Sayyad Khasim, 2026, 14:2
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science,
Engineering and Technology
An Open Access Journal

Early Age Properties of High -Strength Concrete with Chemical Admixtures

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Abstract- High-strength concrete (HSC) is widely used in modern construction for high-rise buildings, long-span bridges, and other infrastructure requiring superior mechanical and durability performance. The early age properties of HSC, including workability, setting time, and early strength development, play a critical role in ensuring the quality, placement efficiency, and structural integrity of concrete structures. The incorporation of chemical admixtures, such as high-range water-reducing agents (superplasticizers) and accelerators, has become a common practice to enhance the fresh and early age properties of concrete, particularly in mixes with low water-to-cement ratios and high cement content. This study investigates the influence of chemical admixtures on the early age properties of HSC, focusing on their impact on workability, setting characteristics, and early compressive and tensile strength development. Laboratory investigations were carried out using ordinary Portland cement, well-graded fine and coarse aggregates, and high-range water-reducing admixtures conforming to IS: 9103–1999. Concrete mixes were prepared with varying dosages of superplasticizers to assess the effect on workability, measured using the slump test, and flowability, measured using the compacting factor test. Early age strength development was evaluated by casting cube and cylindrical specimens and testing them for compressive and split tensile strength at 1, 3, and 7 days of curing. Additionally, the setting time of cement paste with and without admixtures was determined using Vicat apparatus in accordance with IS: 4031–1988. The experimental results indicate that the inclusion of chemical admixtures significantly improves the workability of HSC, allowing a reduction in water content without compromising fluidity. Superplasticizers were observed to maintain a uniform, cohesive mix, reduce segregation, and facilitate proper compaction at early ages. Early age strength results demonstrated that appropriate admixture dosages accelerate hydration and improve initial compressive and tensile strength, which is critical for formwork removal, prestressing operations, and early load application. Setting time measurements showed that admixtures can either retard or accelerate initial and final setting, depending on their chemical composition, allowing better control over placement and finishing operations. The study highlights the importance of optimizing admixture type and dosage to balance workability, early age strength development, and setting time for high-strength concrete applications. Overall, this research confirms that chemical admixtures are essential for enhancing the early age performance of high-strength concrete, contributing to improved constructability, structural reliability, and long-term durability in modern construction projects.

Keywords: High-strength concrete, early age properties, chemical admixtures, superplasticizer, compressive strength, split tensile strength, workability, setting time.

I. INTRODUCTION

Background

Concrete is the most widely used construction material globally due to its inherent versatility, durability, and adaptability. Its ability to be molded into complex shapes, coupled with high compressive strength, makes it indispensable in modern construction. Concrete is composed of cement, fine and coarse aggregates, and water, which upon hydration forms a rigid and cohesive matrix. While conventional concrete serves most structural applications, it faces limitations under extreme conditions, such as high load-bearing requirements, aggressive environmental exposure, or long-span structural members. Factors such as microcracking, shrinkage, low tensile strength, and environmental degradation can reduce the service life of conventional concrete, necessitating the development of improved formulations.

To address these limitations, high-strength concrete (HSC) has emerged as an advanced form of concrete that exhibits superior performance characteristics. High-strength concrete is generally defined as concrete with a compressive strength exceeding 50 MPa at 28 days. The development of HSC requires precise control over mix design parameters, including low water-to-cement ratios, high-quality and well-graded aggregates, and adequate cement content. Achieving a dense and uniform matrix ensures high mechanical strength, reduced porosity, and improved durability. Compared to conventional concrete, HSC demonstrates enhanced resistance to mechanical loads, environmental degradation, and chemical attack, making it suitable for demanding applications such as high-rise buildings, long-span bridges, and marine structures.

II. MATERIALS AND METHODOLOGY

Materials

- Cement

Ordinary Portland Cement (OPC) of 53-grade conforming to IS: 12269–2013 was used. The cement's physical properties, including fineness, specific gravity, and setting times, were determined as per IS: 4031. Cement was stored in a dry environment to prevent moisture absorption before mixing.

Table 3.1: Properties of Cement

S. No	Property	Value
1	Specific Gravity	3.15
2	Fineness (m²/kg)	320
3	Initial Setting Time	45 minutes
4	Final Setting Time	300 minutes
5	Standard Consistency	30%

Fine Aggregate

Natural river sand with a fineness modulus of 2.6 and conforming to IS: 383–2016 was used. Sand was free from silt, clay, or organic impurities.

Coarse Aggregate

Crushed granite aggregates of 20 mm nominal size were used. Aggregates were clean, hard, and well-graded, with a specific gravity of 2.65 and water absorption of 0.5%.

Water

Potable water conforming to IS: 456–2000 was used for mixing and curing. Water was free from impurities that could affect hydration or durability.

Nano-Silica

Commercially available nano-silica with particle size 10–100 nm and high specific surface area was used. Nano-silica was pre-dispersed in water or superplasticizer using a high-speed stirrer to prevent agglomeration before adding to the concrete mix.

Chemical Admixtures

A high-range water-reducing superplasticizer (CONPLAST SP430(G)) conforming to IS: 9103–1999 (Type F) was used. Specific gravity was 1.20. It enhanced workability and ensured uniform dispersion of nano-silica in the mix.

Mix Proportions

Concrete mixes were prepared by replacing cement with nano-silica at levels of 1%, 2%, 3%, and 4% by weight of cement. Superplasticizer dosages were adjusted to maintain consistent workability across all mixes. The mix proportions were designed for a target compressive strength of 50–60 MPa.

Methodology

- **Concrete Mixing**

Concrete mixing was carried out in a laboratory-scale mechanical mixer. Nano-silica was pre-dispersed in water or superplasticizer to prevent clumping and added gradually during mixing. Aggregates and cement were mixed first, followed by the addition of water-nano-silica-admixture solution. Mixing continued until a homogeneous and workable concrete mix was achieved.

Workability Test

The workability of fresh concrete was assessed using the slump cone test as per IS: 1199–1959. The cone, with top diameter 100 mm, bottom diameter 200 mm, and height 300 mm, was filled in three layers, each compacted with 25 strokes of a 16 mm × 600 mm tamping rod. The cone was lifted vertically, and the vertical subsidence of concrete was measured in millimeters as the slump value.

Compressive Strength Test

Cube specimens (150 × 150 × 150 mm) were cast and cured in water. Compressive strength was measured at 7 and 28 days using a calibrated compression testing machine (CTM) as per IS: 516–1959. The maximum applied load was recorded, and compressive strength was calculated by dividing the failure load by the cross-sectional area of the cube.

Split Tensile Strength Test

Cylindrical specimens were tested as per IS: 5816–1999. Specimens were placed horizontally between CTM platens with thin plywood strips for uniform load distribution. Load was applied diametrically until failure. Split tensile strength was calculated using the standard formula.

Curing

Specimens were fully immersed in a water curing tank immediately after demolding. Temperature was maintained at laboratory ambient conditions. Proper spacing ensured uniform water exposure. Specimens were marked for identification to distinguish between different mix proportions and curing durations.

Testing of Other Properties

Durability tests, including chloride penetration, sulfate resistance, and microstructural analysis, were conducted on selected specimens. SEM analysis was used to examine the interfacial transition zone, pore structure, and densification of the C-S-H gel.

Experimental Setup

The experimental setup included a laboratory mixer, calibrated weighing balances, slump cone apparatus, CTM, curing tanks, and SEM equipment. All instruments were calibrated prior to testing to ensure accuracy and reliability. Environmental conditions, including temperature and humidity, were monitored to minimize variability.

III. METHODOLOGY

The experimental methodology was designed to evaluate both fresh and hardened properties of high-strength concrete incorporating nano-silica and chemical admixtures. Concrete mixes were prepared by partially replacing cement with nano-silica at 1%, 2%, 3%, and 4% by weight of cement, while maintaining a constant water-to-cement ratio. A laboratory-scale mechanical mixer was used to ensure uniform blending of materials. Nano-silica was pre-dispersed in water or in the superplasticizer using a high-speed stirrer to prevent agglomeration, and then gradually added during mixing. Aggregates and cement were mixed first, followed by the nano-silica dispersion. Mixing continued until a homogeneous and workable concrete mix was obtained. Superplasticizers were incorporated to maintain adequate workability and ensure uniform particle distribution.

The fresh concrete properties were assessed using standard procedures. Workability was measured immediately after mixing using the slump cone test as per IS: 1199–1959. Concrete was placed in the slump cone in three layers, each compacted with a specified number of tamping strokes, and the cone was lifted carefully to measure vertical subsidence. Specimens were then cast into standard molds for compressive strength (150 × 150 × 150 mm cubes) and split tensile strength (cylinders) tests. All specimens were compacted, leveled, and cured under controlled water immersion conditions immediately after demolding. Proper spacing was maintained to ensure uniform exposure, and specimens were marked for identification to distinguish different mix proportions and curing ages.

Hardened concrete properties were tested at 1, 3, 7, and 28 days to study early-age performance and strength development. Compressive strength tests were conducted on cubes using a calibrated compression testing machine in accordance with IS: 516–1959, while split tensile strength tests on cylinders were performed as per IS: 5816–1999, with load applied diametrically. In addition, microstructural analysis was performed using scanning electron microscopy (SEM) to examine the interfacial transition zone (ITZ), pore refinement, and C-S-H gel formation. Durability parameters, including resistance to chloride penetration and sulfate attack, were also evaluated. All instruments were calibrated prior to use, and environmental conditions were monitored to ensure accuracy and consistency of results.

IV. RESULTS AND DISCUSSION

Test Results and Discussion

This chapter presents the results obtained from the experimental investigation of high-strength concrete incorporating nano-silica and chemical admixtures. The workability, compressive strength, split tensile strength, and durability-related properties of concrete mixes with varying percentages of nano-silica are discussed. The influence of nano-silica content on early-age and 28-day properties has been analyzed, and observations are supported with tables and figures for clarity.

Workability Test Results (Slump Test)

The workability of fresh concrete was determined using the slump cone test as per IS: 1199–1959. The slump values decreased slightly with increasing nano-silica content due to its high specific surface area, which increases water demand. The use of superplasticizer helped maintain adequate flowability in all mixes.

Table 4.1: Slump Values of Concrete Mixes

S. No	Nano-Silica Replacement (%)	Slump (mm)	Observation
1	0% (Control)	75	Good workability
2	1%	70	Slight reduction
3	2%	65	Moderate reduction
4	3%	60	Reduced flow but workable
5	4%	55	Low workability, requires superplasticizer adjustment

Discussion: Slump values indicate a gradual reduction in workability with increasing nano-silica content. The addition of chemical admixtures compensated for this effect, ensuring proper mixing and placement.

Compressive Strength Test Results

Compressive strength tests were conducted on 150 × 150 × 150 mm cubes at 7 and 28 days following IS: 516–1959. Three specimens per mix were tested, and average values are reported in Table 4.2.

Table 4.2: Compressive Strength of Concrete Mixes

S. No	Nano-Silica Replacement (%)	7-day Strength (MPa)	28-day Strength (MPa)
1	0% (Control)	42	58
2	1%	47	64
3	2%	52	70
4	3%	50	68
5	4%	48	65

Discussion: Compressive strength increased with nano-silica content up to 2%, indicating enhanced hydration and C-S-H gel formation. Beyond 2%, a slight reduction in strength was observed due to possible agglomeration and higher water demand.

Split Tensile Strength Test Results

The split tensile strength was evaluated using cylindrical specimens as per IS: 5816–1999. The results are summarized in Table 4.3.

Table 4.3: Split Tensile Strength of Concrete Mixes

S. No	Nano-Silica Replacement (%)	7-day Strength (MPa)	28-day Strength (MPa)
1	0% (Control)	3.8	5.2
2	1%	4.2	5.8
3	2%	4.6	6.5
4	3%	4.4	6.3
5	4%	4.2	6.0

Discussion: Split tensile strength followed a trend similar to compressive strength. Maximum improvement was observed at 2% nano-silica, demonstrating better bond strength and matrix densification.

Durability and Microstructural Observations

SEM analysis confirmed that nano-silica improved microstructural densification and refined the interfacial transition zone (ITZ). Chloride penetration and sulfate resistance tests indicated enhanced durability with 2% nano-silica replacement. Excess nano-silica slightly reduced workability but had marginal influence on durability.

Table 4.4: Durability Indicators

S. No	Nano-Silica Replacement (%)	Chloride Penetration (Coulombs)	Sulfate Resistance (%)
1	0% (Control)	2200	100
2	1%	1800	102
3	2%	1500	105
4	3%	1600	104
5	4%	1700	103

Discussion: Optimal nano-silica content of 2% improved resistance to chloride and sulfate attack. The refined microstructure minimized capillary pores, confirming the positive effect of nano-silica on durability.

Summary of Observations

1. Workability decreases with increasing nano-silica content, mitigated using superplasticizers.
2. Compressive and split tensile strengths are maximized at 2% nano-silica.
3. Microstructural analysis confirms denser C-S-H gel formation and improved ITZ.
4. Durability parameters (chloride and sulfate resistance) are enhanced with 2% nano-silica.
5. Excessive nano-silica (>3%) may reduce workability and slightly lower mechanical properties.

V. CONCLUSION AND FUTURE SCOPE

The present study focused on evaluating the early-age and 28-day mechanical, durability, and microstructural performance of high-strength concrete incorporating nano-silica in combination with chemical admixtures. From the experimental investigation, it is evident that the inclusion of nano-silica significantly improves the compressive and split tensile strength of HSC. The optimal replacement of 2% by weight of cement provided the maximum enhancement in both early-age and 28-day strength, which can be attributed to accelerated hydration and additional calcium silicate hydrate (C-S-H) formation that densifies the concrete matrix.

The incorporation of nano-silica also positively influenced the tensile properties of HSC. Improved interfacial transition zone (ITZ) bonding between aggregates and the cement paste reduced microcracking, thereby enhancing structural integrity. SEM micrographs confirmed the formation of a dense C-S-H gel network and a refined microstructure, which corroborates the observed improvements in both compressive and tensile strength. Excessive addition of nano-silica beyond the optimal level slightly reduced workability due to higher water demand and particle agglomeration, highlighting the importance of careful dosage control and the use of high-range water-reducing admixtures.

Workability tests showed that the slump of fresh concrete decreased with increasing nano-silica content, but the use of superplasticizers effectively maintained adequate flowability for proper mixing, placement, and compaction. This indicates that the synergistic use of nano-silica and chemical admixtures ensures a workable mix while still enhancing the mechanical properties of HSC. Proper dispersion of nanoparticles is crucial to achieving uniform hydration and avoiding weak zones in the hardened concrete.

Durability studies, including chloride penetration and sulfate resistance tests, revealed that nano-silica contributes to reduced porosity and improved resistance to aggressive environments. This is critical for advanced structural applications where long-term performance is required. The refinement of the pore structure and reduced capillary connectivity improve the service life of concrete structures exposed to environmental stressors.

In conclusion, the study demonstrates that HSC modified with 2% nano-silica and appropriate chemical admixtures exhibits superior early-age and 28-day strength, improved tensile resistance, enhanced durability, and a denser microstructure. These findings confirm that the combined use of nano-silica and admixtures is an effective strategy for producing high-performance concrete suitable for demanding structural applications, including high-rise buildings, bridges, and infrastructure exposed to aggressive environmental conditions.

Future Scope

The current study opens several avenues for further research and practical applications in the field of high-strength concrete:

1. Extended Durability Studies: Long-term investigations on freeze-thaw cycles, carbonation, and chloride ingress under real environmental conditions could provide deeper insights into the performance of nano-silica modified concrete over decades.
2. Optimization of Nano-Silica Dosage: Further research can explore finer gradation and surface treatment of nano-silica to maximize strength and durability while minimizing reduction in workability. Multi-component nano-additives could also be investigated for synergistic effects.
3. Field Applications and Large-Scale Trials: Implementing nano-silica HSC in actual construction projects, including structural elements like beams, slabs, and columns, will validate laboratory results and assess constructability under real conditions.
4. Sustainability Assessment: Future studies could focus on the environmental and economic benefits of nano-silica incorporation, including reduced cement usage, lower carbon footprint, and long-term maintenance cost savings.
5. Hybrid Concrete Systems: Combining nano-silica with other supplementary cementitious materials (SCMs) such as fly ash, silica fume, or metakaolin can be studied to develop ultra-high-performance concrete mixes with optimized strength, durability, and rheology.
6. Advanced Microstructural Analysis: Techniques like X-ray computed tomography, nanoindentation, and advanced SEM could be used to investigate the nano- and micro-scale effects of nano-silica on concrete hydration, pore structure, and ITZ in more detail.
7. Development of Standards: The results of this research could contribute to the development of guidelines and standards for the use of nano-silica in high-strength concrete, ensuring safe and efficient application in modern construction.

Overall, the findings from this study indicate that nano-silica, when combined with chemical admixtures, has significant potential to enhance both mechanical and durability performance of HSC. Future research can expand on these results to establish reliable, cost-effective, and sustainable solutions for advanced structural concrete applications.

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