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Research Paper

EXPERIMENTAL ANALYSIS OF PERVIOUS CONCRETE INCORPORATING SILICA FUME

Divyank V. More[1], Amol V. Gorle[2], Nilesh S. Biswal[3], Sachit M. Vitankar[4]
[1,2,3,4]Assistant Professor at Civil Engineering Department, J.D.I.E.T. Yavatmal

ABSTRACT

The increasing use of impermeable pavements in urban areas has led to serious issues such as waterlogging, reduced groundwater recharge, and increased surface runoff. Pervious concrete offers an eco-friendly alternative by allowing rainwater to pass through its porous structure. This study examines the influence of different cement-to-aggregate ratios and silica fume addition on the strength and permeability characteristics of pervious concrete. Experimental tests were carried out to determine compressive strength, void ratio, and hydraulic conductivity after different curing periods. The results revealed that pervious concrete provides excellent drainage performance, while the incorporation of silica fume enhances compressive strength without significantly affecting permeability. The study highlights the potential of pervious concrete as a sustainable pavement material suitable for low-volume traffic areas and urban drainage management.

Keywords: Pervious concrete, Silica fume, Permeability, Compressive strength, Sustainable pavement, Void ratio, Stormwater management.

I. INTRODUCTION

Rapid urbanization and continuous infrastructure development have resulted in a substantial increase in impervious surfaces such as conventional concrete and asphalt pavements, which significantly restrict the natural infiltration of rainwater into the soil. This has led to adverse environmental consequences including increased surface runoff, frequent urban flooding, groundwater depletion, and intensified urban heat island effects. In response to these challenges, sustainable pavement materials that support stormwater management and environmental resilience have gained increasing importance in recent decades. Among these materials, pervious concrete has emerged as a viable and eco-friendly alternative to traditional paving systems.

Pervious concrete, also known as porous or permeable concrete, is a specialized cement-based material characterized by a high volume of interconnected voids, generally ranging between 15% and 30%, which enable water to percolate through the pavement surface. This structure is achieved by adopting gap-graded coarse aggregates while minimizing or completely eliminating fine aggregates. According to the American Concrete Institute (ACI Committee 522, 2010), pervious concrete allows rapid infiltration of stormwater, thereby reducing surface runoff and promoting groundwater recharge. Due to these functional advantages, pervious concrete has been widely used in applications such as parking areas, pedestrian walkways, sidewalks, and low-volume residential roads.

The application of pervious concrete dates back to the mid-19th century in Europe; however, its widespread adoption occurred much later. Ghafoori and Dutta (1995) highlighted that pervious concrete gained significant attention in the United States during the 1970s, primarily due to increasing concerns regarding stormwater runoff and flooding caused by expanding urban development. Tennis, Leming, and Akers (2004) further reported that pervious concrete pavements reduce the dependency on conventional stormwater drainage infrastructure, offering long-term economic and environmental benefits when properly designed and maintained.

Despite its notable environmental advantages, the relatively low compressive strength of pervious concrete remains a major limitation. Yang and Jiang (2003) demonstrated that the open pore structure, while essential for permeability, leads to reduced mechanical strength due to weak bonding at the aggregate–cement paste interface. Their experimental study showed that conventional pervious concrete generally exhibits compressive strength values lower than those of dense concrete, restricting its use to light-load applications. Similarly, Neithalath, Weiss, and Olek (2006) emphasized that the mechanical and hydraulic performance of pervious concrete is strongly governed by pore system characteristics, including void ratio, pore connectivity, and aggregate packing.

Several researchers have explored methods to improve the strength of pervious concrete without compromising permeability. Yang and Jiang (2003) reported that the use of smaller aggregate sizes, silica fume, and chemical admixtures significantly enhances compressive and flexural strength while maintaining adequate infiltration capacity. Obla (2010) provided a comprehensive overview of pervious concrete properties and noted that compressive strengths typically range from 5 to 28 MPa, depending on mix design, aggregate gradation, and compaction techniques. Zhong, Leng, and Poon (2018) conducted a state-of-the-art review and emphasized that recent advancements in high-performance pervious concrete have improved durability, strength, and functional performance, enabling broader pavement applications. Although extensive research has been carried out on the mechanical and hydraulic properties of pervious concrete, limited studies have focused on a combined evaluation of permeability performance and lifecycle economic benefits in comparison with traditional paving systems. In particular, the influence of mix proportion variations and supplementary cementitious materials such as silica fume on balancing strength, void structure, and permeability requires further experimental validation. Moreover, lifecycle considerations including durability, maintenance requirements, and long-term cost effectiveness are often overlooked in conventional material performance studies.

In this context, the present study aims to experimentally evaluate the performance of pervious concrete using different cement-to-aggregate ratios with and without the incorporation of silica fume. The specific objectives of this research are to (i) investigate the effect of mix proportions on compressive strength, void ratio, and permeability of pervious concrete, (ii) assess the role of silica fume in enhancing mechanical strength while preserving sufficient hydraulic conductivity, and (iii) compare the lifecycle performance of pervious concrete with conventional paving systems. The findings of this study are intended to support the development of sustainable, durable, and cost-effective pavement solutions suitable for light traffic and urban infrastructure applications.

II.METHODS AND MATERIAL

Through systematic experimental investigations, the present study evaluates the mechanical and hydraulic behavior of pervious concrete. The study primarily focuses on examining the influence of varying aggregate-to-cement ratios and the inclusion of silica fume on compressive strength, void content, and permeability characteristics.

2.1 Materials

Ordinary Portland Cement (OPC) was used as the primary binding material in all concrete mixes. The cement provided the necessary paste to coat the aggregate particles and develop bonding at the points of contact between aggregates. Gap-graded coarse aggregates were employed to achieve the desired porous structure of pervious concrete. Fine aggregates were deliberately excluded from the mix to maintain a continuous and interconnected void system. The coarse aggregates were sieved to retain a specific size range, ensuring uniform pore distribution and adequate permeability throughout the concrete matrix. Clean, potable water was used for both mixing and curing purposes. The water-to-cement (w/c) ratio was carefully controlled within the range of 0.30 to 0.40 to ensure sufficient workability while preventing paste drain-down, which could otherwise block the pore structure and reduce permeability. Silica fume was incorporated in selected mixes as a supplementary cementitious material to enhance the microstructure of the cement paste. The addition of silica fume was intended to improve the interfacial bond between the cement paste and coarse aggregates, thereby increasing compressive strength without significantly compromising permeability.

2.2 Experimental Mix Design

To evaluate the performance of pervious concrete, three different mix proportions were designed based on the cement-to-coarse aggregate ratio by weight. The selected mix proportions were Mix I: 1:3, Mix II: 1:4, and Mix III: 1:5

For each mix proportion, two types of concrete specimens were prepared. The first category consisted of plain pervious concrete made using cement, water, and coarse aggregates only. The second category included modified pervious concrete mixes in which silica fume was added either as a partial replacement of cement or as an additive to improve mechanical performance.

2.3 Specimen Preparation

Concrete specimens were cast using standard cube moulds of size 150 mm × 150 mm × 150 mm for compressive strength testing. All materials were initially dry-mixed to ensure uniform distribution before the required quantity of water was added.

Due to the absence of fine aggregates and the highly porous nature of pervious concrete, mechanical vibration was avoided during casting to prevent segregation and paste settlement at the bottom of the moulds, which could lead to pore blockage. Instead, controlled rodding or tamping was adopted to achieve sufficient compaction while maintaining the intended void structure.

After casting, the specimens were covered and left undisturbed for 24 hours. Following demoulding, the specimens were cured by immersion in water for curing periods of 7, 14, and 28 days to facilitate proper hydration of cement.

2.4 Testing Methodology

A series of laboratory tests were conducted on the hardened concrete specimens to evaluate their mechanical and hydraulic properties.

A. Compressive Strength Test Compressive strength tests were performed using a Universal Testing Machine (UTM). The specimens were tested after curing periods of 7, 14, and 28 days. During testing, load was applied gradually and uniformly until failure occurred. The maximum load at failure was recorded, and compressive strength was calculated accordingly.

B. Permeability Test (Hydraulic Conductivity) The permeability of the pervious concrete specimens was determined using the falling head permeability test, which is suitable for materials exhibiting high infiltration capacity. A customized permeameter setup was used, allowing water to flow vertically through the concrete specimen. The time required for the water level to fall from an initial head (h_1) to a final head (h_2) was recorded. The coefficient of permeability (k) was calculated using Darcy's law adapted for falling head conditions.

C. Void Ratio (Porosity) Test The void content of the pervious concrete was evaluated using a volumetric method. The dry mass of the specimen was compared with the theoretical mass of a fully solid specimen of the same volume. The void ratio was calculated using the following expression:

$$\text{Void Ratio (\%)} = \left(1 - \frac{W\,(\text{Dry})}{V \times \rho\,(\text{Material})}\right) \times 100$$

Where W_{dry} is the dry weight, V is the sample volume, and $\rho_{material}$ is the specific gravity of the solid materials.

III. RESULTS AND DISCUSSION

3.1 General Overview

A comparative analysis was conducted to evaluate the hydrological and mechanical performance of Conventional Concrete (CC), standard Pervious Concrete (PC), and Pervious Concrete enhanced with Silica Fume (PC+SF). The findings underscore a fundamental characteristic of porous pavement systems: an inverse relationship exists between permeability and compressive strength, representing a critical design trade-off.

3.2 Compressive Strength Test Results

Compressive strength tests were conducted on cubes at 7, 14, and 28 days of curing. The absence of fine aggregates in the pervious concrete creates a porous structure, which naturally results in lower compressive strength compared to conventional concrete. However, the addition of Silica Fume was observed to enhance the bonding between the cement paste and coarse aggregates.

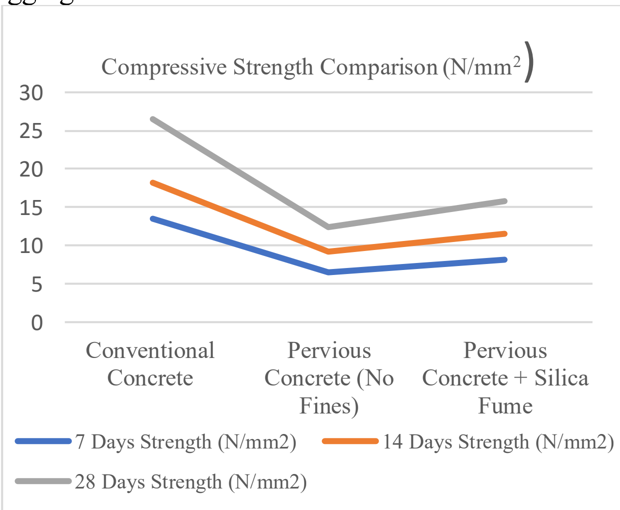


Figure 1. Compressive Strength Development

The graph below represents the Compressive Strength Development based on the representative data discussed in the previous section.

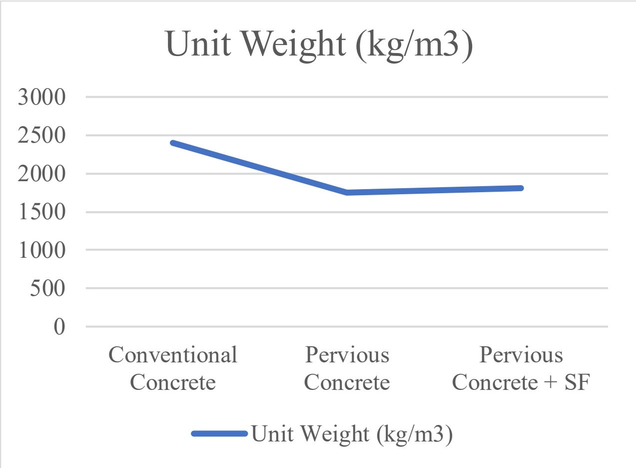
Compressive Strength Development: The results indicate that Conventional Concrete achieved a 28-day strength of 26.5 MPa, whereas the Pervious Concrete achieved 12.4 MPa. This reduction is expected due to the high void ratio (15-25%) required for water drainage. However, the sample containing Silica Fume showed a strength increase of approximately 27% over standard pervious concrete. This suggests that while Pervious Concrete is not suitable for heavy-duty highways, its strength is sufficient for parking lots, walkways, and low-traffic residential roads.

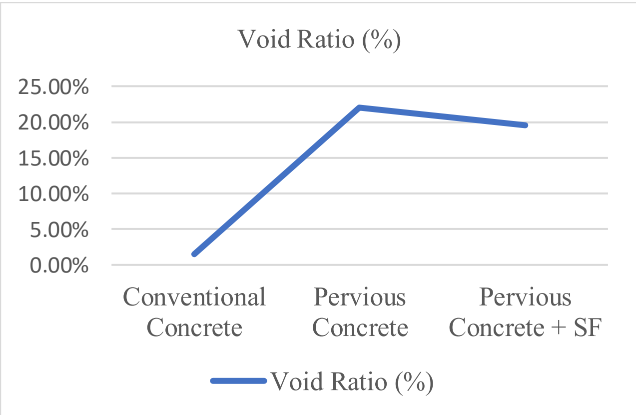
3.3 Void Ratio and Unit Weight

The density of the concrete is directly related to its strength and permeability.

Table 2: Density and Void Ratio Analysis

Mix Type	Unit Weight (kg/m3)	Void Ratio (%)
Conventional Concrete	2410	1.54%
Pervious Concrete	1755	22.1%
Pervious Concrete + SF	1820	19.45%





Discussion: Results indicate that the pervious concrete mixtures were approximately 25–30% lighter in unit weight than standard concrete. Furthermore, the recorded void ratio of 22% satisfies the ACI 522R committee's guidelines, falling squarely within the 15–25% range deemed optimal for managing stormwater.

3.4 Permeability (Infiltration) Results

The primary function of pervious concrete is water transmission. The falling head permeability test was conducted.

Table 3: Coefficient of Permeability

Mix Type	Permeability (mm/s)	Infiltration Rate (Liters/minute/m2)
Conventional Concrete	~0	~0
Pervious Concrete	3.6	190
Pervious Concrete + SF	2.9	160

Discussion on Drainage: While Conventional Concrete is impermeable, the Pervious Concrete samples demonstrated a high infiltration rate capable of handling heavy rainfall events. The sample with Silica Fume showed slightly lower permeability due to the denser cement paste, but still maintained sufficient drainage capacity to prevent surface runoff.

IV.CONCLUSION

The present study successfully evaluated the mechanical and hydraulic performance of pervious concrete with varying mix proportions and the inclusion of silica fume as a supplementary cementitious material. Based on the experimental investigations and analysis, the following conclusions can be drawn:

Pervious concrete demonstrates excellent permeability characteristics due to its interconnected void structure, making it highly effective for stormwater management and groundwater recharge. The observed infiltration rates confirm its suitability for applications such as parking areas, pedestrian pathways, and low-traffic roads, where rapid drainage is essential.

However, the inherent porous nature of pervious concrete results in comparatively lower compressive strength than conventional concrete. This limitation restricts its application in heavy load-bearing structures. Despite this, the strength obtained in the study is adequate for light-duty infrastructure.

The incorporation of silica fume significantly improved the mechanical properties of pervious concrete. An increase of approximately 27% in compressive strength was observed, indicating enhanced bonding between cement paste and aggregates. Although a slight reduction in permeability was noted with silica fume addition, the values remained within acceptable limits for effective drainage performance.

The study also confirmed that an optimal balance between strength and permeability can be achieved through careful selection of mix proportions and material composition. The void ratio and density values obtained were within the recommended range, ensuring both structural stability and functional efficiency.

From a broader perspective, pervious concrete offers a sustainable alternative to conventional pavement systems by reducing surface runoff, mitigating urban flooding, and contributing to environmental conservation. When lifecycle considerations such as reduced drainage infrastructure and long-term environmental benefits are taken into account, pervious concrete proves to be a cost-effective and eco-friendly solution for urban infrastructure development.

In conclusion, the use of silica fume-enhanced pervious concrete can be recommended as a viable material for sustainable pavement construction, particularly in urban areas where stormwater management is a critical concern. Further research may focus on long-term durability, clogging behavior, and field performance to support wider implementation.

REFERENCES

[1] ACI Committee 522, "Report on Pervious Concrete (ACI 522R-10)," American Concrete Institute, Farmington Hills, MI, 2010.

[2] N. Ghafoori and S. Dutta, "Laboratory Investigation of Compacted No-Fines Concrete for Paving Materials," *Journal of Materials in Civil Engineering*, vol. 7, no. 3, pp. 183-191, 1995.

[3] P. D. Tennis, M. L. Leming, and D. J. Akers, "Pervious Concrete Pavements," EB302, Portland Cement Association, Skokie, IL, and National Ready Mixed Concrete Association, Silver Spring, MD, 2004.

[4] J. Yang and G. Jiang, "Experimental Study on Properties of Pervious Concrete Pavement Materials," *Cement and Concrete Research*, vol. 33, no. 3, pp. 381-386, 2003.

[5] N. Neithalath, J. Weiss, and J. Olek, "Characterizing Enhanced Porosity Concrete using Electrical Impedance to Predict Acoustic and Hydraulic Performance," *Cement and Concrete Research*, vol. 36, no. 11, pp. 2074-2085, 2006.