

Study on the Influence of Nano Silica on the Strength and Durability Characteristics of Self Compacting Concrete

Deepak Aggarwal¹, Rahul Kumar², Rakib Ali³

^{1,2}Assistant Professor, Department of Civil Engineering, SCET Ghaziabad, UP, India

³B.Tech Civil Final Year Student, Department of Civil Engineering, SCET Ghaziabad, UP, India

Abstract—Self-compacting concrete (SCC) requires a high volume of fine materials to achieve adequate flowability and segregation resistance, which may compromise its mechanical performance and long-term durability. The incorporation of nano-silica (NS), owing to its ultrafine particle size, high pozzolanic reactivity, and nucleation effects, offers a promising strategy to overcome these limitations. This study presents a comprehensive experimental evaluation of the influence of nano-silica on the rheological behaviour, mechanical strength, and durability performance of SCC. Cement was partially replaced with nano-silica at varying dosages, and the resulting mixes were characterized through standardized fresh-state tests including slump flow, T50 time, V-funnel flow, L-box passing ratio, and J-ring flow diameter to assess deformation capacity, filling ability, and passing ability.

Hardened-state performance was evaluated through compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity at multiple curing ages. Durability assessments included water absorption, sorptivity, rapid chloride penetration (RCPT), sulphate attack resistance, acid attack resistance, and carbonation depth. Microstructural investigations using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) were conducted to analyse hydration products and pore structure refinement

Index Terms—Self-Compacting concrete (SCC); Nano Silica; Mechanical Strength; Durability; Compressive Strength; Workability; Pozzolanic Reaction; Microstructure; Bleeding, Compaction, Deterioration, Durability, Nano Silica, Nanostructure, Segregation, Penetration

I. INTRODUCTION

Self-compacting concrete (SCC) has gained significant global attention since its development in Japan in the late 1980s due to its ability to flow under its own weight, completely fill formwork, and achieve

full compaction without the need for mechanical vibration. These properties make SCC highly advantageous in densely reinforced structural elements, complex geometries, and large-scale concreting operations where conventional compaction is difficult or impractical. The superior deformability, filling ability, and passing ability of SCC are achieved through a carefully balanced mixture of cementitious materials, fine aggregates, chemical admixtures, and viscosity-modifying agents, which collectively enhance the rheological stability of the mix. However, the increased powder content and reliance on chemical admixtures required to maintain self-compatibility often lead to challenges such as higher material costs, increased shrinkage, and potential reductions in mechanical performance compared to conventional vibrated concrete (CVC). To address these limitations, researchers have explored various supplementary cementitious materials (SCMs), including fly ash, silica fume, metakaolin, and ground granulated blast furnace slag (GGBS), with the aim of improving both the fresh and hardened properties of SCC. Among these materials, nanoscale additives have emerged as a promising category due to their high surface area, enhanced pozzolanic reactivity, and ability to significantly modify the microstructure of the cementitious matrix. Nano-silica (NS), in particular, has shown notable potential for improving the performance of SCC. With particle sizes typically ranging from 5 to 100 nm, nano-silica acts as a highly reactive pozzolan that accelerates the hydration of Portland cement, refines pore structure, and contributes to the formation of additional calcium silicate hydrate (C-S-H) gel. Its ultrafine nature also imparts a filler effect, enhancing particle packing density and improving the integrity of the interfacial transition zone (ITZ), which is often the weakest link

in concrete.

Despite these advantages, introducing nano-silica into SCC presents certain complexities. The extremely fine particle size leads to a significant increase in surface area, which can reduce workability and increase water and superplasticizer demand. Improper dispersion may cause particle agglomeration, resulting in reduced flowability and inconsistent mechanical properties. Therefore, understanding the optimal dosage and dispersion characteristics of nano-silica in SCC is essential to maximize its benefits without compromising the fundamental self-compacting properties. Existing research indicates that the incorporation of nano-silica can improve compressive strength, tensile strength, modulus of elasticity, and durability characteristics by reducing permeability, enhancing resistance to chloride ingress, improving sulfate resistance, and mitigating chemical attack. However, the magnitude of improvement varies across studies due to differences in nano-silica type (colloidal or powder), particle size, replacement levels, mixing procedures, and evaluation methods. Furthermore, most available studies focus either on mechanical properties or durability, with relatively fewer offering a comprehensive evaluation encompassing fresh-state behavior, strength development, long-term durability, and microstructural characteristics in an integrated framework. Given the increasing use of SCC in critical and long-lasting infrastructure such as bridges, high-rise buildings, nuclear facilities, and marine structures, understanding the influence of nano-silica on both the performance and durability of SCC is vital. This research aims to provide a systematic experimental investigation into the effects of nano-silica on the fresh properties, strength development, and durability performance of SCC. The study evaluates varying replacement levels of nano-silica and examines their impact through a combination of rheological tests, mechanical strength measurements, durability assessments, and microstructural analyses.

By offering a detailed and comparative understanding of nano-silica's role in SCC, this research contributes to advancing the development of high-performance, durable, and sustainable concrete suitable for modern construction demands. The other advantages of SCC are

- It eliminates noise due to vibration.
- It provides high stability during transport and placement.

- It provides uniform surface quality and homogenous.
- It provides greater freedom for design
- It is useful for casting of underwater structures

II. LITERATURE REVIEW

Self-compacting Concret From the foregoing discussion, it is clear that the main aim of the work is developing a SCC and understands the behaviour of such a SCC under various loading action. In the early 1990's there was only a limited public knowledge about the use of self-compacting concrete, and if available that was mainly in Japanese. The first paper on self-compaction concrete was presented by Ozawa at the second East-Asia and Pacific conference on structural engineering and construction in January 1989. Previous Research Work on Self-Compacting Concrete: Self-compacting concrete extends the possibility of use of various mineral by-products in its manufacturing and with the densification of the matrix, mechanical behaviour, as measured by compressive, tensile and shear strength, is increased.

Hajime Okamura [1]: A new type of concrete, which can be compacted into every corner of a formwork purely by means of its own weight, was proposed by Okamura in 1986, he started a research project on the flowing ability and workability of this special type of concrete, later called self-compacting concrete. The Self-Compactability of this concrete can be largely affected by the characteristics of materials and the mix proportions. In his study, Okamura (1997) has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self compactability could be achieved easily by adjusting the water to cement ratio and superplasticizer dosage only

Kazumasa Ozawa (1988) [2] he succeeded in developing SCC for the first time. The year after that, an open experiment on the new type of concrete was held at the University of Tokyo, in front of more than 100 researchers and engineers. As a result, intensive research has begun in many places, especially in the research institutes of large construction companies and the University of Tokyo.

Domone et al (1999) [3] has done their research on the effect on fresh properties of mortar phase of SCC of four different types of superplasticizer and various

combinations of powder, including Portland cement, GGBS, fly ash, micro silica and lime stone powder. He concluded that many of important parameters that influence the performance SCC can be assessed by testing on mortars. This includes the comparison of the performance of different super plasticizer of the effects of the time of addition of the super plasticizer during mixing process and the work ability and workability retention characteristics of mixes containing binary and ternary blends of powders.

III. METHODOLOGY

SCC, assessing both the fresh and hardened state properties, and comparing them with conventional concrete mixes.

Materials Used:

Cement: Ordinary Portland Cement (OPC), 43 Grade, was used as the primary binder.

Nano-Silica (NS): Nano-silica used in this study was sourced from [NanoLab Pvt. Ltd.]. The specific properties of nano-silica are provided in Table 1, including the particle size (50-80 nm) and specific surface area (200-600 m²/g).

Aggregates: The fine aggregate was Zone II sand, and coarse aggregates conformed to standard specifications.

Admixtures: A superplasticizer was used to improve the workability of the mix, with the dosage adjusted based on the required flowability of the SCC.

Water: Clean, potable water was used for mixing and curing the concrete specimens.

Mix Design: The design of mixes for both the control and modified SCC mixes followed the guidelines from IS 10262:2016 and EFNARC specifications for Self Compacting Concrete. The mixes were proportioned by weight. The mix design for the control and nano-silica modified SCC is provided in

Preparation of Concrete Specimens: Concrete samples were prepared in the laboratory by mixing the specified proportions of cement, nano-silica, aggregates, and admixtures. The mixing process followed a standard procedure to ensure uniform distribution of nano-silica.

Step 1: Dry mixing of cement, nano-silica, and

aggregates to ensure proper blending.

Step 2: Addition of water and superplasticizer while mixing for the required consistency to achieve flowability and passing ability suitable for SCC.

Step 3: The concrete was mixed for 5-10 minutes to ensure uniformity in the mixture, followed by pouring the concrete into molds for various tests.

Test Methods:

Fresh State Properties (Workability Tests):

The fresh concrete properties were evaluated based on the following tests:

Slump Flow Test: To assess the flowability and self-compacting ability.

T50 Test: To measure the time taken for the slump flow to reach a specific diameter.

V-Funnel Test: To measure the flow time and assess viscosity.

L-Box Test: To evaluate the passing ability and blocking resistance of the mix.

Hardened State Properties (Mechanical and Durability Tests):

The hardened properties of the concrete specimens were assessed by performing the following tests:

Compressive Strength: Cubes of 150 mm x 150 mm were cast and tested at 7, 28, and 56 days to determine the compressive strength.

Flexural Strength: Prisms of 100 mm x 100 mm x 500 mm were tested at 28 days to evaluate the bending resistance of the concrete.

Split Tensile Strength: Cylindrical specimens (150 mm diameter, 300 mm height) were tested at 28 days to measure the tensile strength.

Pulse Velocity: The ultrasonic pulse velocity test was performed on 150 mm cubes at 7 and 28 days to assess the concrete's quality and integrity.

Durability Tests:

Water Absorption and Sorptivity Test: To assess the permeability and the ability of the concrete to absorb water.

Rapid Chloride Permeability Test (RCPT): To evaluate the concrete's resistance to chloride ion penetration, which is a key indicator of its durability in aggressive environments.

Table 1

Mix Designation	Cement (OPC-43)	Nano-Silica (NS)	Fine Aggregate (Zone II)	Coarse Aggregate	Water	Superplasticizer
Control SCC	450 kg/m ³	0	750 kg/m ³	1150 kg/m ³	180 L	2% (by weight of cement)
Nano-Silica SCC 1%	450 kg/m ³	4.5 kg/m ³	750 kg/m ³	1150 kg/m ³	180 L	2% (by weight of cement)
Nano-Silica SCC 2%	450 kg/m ³	9 kg/m ³	750 kg/m ³	1150 kg/m ³	180 L	2% (by weight of cement)
Nano-Silica SCC 3%	450 kg/m ³	13.5 kg/m ³	750 kg/m ³	1150 kg/m ³	180 L	2% (by weight of cement)

IV EXPERIMENTAL RESULTS

Compressive Strength Test Results

*Compressive Strength = $(52 \times 9.81 \times 1000) \div (150 \times 150) = 22.67 \text{ MPa}$

Table 2: Compressive Strength of control specimen for 7 days

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.10	52	22.67 *
2	8.34	68	29.65
3	8.36	61	26.59
Mean			26.30

Table 3: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.18	67	29.21
2	8.22	71	30.95
3	8.24	52	22.67
Mean			27.61

Table 4: Compressive Strength of specimen with nano-silica 0.6% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.26	66	28.77
2	8.08	72	31.39
3	7.98	76	33.14
Mean			31.1

Table 5: Compressive Strength of specimen with nano-silica 1% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.24	77	33.57
2	8.14	79	34.44
3	8.30	82	35.75
Mean			34.59

Table 6: Compressive Strength of control specimen for 28 days

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.42	84	36.62
2	8.36	84	36.62
3	8.14	75	32.70
Mean			35.31

Table 7: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.06	66	28.78
2	8.32	88	38.37
3	8.22	88	38.37
Mean			35.17

Table 8: Compressive Strength of specimen with nano-silica 0.6% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.18	83	36.19
2	8.24	80	34.88
3	8.22	88	38.37
Mean			36.48

Table 9: Compressive Strength of specimen with nano-silica 1% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.30	88	38.37
2	8.30	93	40.55
3	8.28	93	40.55
Mean			39.82

COMPARISON OF RESULTS

Comparison of Compressive Strength Results

The change in compressive strength for the blended sample (in %) for 7 and 28 day is shown in Table 10 and Table 11 respectively.

A graphical representation of this result is shown in Fig. I and Fig. II. The change in compressive strength from 7 day to 28 day is shown in Fig III.

Table 10: Comparison of compressive strength for 7 days

7-DAY RESULTS	STRENGTH (MPa)	INCREASE IN STRENGTH (%)
CONTROL	26.30	-
NS 0.3% b.w.c	27.61	4.98
NS 0.6% b.w.c	31.10	18.25
NS 1% b.w.c	34.59	31.52

NS= Nano SiO₂

Table 11: Comparison of compressive strength for 28 days

28-DAY RESULTS	STRENGTH (MPa)	INCREASE IN STRENGTH (%)
CONTROL	35.31	-
NS 0.3% b.w.c	35.17	-0.39
NS 0.6% b.w.c	36.48	3.31
NS 1% b.w.c	39.82	12.77

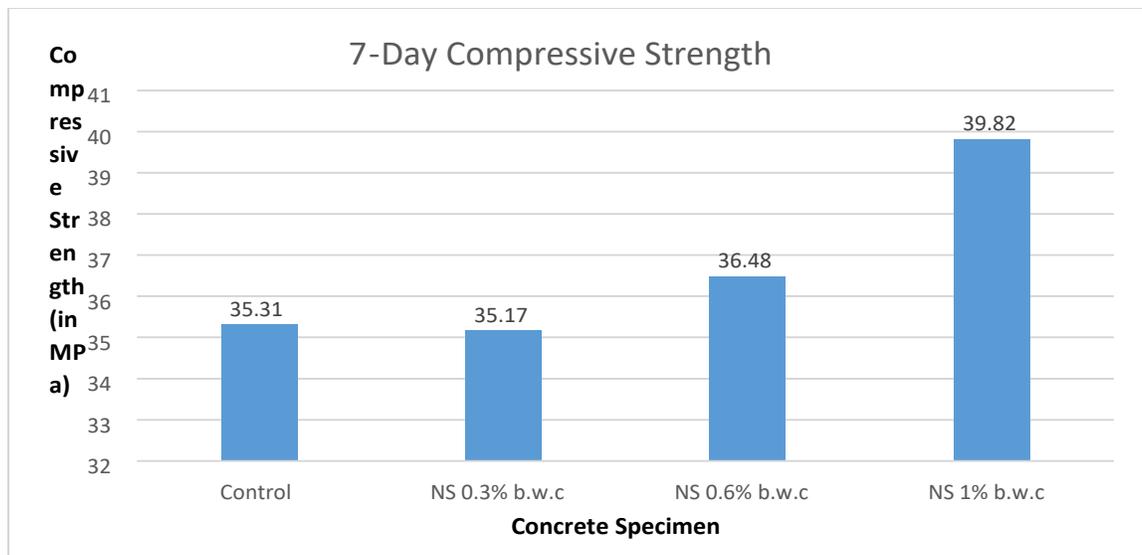


Fig. I: 7-day compressive strength of four specimen

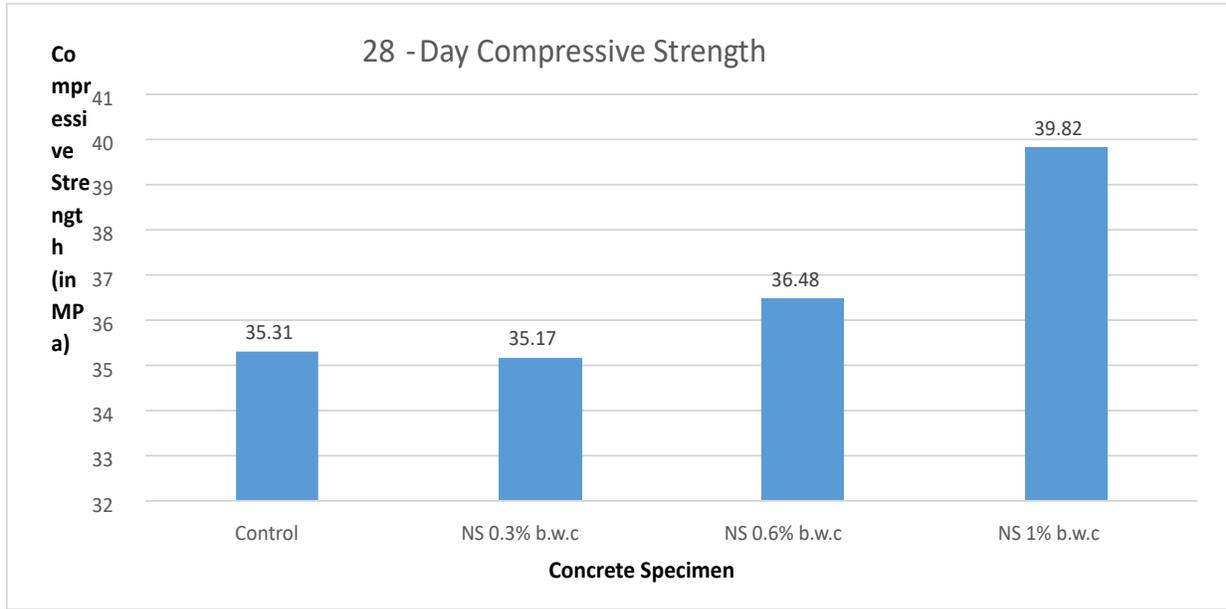


Fig. II: 28-day compressive strength of four specimen

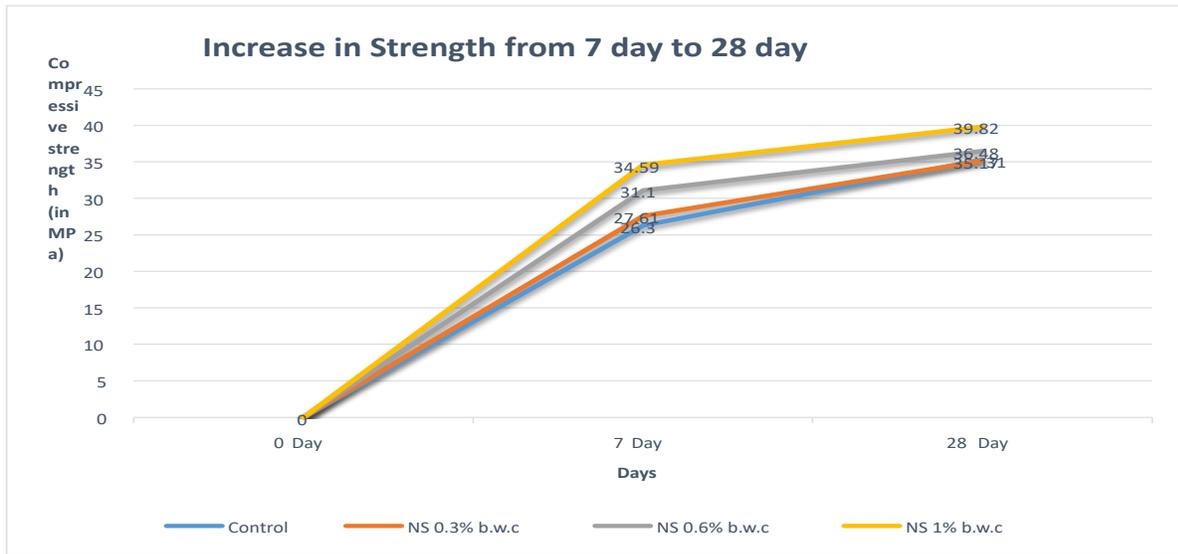


Fig.III : Change in compressive strength of four specimen from 7 day to 28 day

The tables and graphs show that there is an improvement in the early strength of concrete blended with nano silica but later the increase in strength is subdued.

V CONCLUSION

From the test results, the SEM micrographs and the relative chemical composition of the specimen a

number of conclusions can be drawn. These conclusions are justified in the next section. The conclusions drawn are:

1. From the compressive strength results, it can be observed that increase in compressive strength of concrete is observed on addition of a certain minimum quantity of Nano SiO₂. The increase in strength is maximum for NS 1% b.w.c and least

for NS 0.3% b.w.c.

2. On addition of Nano SiO₂ there is a substantial increase in the early-age strength of concrete compared to the 28 days increase in strength.
3. The UPV test results show that the quality of concrete gets slightly affected on addition of Nano SiO₂ but the overall quality of concrete is preserved.
4. The FESEM micrograph shows a uniform and compact microstructure on addition of Nano-SiO₂

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