Experimental Investigation on Mechanical and Durability Properties of Concrete with Partial Replacement of Cement by Silica Fume

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Abstract

Durability of concrete structures exposed to aggressive environments is a major concern in modern construction practice. Acid attack significantly deteriorates concrete by dissolving cement hydration products, leading to strength loss and reduced service life. In this study, an experimental investigation was carried out to evaluate the mechanical and durability performance of concrete with partial replacement of cement by silica fume. M30 grade concrete was designed as per IS 10262:2019, and cement was replaced with silica fume at 0%, 5%, 10%, and 15% by weight. Mechanical properties were assessed through compressive strength and split tensile strength tests, while durability was evaluated using water absorption and acid resistance tests. The results indicated that silica fume significantly improves strength, reduces permeability, and enhances resistance to acid attack. Among the mixes studied, 10% silica fume replacement exhibited optimum performance in terms of both mechanical and durability properties. The study confirms that silica fume concrete is suitable for structures exposed to aggressive acidic environments.

Keywords: Silica fume, Acid resistance, Durability, Compressive strength, Water absorption, M30 concrete.

1. Introduction

Concrete is the most widely used construction material due to its versatility, strength, and economic advantages. However, durability issues arise when concrete structures are exposed to aggressive environments such as industrial effluents, sewage water, and acidic groundwater. Among various durability problems, acid attack is one of the most severe forms of chemical deterioration, as acids directly react with cement hydration products, leading to dissolution of binding material, surface erosion, cracking, and loss of strength.

Conventional Portland cement concrete contains significant amounts of calcium hydroxide, which is highly vulnerable to acid attack. Therefore, improving the durability of concrete requires modification of its microstructure to reduce permeability and limit chemical ingress. The use of supplementary cementitious materials (SCMs) has proven effective in enhancing durability and sustainability of concrete.

Silica fume, an ultrafine pozzolanic material obtained as a by-product during silicon production, has been widely studied for its ability to improve strength and durability of concrete. Due to its high silica content and extremely fine particle size, silica fume contributes to pore refinement and formation of additional calcium silicate hydrate (C–S–H) gel. This study focuses on evaluating the influence of silica fume on mechanical properties and acid resistance of concrete.

2. Experimental Program

2.1 Materials

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269:2013 was used. Natural river sand conforming to Zone II grading as per IS 383:2016 served as fine aggregate. Crushed granite aggregate of 20 mm nominal size was used as coarse aggregate. Silica fume with high amorphous silica content was used as a partial replacement of cement. Potable water was used for mixing and curing.

2.2 Mix Design and Proportions

M30 grade concrete was designed as per IS 10262:2019 considering durability requirements of IS 456:2000. Cement was partially replaced by silica fume at 0%, 5%, 10%, and 15% by weight, while maintaining a constant water–binder ratio of 0.40.

Mix ID	**Cement (kg/m³)**	**Silica Fume (kg/m³)**	**Fine Aggregate (kg/m³)**	**Coarse Aggregate (kg/m³)**	**Water (kg/m³)**
CM	400	0	650	1200	160
SF5	380	20	650	1200	160
SF10	360	40	650	1200	160
SF15	340	60	650	1200	160

2.3 Testing Methods

Compressive strength tests were conducted at 7, 14, 28, and 56 days as per IS 516:2018. Split tensile strength was determined at 28 and 56 days as per IS 5816:1999. Water absorption was measured at 28 days following IS 3085:1965. Acid resistance was evaluated by immersing 28-day cured specimens in 5% acid solution for 28 days and measuring weight loss and residual compressive strength.

3. Results and Discussion

3.1 Compressive Strength

Silica fume concrete exhibited higher compressive strength than control concrete at all ages. The increase in strength is attributed to pozzolanic reaction and micro-filler effect of silica fume. The SF10 mix showed the highest compressive strength, indicating an optimum replacement level.

Table 2. Compressive Strength Results

Mix ID	**7 Days (MPa)**	**14 Days (MPa)**	**28 Days (MPa)**	**56 Days (MPa)**
CM	22.4	27.6	33.2	35.8
SF5	24.1	29.4	36.8	39.6
SF10	26.3	31.8	39.5	42.7
SF15	25.0	30.1	37.2	40.0

Discussion:

Compressive strength increased with silica fume content up to 10%. The SF10 mix showed about **19% higher strength at 28 days** compared to control concrete due to pozzolanic reaction and micro-filler effect.

3.2 Split Tensile Strength

Split tensile strength increased with silica fume content up to 10%, indicating improved crack resistance. The refined interfacial transition zone and improved bond between aggregate and paste contributed to enhanced tensile performance.

3.2 Split Tensile Strength

Table 3. Split Tensile Strength Results

Mix ID	28 Days (MPa)	56 Days (MPa)
CM	2.85	3.05
SF5	3.10	3.35
SF10	3.42	3.70
SF15	3.25	3.50

Discussion:

Silica fume improved tensile strength by enhancing the interfacial transition zone. SF10 exhibited the highest tensile strength, indicating improved crack resistance.

3.3 Water Absorption

Water absorption decreased significantly with silica fume incorporation. The lowest water absorption was observed for SF10, indicating a denser microstructure and reduced permeability, which directly improves durability.

Table 4. Water Absorption Results

Mix ID	Water Absorption (%)
CM	3.10
SF5	2.45
SF10	1.90
SF15	2.15

Discussion:

Water absorption decreased significantly with silica fume addition, indicating reduced permeability. The minimum value was observed for SF10.

3.4 Acid Resistance

Silica fume concrete showed reduced weight loss and higher residual strength compared to control concrete after acid exposure. The improved acid resistance is attributed to reduced calcium hydroxide content and lower permeability. SF10 exhibited the highest resistance to acid attack.

Table 5. Weight Loss Due to Acid Attack

Mix ID	Weight Loss (%)
CM	5.6
SF5	4.1
SF10	2.9
SF15	3.3

Table 6. Residual Compressive Strength After Acid Exposure

Mix ID	Strength Before Acid (MPa)	Strength After Acid (MPa)	Strength Retention (%)
CM	33.2	25.4	76.5
SF5	36.8	30.2	82.1
SF10	39.5	34.6	87.6
SF15	37.2	31.5	84.7

Discussion:

Silica fume concrete showed significantly lower deterioration under acid exposure. The SF10 mix retained nearly 88% of its original strength, confirming superior acid resistance.

4. Conclusions

Based on the experimental investigation, the following conclusions are drawn:

1. Partial replacement of cement with silica fume improves mechanical strength of concrete.
2. Silica fume significantly reduces water absorption and permeability.
3. Acid resistance of concrete is enhanced due to reduced calcium hydroxide and refined pore structure.
4. Optimum performance was observed at 10% silica fume replacement.
5. Silica fume concrete is suitable for structures exposed to acidic environments.

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