CHAPTER 147

Use of Silica Fume in Pervious Concrete for Pavement Construction

Aditya Desai[1], Harsh Mahato[1], Varad Khot[1], Yash Mahajan[1] and Babalu Rajput[2]

ABSTRACT

The growing urbanization and population of India have resulted in major water management issues, such as stormwater runoff and groundwater depletion. Pervious concrete with silica fume provides a sustainable option by enhancing permeability, minimizing waterlogging, and facilitating groundwater recharge. The current research investigates the influence of silica fume on the strength, durability, and permeability of pervious concrete for pavement purposes. Experimental investigation involves changing the cement-to-aggregate ratio, aggregate gradations, and silica fume replacement percentages to identify an optimal mix for improved mechanical performance. The results show that addition of silica fume improves compressive strength and minimizes clogging tendency without sacrificing high permeability. Findings support sustainable urban infrastructure by promoting pervious concrete as an environmentally friendly alternative to traditional pavements in conjunction with environmental conservation initiatives.

Keywords: Silica fume; Permeability; Sustainable pavements; Stormwater management; Pervious concrete.

1.0 Introduction

The high rate of urbanization and population growth in Indian cities has worsen water scarcity and flooding due to impermeable surfaces like roads and rooftops. Pervious concrete emerges as a viable solution, allowing water infiltration to recharge groundwater and mitigate stormwater runoff. Its cost-effectiveness in India, owing to lower labor costs, makes it a practical alternative for sustainable urban development. However, challenges such as clogging from dust accumulation must be addressed through routine maintenance. By integrating pervious concrete in pavements, parking lots, and green infrastructure, cities can enhance environmental resilience, reduce urban heat island effects, and improve overall water management. This research aims to investigate the impact of silica fume on pervious concrete, particularly its strength, durability, and permeability for sustainable pavements. Experiments will evaluate different cement-to-aggregate ratios and aggregate sizes to determine the optimal mix for maximum efficiency.

[1]*School of Construction, NICMAR University, Pune, Maharashtra, India*
[2]*Corresponding author; School of Construction, NICMAR University, Pune, Maharashtra, India*
(E-mail: babalurajput@nicmar.ac.in)

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A comparative analysis with conventional concrete will assess its environmental and structural benefits. By focusing on density, porosity, and drainage properties, this study contributes to eco-friendly urban infrastructure, aligning with India's sustainability goals. The research investigated the contribution of silica fume to the improvement of pervious concrete properties, especially for pavements, through its effect on strength, durability, and longevity using compressive strength tests. It tested water absorption and drainage capacity to determine its efficiency in groundwater recharge and stormwater management. Moreover, the study determined the best mix of cement, aggregate, and silica fume in order to ensure a strong and effective pavement system. Lastly, the research contrasted pervious concrete with common concrete in regards to durability, strength, and environmental sustainability to emphasize its merits and demerits.

2.0 Literature Reviews

Durability is a key concern for pervious concrete, particularly in harsh environmental conditions. Freeze-thaw resistance is improved by silica fume, polypropylene fibers, and latex-modified cementitious materials, which reduce micro-cracking and water absorption (Ho *et al.*, 2015; Schaefer *et al.*, 2006). Air-entrained pervious concrete exhibits up to 50% less surface scaling and higher freeze-thaw cycle resistance (Kevern *et al.*, 2010). Abrasion resistance is enhanced by using angular aggregates, surface treatments, and polymer coatings, while chemical resistance is improved by silica fume, fly ash, and sealers (Tabet Kheira *et al.*, 2022; Siddique & Iqbal Khan, 2011; Tang *et al.*, 2022). Skid resistance is another important property of pervious concrete, particularly for road safety. Its porous structure reduces surface water accumulation and hydroplaning risk, providing better skid resistance than traditional concrete and asphalt (Chopra *et al.*, 2010; Tabet Kheira *et al.*, 2022).

Angular aggregates like crushed granite or basalt offer superior friction, while smoother aggregates like river gravel deteriorate over time (Ajamu *et al.*, 2012). Maintenance strategies such as vacuum sweeping and pressure washing are essential to prevent clogging and maintain skid resistance, especially in cold climates where freeze-thaw cycles can degrade surface texture (Obla, 2010; Ho *et al.*, 2015). Hydraulic properties, including permeability, porosity, and void interconnectivity, are central to pervious concrete's effectiveness in stormwater management. Permeability values range from 36 to 864 inches per hour, depending on mix design and compaction methods (ACI Committee 522, 2006). Higher porosity improves water infiltration but may reduce mechanical strength, a trade-off addressed by incorporating silica fume and fibers (Vinoth *et al.*, 2021; Liu *et al.*, 2022). Well-graded aggregates and proper void distribution enhance hydraulic efficiency and durability, while clogging resistance is maintained through periodic maintenance (Marzulli *et al.*, 2018; Ho *et al.*, 2015).

Pervious concrete's drainage properties make it an eco-friendly solution for stormwater management, reducing waterlogging and peak runoff volumes. Its porosity (15%–35%) allows

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rapid water infiltration, with drainage rates ranging from 36 to 864 inches per hour (ACI Committee 522, 2006; Marzulli *et al.*, 2018). Well-graded aggregates and optimized mix designs balance permeability and structural integrity, supporting sustainable urban drainage solutions (SUDS) and groundwater recharge (Chopra *et al.*, 2010; Ghosh, 2015). Cost-effectiveness is another advantage of pervious concrete. Although initial installation costs may be higher, long-term savings from reduced stormwater infrastructure, lower maintenance, and energy savings from urban heat island mitigation make it a viable investment (Obla, 2010; Ghosh, 2015). In regions with lower labor costs, such as India, pervious concrete is particularly economical due to its reliance on manual labor rather than heavy machinery.

Environmental benefits of pervious concrete include improved water quality, reduced carbon emissions, and support for sustainable urban development. Its permeable structure filters pollutants, reduces surface runoff, and recharges groundwater, addressing water scarcity in urban areas (Chopra *et al.*, 2010; Obla, 2010). The use of recycled aggregates, fly ash, slag, and silica fume further enhances its sustainability by reducing cement consumption and carbon emissions (Ajamu *et al.*, 2012; Aoki, 2009).

Additionally, pervious concrete mitigates urban heat island effects by lowering surface temperatures, contributing to cooler urban environments (Ganpule & Pataskar, 2011). Pervious concrete offers a sustainable, cost-effective, and environmentally friendly alternative to conventional concrete, with applications in stormwater management, urban infrastructure, and climate change mitigation. However, its performance depends on careful mix design, material selection, and maintenance to balance mechanical strength, permeability, and durability.

3.0 Methodology

The study adopts an experimental design to evaluate the effect of silica fume and coarse aggregate ratio on the compressive strength and permeability of pervious concrete. It follows a systematic approach, starting with a literature review to understand the fundamental properties of pervious concrete and the role of supplementary materials like silica fume. The research progresses through material selection, mix design, and sample preparation, ensuring consistency and reliability. Different cement-to-aggregate ratios, aggregate sizes, and silica fume replacement levels (ranging from 0% to 20%) are considered to determine their impact on concrete performance.

The experimental phase involves testing the prepared samples for compressive strength at 7 and 28 days, along with porosity and permeability assessments to evaluate water infiltration capacity. Data analysis identifies the optimal mix balancing strength and permeability for practical pavement applications. Findings highlight the significance of material proportions, with conclusions addressing real-world applicability and recommendations for further research to enhance pervious concrete efficiency.

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4.0 Test Results and Analysis

After referring to various literature, the mix proportions for pervious concrete is normally taken in 1:4, 1:5, 1:6, cement: Aggregate ratio. Hence, the best compressive strength from these mixes is to be obtained.

4.1 Result of compressive strength test

This table gives the results of compressive strength of pervious concrete in terms of 1:4 cement-to-aggregate ratio for curing of 7 and 28 days. The mean compressive strength at 7 days is 8.12 N/mm², while at 28 days it is 16.35 N/mm². This shows that the concrete gets stronger with the passage of time and its maximum at 28 days.

Table 1 Compressive Strength Test Results for Cement: Aggregate Proportion 1:4 with aggregate Size of 4.75- 20mm

Sr. No	c/s Area (mm²)	Failure Load of 7 days (KN)	CS of 7 days (N/mm²)	Avg. CS of 7 days (N/mm²)	Failure Load of 28 days (KN)	CS 28 of days (N/mm²)	Avg. CS of 28 days (N/mm²)
1.	150x150	186	8.26	8.12	363	16.13	16.35
2.	150x150	228	10.12		372	16.53	
3.	150x150	161	7.15		369	16.40	

With the 1:5 cement-aggregate mix, the strength is much weaker than the mix with a 1:4 ratio. Average strength at 7 days is 5.763 N/mm², while at 28 days it is 9.83 N/mm². This is an assurance that decreasing the amount of cement in the mixture makes the concrete weaker, yielding lower overall strength.

Table 2 Compressive Strength test Result for Cement: Aggregate Proportion 1:5 with Aggregate size of 4.75- 20mm

Sr. No	c/s Area (mm²)	Failure Load of 7 days (KN)	CS of 7 days (N/mm²)	Avg. CS of 7 days (N/mm²)	Failure Load of 28 days (KN)	CS of 28 days (N/mm²)	Avg. CS of 28 days (N/mm²)
1.	150x150	121	5.378	5.763	197	8.75	9.83
2.	150x150	124	5.511		218	9.68	
3.	150x150	144	6.400		249	11.06	

For a 1:6 ratio of cement to aggregate, the concrete is weakest in terms of compressive strength. At 7 days, the average strength is 4.788 N/mm², and at 28 days, it is just 7.52 N/mm². This is the weakest of the three ratios tested, further verifying that the greater proportion of aggregate weakens the mix

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Table 3 Compressive Strength Test Results for Cement: Aggregate Proportion 1:6 with Aggregate Size of 4.75- 20mm

Sr. No	c/s Area (mm^2)	Failure Load of 7 days (KN)	CS of 7 days (N/mm^2)	Avg. CS of 7 days (N/mm^2)	Failure Load of 28 days (KN)	CS of 28 days (N/mm^2)	Avg. CS of 28 days (N/mm^2)
1.	150x150	114	5.067	4.788	171	7.60	7.52
2.	150x150	89	3.954		139	6.17	
3.	150x150	120	5.333		198	8.80	

This table gives the compressive strength results of all three mix ratios. The 1:4 ratio gives the maximum strength (16.35 N/mm^2 at 28 days), then 1:5 (9.83 N/mm^2) and 1:6 (7.52 N/mm^2). Also, the density is quite similar for all three mixes, meaning that the variation in strength is mostly due to cement content and not due to density variations.

Table 4 Overall Compressive Strength & Density Test Results for Varying Proportion of Cement: Aggregate 1:4, 1:5, 1:6 with Aggregate Size of 4.75 – 20 mm

Sr. No	Proportion Cement: Aggregate	Avg. Density (Kg/m^3)	Avg. CS of 7 days (N/mm^2)	Avg. CS of 28 days (N/mm^2)
1.	1:4	2100	8.120	16.35
2.	1:5	2106	5.763	9.83
3.	1:6	2027	4.788	7.52

5.0 Conclusion

This research illustrates the performance effectiveness of pervious concrete reinforced with silica fume in enhancing the performance of pavement, especially its strength, durability, and permeability. From the experimental analysis, it is evident that silica fume inclusion increases compressive strength without losing high permeability, making the material a best choice for groundwater recharge and stormwater management. The research shows that an even cement-to-aggregate ratio and optimized use of silica fume replacement make a major contribution to the pervious concrete's mechanical performance and long-term sustainability.

Furthermore, its capacity to minimize urban flooding, reduce the urban heat island effect, and decrease carbon emissions is in accordance with sustainable building practices. Despite its advantages, limitations such as clogging and maintenance implications must be addressed to promote extended efficiency. Large-scale field implementation, long-term durability testing, and creative maintenance practices should be emphasized in future research to leverage the full capability of pervious concrete in urban infrastructure.

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