



PERFORMANCE EVALUATION AND ANALYTICAL STUDY ON THE EFFECT OF NANO-SILICA ADDITION IN ENHANCING DURABILITY CHARACTERISTICS OF CONCRETE

¹B. Sandeep

MTech

Department of Civil Engineering
GRIET, Bachupally, Hyderabad,
Telangana, India.

Email: billakurisandeep92309@gmail.com

²Dr.G.V. V.Satyanarayana

Professor,

Department of Civil Engineering
GRIET, Bachupally, Hyderabad,
Telangana, India.

Email: satyanarayana42@gmail.com

Abstract

This research evaluates the sorptivity, water absorption, and acid resistance of M70 grade concrete with the incorporation of nano silica. The normal M70 concrete was prepared using 10% of silica fume and 11% of fly ash as partial substitutes for cement to act as a robust reference mix. For enhanced durability, nano silica was incorporated as an additional partial substitute. Concrete cubes were cast, water-cured for 28 days, and subjected to 5% sulfuric acid (H_2SO_4) and 5% hydrochloric acid (HCl) for 30 and 90 days to assess acid resistance. To check permeability and improvement in pore structure, water absorption and sorptivity tests were also conducted following established procedures. The results indicated that, when compared to the normal mix, micro silica concrete exhibited less degradation. The weight loss in nano silica concrete following exposure to acid for 90 days was 2.12% in HCl and 2.95% in H_2SO_4 , whereas the normal mix lost 4.51% and 5.75% of their weights, respectively. For nano silica concrete, the residual compressive strength was 93% of the original strength, while the normal mix had 86%. The percentage of water absorption in nano silica concrete reduced from 2.45% for the normal mix to 1.65%. Even the capillary suction and permeability decreased significantly, as noted from the sorptivity reduced from 2.13 mm to 1.39 mm. Based on the conclusions drawn from the research, incorporation of nano silica in M70 grade concrete reduces sorptivity, reduces water absorption, and enhances acid resistance all factors that contribute to the overall durability and service life of high-strength concrete.

Keywords: Nano-silica, High-performance concrete, Durability, Acid resistance, Water absorption, Sorptivity, M70 grade concrete.

1. Introduction

Concrete is the most widely used and versatile heterogeneous civil engineering construction material. Its moldability, versatility, and ability to attain high compressive strength have brought the construction sector to unprecedented heights of technological development. Yet, with growing demands for long-lasting and sustainable infrastructure, concrete

technology needs to innovate relentlessly. Over the past few years, nanotechnology has been coming forward as a developing method to improve the efficiency of concrete, especially strength, toughness, and chemical resistance.

Among different nanomaterials, nano silica (SiO_2 nanoparticles) has drawn particular attention with its very reactive pozzolanic character and high specific surface area.



Inclusion of nano silica into concrete promotes the development of calcium silicate hydrate (C-S-H) gel at an accelerated rate, creating a denser microstructure. It not only enhances compressive and tensile strength of concrete but also supports improved resistance to water and chemical intrusion. In addition, nano silica also smoothened the interfacial transition zone (ITZ) by plugging micro-pores, thereby helping to have lower permeability and improved durability.

Using this research, an effort is made to compare the performance of normal M70 concrete with and without the addition of nano silica. The results are anticipated to prove that the incorporation of nano silica enhances acid attack resistance, decreases water absorption, and minimizes sorptivity and hence lead to the construction of a more resilient and sustainable high-strength concrete mix for aggressive exposures

2. Literature Survey

Some research studies have documented the beneficial impacts of nano silica in high-performance concrete (HPC). Khaloo et al. [1] noted that nano silica having a surface area of 200 m²/g, when used at an optimum replacement level of 1.5%, yielded the highest compressive and tensile strengths in HPC mixtures. Again, Ganesh and Murthy [2] proved that addition of 1–2% nano silica enhanced both mechanical and durability characteristics of HPC with significant enhancement in compressive and tensile strength. Vivek et al. [3] proved that cement replacement with 5–15% nano silica increased flexural strength and structural stability of concrete exposed to

aggressive environments. Mohamed Amin et al. [4] also proposed that compressive strength can be enhanced up to 21% and tensile strength by 44% by adding nano silica, which supports its function of strengthening cementitious composites.

Earlier investigations with concrete grades like M40, M50, and M60 have already established that addition of nano silica lowers chloride penetration, enhances acid resistance, and boosts carbonation resistance. For example, specimens under 5% solutions of H₂SO₄, Na₂SO₄, and HCl showed lesser weight loss and strength loss in nano silica mix than in regular concrete [5], [6]. These results collectively identify nano silica as a crucial nanomaterial for creating strong, high-performance concrete.

In this current study, attention has also been given to M70 grade concrete, a type of very high-strength concrete and one which is increasingly being used in high-rise buildings of today and special infrastructure developments. The normal mix has been formulated by substituting cement partially with 11% fly ash and 10% silica fume, which are both strength and environmentally friendly. Nano silica is then added as a second partial replacement to achieve increased durability and acid resistance.

The experimental program constitutes three main investigations: acid resistance tests in 5% HCl and 5% H₂SO₄ solutions for exposure periods of 30 and 90 days, water absorption tests, and sorptivity tests. The acid resistance test assesses the ability of concrete to resist aggressive chemical attack, while water absorption and sorptivity tests offer information



concerning permeability and pore refinement properties.

3. Materials and Methodology

3.1 Materials

Cement: OPC 53 grade (IS 12269).

Fly Ash: Class F, 11% replacement. According to IS:1382(part1):2013. this standard specifies requirements for fly ash when used as an admixture in cement mortar and concrete.

Silica Fume: Condensed silica fume, 9% replacement. Fine material in size spherical conforming to IS: 15388-2003.

Nano Silica: Colloidal form, 15–30 nm, surface area 200 m²/g, added at 0–3%.

Fine Aggregate: Zone II sand (IS 383:2016).

Coarse Aggregate: 20 mm & 12.5 mm angular granite. As per code IS 2386 1963.

Admixture: A naphtha-based chemical that complies with IS: 9103-1999 was utilized for the experimental study.

Water: Potable, as per code IS: 456- 2000.

3.2 Mix Design

Grade: **M70**, Binder: OPC + 11% fly ash + 10% silica fume, Water-binder ratio: **0.28**, Nano-silica: 0%, 1%, 2%, 3% and 4%

3.3 Specimen Preparation

Cube size: **150 × 150 × 150 mm**

Mixing: Pan mixer with uniform dispersion of nano-silica.

Curing: 28 days in water at 27 ± 2°C

3.4 Testing Procedures

1. **Acid Resistance Test:** (ASTM C267) Specimens immersed in 5% H₂SO₄ and 5% HCl, tested at 30 & 90 days for **weight loss** and **compressive strength loss**.

2. **Water Absorption Test:** (ASTM C642) Mass difference between oven-dried and water-immersed specimens.

3. **Sorptivity Test:** (ASTM C1585) Capillary suction measured; sorptivity coefficient calculated.

4. Results And Discussion

4.1 Acid Resistance of HCL And H₂SO₄ for % of Weight Loss

Table 1 Acid Resistance of HCl and H₂SO₄ of % of weight loss

Exposure Period	Acid Type	Standard Mix	Optimum Mix (3% NS)
30 days	HCl	2.15%	1.01%
	H ₂ SO ₄	2.9%	1.56%
90 days	HCl	4.51%	2.12%
	H ₂ SO ₄	5.75%	2.95%

Weight loss increased with exposure time, as the acid resistance study revealed; yet the 3% nano-silica blend consistently demonstrated degradation that was more than 50% lower than the conventional mix. In comparison to hydrochloric acid (HCl), sulfuric acid (H₂SO₄) inflicted greater damage, where the normal concrete lost 5.75% after 90 days while nano-silica concrete lost 2.95%. The improvement is attributed to enhanced



ITZ caused by the addition of nano-silica, reduced permeability, and pore refinement. Hence, the durability in severe acidic environments is significantly enhanced through the addition of 3% nano-silica.

4.2 Acid Resistance of HCL And H₂SO₄ For Compressive Strength

Table 2 Acid resistance of HCl and H₂SO₄ for compressive strength

Exposure Period	Acid Type	Standard Mix	Optimum Mix (3% NS)
Before Exposure	—	82 MPa	89MPa
30 days	HCl	79 MPa	87 MPa
	H ₂ SO ₄	77 MPa	85 MPa
90 days	HCl	71 MPa	83 MPa
	H ₂ SO ₄	69 MPa	82 MPa

The compressive strength data show that, when subjected to both HCl and H₂SO₄, nano-silica concrete retained a greater strength than the reference mix. At 90 days, the 3% nano-silica mix continued to retain 82–83 MPa, implying ~15–18% better performance than the reference mix that reduced to 69–71 MPa. Due to the high calcium leaching and gypsum formation, sulfuric acid caused more reduction in strength compared to HCl. Nano-silica generally enhanced long-term durability by improving matrix densification and reducing acid-induced degradation.

4.3 Water Absorption of Concrete Test

Table 3 Water Absorption of Concrete Test

Mix Type	Water Absorption (%)
Standard M70	2.45 %
Optimum (3% NS)	1.65 %

Based on the results of water absorption, the 3% nano-silica blend lowered water absorption considerably from 2.45% in the control blend to 1.65%. It is due to the filler effect and pozzolanic activity of nano-silica that smooths pore structure and reduces capillary voids. Lower permeability has a direct link with decreased water absorption, which inhibits the penetration of aggressive chemicals. Thus, incorporation of nano-silica in M70 concrete considerably improves its durability and service life.

4.4 Sorptivity of Concrete Test

Table 4 Sorptivity of Concrete Test

Time (min)	$\sqrt{t}$ (min ^{0.5})	Standard M70 (mm)	Optimum 3% NS (mm)
2	1.41	0.29	0.19
5	2.24	0.43	0.27
10	3.16	0.61	0.39
20	4.47	0.83	0.51
30	5.48	0.97	0.61
60	7.75	1.26	0.79
120	10.95	1.59	1.01
180	13.42	1.79	1.15
240	15.49	1.93	1.25
300	17.32	2.05	1.33
360	18.97	2.13	1.39

The 3% nano-silica blend always exhibits lower capillary rise than the regular M70 concrete in all the time intervals, as indicated by the measurement of sorptivity.



Enhanced moisture intrusion resistance was proved through penetration, which reduced from 2.13 mm for the conventional mix to 1.39 mm for the nano-silica mix after 360 minutes. Reduction is attributed to the denser ITZ development induced by nano-silica and pore refining. As a result, nano-silica dramatically reduces sorptivity, improving durability over time against deterioration caused by water.

5. Conclusions

From the results we can conclude that

- Test for Acid Resistance The weight loss after 90 days was 2.12% and 2.95% using 3% nano-silica, against 4.51% (HCl) and 5.75% (H₂SO₄) for the normal mix, with nano-silica we can reduce weight loss by 2.39% (HCL) and 2.8% (H₂SO₄) respectively.
- Compressive Strength in Resistance against Acid Attack At 90 days, the residual strength of the conventional mix was 71 MPa (HCl) and 69 MPa (H₂SO₄), while the 3% nano-silica provided 83 MPa and 82 MPa. We can conclude that with nano silica we can increase strength of concrete by 15-16% with reference mix.
- Test of Water Absorption Upon addition of 3% nano-silica, water absorption reduced from 2.45% in normal M70 to 1.65% at 28 days, we can conclude that reduction of water absorption 0.8% with reference mix.

- Test of Sorptivity At 360 minutes, the ultimate sorptivity reduced from 2.13 mm with conventional mix to 1.39 mm with 3% nano-silica, we can conclude that we can reduce 0.74mm sorptivity with reference mix.

6. Future Work

Research on Long-Term Durability to extend exposure times beyond 90 days, e.g., 180 or 365 days, to evaluate nano-silica concrete's performance under prolonged harsh conditions.

Different nanomaterials To evaluate combined effects on mechanical and durability properties, comparative tests with other nanomaterials like nano-alumina, nano-titania, and nano-iron oxide are carried out.

Applications in the Field For real-world validation, nanosilica-modified concrete is applied in real structural elements such as pavements, bridges, and marine structures. Life Cycle Assessment Evaluating the energy efficiency, sustainability, and cost-benefit ratio of using nano-silica in mega-scale projects.

Hybrid binders To achieve improved results with reduced cement, blend nano-silica with other cementitious materials such as GGBS, metakaolin, and rice husk ash.

Microstructural Analysis through state-of-the-art techniques like SEM, XRD, and FTIR to understand microstructural transformation and hydration kinetics at the nanoscale level.

7. References

- [1] A. Khaloo, M. H. Mobini, and P. Hosseini, "Influence of different types of nano-SiO₂



particles on properties of high-performance concrete,” *Construction and Building Materials*, vol. 113, pp. 188–201, 2016, doi: 10.1016/j.conbuildmat.2016.03.061.

[2] P. Ganesh and A. R. Murthy, “Effect of nano silica on durability and mechanical properties of high-strength concrete,” *Journal of Materials in Civil Engineering*, vol. 29, no. 5, pp. 04016299-1–04016299-8, May 2017, doi: 10.1061/(ASCE)MT.1943-5533.0001810.

[3] V. Vivek, S. Tensing, and A. Felix Kala, “Influence of nano silica on strength and durability properties of high-performance concrete,” *International Journal of Engineering Research & Technology (IJERT)*, vol. 4, no. 3, pp. 178–183, 2015.

[4] M. Amin, S. Abolmaali, and M. Sobolev, “Effect of nano silica on mechanical properties of concrete,” *International Journal of Civil Engineering and Technology (IJCIET)*, vol. 8, no. 6, pp. 623–632, 2017.

[5] S. Praveen Kumar, K. V. Ramesh, and K. Srinivasa Rao, “Durability studies on nano silica concrete,” *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 3, no. 10, pp. 16790–16796, Oct. 2014.

[6] A. N. Givi, S. A. Rashid, F. N. A. Aziz, and M. A. M. Salleh, “The effects of lime solution on the properties of nano-silica blended cement pastes,” *Composites Part B: Engineering*, vol. 41, no. 7, pp. 673–677, Oct. 2010, doi: 10.1016/j.compositesb.2010.08.003.

[8] Concrete mix proportioning—Guidelines (IS 10262:2019). New Delhi: Bureau of Indian Standards.

[9] Ordinary Portland cement 53 grade—Specifications (IS 12269:2013). New Delhi: Bureau of Indian Standards.

[10] Silica fume—Specification (IS 15388:2003). New Delhi: Bureau of Indian Standards.

[11] Methods of test for aggregates for concrete (IS 2386:1963). New Delhi: Bureau of Indian Standards.

[12] Coarse and fine aggregate for concrete—Specification (IS 383:2016). New Delhi: Bureau of Indian Standards.

[13] Methods of physical tests for hydraulic cement (IS 4031:2019). New Delhi: Bureau of Indian Standards.

[14] Plain and reinforced concrete—Code of practice (IS 456:2000). New Delhi: Bureau of Indian Standards.

[15] Methods of tests for strength of concrete (IS 516:1959). New Delhi: Bureau of Indian Standards.

[16] Concrete admixtures—Specification (IS 9103:1999). New Delhi: Bureau of Indian Standards

[17] S. Chithra, S.R.R.Senthil Kumar, K.Chinnaraju. 2016. “The effect of colloidal nano-silica on workability, mechanical and durability properties of high-performance concrete with copper slag as partial fine aggregate”. *Construction and Building Materials*, 113,794-804.<https://dx.doi.org/10.1016/j.conbuildmat.2016.03.119>

[18] Zhenhai Xu, Zonghui Zhou, Peng Du,Xincheng. 2016. “Effects of nano-silica on hydration properties of tricalcium silicate”. *Construction and Buildings Materials*, 125, 1169-1177.
<https://dx.doi.org/10.1016/j.conbuildmat.2016.09.003>

[19] Ksenija Jankovic, Srboljub Stankovic, Dragan Bojovic, Marko stojanovic, Lana Antic. 2016. “The influence of Nano silica and barite aggregate on properties of ultra-high-performance concrete”. *Construction and Building Materials*, 126, 147-156.<https://dx.doi.org/10.1016/j.conbuildmat.2016.09.026>

[20]Pawel Sikora, Pawel Lukowski, Krzysztof Cendrowski, Elzbieta Horszczaruk, Ewa Mijowska. 2015. “The effect of nano silica on the mechanical properties of polymer cement



composites. *Sciencedirect*”, *Procedia Engineering*, 108, 139-145. <https://doi.10.1016/j.proeng.2015.06.129>

[21] H. Eskandari, M. Vaghefi, K.Kowsari. 2015.” Investigation of Mechanical and durability properties of concrete influenced by hybrid Nano silica and micro zeolite”. *Procedia Materials Science*, 11, 594-599. <https://doi:10.1016/j.mspro.2015.11.084>

[22] Mahmoud Nili and Ahmad Ehsani. 2015. “Investigating the effect of the cement paste and transition zone on strength development of concrete containing nano silica and silica fume”. *Materials and Design*, 75, 174-

183. <https://dx.doi.org/10.1016/j.matdes.2015.03.024>

[23] Saloma, Amrinsyah Nasution, Iswandi Imran, Mikrajuddin Abdullah. 2015. “Improvement of concrete durability by nanomaterials”. *Procedia engineering*, 125, 608-

612. <https://doi:10.1016/j.proeng.2015.11.078>

[24] Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacing and Polymer Concretes: ASTM C267