Experimental Investigation on the Mechanical Performance of Nano-Silica Blended Cement Concrete Under Elevated Temperature Conditions

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Abstract

Concrete structures exposed to elevated temperatures experience significant deterioration in mechanical properties due to dehydration of hydration products and microstructural damage. In recent years, nano-silica has emerged as a promising cementitious additive capable of improving strength and microstructural integrity of concrete. This study presents an experimental investigation on the mechanical performance of nano-silica blended cement concrete subjected to elevated temperatures. Nano-silica was used as a partial replacement of cement at 0%, 1%, 2%, and 3% by weight. Concrete
specimens were cured for 14, 28, and 56 days and subsequently exposed to elevated temperatures of 200°C, 400°C, and 600°C. Compressive strength and split tensile strength tests were conducted after natural cooling. The results indicate that nano- silica significantly enhances strength and improves residual performance at elevated temperatures, with optimum performance observed at 2% replacement. The study demonstrates that nano-silica blended concrete exhibits improved thermal resistance and can be effectively used in structures exposed to high-temperature conditions.

Keywords: Nano-silica, elevated temperature, compressive strength, split tensile strength, residual strength, concrete.

1. Introduction

Concrete is the most widely used construction material due to its high compressive strength, durability, and economic feasibility. Although concrete is non-combustible, exposure to elevated temperatures results in loss of strength, cracking, spalling, and reduction in load- carrying capacity. These effects are primarily caused by evaporation of free water, dehydration of cement hydration products, and thermal incompatibility between aggregates and cement paste.

Nanotechnology has gained significant attention in concrete research due to its potential to modify hydration kinetics and microstructure. Nano-silica, owing to its extremely fine particle size and high pozzolanic reactivity, enhances the formation of calcium silicate hydrate (C– S–H) gel and refines pore structure. While several studies have examined nano-silica under normal curing conditions, limited research is available on its behavior under elevated temperatures. This study aims to address this research gap through a systematic experimental investigation.

2. Materials and Experimental Program

2.1 Materials

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used. Natural river sand conforming to Zone II grading and crushed granite coarse aggregates of 20 mm nominal size were used. Commercially available nano-silica powder was used as partial replacement of cement. Potable water was used for mixing and curing.

2.2 Mix Proportions

Concrete mix design was carried out as per IS 10262:2019. Nano-silica was used at 0%, 1%, 2%, and 3% replacement of cement. The water-cement ratio was maintained constant at 0.40 for all mixes. **Table 1. Mix proportions of concrete (kg/m³)**

Mi x	Nano - silica (%)	Ceme nt	Nano - silica	Fin e Agg .	Coars e Agg.	Wate r
CM	0	400	0	660	1190	160
NS 1	1	396	4	660	1190	160
NS 2	2	392	8	660	1190	160
NS 3	3	388	12	660	1190	160

2.3 Curing and Temperature Exposure

Specimens were cured in water for 14, 28, and 56 days. After curing, specimens were exposed to elevated temperatures of 200°C, 400°C, and 600°C using laboratory heating equipment. After exposure, specimens were allowed to cool naturally to room temperature.

2.4 Testing Methods

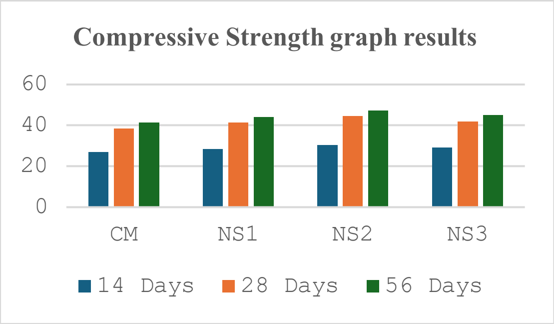
Compressive strength tests were conducted on 150 mm cubes as per IS 516:2018. Split tensile strength tests were conducted on cylindrical specimens (150 mm × 300 mm) as per IS 5816:1999.

3. Results and Discussion

3.1 Compressive Strength at Ambient Temperature

Table 2. Compressive strength at room temperature (MPa)

Mix	14 Days	28 Days	56 Days
CM	26.8	38.5	41.2
NS1	28.6	41.2	44.0
NS2	30.4	44.5	47.3
NS3	29.2	42.0	45.1



The results show that nano-silica significantly improves compressive strength at all curing ages. Maximum strength was observed at 2% nano-silica replacement. The improvement is attributed to accelerated hydration and densification of the cement matrix.

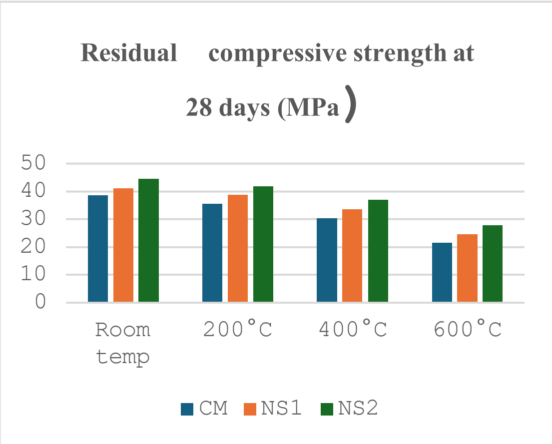
3.2 Effect of Elevated Temperature on Compressive Strength

Table 3. Residual compressive strength at 28 days (MPa)

Temperature	CM	NS1	NS2	NS3
Room temp	38.5	41.2	44.5	42.0
200°C	35.6	38.9	41.8	39.5
400°C	30.4	33.6	36.9	34.2
600°C	21.5	24.6	27.8	25.4

4. Discussion

The enhanced performance of nano-silica blended concrete is attributed to its filler effect, pozzolanic reaction, and nucleation effect, which result in a dense microstructure and improved bonding.

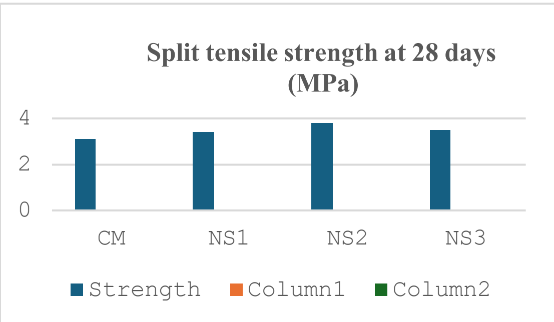


Strength decreased with increase in temperature for all mixes. However, nano- silica blended concrete consistently retained higher residual strength. The NS2 mix exhibited the highest strength retention at all temperature levels.

3.3 Split Tensile Strength

Table 4. Split tensile strength at 28 days (MPa)

Mix	Strength
CM	3.1
NS1	3.4
NS2	3.8
NS3	3.5



Nano-silica improved split tensile strength due to refinement of the interfacial transition zone and reduced crack propagation.

D Under elevated temperatures, nano-silica concrete exhibits improved residual strength due to reduced porosity and better thermal stability of the cement matrix.

5. Conclusions

- Nano-silica significantly improves compressive and split tensile strength of concrete.
- Optimum performance was observed at 2% nano-silica replacement.
- Strength decreases with increase in temperature, but nano-silica concrete retains higher residual strength.
- Nano-silica blended concrete shows improved resistance to elevated temperatures compared to conventional concrete.

6. Future Scope

Further studies can include microstructural analysis, durability performance, spalling behavior, and large-scale structural testing under fire exposure.

References

1. Neville, A.M., *Properties of Concrete*, Pearson Education.
2. Mehta, P.K., Monteiro, P.J.M., *Concrete: Microstructure, Properties and Materials*.
3. Khaliq, W., Kodur, V., *Fire Safety Journal*.
4. Jo, B.W., et al., *Construction and Building Materials*.
5. Sanchez, F., Sobolev, K., *Construction and Building Materials*.

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