

Application of Silica Sand and Silica Fume for Improving Workability and Surface Hardness Properties of M30 Grade Concrete

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Abstract— The impact of silica fume and sand on the surface hardness and workability of M30 grade concrete is investigated in this study. At 1% PCE-based superplasticizer was combined with 0%, 15%, and 20% silica sand and 7% silica fume. The slump test was used to determine workability, while the rebound hammer test was used to determine surface hardness. The results show increased surface hardness with the addition of silica-based materials and improved workability because of the superplasticizer. At 15% silica sand substitution, optimal performance was noted, exhibiting improved surface quality and consistency. The modified concrete is appropriate for real-world construction applications, according to the study's findings.

Keywords— High-Strength Concrete, Silica sand, Silica fume, M30 Concrete, Workability, Rebound Hammer Test.

I. INTRODUCTION

Concrete performance depends on workability and surface characteristics in addition to strength [5], [6]. Adequate workability ensures proper placement, compaction, and finishing, while surface hardness reflects the quality and uniformity of hardened concrete [10], [13].

In this study, silica sand (0%, 15%, and 20%) is used as a partial replacement of fine aggregate, and silica fume (7%) as a partial replacement of cement, along with 1% PCE-based superplasticizer at a constant water–cement ratio of 0.40 [2], [4], [11]. Silica sand improves particle packing and reduces voids, whereas silica fume enhances microstructure through pozzolanic action [1], [8], [11]. The superplasticizer improves flowability without increasing water content [10], [16].

The use of these materials is expected to improve consistency, reduce segregation, and enhance surface quality of concrete [7], [17]. Workability and surface hardness are evaluated using slump test and rebound hammer test, respectively, to assess the performance of modified M30 grade concrete [12], [13].

II. LITERATURE REVIEW

1. **Malathy et al. (2022)** reported that the use of industrial silica sand as a fine aggregate improves particle packing and enhances surface quality of concrete.
2. **Hamada (2023)** observed that silica fume significantly refines microstructure and improves overall performance of cementitious materials.
3. **Amini and Farahani (2024)** demonstrated that the combined use of silica sand and silica fume produces a synergistic effect, improving density and surface characteristics.
4. **Li et al. (2019)** highlighted that PCE-based superplasticizers enhance workability and flowability without increasing the water–cement ratio.
5. **Nguyen and Hoang (2024)** showed that silica fume contributes to better microstructural development and surface quality through additional C–S–H gel formation.
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7. **Arivalagan (2025)** concluded that silica-based materials are effective in producing dense and high-performance concrete with improved surface properties

III. MATERIALS AND METHODOLOGY

1.1 Materials :

1.1.1 Cement:

Ordinary Portland Cement (OPC) of 43-grade conforming to IS 12269:2013 was used as the main binding material [3]. Its high fineness, low alkali content, and balanced composition of tricalcium silicate (C₃S) and dicalcium silicate (C₂S) ensured better hydration and early strength development required for high-strength concrete [5], [7].



Fig.1: Cement

1.1.2 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 [1].



Fig.2: Fine Aggregate

1.1.3 Silica sand

Silica Sand (often a clean, washed quartz sand, predominantly may be considered for this study to replace normal fine aggregate [1]. Using high-quality, sometimes micro-quartz, silica sand, especially in high-performance mixes, is aimed at optimizing the particle packing density of the mix [8]. This is done to achieve a more compact matrix that complements the pore-refining action of silica fume [11]. Silica Sand is proposed as a partial replacement of fine aggregate at varying percentages such as 0%, 15%, and 20% [4], [8].



Fig.3: Silica sand

1.1.4 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

1.1.5 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 7% replacement of cement, it reacts with calcium hydroxide to form secondary C-S-H gel, refining the microstructure and improving both strength and durability. It also contributes to a denser interfacial transition zone (ITZ) and lower permeability [11].



Fig.5: Silica Fume

1.1.6 Superplasticizer: Polycarboxylic acid solution

This study examines the use of PCE-based superplasticizer at 1% of cement weight [16]. It significantly improves workability without increasing water content [10]. Enhanced dispersion leads to better strength and uniformity [16]. Concrete shows reduced permeability and improved durability [20].



Fig.6: Polycarboxylic acid solution

1.1.7 Water:

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

1.2 Mix Proportioning :

The concrete mix was designed for M30 grade with a constant water–cement ratio of 0.40. Different mixes were prepared by varying silica sand content (0%, 15%, 20%), while maintaining constant silica fume (7%) and superplasticizer (1%) [2], [11]. The mix proportions were selected to achieve uniform consistency and improved particle packing [4], [8].

1.3 Mixing Procedure:

All dry materials (cement, fine aggregate, coarse aggregate, silica sand, and silica fume) were thoroughly mixed to ensure uniform distribution [7]. The calculated amount of water mixed with superplasticizer was then added gradually, and mixing was continued until a homogeneous concrete mix was achieved [10].

1.4 Casting of Specimen:

The prepared concrete was cast into standard 150 mm cube moulds [6]. The moulds were properly oiled before casting. Concrete was placed in layers and compacted using a vibrating table to eliminate air voids and ensure uniform density [14].



Fig 6: Compacting of concrete cube

1.5 Curing Process:

After 24 hours, the specimens were demoulded and immersed in water maintained at $27 \pm 2^\circ\text{C}$ [6]. Curing was carried out until the testing age to ensure proper hydration and strength development [11].

1.6 TESTING METHODS:

1.6.1 Workability Test (Slump Test):

Workability of fresh concrete was evaluated using the standard slump cone test as per IS 1199:1959 [12]. The mould was filled in three equal layers, each compacted using a standard tamping rod [12]. After lifting the cone vertically, the subsidence of concrete was measured as slump value in millimetres [18].

The test was used to assess consistency, flowability, and the effect of silica sand and superplasticizer on fresh concrete behaviour [10], [16].



Fig 7: Slump Test

1.6.2 Rebound Hammer Test :

Surface hardness of hardened concrete was determined using the rebound hammer test as per IS 13311 (Part 2) [13]. The test was performed on clean and smooth concrete surfaces after curing.

Multiple readings were taken at different points on each specimen, and the average rebound number was recorded. This provided an indirect assessment of surface quality, uniformity, and degree of compaction of concrete [13], [19].



Fig 8: Rebound Hammer Test

IV. MIX DESIGN

1.7 Design Parameters:

The concrete mix design for M30 grade was carried out in accordance with the provisions of Bureau of Indian Standards, following IS 10262:2019 and IS 456:2000 [2], [6]. The design objective was to achieve the target mean compressive strength with adequate workability, durability, NDT and optimized particle packing using supplementary materials [2],[7].

Table 1: Design Parameters

Parameter	Value
Characteristic compressive strength (28 days)	30 MPa [6]
Target mean strength	38.25MPa [6]
NDT(Rebound Hammer Test)	35- 45 [13]
Maximum aggregate size	20mm, 10mm [6]
Exposure condition	Severe [6]
Workability (Target Slump)	100-150mm [10], [16]
Water – cement ratio	0.40 [2], [11]
Water content (kg/m ³)	158 [6]
Cement content (kg/m ³)	400 [6]
Superplasticizer (kg/m ³)	4 [16]
Specific gravity of cement	3.15 [5]
Specific gravity of coarse aggregate	2.68 [4]
Specific gravity of fine aggregate	2.63 [4]
Specific gravity of silica sand	2.63 [1], [8]

The mix design procedure and parameters are based on standard guidelines and concrete technology principles [2], [7].

1.8 Specimen Preparation and curing:

Concrete mixes were prepared with silica fume (7%) as partial replacement of cement and silica sand (0%, 15% and 20%) as partial replacement of fine aggregate [1], [2]. A PCE-based superplasticizer (1%) was used to maintain workability [10].

Dry materials were mixed thoroughly, followed by the addition of water mixed with admixture to obtain a homogeneous mix [5], [7]. The concrete was cast into 150 mm cube moulds and compacted using vibration [6], [14]. After 24 h, specimens were demoulded and cured in water at $27 \pm 2^\circ\text{C}$ until testing [6], [11]. The hardened concrete was evaluated for NDT (Rebound hammer test) [13].



Fig 9: Cube Casting & Curing

V. RESULTS AND DISCUSSION

1.9 Workability Test (Slump Test):

Workability of M30 grade concrete ($w/c = 0.40$) was evaluated using the slump test in accordance with IS 1199 [12]. Silica fume (7%) and a polycarboxylic acid-based superplasticizer were incorporated in the mixes, while silica sand was varied at 0%, 15%, and 20% [10], [11].

Table: Slump Value

Mixed no.	Silica Sand (percentage)	Slump Value (mm)
M1	0	70
M2	15	120
M3	20	100

1.9.1 Discussion:

The experimental results show a significant improvement in workability with the incorporation of silica sand up to 15%, followed by a slight reduction at higher replacement levels [1].

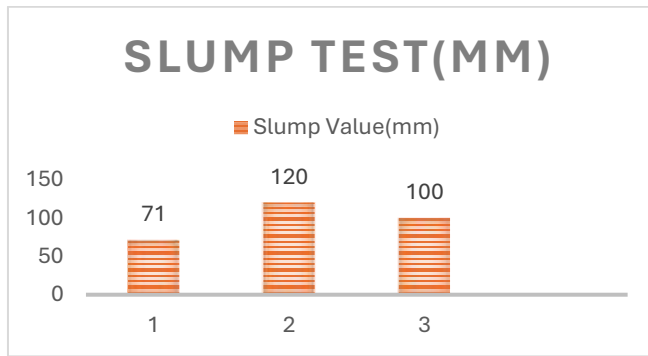
The control mix (0%) exhibits a slump of 70 mm, indicating moderate workability. This is primarily governed by the presence of silica fume, which increases water demand due to its very fine particles, thereby limiting flowability [11], [15].

At 15% silica sand replacement, the slump value increases sharply to 120 mm, indicating high workability [4]. This improvement can be attributed to optimized particle packing, where silica sand fills voids between aggregates and cement particles reduction in internal friction due to better gradation.

Enhanced dispersion effect of the polycarboxylic acid-based superplasticizer, which improves fluidity by separating cement particles [10], [16].

At 20% replacement, the slump slightly decreases to 100 mm, although it still remains high [12]. This reduction is due to:

Increase in finer particles, leading to higher surface area
Greater water demand, which reduces the amount of free water available for flow [7].



1.10 Rebound Hammer Test:

Rebound hammer test was performed on M30 grade concrete with 0%, 15%, and 20% silica sand replacement, keeping silica fume constant at 7% and w/c ratio at 0.40 [13].

Table 3: Rebound Hammer Test (value)

Samp le no.	Silic a sand (%)	Directi on (Angle)	Rebound Hammer value on Point scale	Avg. Rebou nd value (N/mm ²)
S1	0	90	36,34,32,30,34,31,32, 36,37	34
S2	15	90	41,41,48,40,41,35,44, 39,40	41
S3	20	90	36,41,35,34,33,36,40, 39,37	37

$$S1(\text{Sum}) = 302/9 = 34$$

$$S2(\text{Sum}) = 369/9 = 41$$

$$S3(\text{Sum}) = 331/9 = 37$$

The rebound number increases up to 15% replacement and then decreases at 20% [1], [8].

1.10.1 Discussion:

The increase in rebound value from 0% to 15% silica sand indicates improvement in surface hardness due to better particle packing and reduced voids [4]. The presence of 7% silica fume further enhances the microstructure by filling finer pores, while superplasticizer improves compaction and uniformity of concrete [10].

At 15% replacement, the highest rebound value (41) is obtained, indicating optimum mix composition. However, at 20%, the rebound value decreases to 37, which suggests that excess silica sand disturbs proper grading and reduces density [8].

Although rebound hammer provides indirect strength estimation, the overall trend clearly shows that strength improves up to 15% replacement and decreases beyond this level [13], [19].

VI. CONCLUSION

The incorporation of silica sand and 7% silica fume significantly influences the performance of M30 grade concrete [11].

Workability improves from 0% to 15% replacement (70 mm & 120 mm slump) due to better particle packing and superplasticizer efficiency [4], [8].

At 20% replacement, workability slightly decreases (100 mm slump) because of increased fines and higher water demand [17].

Rebound hammer values indicate an increase in surface hardness from 34 (0%) to 41 (15%), showing improved density and strength characteristics [13].

At 20%, rebound value drops (~37), suggesting excess silica sand negatively affects compaction and uniformity [1], [8].

The optimum replacement level is 15% silica sand, providing the best balance of workability and strength [20].

Overall, the mix with 15% silica sand + 7% silica fume results in a denser, more durable, and efficient concrete suitable for practical applications [11].

The study confirms that combined use of silica sand and silica fume enhances both fresh and hardened properties of concrete [8].

Silica fume (7%) contributes to microstructure refinement by forming additional C-S-H gel, leading to improved density [11].

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