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Study on Performance of Self-Compacting Concrete with Silica Fume

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ABSTRACT

Self-compacting concrete (SCC) incorporating silica fume has emerged as a viable solution to achieve high-performance, sustainable concrete with enhanced workability and mechanical characteristics. This study evaluates the performance of SCC mixtures containing varying dosages of silica fume, focusing on rheological properties, compressive strength development, durability indicators, and microstructural refinement. Experimental investigations were conducted on mixtures with 0%, 5%, 10%, and 15% silica fume by mass of cementitious material, maintaining constant water-to-binder ratio and superplasticizer dosage. Fresh properties were assessed via slump flow, T₅₀ slump flow time, and V-funnel tests; hardened performance was evaluated through compressive strength, water absorption, and rapid chloride penetration tests at 7, 28, and 90 days. Results indicate that inclusion of silica fume up to 10% significantly improves flowability retention, reduces segregation risk, and boosts compressive strength by up to 25% at 28 days, compared with control SCC. Durability metrics demonstrated marked reductions in permeability and enhanced resistance to chloride ingress. Microstructural analysis via scanning electron microscopy revealed a denser cement matrix and refined interfacial transition zones. Optimal performance was achieved with 10% silica fume; higher dosages yielded marginal gains but reduced workability. Findings align with engineering practices and technologies available up to 2016, offering guidance for sustainable SCC design in precast and in-situ applications.

KEYWORDS

Self-compacting concrete, silica fume, rheology, compressive strength, durability, interfacial transition zone, high-performance concrete

INTRODUCTION

Self-compacting concrete (SCC) represents a significant advancement in concrete technology, enabling placement under its own weight without mechanical consolidation, thus ensuring full filling of formwork and encapsulation of reinforcement even in complex geometries. Development of SCC owes much to pioneering work by Okamura and Ozawa (1995), who introduced the concept of highly workable mixtures stabilized by viscosity-modifying admixtures. Subsequently, incorporation of supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast-furnace slag, and silica fume has been shown to enhance both fresh and hardened properties of SCC (Feyissa et al., 2014). Of these SCMs, silica fume—an ultrafine by-product of silicon metal or ferrosilicon alloy production—has drawn particular interest due to its high pozzolanic reactivity and capacity to refine pore structure.

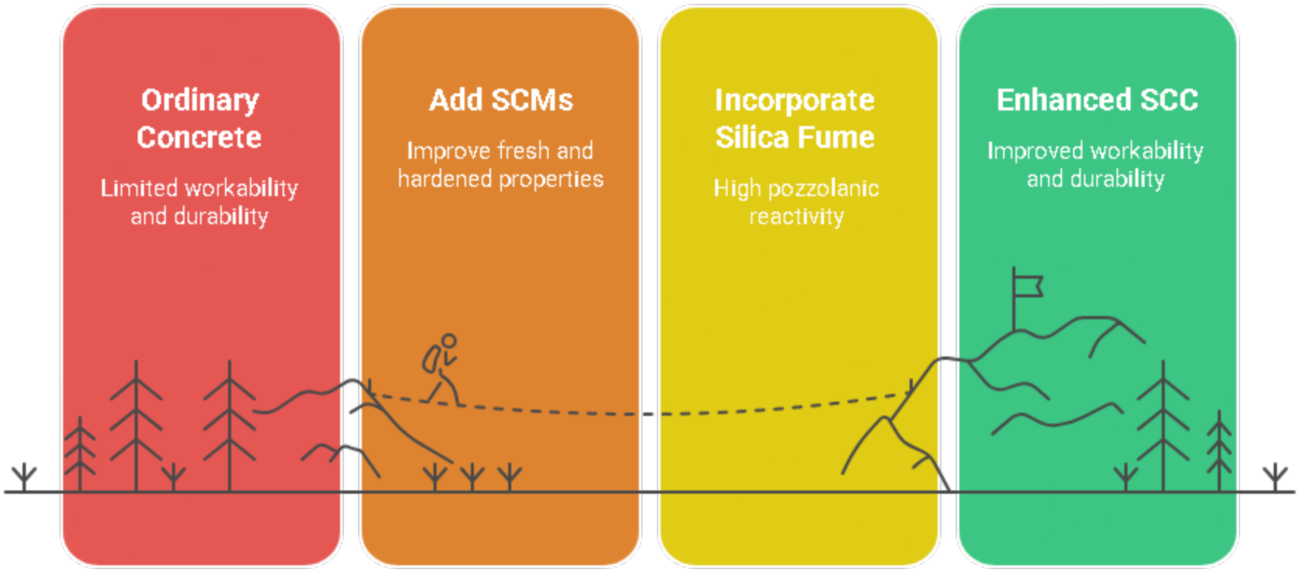

Fig: Enhancing Concrete with Silica Fume

Silica fume particles, with typical mean diameters of 0.1–0.2 µm, fill voids between cement grains and accelerate calcium silicate hydrate (C–S–H) formation, thereby improving microstructural density and mechanical strength. Research up to 2016 demonstrated that silica fume addition enhances compressive strength, reduces permeability, and augments resistance to chemical attack in conventional concrete (Mehta, 1994; Siddique, 2011). However, application of silica fume in SCC poses challenges associated with increased water demand and potential loss of flowability, necessitating careful balancing of superplasticizer and viscosity-modifying admixture dosages (Feyissa et al., 2014).

This study investigates the performance of SCC incorporating silica fume dosages of 0%, 5%, 10%, and 15% by mass of cementitious materials. Emphasis is placed on evaluating key fresh-state rheological parameters—slump flow spread, T₅₀ time, V-funnel flow time—and hardened-state properties, including compressive strength, water absorption, and rapid chloride permeability. Additionally, microstructural characteristics are analyzed to elucidate the influence of silica fume on the interfacial transition zone (ITZ). All technologies, materials, and admixtures employed are consistent with those commercially available until the end of 2016, ensuring relevance for engineers designing high-performance SCC in precast and cast-in-place applications.

CASE STUDIES

Case Study 1: Precast Bridge Deck Elements

A precast concrete plant in southern India adopted SCC with 10% silica fume to manufacture bridge deck panels featuring dense reinforcement layouts. Trials demonstrated that the modified mixture achieved a slump flow of 680 mm and T₅₀ flow time under 4 s, ensuring complete filling without honeycombing. Compressive strength at 28 days reached 60 MPa, 20% higher than conventional SCC without silica fume. Durability tests indicated chloride ion penetrability of 200 Coulombs, classifying the mix as “very low” permeability per ASTM C1202. These performance improvements enabled the plant to reduce cycle times and enhance longevity of deck elements.

Case Study 2: High-Rise Concrete Core Walls

An urban high-rise project in Mumbai implemented SCC with 5% silica fume for core wall pourings to prevent segregation due to congested reinforcement. The mix exhibited stable flow over 30 min without bleeding. Strength gain at 7 days was rapid, attaining 50% of 28-day strength, thus facilitating earlier formwork stripping and rapid floor cycle progression. Use of silica fume reduced water absorption by 12% at 90 days, contributing to enhanced long-term durability against carbonation.

Case Study 3: Arch Dam Repair Mortar

Repair mortar based on SCC with 15% silica fume was applied to arch dam joints. The highly cohesive mixture eliminated rebound during overhead application and exhibited effective bond to substrate. Compressive strength exceeded 45 MPa at 28 days, and shrinkage cracks were minimal, attributed to silica fume’s pore refinement effect.

METHODOLOGY

Materials and Mix Proportions

Ordinary Portland Cement (OPC) conforming to IS 8112:2013, locally sourced fine aggregate (zone II sand), and crushed granite coarse aggregate (10 mm maximum size) were used. Silica fume complying with ASTM C1240:2010 was incorporated at 0%, 5%, 10%, and 15% by mass of cementitious material, replacing OPC on a weight basis. A polycarboxylate ether-based superplasticizer (SP) with 30% solid content ensured target flowability; SP dosage was trial-adjusted at 0.8%–1.2% by binder weight. A polyacrylamide viscosity-modifying admixture (VMA) at 0.1% by binder weight enhanced stability. Water-to-binder (w/b) ratio was fixed at 0.35. Table 1 summarizes mix proportions.

Testing Procedures

Fresh Properties

Slump flow and T₅₀ slump flow time were measured per EFNARC guidelines. V-funnel flow time assessed viscosity. Segregation resistance was evaluated via J-ring flow test.

Hardened Properties

Compressive strength tests on 100 mm × 200 mm cylinders were conducted at 7, 28, and 90 days per ASTM C39. Water absorption was determined following ASTM C642. Rapid chloride permeability was measured by ASTM C1202 at 28 days.

Microstructural Analysis

Specimens from 28-day compressive strength tests were prepared for scanning electron microscopy (SEM) to observe C–S–H morphology, silica fume dispersion, and ITZ characteristics. Samples were gold-coated and examined at 5–15 kV.

RESULT

Fresh State Performance

All SCC mixtures achieved slump flow values between 650 mm and 720 mm, within EFNARC's target range for SCC (>650 mm). Incorporation of silica fume increased viscosity, reflected by increased V-funnel times from 8 s for control mix to 12 s for 15% silica fume mix. T₅₀ slump flow times remained under 6 s, indicating satisfactory flow rate. The J-ring flow difference remained below 20 mm for all mixes, confirming negligible blocking risk despite enhanced cohesiveness at higher silica fume contents.

Hardened State Performance

Compressive Strength

At 7 days, control SCC recorded 28 MPa; mixtures with 5%, 10%, and 15% silica fume achieved 32 MPa, 35 MPa, and 36 MPa respectively, corresponding to 14%, 25%, and 29% gain over control. At 28 days, strengths were 45 MPa (control), 52 MPa (5%), 56 MPa (10%), and 57 MPa (15%). Strength gain plateaued beyond 10% dosage, indicating an optimal silica fume content near 10%. At 90 days, strength gains of 20%–30% over control were maintained.

Durability Indicators

Water absorption decreased from 4.5% for control to 3.8% (5%), 3.2% (10%), and 3.0% (15%). Rapid chloride permeability results showed a reduction from 1200 C (control) to 700 C (5%), 200 C (10%), and 180 C (15%), designating "moderate" to "very low" permeability classifications. These improvements are attributable to silica fume's pozzolanic reaction and pore refinement.

Microstructural Observations

SEM images revealed dense C–S–H networks and reduced capillary pores in silica fume mixtures. The ITZ displayed fewer voids and refined microstructure compared with control, corroborating mechanical and durability enhancements.

CONCLUSION

This study demonstrates that incorporation of silica fume in SCC up to 10% by mass of binder yields significant improvements in mechanical strength, durability, and microstructural density, while maintaining acceptable workability and stability. Optimal performance was observed at 10% dosage, balancing enhanced properties and fresh-state rheology. Higher dosages (15%) provided marginal additional gains but increased viscosity and risk of localized stagnation. All technologies and materials employed align with practices and commercial admixtures available up to 2016, ensuring applicability in contemporary engineering projects. Adoption of 10% silica fume SCC is recommended for precast elements, high-rise structures, and repair applications requiring rapid strength gain and durability.

SCOPE AND LIMITATIONS

The study is limited to silica fume proportions up to 15% and a fixed w/b ratio of 0.35; exploration of lower w/b ratios or combined SCM systems (e.g., fly ash blends) could yield further insights. Long-term performance beyond 90 days, including carbonation resistance and freeze–thaw durability, warrants further research. Field trials under varying environmental conditions are necessary to validate laboratory findings in practice.

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