International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 19s, 2025
https://theaspd.com/index.php

Experimental Evaluation Of Nano Silica Effects On Mechanical Properties Of Concrete

Sourabh Abhay Patil[1], Ravindra Maruti Desai[2], Sachin Popat Patil[3]
[1]PG Scholar, Department of Civil Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India
[2,3]Professor, Department of Civil Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India
sourabhabhaypatil@gmail.com[1], ravi.civil1983@gmail.com[2], sachin.patil@ce.sguk.ac.in

Abstract: *Concrete is one of the most widely used materials in the construction industry, with its production heavily reliant on cement a major contributor to global CO_2 emissions. To address the environmental concerns associated with high cement usage, this study investigates the potential of nanosilica (NS) as a partial replacement for cement in concrete. Nanosilica, owing to its high surface area-to-volume ratio, can significantly enhance the microstructure of concrete, improving its mechanical and durability properties. This experimental research evaluates the effect of nanosilica on the mechanical performance of M30 and M40 grade concrete. Concrete mixes were prepared with varying nanosilica replacement levels of 2%, 2.5%, 3%, and 3.5% by weight of cement. The study focuses on the compressive strength of the concrete both before and after exposure to acid attack, aiming to determine the optimum nanosilica content for maximum strength and durability. Results indicate that the incorporation of nanosilica not only improves compressive strength but also enhances acid resistance, contributing to longer-lasting and more sustainable concrete structures.*
Keywords: *Concrete, Nano silica, Cement replacement, Compressive strength, Concrete durability*

1. INTRODUCTION
The combination of suitable materials will produce a high strength concrete or high-performance concrete. The concrete will exhibit excellent performance in the structure due to the selected mix design, properly mixing, compaction and curing. There are many factors such as specified performance properties, locally available materials, local experience, personal preferences and construction that decide the mixing proportions for high strength concrete. [1] There are many products available for use in concrete to develop the properties in the present technology. The constituent materials and curing technique fluctuations enhance the strength with time. An efficient amount of moisture is needed to ensure that hydration of cement to reduce the porosity to a level necessary to attain the desired strength.[2]
In the current research, the mineral admixtures in the form of nano silica are used as partial replacement of cement by weight to improve the microstructural characteristics of concrete. Particle packing is fundamental to concrete. The better the packing of the particle system, the lesser the binder is required in the concrete. [3] The problem with concrete is, however, that concrete must flow and be compactable in the fresh state which stands in conflict with optimal packing. Introduction of large amounts of fine particles in like cement, nano silica and micro silica will enhance the strength of the concrete. Then, the particle size distribution of the whole mix composition, including cement, pozzolans and/or fillers, should be taken into account while calculating the packing density. The particle packing is an important issue not only for concrete materials [4]
Fig 1 explains the concept behind particle packing. Cubical particles are capable of being packed without any voids, but this is not possible for wet concrete in a colloidal suspension. Generally the key particle sizes enhancing the packing density are those smaller than 125 μm. These particles are smaller than the capillary pores. When they are well dispersed they will block the capillary pores. In addition the fine powder effect will augment the cement reaction. This increases the degree of hydration for a given period of curing. [5].

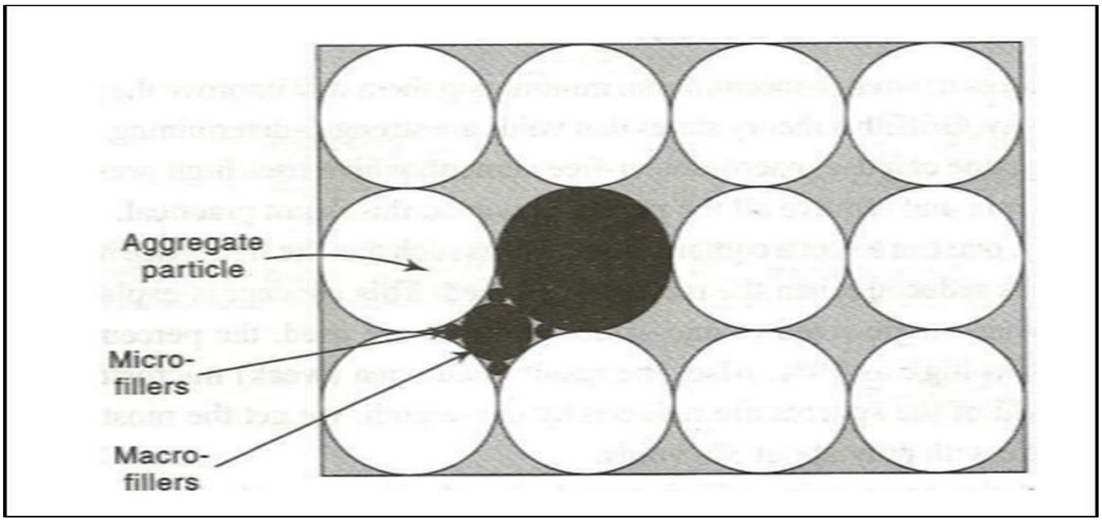


Fig 1 Concept of particle packing [5]

1.1 Concrete Properties and Its Behaviors

The combination of suitable materials will produce a high strength concrete or high-performance concrete. The concrete will exhibit excellent performance in the structure due to the selected mix design, properly mixing, compaction and curing [6]. There are many factors such as specified performance properties, locally available materials, local experience, personal preferences and construction that decide the mixing proportions for high strength concrete. There are many products available for use in concrete to develop the properties in the present technology. The constituent materials and curing technique fluctuations enhance the strength with time. An efficient amount of moisture is needed to ensure that hydration of cement to reduce the porosity to a level necessary to attain the desired strength [7].

1.1.1 Constituents of Concrete

1) Air- 0–3%
2) Aggregate (60–70%)
- Fine Aggregate: 20–30%
- Coarse Aggregate: 40–50%

3) Hydrated Cement Paste (20–40%)
- Cement: 5–15%
- Water: 5–20%

1.2 Microstructure of Concrete

Concrete has a highly heterogeneous and complex microstructure. It is difficult to predict the actual models of its microstructure from which the action of the contents can be properly predicted. The acquaintance of the microstructure, the properties and influences of the individual components of concrete and their inter-relationship are useful for working out control on the properties of concrete [8]. The study on such properties describes the three main components of the concrete microstructure, namely, hydrated cement paste, aggregate, and interfacial transition zone between the cement paste and aggregate. The microstructure property relationships with respect to their influence on strength, dimensional stability and durability of concrete can be assessed [9].

2. RESEARCH SIGNIFICANCE

This study is significant as it investigates the influence of nano silica on the mechanical and durability properties of concrete, addressing the growing demand for sustainable and high-performance construction materials. By partially replacing cement with varying percentages of nano silica in M35 and M40 grade concretes, the research aims to enhance strength, durability, and resistance to acid attack. The findings will help identify the optimal nano silica dosage for improved performance, contributing to reduced cement usage, lower CO_2 emissions, and advancement in durable concrete technology.

3. NANO MATERIALS IN CONCRETE

The mechanical properties enhance in high range due to nano silica that is recognized as a pozzolanic admixture. A higher compressive strength is obtained by using nano silica along with super plasticizers. The durability of concrete improves by the addition of nano silica through reduction in permeability. The enhancement of pozzolanic activity in the concrete helps in the reduction of pore size and thus the calcium silicate hydrate is formed in higher percentage. The durability enhancement will improve the ability of silica fume concrete in protecting the embedded steel from corrosion.[10]

3.1 Nano-silica

According to research, nano-silica exhibits superior performance in terms of the filling effect and particle size distribution compared to conventional mineral admixtures. Incorporating nano-silica into concrete mixtures reduces porosity and enhances the pozzolanic breakdown of nano-silica with calcium hydroxide, causing the production of CSH and enhancing the mechanical properties. Additionally, research has shown that nano-silica can develop the cement setting process and enhance the cohesiveness of fresh mixes. [11] [12]

Fig 2 The nano-silica powder

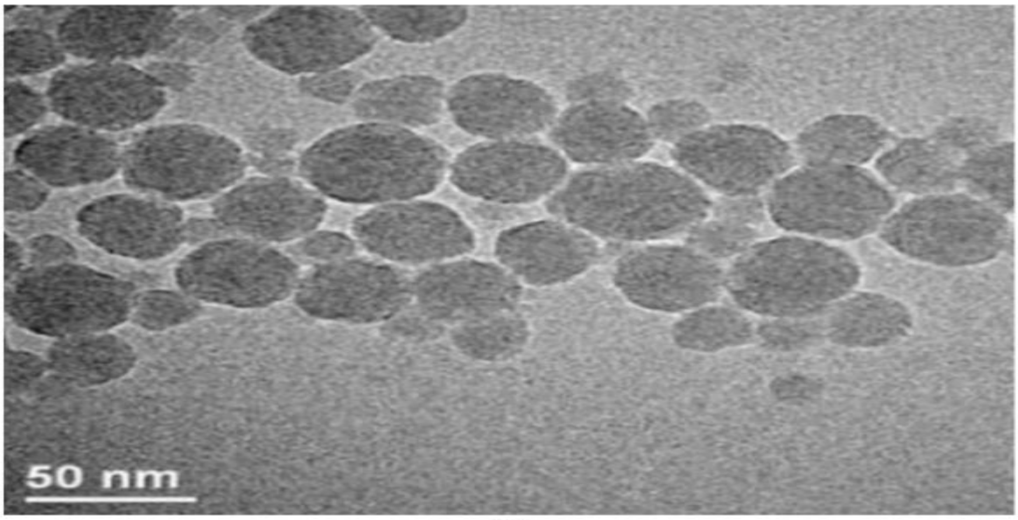


Fig 3 transmission electron microscope image of nano-silica

In this project Nanosilica is used as nanomaterial for the replacement of cement. Adding a small proportion of Nanosilica (NS) to concrete could change concrete's configuration at the Nano level. Nanosilica (NS) or silica nanoparticles, also known as silicon dioxide nanoparticles, can be used as additives for improving concrete's mechanical and durability properties.

4. RELATED WORK

Pandiaraj Karthigai Priya (2022) This review paper evaluates the role of nano silica in improving the properties of cement-based materials like mortar and concrete. It highlights that nano silica increases strength and durability but reduces workability due to higher water absorption. The pozzolanic nature and refined microstructure of nano silica make it a promising partial cement replacement [10].

D.S.V.S.M.R.K. Chekravarty (2022) This experimental study investigates the mechanical behavior and acid resistance of M40–M60 grade concretes with varying nano silica dosages. Results indicate that a 3% replacement level optimizes strength and durability. Higher dosages show diminishing returns. The study supports nano silica's role in reducing CO_2 emissions and enhancing concrete performance [4].

Fadi Althoey (2023) A comprehensive review of how nano silica affects hydration, microstructure, strength, and durability of concrete. Nano silica promotes C-S-H gel formation, densifies the matrix, and enhances bond strength. Optimal performance is observed with 2–4% nano silica content. The paper also discusses practical implementation challenges in the concrete industry [2].

Ms. S. Bharathi (2024) This study assesses ultra-fine amorphous colloidal silica (UFACS) combined with metakaolin as a cement replacement. Using 5% nano silica and 10% metakaolin led to a 15% rise in compressive strength and a 40% improvement in flexural and tensile strength. Tests were conducted at 7, 14, and 28 days as per Indian standards [3].

Dr. Ashwini B. (2024) The study examines the combined effect of nano silica and partial fly ash replacement on concrete's mechanical properties. It focuses on finding the optimal mix and dispersion method to improve strength and durability. The research aims to enhance the performance of concrete using sustainable and advanced materials [21].

4.1 GAP Identification

- Nano silica significantly enhances the compressive strength and microstructure of concrete due to its high pozzolanic reactivity and filler effect.
- Partial replacement of cement with nano silica generally improves durability, including resistance to chloride penetration and acid attack.
- Use of nano silica improves early strength gain, densifies the matrix, and reduces porosity.
- Most existing studies focus on low to medium strength concrete and emphasize strength more than long-term durability.
- Limited Research on Higher Grades: Few studies focus on M35 and M40 grade concretes, especially with nano silica incorporation.
- Durability Aspects Underexplored: Chloride resistance (RCPT) and acid resistance in nano silica concrete are not thoroughly investigated.
- Narrow Dosage Optimization: The specific range of 2.0% to 3.5% nano silica replacement lacks detailed evaluation for both strength and durability.

5. METHODOLOGY

The study aims to investigate the performance of M35 and M40 grade concretes with varying percentages of nano silica (2.0%, 2.5%, 3.0%, and 3.5%) as partial replacement of cement. The methodology includes mix design, material selection, and specimen preparation, curing, and testing protocols. Mechanical properties are assessed through compressive strength tests, while durability is evaluated using Rapid Chloride Penetration Test (RCPT) and acid attack resistance tests. The procedures are designed to ensure consistency, accuracy, and relevance to the study objectives, with the ultimate goal of determining the optimal nano silica content for enhanced performance.

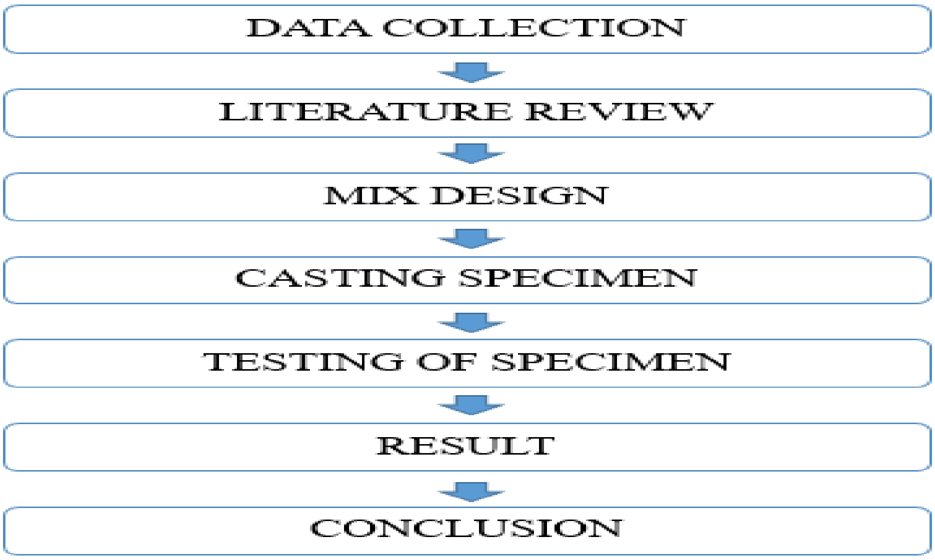


Fig 4 Methodology

5.1 Material Preparation

5.1.1 Concrete Mix Design: M30- As per IS 456 and IS 10262 -2019

- Cement = 350 kg/m3
- Water = 123 kg/m3
- Fine aggregate = 812 kg/m3
- Coarse aggregate = 1284 kg/m3
- Chemical admixture = 3.5 kg/m3
- Free water-cement ratio = 0.35

Sample Calculation for Cube Casting:

- Cube Size: 150x150x150 mm
  = 0.003375 m^3 (wet Volume)
- Dry Volume add 54% in wet volume
  = 1.54 x 0.003375
  = 0.005198 m^3
- Cement = 0.005198 x 350 =1.81 Kg
- Sand =0.005198 x 812 =4.22 Kg
- Coarse Agg =0.005198 x 1284 = 6.67 Kg

Table 1 Mix Proportion for For M30

Nano Silica (%)	Cement (Kg)	Nano-Silica (Kg)	Sand (Kg)
0% NS	1.81	0	4.22
2% NS	1.7738	0.0362	4.22
2.5% NS	1.76	0.0453	4.22
3% NS	1.76	0.0543	4.22
3.5% NS	1.75	0.0634	4.22
Nano Silica (%)	Aggregates (Kg)	Water (Ltr)	Admixture (Ltr)
0% NS	6.67	0.634	0.0181
2% NS	6.67	0.621	0.0177

2.5% NS	6.67	0.618	0.0176
3% NS	6.67	0.614	0.0176
3.5% NS	6.67	0.611	0.0175

5.1.2 Concrete Mix Design: M40- As per IS 456 and IS 10262 -2019:-

- Cement = 445 kg/m3
- Water = 155 kg/m3
- Fine aggregate = 630 kg/m3
- Coarse aggregate = 1 210 kg/m3
- Chemical admixture = 4.45 kg/m3
- Free water-cement ratio = 0.35

Sample Calculation for Cube Casting:
Cube Size: 150x150x150 mm
= 0.003375 m^3 (wet Volume)
Dry Volume add 54% in wet volume
=1.54 x 0.003375
=0.005198 m^3
Cement = 0.005198 x 445 =2.31 Kg
Sand =0.005198 x 630 =3.27 Kg
Coarse agg =0.005198 x 1210 = 6.28 Kg

Table 2 Mix Proportion for For M40

Nano Silica (%)	Cement (Kg)	Nano-Silica (Kg)	Sand (Kg)
0% NS	2.31	0	3.27
2% NS	2.2638	0.0462	3.27
2.5% NS	2.25	0.0578	3.27
3% NS	2.24	0.0693	3.27
3.5% NS	2.23	0.0809	3.27
Nano Silica (%)	Aggregates (Kg)	Water (Ltr)	Admixture (Ltr)
0% NS	6.28	0.809	0.0231
2% NS	6.28	0.792	0.0226
2.5% NS	6.28	0.788	0.0225
3% NS	6.28	0.784	0.0224
3.5% NS	6.28	0.78	0.0223

6. PROBLEM STATEMENT

Conventional concrete often suffers from limitations such as low tensile strength, high porosity, and durability concerns. While nano-silica has shown potential to enhance concrete's mechanical properties due to its high reactivity and fine particle size, there is no clear consensus on the optimal dosage or consistent performance outcomes. This study aims to experimentally evaluate the effects of varying nano-silica content on the compressive strength of concrete to identify the most effective and practical use of this nanomaterial.

This research work focused on comparison of mechanical properties of nano silica concrete for M30 and M40 grade with replacement of cement with nano silica by 2%, 2.5%, 3% and 3.5%, study compressive strength before and after acid attack of nano silica concrete and exactly evaluate percentage of nano silica for which the concrete achieves maximum strength. Cubes (150 mm x 150 mm x 150 mm)

The methodology includes mix design, material selection, and specimen preparation, curing, and testing protocols. Mechanical properties are assessed through compressive strength tests, while durability is evaluated using Rapid Chloride Penetration Test (RCPT) and acid attack resistance tests. The procedures are designed to ensure consistency, accuracy, and relevance to the study objectives, with the ultimate goal of determining the optimal nano silica content for enhanced performance

6.1 Test conducted on specimen

- Compressive test M30 & M40 - 7 Days, 28 Days
- RCPT M40 - 30 Days, 60 Days, 90 Days, 120 Days

7. RESULT AND DISCUSSION

7.1 Compressive Strength Results

Compressive strength is a key indicator of concrete's ability to withstand axial loads and ensure structural integrity. In this thesis, it is used to evaluate the performance of M30 and M35 grade concrete with varying nanosilica content.

Fig 5 Rebound hammer test on cube

The Rebound Hammer Test, also known as the Schmidt Hammer Test, is a non-destructive testing (NDT) method used to assess the surface hardness and estimate the compressive strength of concrete. It is widely applied due to its simplicity, speed, and ability to evaluate in-situ concrete without damaging the structure. The test involves using a spring-loaded hammer that strikes the surface of a concrete cube, and the rebound distance of the plunger is measured. This rebound number is then correlated with the compressive strength of the concrete. It is particularly useful for quality control, uniformity assessment, and comparative analysis of concrete elements

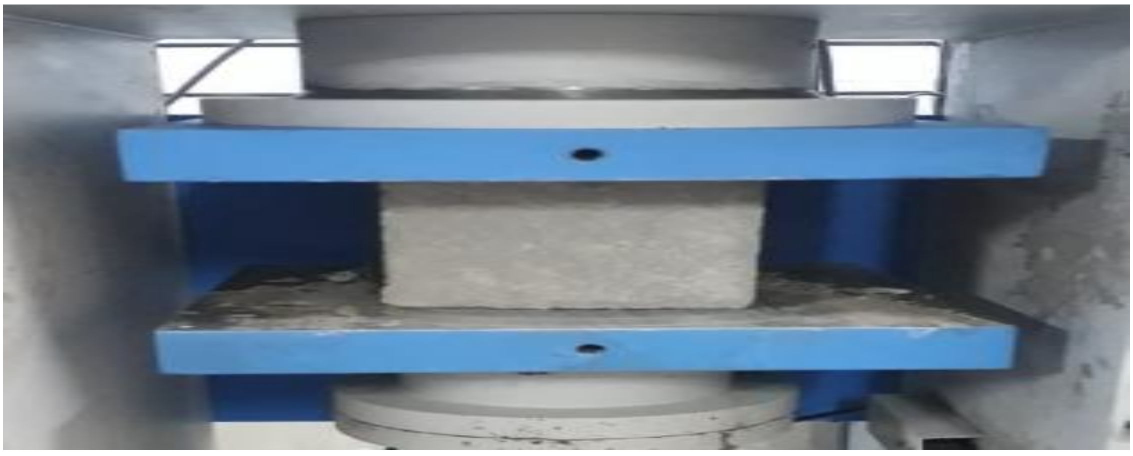


Fig 6 Compressive Strength test on cube

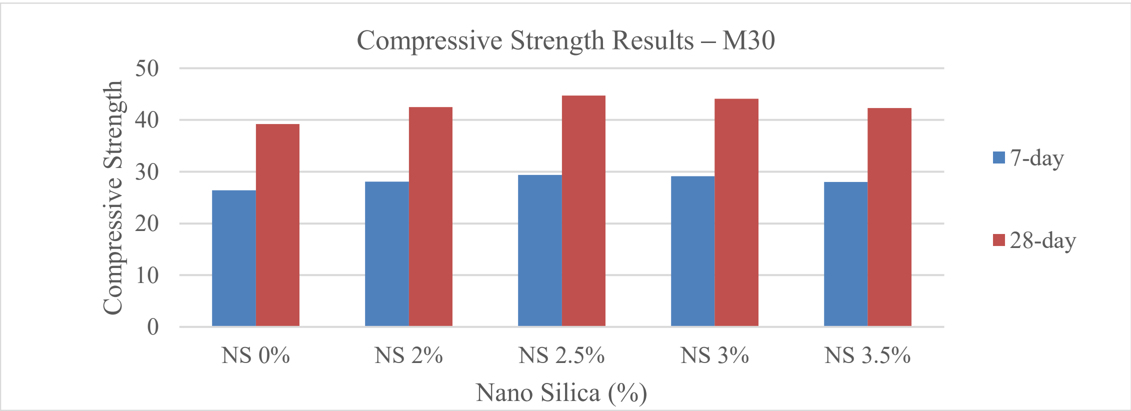
The image shows a Compressive Strength Test setup on a concrete cube using a Compression Testing Machine (CTM)

Fig 7 Cube Break after testing

The image shows a concrete cube after undergoing a compressive strength test, captured at the failure stage in a Compression Testing Machine (CTM). Debris and cracked fragments are scattered around the base, which is typical after a cube reaches its compressive limit

Table 3 Compressive Strength Results – M30 Grade Concrete

Nano Silica (%)	7-day Compressive Strength (MPa)	28-day Compressive Strength (MPa)
NS 0%	26.4	39.2
NS 2%	28.1	42.5
NS 2.5%	29.4	44.7
NS 3%	29.1	44.1
NS 3.5%	28	42.3

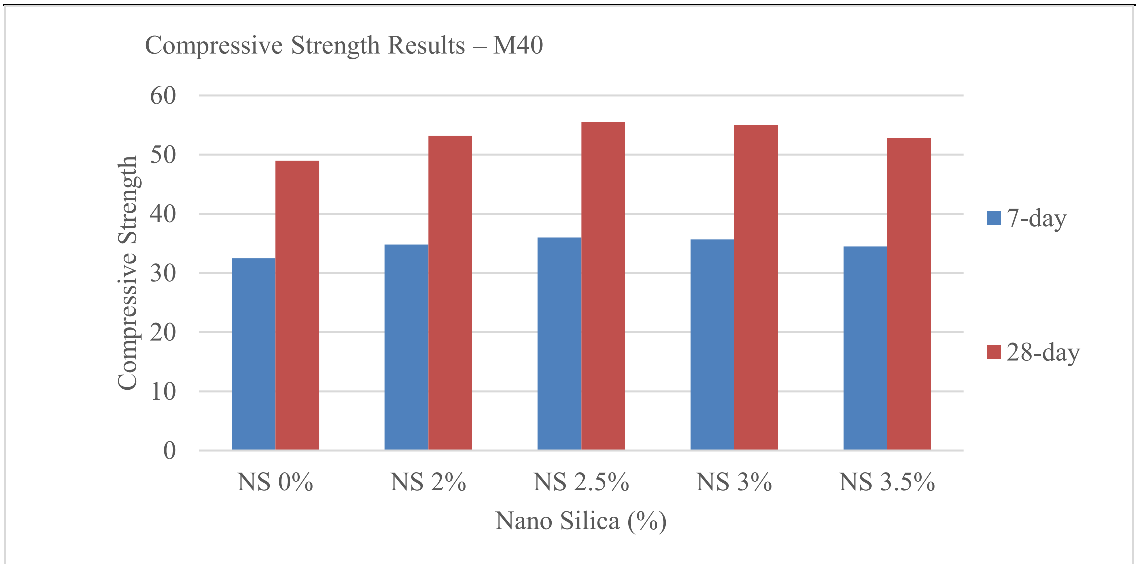


Graph 1 Compressive Strength Results – M30 Grade Concrete

Table 3 summarizes the 7-day and 28-day compressive strength results of M30 grade concrete with different Nano Silica (NS) percentages. The data shows a clear trend of increasing strength with NS addition up to 2.5%, achieving the highest strengths of 29.4 MPa (7-day) and 44.7 MPa (28-day). Beyond this point, both early and later strength slightly decline, indicating that 2.5% NS is the optimal dosage for maximizing compressive strength, while higher percentages may negatively affect the mix due to reduced workability or poor particle dispersion.

Table 4 Compressive Strength Results – M40 Grade Concrete

Nano Silica (%)	7-day Compressive Strength (MPa)	28-day Compressive Strength (MPa)
NS 0%	32.5	49
NS 2%	34.8	53.2
NS 2.5%	36	55.5
NS 3%	35.7	55
NS 3.5%	34.5	52.8



Graph 2 Compressive Strength Results – M40 Grade Concrete

Table 4 summarizes the 7-day and 28-day compressive strength of M40 grade concrete with varying Nano Silica (NS) content. Both early and later strengths increase with NS addition up to 2.5%, where the highest values of 36 MPa (7-day) and 55.5 MPa (28-day) are recorded. Beyond 2.5%, a slight decrease in strength is observed, indicating that excessive NS may negatively impact performance. These results confirm that 2.5% NS is the optimum dosage for maximizing compressive strength in M40 concrete.

7.2 RCPT Results – M40 Grade Concrete

In the RCPT, a direct current (DC) voltage of 60 volts is applied across a concrete specimen for 6 hours. One side of the specimen is in contact with a sodium chloride (NaCl) solution and the other with a sodium hydroxide (NaOH) solution. The total charge passed (in coulombs) is measured, indicating the concrete's permeability to chloride ions.

Table Classification Reference as per IS 516 / ASTM C1202

Charge Passed (Coulombs)	Chloride Ion Penetrability
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very Low
< 100	Negligible

The Rapid Chloride Penetration Test (RCPT) is conducted to assess the permeability of concrete to chloride ions, which is a critical factor in determining the durability of reinforced concrete structures. For M40 grade concrete, which is a high-strength mix, RCPT is particularly useful in evaluating its resistance to chloride ingress and ensuring long-term performance in aggressive environments, and the RCPT of the template is compiled as follows.

Fig 8 Casting of M40Cubes and curing for 30, 60, 90, 120 days.

The image shows concrete cube specimens submerged in water for curing, which is a standard method for ensuring strength development and hydration. These are M40 grade concrete cubes, visibly marked with curing durations such as 30, 60, 90, and 120 days.

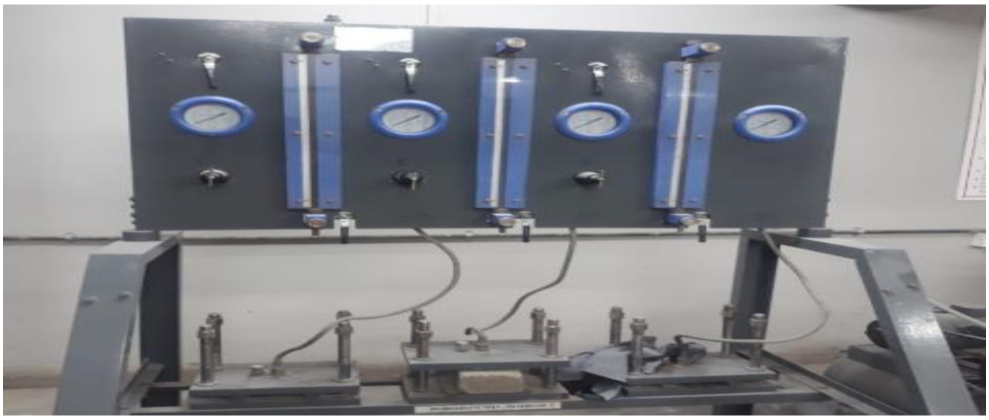


Fig 9 Rapid Chloride Penetration Test setup

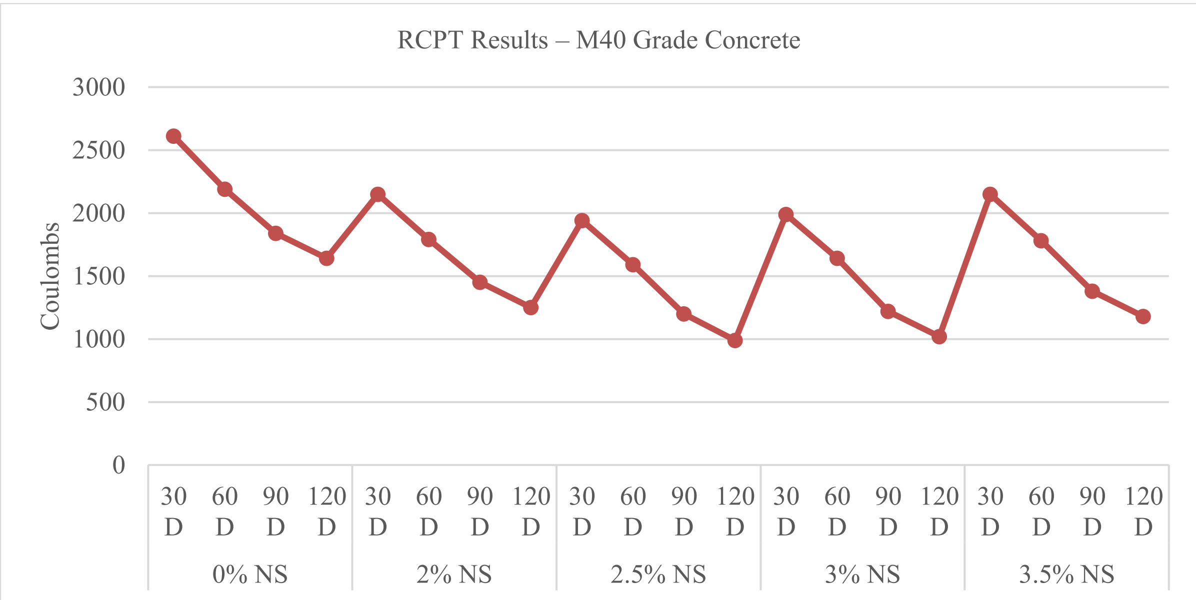
The image shows a Rapid Chloride Penetration Test (RCPT) apparatus, which is used to evaluate the chloride ion permeability of concrete an essential test for assessing concrete durability, especially in aggressive environments.

Fig 10 Cube placed for RCPT

The image shows concrete specimens placed in the RCPT apparatus to evaluate their resistance to chloride ion penetration a critical test for assessing concrete durability, especially in marine and corrosive environments

Table 5 RCPT Results – M40 Grade Concrete

Nano Silica (%)	Age (Days)	Average (Coulombs)	Classification
0% NS	30	2610	Moderate
	60	2190	Moderate
	90	1840	Low
	120	1640	Low
2% NS	30	2150	Moderate
	60	1790	Low
	90	1450	Low
	120	1250	Low
2.5% NS	30	1940	Moderate
	60	1590	Low
	90	1200	Low
	120	990	Very Low
3% NS	30	1990	Moderate
	60	1640	Low
	90	1220	Low
	120	1020	Low
3.5% NS	30	2150	Moderate
	60	1780	Low
	90	1380	Low
	120	1180	Low



Graph 3 RCPT Results – M40 Grade Concrete

Table 5 and Graph 2 presents the RCPT (Rapid Chloride Penetration Test) results for M40 grade concrete with varying Nano Silica (NS) content over 30, 60, 90, and 120 days. The results show a consistent decrease in charge passed (Coulombs) with increasing curing age, indicating improved resistance to chloride penetration over time. The optimum performance is observed at 2.5% NS, achieving the lowest average of 990 Coulombs at 120 days, classified as "Very Low" permeability. All other mixes, including the control (0% NS), show "Moderate" to "Low" classifications, with performance improving over time. This highlights that 2.5% NS significantly enhances the durability of concrete, especially in long-term exposure conditions.

- Best performance at 2.5% Nano Silica, reaching "Very Low" category at 120 days.
- RCPT values decrease significantly over time, confirming improved durability with age and Nano Silica.
- 3.5% Nano Silica shows slightly higher values than 2.5%, suggesting diminishing returns beyond optimal dosage.

8. CONCLUSION

Based on the experimental results, the following key conclusions can be drawn regarding the effect of Nano Silica (NS) on the mechanical and durability properties of M30 and M40 grade concrete:

Compressive Strength – M30 Concrete:

- At 7 days, compressive strength increased from 26.4 MPa (0% NS) to 29.4 MPa (2.5% NS), showing an increase of approximately 11.36%.
- At 28 days, strength improved from 39.2 MPa (0% NS) to 44.7 MPa (2.5% NS), an increase of around 14.03%.
- Beyond 2.5% NS, a slight decrease in strength was observed. For example, at 3.5% NS, 28-day strength dropped to 42.3 MPa, a 5.37% decrease from the peak at 2.5%.

Compressive Strength – M40 Concrete:

- At 7 days, strength increased from 32.5 MPa (0% NS) to 36 MPa (2.5% NS), an increase of 10.77%.
- At 28 days, strength improved from 49 MPa (0% NS) to 55.5 MPa (2.5% NS), showing an increase of 13.27%.
- Similar to M30, strength declined slightly beyond 2.5% NS; at 3.5% NS, 28-day strength dropped to 52.8 MPa, a 4.86% decrease from the peak.

Durability – RCPT (M40 Concrete):

- Chloride ion permeability significantly decreased with NS addition and curing time.
- At 120 days, RCPT values dropped from 1640 Coulombs (0% NS) to 990 Coulombs (2.5% NS) – a 39.63% reduction, moving the classification from "Low" to "Very Low".
- Beyond 2.5%, a slight increase in permeability was observed; at 3.5% NS, the value was 1180 Coulombs, 19.19% higher than the optimal 2.5% mix.

Optimal Nano Silica Dosage:

- 2.5% NS was found to be the most effective in enhancing both compressive strength and durability while maintaining acceptable workability.
- Higher percentages resulted in diminishing returns and possible adverse effects on workability and uniformity of mix.

Nano Silica is a highly effective mineral admixture that, when used at an optimal dosage of 2.5%, significantly improves the mechanical strength and durability of concrete. Its proper utilization can lead to more durable and sustainable high-performance concrete for advanced construction applications.

9. ACKNOWLEDGMENTS

The authors would like to express their heartfelt gratitude to the Department of **Civil Engineering, Sanjay Ghodawat University, Kolhapur**, for providing the necessary resources, laboratory facilities, and academic environment essential for the successful completion of this research work titled "Experimental Evaluation of Nano Silica Effects on Mechanical Properties of Concrete."

We are especially thankful to Professor **Ravindra Maruti Desai**, whose invaluable guidance, constant encouragement, and expert insights greatly contributed to the direction and quality of this study. His mentorship played a key role in shaping the research methodology and interpretation of results.

10. REFERENCES

[1] Abhilash P. P., Dheeresh Kumar Nayak, Bhaskar Sangoju , Rajesh Kumar, Veerendra Kumar "Effect of nano-silica in concrete; a review" Construction and Building Materials, Volume 278, 2021, pp. 211-219.
https://doi.org/10.1016/j.conbuildmat.2021.122347
[2] Fadi Althoey, Osama Zaid , Rebeca Martínez-García, Fahad Alsharari , Mohd Ahmed , Mohamed M. Arbili "Impact of Nano-silica on the hydration, strength, durability, and microstructural properties of concrete: A state-of-the-art review" Case Studies in Construction Materials, 2023, pp. 1-22.
https://doi.org/10.1016/j.cscm.2023.e01997
[3] Bharathi, Ms. S., Dr. A. M. Arunmohan, Dr. A. Karthik, Hariharan A, Arwin S. "Experimental Study On Strength of Concrete Using Nano silica" International Research Journal on Advanced Engineering Hub, 2024, pp. 41-46.
https://doi.org/10.47392/IRJAEH.2024.0009
[4] D.S.V.S.M.R.K. Chekravarty, A. Mallika, P. Sravana, Srinivasa Rao. "Effect of using nano silica on mechanical properties of normal strength concrete" Materials Today Proceedings, 2022, Vol. 58, pp. 2573-2578.
https://doi.org/10.1016/j.matpr.2021.12.409
[5] Saber Fallah, Mahdi Nematzadeh "Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume" Construction and Building Materials, Vol. 132, 2017, pp. 170-187.
https://doi.org/10.1016/j.conbuildmat.2016.11.100
[6] Prakasam Ganesh, M. Mohammed Saffiq Reheman, Avadhanam Ramachandra Murthy "Effect of nanosilica on durability and mechanical properties of high-strength concrete" Magazine of Concrete Research, Vol. 68, 2016, pp. 229-236
https://doi.org/10.1680/jmacr.14.00338
[7] S. Gopinath, P. Ch. Mouli, A.R. Murthy, N.R. Iyer, S. Maheswaran. "Effect of Nano silica on mechanical properties and durability of normal strength of concrete" Archives of Civil Engineering , 2016, pp. 433-444
https://doi.org/10.2478/v.10169-012-0023-y
[8] Farid Hasan-Nattaj, Mahdi Nematzadeh "The effect of forta-ferro and steel fibers on mechanical properties of high-strength concrete with and without silica fume and nano-silica" Construction and Building Materials, Vol. 137, 2017, pp. 557-572
https://doi.org/10.1016/j.conbuildmat.2017.01.078
[9] Mostafa Jalal , Alireza Pouladkhan , Omid Fasihi Harandi , Davoud Jafari "Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self-compacting concrete" Construction and Building Materials, Vol. 94, 2015, pp. 90-104
https://doi.org/10.1016/j.conbuildmat.2015.07.001
[10] Pandiaraj Karthigai Priya, Sankararajan Vanitha "Effect of nano silica on the properties of concrete and mortar – A state of art" International Review of Applied Sciences and Engineering, Vol. 13, 2022, pp. 70-79.
https://doi.org/10.1556/1848.2021.00309
[11] Ranjith Kumar L, Dr. Mageswari. M. "Characterisitc Study Of Nanosilica In Durability On Varying Water-Cement Ratio" International Journal of Advanced Research in Engineering and Technology, Vol. 10, 2019, pp. 86-93.
http://iaeme.com/Home/issue/IJARET?Volume=10&Issue=4
[12] Bibhuti Bhusan Mukharjee, Sudhirkumar V. Barai "Influence of Incorporation of Colloidal Nano-Silica on Behaviour of Concrete" Iranian Journal of Science and Technology, Transactions of Civil Engineering, Vol. 44, 2020, pp. 657-668.
https://doi.org/10.1007/s40996-020-00382-0
[13] A. Novriansyah , U. Mursyidah , Novrianti , S. S Putri , and S. S. Riswati "Effect of silica-palm shell carbon composite additive in enhancing the strength of the concrete in the oil-well cementing job" International Conference on Materials Engineering and Applications, Vol. 348, 2018, pp. 1-6.
https://doi.org/10.1088/1757-899X/348/1/012012
[14] Peem Nuaklong, Vanchai Sata, Ampol Wongsa, Korb Srinavin, Prinya Chindaprasirt "Recycled aggregate high calcium fly ash geopolymer concrete with inclusion of OPC and nano-SiO2" Construction and Building Materials, Vol. 174, 2018, pp. 244-252.
https://doi.org/10.1016/j.conbuildmat.2018.04.123
[15] A Paktiawal , and M Alam "Nano-Silica and its Role on Performance of Cement Concrete – A Review of Experimental Investigation" IOP Conference Series: Earth and Environmental Science, Vol. 614, 2020, pp. 1-12.
https://doi.org/10.1088/1755-1315/614/1/012085
[16] R. Shashank, Mr. E. Balaji "Flexural Behavior Of Nano Silica Concrete" International Research Journal of Engineering and Technology, Vol. 03 Issue 4, 2016, pp. 799-803.
https://www.irjet.net/archives/V3/i4/IRJET-V3I4158
[17] Mohd Mufasshir Alam Shah, E. Balaji, Prof. G. Augustine Maniraj Pandian "Experimental study on mechanical properties of high strength concrete using Nano-Silica" International Research Journal of Engineering and Technology, Vol. 3, 2018, pp. 455-459.

https://www.irjet.net/archives/V3/i4/IRJET-V3I491
[18] S. Thenmozhi, V. Gowri, A. Vignesh and S. Suganthan "Experimental investigation of the effect of Nano-silica on the mechanical properties of concrete" IOP Conference Series: Materials Science and Engineering, Vol. 923, 2020, pp. 1-7. https://doi.org/10.1088/1757-899X/923/1/012057

[19] Jumah Musdif Their, Mustafa Özakça. "Developing geopolymer concrete by using cold-bonded fly ash aggregate, nano-silica, and steel fiber" Construction and Building Materials, Vol. 180, 2018, pp. 12-22.
https://doi.org/10.1016/j.conbuildmat.2018.05.274
[20] Wang Yonggui, Li Shuaipeng, Peter Hughes, Fan Yuhui "Mechanical properties and microstructure of basalt fibre and nano-silica reinforced recycled concrete after exposure to elevated temperatures" Construction and Building Materials, Vol. 247, 2020, pp. 70-79.
https://doi.org/10.1016/j.conbuildmat.2020.118561
[21] Dr. Ashwini. B, Ramprasath. R. "Effect of Mechanical Properties of Concrete using Nano Silica and Partial Replacement of Fly Ash in Cementitious Material" International Journal of Research Publication and Reviews, Vol. 5, 2024, pp. 6944-6954.
https://doi.org/10.55248/gengpi.5.0424.1099

IS codes

- IS 456:2000 — Code of Practice for Plain and Reinforced Concrete (General guidelines for concrete mix design, construction, and quality control)
- IS 516:1959 — Methods of Tests for Strength of Concrete (Includes procedures for compressive strength, flexural strength, and tensile strength testing)
- IS 383:2016 — Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (Aggregate grading and quality requirements)
- IS 1199:1959 — Methods of Sampling and Analysis of Concrete (Sampling procedures for fresh and hardened concrete)
- IS 10262:2019 — Concrete Mix Proportioning — Guidelines (Mix design procedures for concrete)