 2. The density of pervious concrete depends on the type of aggregates and is directly related to the porosity of the sample specimen. The densities in this study were between 1790 and 1925 kg/m3, which were lower than that of the conventional concrete (about 2400–2500 kg/m3) due to the high voids of pervious concrete.

6.2 Properties of all pervious concrete mixes

Type	**Age (days)**	**Density (kg/m^3)**	**Porosity (%)**	**Strength (N/mm^2)**	**Slump value** (mm)
Conventional	28	2398	0.09	22	70
Pervious	28	1925	0.26	11.52	20
Mix-A	28	1790	0.30	10.36	15
Mix-B	28	1865	0.22	9.92	25

Table 2: Properties of all pervious concrete mixes



Graph 4: Comparative graphical representation on compressive strength of conventional concrete cube, pervious concrete cube, Pervious concrete Mix-A and MixB

The graph shows that conventional concrete has the highest compressive strength (14.22 N/mm²), followed by pervious concrete with 20% silica fume and 10% GGBS (5.03 N/mm²). The lowest strength is observed in pervious concrete Mix-B (5.03 N/mm²), indicating that partial replacements slightly reduce early strength.

The trend continues with conventional concrete leading (16.10 N/mm²), while pervious concrete mixes with silica fume and GGBS show gradual improvement (9.18 N/mm² and 8.44 N/mm²). This suggests that GGBS contributes to slower strength development compared to silica fume.

Conventional concrete achieves the highest strength (22 N/mm²), while pervious concrete with 10% silica fume and 20% GGBS performs better (10.36 N/mm²) than the 20% silica fume mix (9.92 N/mm²). This indicates that higher GGBS content may enhance long-term strength.

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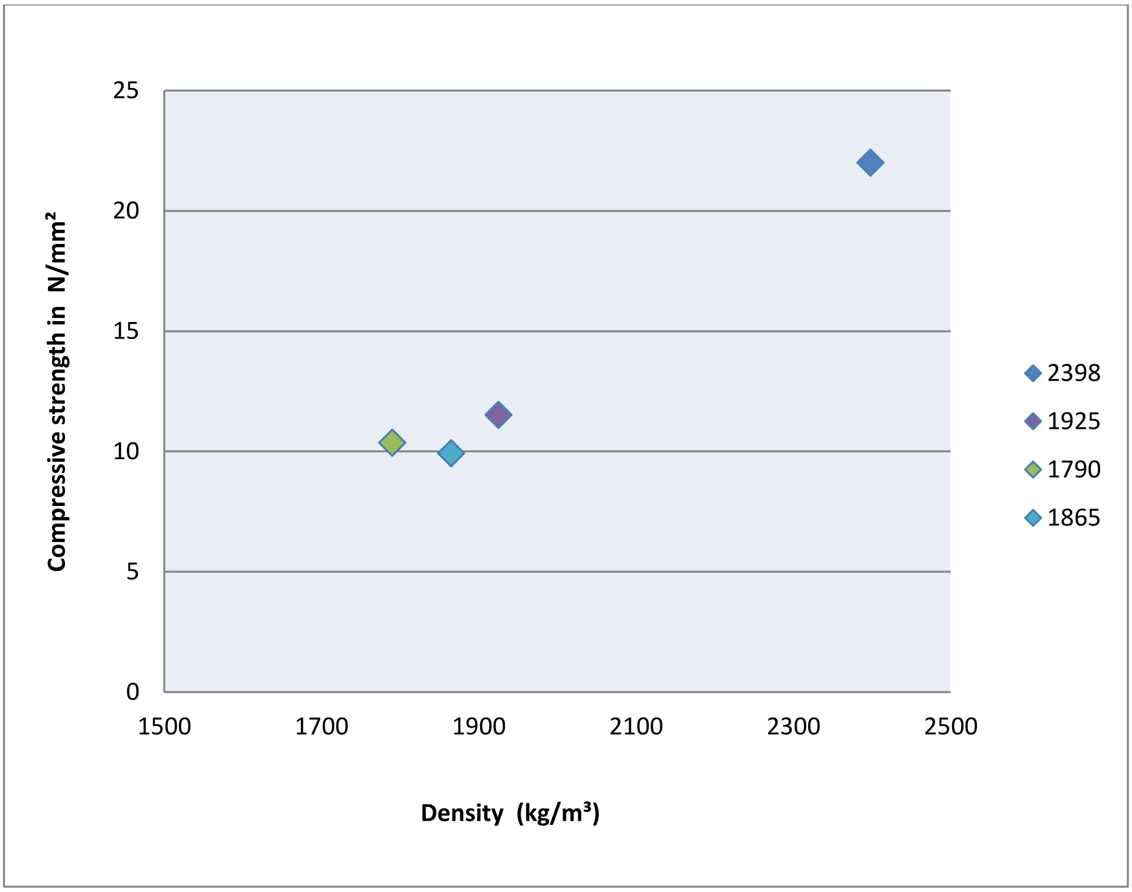
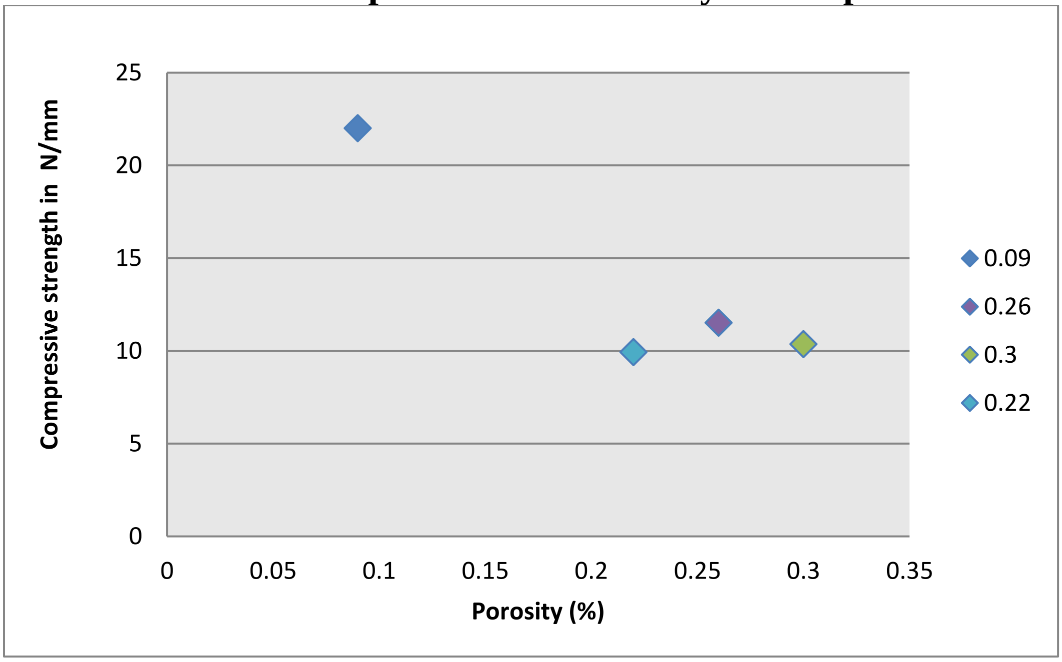
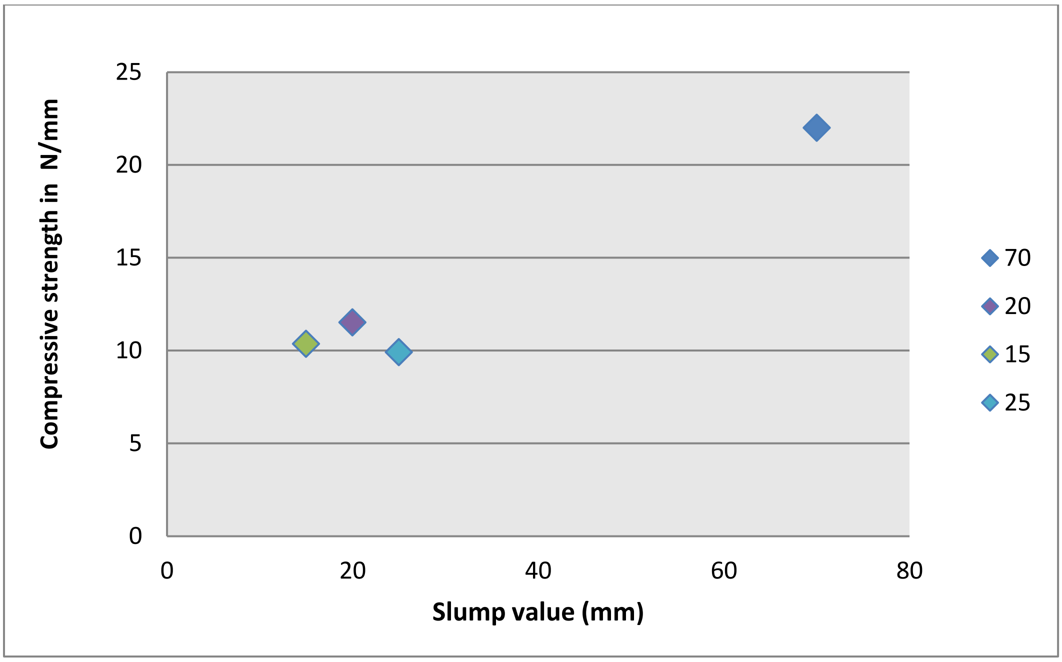


Graph 5: Effect of density on compressive strength.



Graph 6: Effect of porosity on compressive strength



Graph 7: Effect of slump on compressive strength of concrete

- The effect of density on compressive strength is shown in graph 6. The compressive strength of pervious concrete increased with an increase of density

- The effect of porosity on compressive strength is shown in graph 6. A considerable scatter is noted. Overall, porosity affected the compressive strength. The compressive strength decreased from 22 MPa to 11.52 MPa with an increase in porosity by 0.17.

- The study shows that replacing up to 30% of cement with silica fume and GGBS is an effective way to make concrete more sustainable while maintaining performance. This approach reduces cement consumption, supporting eco-friendly construction.

- However, when replacements exceed 30%, the concrete's workability decreases noticeably. While higher replacements offer environmental advantages, they require careful handling during mixing and placement to maintain practicality.

- Furthermore, the study observes a slight decrease in compressive strength with 10% and 20% replacements of silica fume and ggbs respectively. This underscores the importance of finding a balance between sustainability goals and maintaining structural integrity, prompting further investigation into optimizing replacement ratios to minimize any adverse effects on concrete performance.

7. CONCLUSION

The experimental findings show pervious concrete containing silica fume and GGBS as cement substitutes achieves encouraging outcomes although it requires balanced compromises. Conventional concrete maintained superior strength than pervious concrete mixes during compressive tests because it achieved its highest strength of 22 N/mm² at 28 days.The combination of 10% silica fume with 20% GGBS in Mix-A produced a compressive strength of 10.36 N/mm² while the 20% silica fume with 10% GGBS mixture (Mix-B) resulted in a lower strength of 9.92 N/mm². Higher GGBS content contributes to better long-term strength because of its pozzolanic reaction properties. The functional properties of pervious concrete remained viable for storm water applications according to porosity and permeability testing results because the material exhibited porosity measurements between 0.22 and 0.30. The research establishes silica fume and GGBS as viable ingredients for sustainable pervious concrete production but shows that proper optimization remains necessary.

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