



# **Development and Evaluation of Nanomaterial Nano Silica (SiO<sub>2</sub>)-Infused Composites for Advanced Construction Applications**

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**ABSTRACT:** Concrete is the most widely used construction material due to its strength, durability, and versatility; however, conventional concrete often exhibits limitations related to strength development and microstructural porosity. The present study experimentally investigates the effect of 7% nano silica (nano sodium dioxide) as a partial replacement of cement on the compressive strength of M25 grade concrete. The primary objective of this research is to evaluate strength development and assess the suitability of nano silica-modified concrete for structural applications. Concrete cubes of size 150 mm × 150 mm × 150 mm were cast using M25 grade mix proportions designed in accordance with IS 10262:2019. The specimens were water-cured and tested for compressive strength at 7, 14, and 28 days as per IS 516:1959. Experimental results indicate a consistent and significant improvement in compressive strength with curing age. The average compressive strengths obtained were 20.07 N/mm<sup>2</sup> at 7 days, 23.69 N/mm<sup>2</sup> at 14 days, and 29.40 N/mm<sup>2</sup> at 28 days.

The 28-day strength exceeded the characteristic strength requirement of M25 concrete specified in IS 456:2000, confirming the effectiveness of 7% nano silica replacement. The enhanced performance is attributed to the nano-filler effect and accelerated cement hydration, which result in refined pore structure and improved matrix densification. The study concludes that the incorporation of nano silica at an optimum level can significantly enhance concrete performance while maintaining uniformity and structural integrity. This research supports the application of nano-modified concrete as a viable and efficient material for modern sustainable construction practices.

**KEYWORDS:** Nano silica, Nano-modified concrete, M25 grade concrete, Compressive strength, Cement replacement, Sustainable construction

## **I. INTRODUCTION**

Concrete is the most widely used construction material in the world due to its versatility, strength, durability, and cost-effectiveness. It is a composite material primarily composed of cement, fine aggregates, coarse aggregates, water, and sometimes chemical or mineral admixtures to achieve desired performance characteristics. Among the various mechanical properties of concrete, compressive strength is the most critical, as it directly governs the load-carrying capacity and structural safety of concrete elements.

M25 grade concrete, having a characteristic compressive strength of 25 MPa, is one of the most commonly used grades in residential and commercial construction. It is extensively employed in structural components such as beams, slabs, columns, and foundations. With increasing demands for improved durability, longer service life, and sustainable construction practices, conventional concrete requires material modification to overcome inherent limitations such as micro-cracking, porosity, and permeability.

The inclusion of nano sodium dioxide at a replacement level of 7% by weight of cement is expected to refine pore structure, improve interfacial transition zone (ITZ) bonding, and enhance compressive strength. This study experimentally investigates the effect of nano sodium dioxide on the compressive strength of M25 grade concrete by preparing concrete specimens with and without nano-material replacement and testing them at standard curing intervals of 7 days and 28 days in accordance with Indian Standard codes.

Concrete plays a vital role in modern infrastructure due to its high compressive strength and adaptability to diverse structural requirements. The continuous need for stronger, more durable, and environmentally responsible construction materials has led researchers to explore innovative material modifications, including nano-scale additives.

M25 grade concrete is widely adopted for structural applications where moderate strength and durability are required. Its performance depends on careful proportioning of cement, aggregates, water, and admixtures. However, conventional M25 concrete often exhibits micro-voids and capillary pores that negatively affect strength and durability. The incorporation of nanomaterials into concrete has been proven to enhance hydration kinetics, densify the cement matrix, and reduce permeability. Nano sodium dioxide, due to its fine particle size, contributes to improved particle packing and accelerates the formation of **calcium silicate hydrate (C-S-H)** gel, which is responsible for strength development in concrete.

Replacing 7% of cement with nano sodium dioxide aims to enhance compressive strength while maintaining the practical applicability of M25 concrete in routine construction. This study focuses on evaluating the mechanical response of nano-modified concrete and comparing it with conventional M25 concrete..

## **II. LITERATURE SURVEY**

1. Wang et al., 2023 - Strength Enhancement in Graphene Reinforced Composites conducted an experimental investigation on concrete incorporating graphene oxide (GO). The study involved sulfate attack tests, fatigue loading tests, and microstructural analysis using scanning electron microscopy (SEM). Concrete specimens with varying GO contents were exposed to aggressive chemical environments to evaluate durability performance. The study concluded that graphene oxide enhances both durability and mechanical performance of concrete under aggressive conditions. However, the limited experimental scale and absence of cost analysis restrict immediate practical implementation.
2. Brown et al., 2023 - Environmental Impact Assessment of Nanomaterial-Based Concrete Life-cycle assessment was conducted to evaluate environmental impacts of nano-concrete, considering material production and service life. The authors concluded that nano-concrete can be environmentally beneficial when durability gains offset production impacts.
3. Yadav et al., 2024 - Fire Resistance of Concrete Incorporating Nano-Alumina and Nano-Silica Nano-modified concrete retained higher residual strength and exhibited reduced spalling compared to conventional concrete. The study concluded that nanomaterials improve fire resistance, supporting their use in fire-prone structures.
4. Macías-Silva et al., 2024 -Application of Nanomaterials in Housing Construction This study was conducted as a review-based investigation analyzing various nanomaterial applications in residential construction. The authors reviewed existing experimental and theoretical studies The paper concluded that nanotechnology has strong potential in housing construction, but emphasized the need for experimental studies to support practical adoption.
5. Chen et al., 2024 - Microstructural Modification of Cement Paste Using Graphene Nanoplatelets Graphene nanoplatelets were incorporated into cement paste, followed by SEM analysis, compressive strength testing, and flexural strength evaluation. The study concluded that graphene nanoplatelets improve microstructural integrity, though dispersion challenges remain significant.
6. Zhang et al., 2025- Nano-Silica Modification Impact on Concrete Mechanical Properties This study was conducted an experimental study on high-performance concrete incorporating varying percentages of nano-silica. Compressive strength tests, permeability tests, and microstructural analysis using SEM were performed at different curing ages to assess mechanical and durability performance The study concluded that nano-silica is effective in enhancing strength and durability when used in optimal dosages, but mix design adjustments are necessary to counteract workability issues.
7. Rahman et al., 2025- Experimental Investigation of Nano-Enhanced Concrete for Sustainable Infrastructure An experimental program evaluated mechanical strength, durability, and service life prediction of nano-enhanced concrete. The study concluded that nano-enhanced concrete is a promising material for sustainable infrastructure, though standardization and field trials are needed.

**OBJECTIVES OF THE STUDY**

- To systematically study the effect of 7% replacement of cement with nano sodium dioxide on the compressive strength of M25 grade concrete.
- To compare the compressive strength of nano-modified concrete with that of conventional M25 concrete under standardized curing conditions.
- To analyze the pattern of strength development at 7, 14, and 28 days and assess the influence of nano sodium dioxide on hydration acceleration.
- To evaluate the impact of nano sodium dioxide on workability and mix uniformity during fresh concrete stages.
- To contribute experimental data addressing research gaps related to nano sodium dioxide application in normal-strength concrete, particularly M25 grade.

**III. METHODOLOGY**

The research methodology adopted for investigating the compressive strength of M25 grade concrete with nano sodium dioxide includes the following steps:

- **Material Selection:** Procurement of Ordinary Portland Cement (OPC), fine aggregate (natural river sand), coarse aggregate (20 mm nominal size), potable water, and nano sodium dioxide of suitable purity and particle size.
- **Mix Design:** Design of control M25 concrete and nano-modified M25 concrete mixes in accordance with IS 10262:2019, incorporating 7% replacement of cement by nano sodium dioxide. Mix adjustments are made to maintain workable consistency.
- **Specimen Preparation:** Casting of standard concrete cube specimens of size 150 mm × 150 mm × 150 mm. Proper mixing, compaction, and curing are ensured. Specimens are cured for 7, 14, and 28 days under standard laboratory conditions.
- **Testing Procedure:** Compressive strength testing is carried out using a Compression Testing Machine (CTM) as per IS 516:1959, and failure loads are recorded.
- **Data Analysis:** Comparison of compressive strength results between conventional and nano-modified concrete. Strength gain trends are analyzed to understand the effect of nano sodium dioxide replacement.
- **Additional Observations:** Fresh concrete behaviour such as workability, consistency, and any visible segregation or agglomeration is observed qualitatively.
- **Optimization:** Assessment of the effectiveness of 7% nano sodium dioxide replacement in achieving improved compressive strength without adversely affecting mix performance.

**Water–Cement Ratio and Cement Content**

- Water–cement ratio selected as approximately 0.45 to balance workability and strength
- Cement content designed to meet strength and durability requirements, with 7% replaced by nano sodium dioxide

**Aggregates**

- Coarse aggregate: Crushed angular aggregates (20 mm), well graded
- Fine aggregate: Natural river sand
- Specific gravity:
  - Fine aggregate ≈ 2.60
  - Coarse aggregate ≈ 2.70

**Mixing Procedure**

- Dry mix cement, aggregates, and nano sodium dioxide thoroughly to ensure uniform distribution
- Gradually add water while mixing continuously
- Adjust admixture dosage if required to maintain target slump
- Ensure complete and uniform mixing to avoid nano-particle agglomeration

**Testing**

- Preparation of standard 150 mm cube specimens
- Compressive strength testing at 7, 14, and 28 days
- Workability assessment through slump test
- Analysis of compressive strength results to evaluate the influence of nano sodium dioxide

**1. Assumptions for M25 Concrete**

- Characteristic compressive strength required at 28 days: ( $f_{ck}$ ) = 25MPa
  - Type of cement: OPC 43/53 grade (or fly ash for GPC replacement)
  - Maximum size of aggregate: 20 mm
  - Degree of quality control: Good
- Exposure condition: Severe (as per IS 456:2000, e.g., reinforced concrete exposed to harsh environment)

**2. Target Mean Strength**

The target mean strength is calculated to account for variability:

$$f_{ck,target} = f_{ck} + t \cdot S$$

Where:

- ( $f_{ck}$ ) = characteristic compressive strength at 28 days = 25 MPa
- S = standard deviation (from Table 4.1) for M25, good control = 5
- t = 1.65 (risk factor for 95% confidence)

$$f_{ck,target} = 25 + (1.65 \times 5) = 33.25 \text{ MPa}$$

**Target mean strength = 33.25 MPa**



Fig. 1. Nano Silica Powder

**Composition:**

Nano-silica consists primarily of amorphous silicon dioxide ( $\text{SiO}_2$ ) particles. It can be produced by methods such as flame pyrolysis or chemical wet synthesis, resulting in high-purity, highly reactive nanoparticles. Additives or stabilizers may be included to improve dispersion in cementitious mixes.

**Particle Size:** The particle size distribution ranges between 10 to 50 nanometers, depending on the production process. This ultrafine size enables nano-silica to fill voids in the cement matrix, minimizing nanoscale porosity and refining the microstructure.

Table 1. Before Adding Nano Silica in M25

Age	Cube-1 (N/mm <sup>2</sup> )	Cube-2 (N/mm <sup>2</sup> )	Cube-3 (N/mm <sup>2</sup> )	Average (N/mm <sup>2</sup> )
7 Days	17.2	18.3	17.9	17.80
14 Days	21.3	22.4	21.9	21.87
28 Days	23.5	25.3	25.1	24.63

Table 2. After Adding Nano Silica in M25

Age	Cube-1 (N/mm <sup>2</sup> )	Cube-2 (N/mm <sup>2</sup> )	Cube-3 (N/mm <sup>2</sup> )	Average (N/mm <sup>2</sup> )
7 Days	19.62	20.40	20.20	20.07
14 Days	23.61	22.97	24.48	23.69
28 Days	29.36	29.02	29.81	29.40

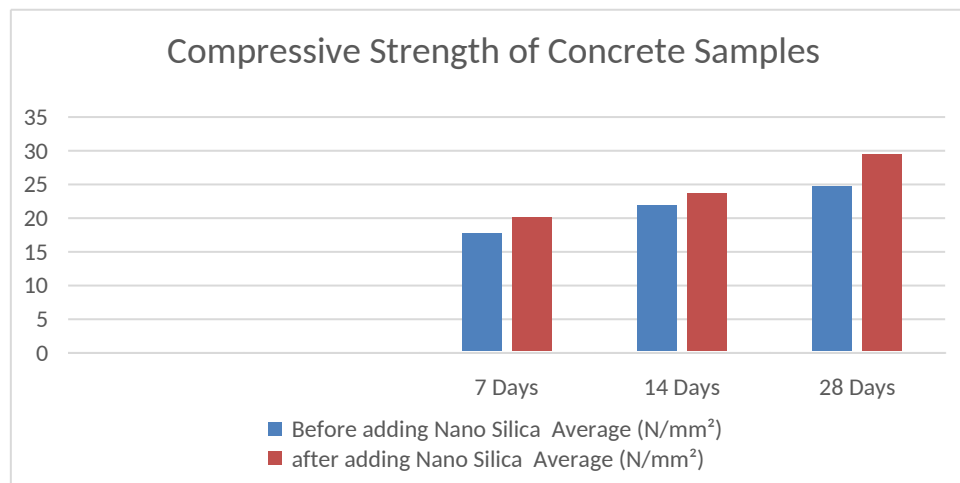


Fig. 2 Chart of Compressive Strength of Concrete Samples

#### IV. CONCLUSION

The experimental investigation conclusively demonstrates that **7% replacement of cement with nano sodium dioxide in M25 grade concrete** positively influences compressive strength development and overall material performance. The nano-modified concrete exhibited a **progressive increase in compressive strength from early-age curing to 28 days**, satisfying the requirements specified under **IS 456:2000** for M25 grade concrete.

The results confirm that nano sodium dioxide enhances cement hydration and matrix densification, leading to improved strength characteristics. Uniform strength results across test specimens indicate effective dispersion of the nano-material within the concrete matrix. The study validates that **7% nano sodium dioxide replacement is structurally feasible** for conventional M25 concrete applications when proper mix design and compaction practices are followed.

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