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Research Article

Analysis of the Effect of Silica Fume as an Additive on the Workability and Compressive Strength of Porous Concrete

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Abstract

The use of porous concrete is a crucial strategy for mitigating surface water runoff in urban areas. However, low compressive strength often poses a major challenge in its application. This study aims to analyze the effect of adding silica fume on the mechanical and hydraulic properties of porous concrete. The research was conducted experimentally in a laboratory setting, following ACI 522R-10 standards for mix proportions and ASTM C39 for compressive strength testing. The silica fume content was varied at 0%, 3%, 5%, and 7% of the total cement weight, with a total of 24 test specimens, each a 10x20 cm cylinder. Test procedures included a slump test for workability, a permeability test, and a 28-day compressive strength test. The results showed that increasing the silica fume content significantly reduced the slump to 0 cm at a 7% increase, indicating that the mixture became stiffer. As the micro-structural density increased, the permeability coefficient decreased from 0.0288 cm/s to 0.0082 cm/s. Although drainage capacity decreased, the compressive strength of the concrete increased significantly by 69.6%, from 6.58 MPa to 11.16 MPa at the 7% content. The novelty of this study lies in identifying the optimal level of silica fume use to achieve a structural compressive strength above 10 MPa while preserving drainage functionality. These findings confirm that silica fume effectively enhances the mechanical performance and durability of porous concrete, making it highly suitable for use in eco-friendly infrastructure, such as parking lots and neighborhood roads, that require a balance between structural strength and water infiltration efficiency.

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Introduction

Pervious concrete is a construction material designed with a high level of porosity, allowing water to flow through its internal cavities. This material is widely used in parking areas, pedestrian paths, and sustainable drainage systems due to its ability to reduce surface runoff and increase groundwater

infiltration. Furthermore, pervious concrete helps reduce waterlogging and mitigate the urban heat island effect through its permeable nature (Rahul & Ravikumar, 2025).

On the other hand, pervious concrete has limitations, including relatively low compressive strength and limited workability. This condition is associated with the absence of fine aggregate in the mixture, resulting in the formation of large voids and weak interparticle bonds (Manalip & Wallah, 2019). These limitations are a major obstacle in the development of pervious concrete, especially for applications that still require adequate mechanical performance.

Various approaches have been taken to improve the performance of pervious concrete, including the use of pozzolanic admixtures such as silica fume. This material has a very fine particle size and a high reactive silica content, which can increase microstructural density and improve the interfacial transition zone between the cement paste and aggregate. Previous research has shown that adding silica fume can increase the compressive strength of porous concrete by forming additional hydrate products (Sharma et al., 2021; Hung et al., 2021). Furthermore, Kumar & Srikanth (2023) reported an increase in mechanical performance at certain concentrations while maintaining drainage function.

However, increasing the silica fume content also resulted in decreased workability and permeability. (Zalalludin & Ryanto, 2022) showed that high silica fume content increased compressive and splitting tensile strength but decreased workability. Similar results were reported by Tariq & Kaushal (2023), who stated that increasing the silica fume content improved the concrete's structural density but was accompanied by a decrease in slump. These findings indicate a complex interaction between mechanical and functional parameters in porous concrete.

In addition to admixture factors, coarse aggregate characteristics also influence the porosity, compressive strength, and permeability of porous concrete (I. V. Simanjuntak & Tampubolon, 2022). Therefore, designing porous concrete mixes requires a comprehensive approach to balance mechanical strength and optimal drainage.

Although the use of silica fume has proven effective in improving the mechanical properties of porous concrete, the current literature remains ambiguous regarding the optimal balance between increased strength and the retention of hydraulic function. Most previous studies have examined these parameters only partially, thus failing to provide a complete picture of the interaction between the variables. There is scientific uncertainty about whether microstructural densification efforts through the addition of pozzolans often have a linear impact on the risk of drastic pore clogging, but the threshold silica fume content that ensures both functions continue to operate simultaneously has not been comprehensively mapped.

This research gap is underscored by the limited understanding of how reduced workability, due to the hydrophilic nature of silica fume, affects the effectiveness of interconnecting voids in porous concrete. Without a systematic analysis of these trade-offs, the field application of pervious concrete risks drainage failure from excessive density or, conversely, structural degradation from uncontrolled porosity.

Therefore, this study aims to analyze, in an integrated manner, the effect of varying silica fume content (0%, 3%, 5%, and 7%) on the synergy among workability, permeability, and compressive strength. The novelty of this research lies in identifying the functional threshold for silica fume use to produce pervious concrete with a compressive strength above 10 MPa, while maintaining a permeability coefficient that meets groundwater infiltration standards. The results of this study are expected to provide new guidelines for designing more scientific and applicable pervious concrete mixes to support sustainable urban infrastructure development.

Research Method

Metode Penelitian

This study used a laboratory experimental method to analyze the effect of silica fume addition on the properties of porous concrete. The test specimens used were cylindrical with a diameter of 10 cm and a height of 20 cm, in accordance with concrete compressive strength testing standards. The entire research process was conducted at the Civil Engineering Laboratory of Universitas Indo Global Mandiri, Palembang.

Concrete mixture variations were performed with silica fume additions of 0% (normal concrete), 3%, 5%, and 7% of the total mixture weight. Three specimens were prepared for each test type,

resulting in a total of 12 specimens for the compressive strength test and 12 for the permeability test. The following is the concrete mixture composition.

Table 1. Concrete Mix Proportions for 1 Cylinder

Type of Test Specimen	Water (kg)	Coarse Aggregate (kg)	Semen (kg)	Silica fume (kg)
BP	0,211	2,920	0,602	-
BSF 3%	0,211	2,920	0,602	0,084
BSF 5%	0,211	2,920	0,602	0,140
BSF 7%	0,211	2,920	0,602	0,196

Description, BP = Porous Concrete without silica fume, and BSF = Porous Concrete + Silica Fume

The parameters tested included

1. Workability (slump test)
2. Permeability of porous concrete
3. Compressive strength of concrete

The test data were analyzed comparatively across variations, with porous concrete without silica fume used as the reference. This analysis aimed to evaluate the extent to which the addition of silica fume affected the mechanical and functional properties of porous concrete.

Analysis Method

Before designing the concrete mix composition, a series of aggregate tests was conducted to understand the basic properties of the materials to be used. These tests are crucial because they provide the information needed to determine the most appropriate concrete mix proportions for the research objectives. By understanding the material characteristics, the concrete mix can be adjusted to ensure optimal results in both workability and strength.

Results and Discussion

Aggregate Testing

Coarse aggregate testing is conducted as a preliminary step to ensure that the material used meets the requirements for porous concrete. Aggregate characteristics such as gradation, specific gravity, water content, and silt content significantly influence concrete properties, particularly compressive strength, porosity, and workability. The following section presents figures and tables containing the results of coarse aggregate testing.



Figure 1. Coarse Aggregate Testing

Based on the test results, the coarse aggregate used had a specific gravity of 2.61, a mud content of 0.89%, and a water content of 3.864%, all of which were within the standard requirements. The aggregate gradation showed a single-size condition with a maximum size of 12.5 mm, which is in accordance with the recommendations for porous concrete.

These results indicate that the coarse aggregate is of good quality and suitable for this research. The suitability of these aggregate characteristics is crucial to ensuring that variations in the resulting

concrete properties are driven primarily by the addition of silica fume, rather than by unsuitable base materials.

Table 2. Coarse Aggregate Test Results

Testing	Specification	Requirement	Result	Remarks
Sieve Analysis	ACI 522R-10	Satu Ukuran	-	*Compliant*
Specific Gravity and Water Absorption	SNI 03-1970-1990	2,58 % - 2,83 %	2,61 %	*Compliant*
Silt Content	SNI 03-4428-1997	1 %	0,89 %	*Compliant*
Moisture Content	SNI 03-1971-2011	3 % - 5%	3,864 %	*Compliant*

Slump Testing

Slump testing is conducted to evaluate the workability of porous concrete mixtures. Test results indicate that porous concrete without admixtures has a slump of 4 cm. This value decreases to 2 cm with the addition of 3% silica fume and reaches 0 cm at 5% and 7%.

Therefore, slump testing is necessary to ensure that the concrete mixture has the workability required for porous concrete. The following figures and tables show the results of the slump testing for each concrete mixture variation.



Figure 2. Slump Test

Table 3. Slump Test Results

Concrete Mix Variations	Slump Value (cm)
Normal Porous Concrete	4
3% Silica Fume Admixture	2
5% Silica Fume Admixture	0
7% Silica Fume Admixture	0

This decrease in slump value indicates that the addition of silica fume significantly reduces the workability of the concrete mixture. This is due to the very fine particle size of silica fume, which increases the specific surface area and water requirement in the mixture. As a result, the mixture becomes stiffer and more difficult to work with.

These results align with research by Tariq & Kaushal (2023), which reported a decrease in slump value due to the addition of silica fume. However, the decrease in this study was more pronounced, particularly at the 5% and 7% variations, which showed no slump. This difference indicates that in porous concrete without fine aggregate, the effect of silica fume on workability is more dominant than in conventional concrete.

However, the very low slump values at 5% and 7% variations in this study indicate a higher level of stiffness than in several previous studies. This indicates that the effect of silica fume on workability in porous concrete can be more dominant, especially due to the absence of fine aggregate in the mixture. Therefore, the results of this study reinforce the conclusion that the use of silica fume in porous concrete requires adjustments to fieldwork methods.

Permeability Testing

Permeability testing of porous concrete aims to determine its ability to transmit water through the cavities formed by the aggregate structure. This parameter is crucial because porous concrete is designed to allow efficient water infiltration in sustainable pavement systems. ACI 522R-10 (2010) states that permeability is one of the main indicators of the success of porous concrete as a pavement that supports surface runoff control. The characteristics of the pore structure, influenced by aggregate gradation and compaction in the mix design, are crucial factors that directly govern the water flow rate, or permeability, of porous concrete (Muthaiyan, 2023).

In this study, permeability testing was conducted using the falling head flow test method in accordance with ASTM D5084 (2016). This method involves flowing water from a graded tube into the concrete specimen and then recording the time for the water level to fall. This data is used to calculate the permeability coefficient using the equation specified in the test standard. The falling-head method was chosen because it provides an accurate representation of water flow in porous materials such as permeable concrete.

Understanding this permeability value is crucial in determining the suitability of permeable concrete for field applications, particularly in pavements requiring high infiltration capacity. The permeability test results from this study are presented in Table 4 and Figure 3. This provides the basis for evaluating the performance of each concrete mix variation.

Table 4. Permeability Test Results

Concrete Sample	Test Specimen	Flow Time (seconds)	Permeability (cm/second)	Average
Porous Concrete	I	25.69	0.0328	0.0288
	II	29.49	0.0249	
	III	27.53	0.0286	
Silica Fume 3% Additive	I	39.07	0.0142	0.0147
	II	36.03	0.0167	
	III	40.51	0.0132	
Silica Fume 5% Additive	I	46.98	0.0098	0.0104
	II	42.52	0.0120	
	III	47.78	0.0095	
Silica Fume 7% Additive	I	52.47	0.0079	0.0082
	II	50.31	0.0086	
	III	51.67	0.0081	

Permeability test results showed that porous concrete without additives had a value of 0.0288 cm/s. This value gradually decreased to 0.0147 cm/s (3%), 0.0104 cm/s (5%), and 0.0082 cm/s (7%) as the silica fume content increased.



Figure 3. Permeability Testing

This decrease in permeability is due to the very fine and reactive nature of silica fume, which can fill the voids between aggregates and reduce pore size. Consequently, water flow paths become narrower, and the infiltration rate decreases.

These results are consistent with research by Kumar & Srikanth (2023), which showed that the addition of silica fume can reduce permeability by increasing concrete density. Furthermore, Sharma et al. (2021) also reported that the pozzolanic reaction in silica fume produces a denser microstructure, thereby reducing effective porosity. However, the decrease in permeability observed in this study remained within the acceptable range for porous concrete. Compared with several other studies, the resulting permeability values still indicate that concrete maintains good drainage. This demonstrates that silica fume, at concentrations up to 7%, can still preserve the primary characteristics of porous concrete as a permeable material.

Compressive Strength Testing

After the test specimens have formed and cured, the next stage is to test the concrete's compressive strength. This test is conducted at 28 days to determine the maximum strength the concrete can achieve. Compressive strength is a key parameter for assessing the structural performance of concrete, including porous concrete, as it indicates the material's ability to withstand compressive forces on structural elements (Oktavian, 2022).

A total of 12 test specimens were used in this test, consisting of four mixture variations, with three specimens per variation. The compressive strength is influenced by several factors, including the quality of the constituent materials, mixture proportions, density, and chemical reactions that occur during the concrete hardening process. (Putra, 2025) states that the mechanical characteristics of concrete are largely determined by the microstructure formed during hydration, so variations in admixtures such as silica fume can affect the final properties of the concrete.

Furthermore, (J. O. Simanjuntak et al., 2021) explain that variations in the type and properties of coarse aggregate also determine the compressive strength of concrete because the resulting pore structure is significantly influenced by the distribution of aggregate grains. (Wu et al., 2022) Also confirmed that increasing the microstructural density of concrete by using high-efficiency materials can increase compressive strength. Meanwhile, Manilal et al. (2025) stated that successful concrete curing plays a crucial role in ensuring optimal hydration reactions, thereby increasing concrete strength over the test period.

The results of the compressive strength tests on all concrete mix variations are presented in Table 5 and Figure 4. These data were used as the basis for analyzing the effect of varying silica fume content on the compressive strength of porous concrete.

Table 5. Compressive Strength Test Results

Sampel Beton	Benda Uji	Kuat Tekan (Mpa)	Kuat Tekan (MPa) Rata-Rata
Beton Berpori	I	6.11	6.58
	II	7.01	
	III	6.62	
Beton Berpori + Bahan Tambah *Silica Fume* 3%	I	8.28	7.94
	II	7.64	
	III	7.90	
Beton Berpori + Bahan Tambah *Silica Fume* 5%	I	8.91	8.78
	II	8.40	
	III	9.04	
Beton Berpori + Bahan Tambah *Silica Fume* 7%	I	10.83	11.16
	II	11.20	
	III	11.46	

Testing was conducted at 28 days on four concrete mix variations: porous concrete without admixtures and porous concrete with silica fume additions of 3%, 5%, and 7%. The test results showed that the porous concrete without admixtures produced an average compressive strength of 6.58 MPa.

The addition of 3% silica fume increased the compressive strength to 7.94 MPa, while the addition of 5% resulted in an average compressive strength of 8.78 MPa. The highest compressive strength was achieved with the addition of 7% silica fume, at 11.16 MPa. Compared with previous studies (Sharma et al., 2021; Hung et al., 2021), increases in compressive strength due to the addition of silica fume have been widely reported. However, the increase in this study was relatively higher, particularly at the 7% variation, which showed a significant increase compared to normal concrete.

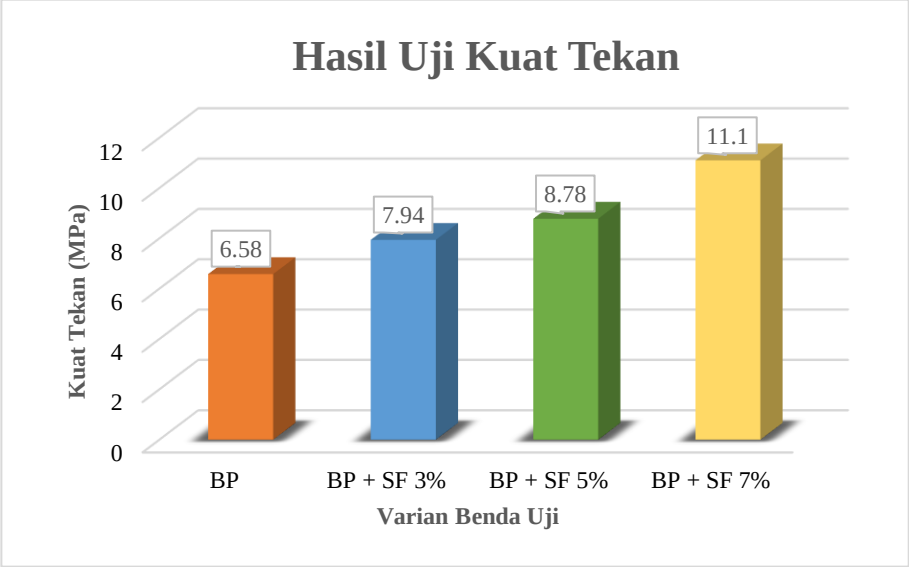


Figure 4. Compressive Strength Graph

This difference indicates that in porous concrete, the contribution of silica fume to strength increases can be more dominant due to the concrete's initial structure containing many cavities. With the addition of silica fume, these voids are partially filled, resulting in a more significant increase in strength compared to conventional concrete.

However, this increase in compressive strength does not occur without consequences. The simultaneous decrease in workability and permeability indicates a trade-off between these parameters. Therefore, although a 7% variation produces the highest compressive strength, determining the optimum content requires considering the balance between the concrete's strength and permeability functions.

Conclusion

Based on the research and analysis conducted, it can be concluded that the addition of silica fume significantly impacts the properties of porous concrete, both mechanically and functionally. The addition of up to 7% silica fume increased the concrete's compressive strength by 69.6% (to 11.16 MPa) but reduced the slump to 0 cm and the permeability coefficient to 0.0082 cm/s due to microstructural densification. A silica fume content of 5%–7% is the functional threshold capable of producing structurally porous concrete (>10 MPa), although there is a trade-off in the form of reduced drainage capacity that must be adjusted to the intensity of rainfall at the application site. This research was limited to macro-laboratory testing without microstructural analysis (SEM/XRD).

Therefore, further research is recommended, including the use of a superplasticizer to improve workability and the conduct of clogging tests to ensure long-term drainage durability.The Conclusions section should concisely summarize the main findings of the study in relation to the stated objectives, without repeating detailed results or discussion. It should highlight the key contributions and implications of the work for engineering practice and/or theory, and, where appropriate, acknowledge the main limitations of the study. Authors may also briefly indicate potential directions for future research or practical application. No new data, analysis, or references should be introduced in this section.

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Conflicts of Interest

The authors declare no conflict of interest.

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