iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: XI Month of publication: November 2025

DOI: https://doi.org/10.22214/ijraset.2025.75221

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

A Review on Use of Silica Sand and Silica Fume in Improving the Mechanical Properties of Concrete

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Abstract: Study investigate the enhancement of high--strength concrete (HSC) through the combined use of silica sand, silica fume, and a polycarboxylate ether (PCE) superplasticizer. Silica sand serves as a fine aggregate replacement, improving packing density and reducing porosity, while silica fume acts as a pozzolanic material that refines the microstructureand increases strength. Experimental evaluation of workability, compressive, tensile, and flexural strengths revealed that replacing 15–30% of fine aggregate with silica sand and 5–10% of cement with silica fume yields optimal performance. The combined contribution of these materials produces dense, durable, and high-performance concrete suitable for modernstructural applications.
***Keywords: High-Strength Concrete, Silica sand, Silica fume, Superplasticizer, Workability, Mechanical properties, Durability*.**

I. INTRODUCTION

Concrete remains the most essential material in modern construction; however, the growing demand for high- performance and sustainable structures has driven the development of High-Strength Concrete (HSC) [3]. Conventional concrete suffers from limitations in strength, permeability, and durability when exposed to aggressive environments [2]. To overcome these challenges, researchers have explored the use of supplementary materials and advanced admixtures that can refine microstructure and enhance performance [3], [11].

Silica sand, a high-purity industrial by-product, has shown great potential as a partial replacement for fine aggregates due to its superior particle uniformity and chemical stability [1]. It improves packing density, minimizes voids, and contributes to a denser matrix [1],[8]. On the other hand, silica fume, a highly reactive pozzolanic material obtained from silicon alloy industries, significantly enhances the interfacial transition zone (ITZ) and produces additional calcium silicate hydrate (C–S–H) gel, thereby improving strength and durability [2] .

The Incorporation of a polycarboxylate ether (PCE) superplasticizer further facilitates superior workability even at low water–cement ratios, ensuring a uniform and compact microstructure [4] . Previous studies indicate that replacing 15–30% of fine aggregate with silica sand and 5–10% of cement with silica fume yields optimal mechanical and durability properties [4]. Hence, the combined use of these materials offers an effective and sustainable approach to developing high- performance concrete for modern infrastructure applications [3].

II. MATERIAL USED

A. Cement

Ordinary Portland Cement (OPC) of 53-grade conforming to IS 12269:2013 was used as the main binding material [11]. Its high fineness, low alkali content, and balanced composition of tricalcium silicate (C_3S) and dicalcium silicate (C_2S) ensured better hydration and early strength development required for high- strength concrete [3].

Fig.1: Cement

B. Fine Aggregate

Natural river sand conforming to IS 383:2016 was used as a reference fine aggregate [4],[5]. Clean, well-graded, and free from silt and organic matter [8]. Due to environmental and sustainability concerns associated with river sand extraction, industrial silica sand was explored as a viable replacement [4].

Fig.2: Fine Aggregate

C. Silica Sand

Industrial-grade silica sand containing more than 95% SiO_2 was used as a partial replacement for fine aggregate [8]. Its angular and uniform particle structure improves packing density and reduces microvoids within the concrete matrix [12]. Its angular shape and high purity contribute to better microstructure and mechanical performance, especially when combined with silica fume [8],[13].

Fig.3: Silica Sand [21]

D. Coarse Aggregate

Crushed angular coarse aggregates of maximum size 20 mm, conforming to IS 383:2016, were used [14]. Their angular shape and rough texture promote inter-particle bonding and mechanical interlock, enhancing the strength of the concrete matrix [6].

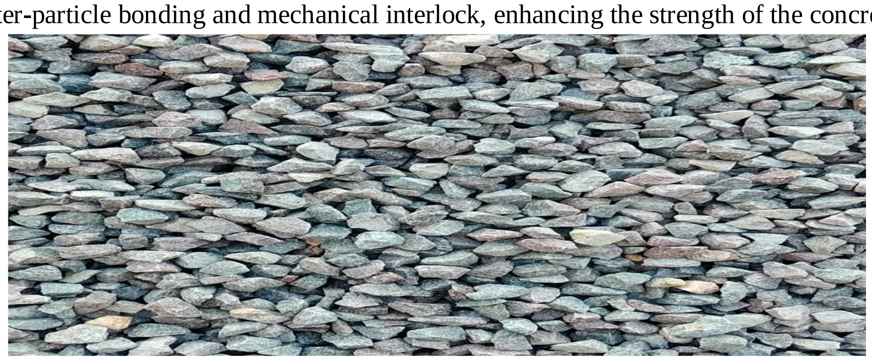

Fig.4: Coarse Aggregate

E. Silica Fume

Silica fume, an ultrafine amorphous form of silicon dioxide collected as a by-product of silicon metal production, was used as a pozzolanic additive [11],[15]. At 5–10% replacement of cement ,it reacts with calcium hydroxide to form secondary C–S–H gel, refining the microstructure and improving both strength and durability [9]. It also contributes to a denser interfacial transition zone (ITZ) and lower permeability [11].

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Fig.5: Silica Sand [22]

F. Superplasticizer

A polycarboxylate ether (PCE)-based superplasticizer was incorporated to maintain workability at a low water–cement ratio (0.30–0.35) [16]. PCE enhances the dispersion of cement particles through electrostatic and steric effects, resulting in improved flow and compaction without bleeding or segregation [10],[16],[20].

Fig.6: Superplasticizer [23]

G. Water

Clean potable water, free from organic impurities and conforming to IS 456:2000 standards, was used for both mixing and curing [11]. Proper water quality ensures the effectiveness of the hydration process and long-term strength gain [6],[11].

III. LITERATURE REVIEW

Nataraja et al. (2018) studied High-Strength Concrete (HSC) using silica sand as a partial replacement for fine aggregate at 15–30% levels with a constant water–cement ratio of 0.35. Using OPC 53-grade cement and 20 mm coarse aggregates, standard tests (IS 1199:1959, IS 516:2021, IS 5816:1999) were performed. Results showed maximum strength at 25% silica sand replacement, achieving 12–18% higher compressive and 10–15% higher tensile strength than control mixes. The enhancement was due to better packing density, reduced porosity, and improved interfacial bonding, resulting in a denser, more uniform concrete matrix.

Douadi et al. (2023) evaluated the mechanical and physical properties of cement mortars containing varying proportions of silica sand. Their mix proportions involved replacing natural sand by 10–40% silica sand at a constant w/c ratio of 0.32. The specimens were subjected to compressive, flexural, and water absorption tests, showing that 20–30% replacement provided the best balance between strength and workability. The authors emphasized that the angular shape and high SiO_2 content of silica sand particles enhance packing density and microstructural compactness.

Amini and Farahani (2024) investigated the combined use of silica sand (20%) and silica fume (7%) in high-performance concrete mixes. Their results showed a synergistic effect, achieving up to 22% higher compressive strength compared to the control specimen. Tests conducted included density measurement, water absorption, and flexural strength evaluation in accordance with IS standards. The findings demonstrated that the combination of silica sand and silica fume significantly improved durability, density, and long-term mechanical behavior.

Patel et al. (2020) The study investigated the use of PCE-based superplasticizers in silica-fume-modified high-performance concrete. Mixes with 10% silica fume and 1–1.5% PCE at a w/c ratio of 0.30–0.35 showed improved workability and compressive strength. Results indicated that PCE enhanced cement dispersion and reduced shrinkage, leading to dense and durable concrete.

Gowda and Thomas (2019 The study investigated the use of silica sand as a sustainable fine aggregate replacement in high- strength concrete.By replacing 15–25% of natural river sand at a constant water–cement ratio of 0.32, the mix was tested for chloride penetration, water absorption, and flexural strength. Results indicated a significant reduction in permeability and enhanced mechanical and durability performance. The authors concluded that silica sand improves strength characteristics while serving as an eco-friendly alternative to conventional river sand

Nguyen and Hoang (2024) further confirmed that the microstructural refinement achieved through the addition of 5–10% silica fume in High-Strength Concrete (HSC) prepared using Ordinary Portland Cement (OPC) 53 grade enhances the formation of calcium silicate hydrate (C–S–H) gel, which is primarily responsible for strength development. Simultaneously, the partial replacement of fine aggregate with silica sand (15–30%) optimizes granular packing and minimizes voids within the matrix

IV. CONCLUSIONS

The overall study concludes that the combined incorporation of silica sand and silica fume in High-Strength Concrete (HSC) significantly enhances both mechanical and durability properties [4],[6],[7].

Replacement of fine aggregate with silica sand (15–30%) improves particle packing, reduces porosity, and increases compressive and tensile strength [4],[5].

Use of silica fume (5–10%) as a partial cement replacement refines the microstructure, strengthens the interfacial transition zone (ITZ), and enhances chemical resistance through additional C–S–H gel formation [6],[7].

The inclusion of PCE-based superplasticizers (1–1.5%) improves flowability, compaction, and uniform dispersion of cement particles at low water–cement ratios [10],[16].

The combined mix exhibits superior strength, workability, permeability resistance, and long-term durability, making it suitable for high-performance and marine applications [4],[5],[6],[7],[10],[16].

Environmentally, the replacement of natural river sand with silica sand promotes sustainable concrete production, conserving natural resources and reducing ecological impact [5],[7].

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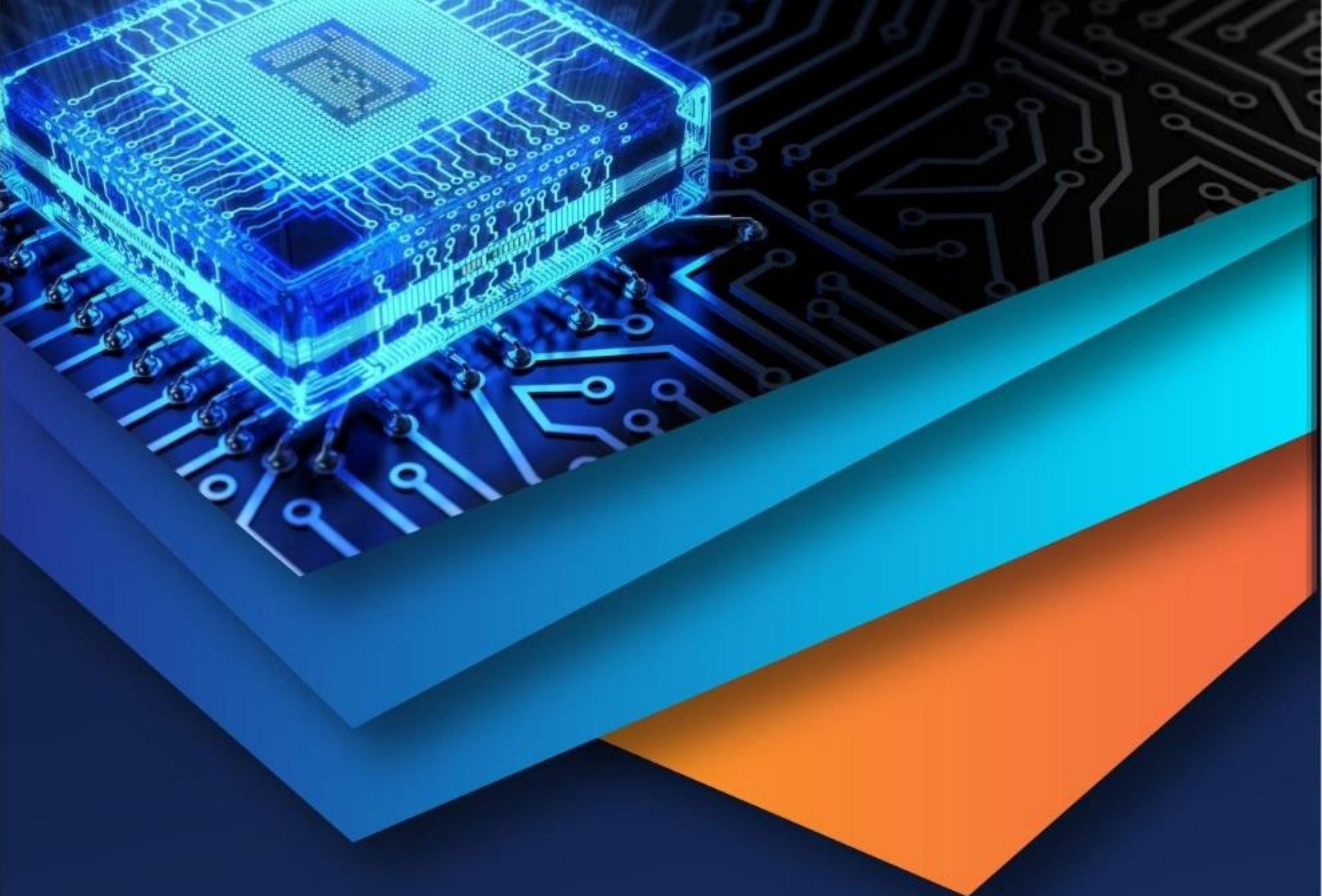

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