

NANO PARTICLE INCORPORATION FOR AUGMENTED PERFORMANCE OF CEMENTITIOUS COMPOSITE: AN EXPERIMENTAL INVESTIGATION

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ABSTRACT

The incorporation of nanotechnology in civil engineering has emerged as a focal point of interest owing to its promising capacity to augment the intrinsic characteristics of cement concrete. This investigative endeavor delves into the nuanced optimization of cement concrete properties through the deliberate integration of nano-particles, with a specific emphasis on silica nanoparticles (SNPs). The study adopts a methodical approach to scrutinize the ramifications of varying concentrations of SNPs on critical parameters such as compressive strength, durability, and the microstructural characteristics. M35 grade concrete, conforming to the mix design stipulated in IS10262:2019, serves as the experimental substrate for this research. The findings elucidate a discernible enhancement in compressive strength and durability upon judiciously incorporating silica nanoparticles in optimal proportions. These improvements can be ascribed to the inherent pozzolanic and nucleation effects exhibited by silica nanoparticles. Silica nanoparticles induce supplementary C-S-H gel formation through interaction with calcium hydroxide in concrete. Advance instrumentation technique, such as Scanning Electron Microscopy (SEM), facilitates a comprehensive examination of the concrete's surface morphology and micropore characteristics. The utilization of silica nanoparticles emerges as a pivotal element in the pursuit of innovative and robust construction materials.

Keywords: SNP, SEM, Pozzolanic, Nucleation Effect, C-S-H.

1. INTRODUCTION

The Cement concrete, a cornerstone in modern civil engineering structures, assumes a critical role in shaping infrastructure's service life and performance, necessitating continuous exploration of innovative methods for improvement. Amidst these endeavors, the integration of nano particles, particularly silica nano particles (SNP), into the concrete matrix has emerged as a noteworthy avenue. This study focuses on harnessing the potential of nano particles to elevate cement concrete properties, specifically targeting strength, durability, and sustainability. The inclusion of nano particles, particularly those with dimensions below 100 nanometers, introduces transformative prospects for conventional concrete, converting it into a high-performance material. This transformation is driven by exploiting the unique attributes of nano particles, encompassing their expansive surface area, heightened reactivity, and adeptness in occupying micro-scale voids, thereby facilitating the optimization of various concrete characteristics.

In the realm of civil engineering, this research probes the intricate dynamics between nano particles and cement concrete, emphasizing their impact on concrete cube compressive strength and durability. Notably, silica nano particles exhibit a pozzolanic effect and nucleation capabilities, contributing significantly to enhanced compressive strength and durability. Advanced instrumentation, such as Scanning Electron Microscopy (SEM), is also deployed to scrutinize surface morphology and micropores, providing nuanced insights into the material's durability. This study extends its gaze to the sustainable dimensions of nano particle integration, considering reduced carbon footprint and heightened energy efficiency. The overarching objective is to unravel both the potential advantages and challenges inherent in incorporating nano particles into cement concrete, fostering a deeper understanding and broader application of these innovative materials in the domain of civil engineering. Through such endeavors, we aspire to contribute meaningfully to the ongoing quest for resilient, sustainable, and high-performance concrete structures attuned to the evolving demands of our built environment.

2. METHODOLOGY

The investigative methodology implemented in this study was fundamentally oriented towards enhancing the attributes of cementitious composites by integrating silica nanoparticles. The research protocol encompassed a thorough series of systematic procedures, involving stringent experimental protocols and meticulous data acquisition techniques. The primary objective was to attain precision and reliability in the research pursuits. The experimental framework adhered to a meticulous design, following the principles of robust scientific inquiry. Rigorous attention was given to control

variables, ensuring the isolation of specific factors influencing the properties of cementitious composites. The systematic execution of the experimental procedures allowed for a comprehensive analysis of the impact of silica nanoparticles on the structural and mechanical characteristics of the cementitious matrix. This methodological approach, grounded in precision and methodical rigor, enhances the credibility and applicability of the findings, contributing to the broader scientific understanding of nano-enhanced cementitious materials.

2.1 Material Procurement

Premium Ordinary Portland Cement, fine and coarse aggregates, and high-purity silica nanoparticles (SNP) with an average nanoparticle size ranging between 30 and 40 nanometers were meticulously selected for experimentation, ensuring optimal material quality and composition.

2.2 Nano Particle Dispersion

Silica nanoparticles underwent a meticulous dispersion procedure within an aqueous medium, employing manual agitation methodologies to attain a homogeneous nano-suspension characterized by heightened stability. The resulting nano-suspension was methodically incorporated into the dry concrete blend, ensuring a uniform dissemination and optimal amalgamation of silica nanoparticles into the concrete matrix. This meticulous approach aimed to facilitate an even distribution of nano-sized particles throughout the concrete structure, maximizing their potential impact on the material's overall properties. The utilization of manual agitation techniques in the dispersion process underscores the precision employed to achieve a consistently dispersed nano-suspension, contributing to the scientific rigor of the investigation.

1.3 Mix Design & Concrete Cube Casting

This investigative research delved into the optimization of cement concrete properties by adhering to the stipulations set forth in IS 10262:2019 and IS 456:2000 for concrete mix design. Systematic experimentation involved the methodical inclusion of varying proportions of silica nanoparticles, ranging from 0% to 5% by weight of cement. The primary focus was the enhancement of mechanical strength and durability in cementitious composites. Control specimens, bereft of nanoparticles, were meticulously formulated according to the specifications outlined in Table 1 and Table 2. A meticulous comparative analysis of the ensuing test results was undertaken to discern the most effective cement concrete mixture, characterized by heightened strength and an extended service life, achieved through the judicious integration of silica nanoparticles. The study specifically utilized M30 grade concrete in line with IS10262:2019 mix design for experimental purposes. The results elucidated substantial improvements in compressive strength and enhanced durability with the addition of silica nanoparticles in appropriate proportions, attributable to their pozzolanic and nucleation effects. Employing advanced instrumentation techniques such as Scanning Electron Microscopy (SEM) provided insights into surface morphology and micropores, contributing to the overall understanding of the enhanced durability of the cement concrete. These findings present a promising trajectory for sustainable and resilient construction practices within civil engineering applications.

Table 1 Mix Design Proportions for Control sample obtained through IS 10262:2019 & IS 456:2000

| Cement | Fine Aggregate (kg) | Coarse Aggregate (kg) | Water (kg) | Admixture (kg) | W/C Ratio |
|--------|---------------------|-----------------------|------------|----------------|-----------|
| 346 | 661.67 | 1253.68 | 155.6 | 3.46 | 0.45 |
| 1 | 1.91 | 3.62 | - | - | - |

The nomenclature employed for delineating concrete compositions is systematically structured in relation to the incorporation of Silica Nano Particles (SNP). Specifically, the nomenclature designates Concrete Mix with no Silica Nano Particles as SNP 0, Concrete Mix featuring a 3% concentration of Silica Nano Particles as SNP 3, Concrete Mix containing 4% Silica Nano Particles as SNP 4, and Concrete Mix with a 5% content of Silica Nano Particles as SNP 5. These alphanumeric labels function as a comprehensive coding system, facilitating the categorization and discrimination of the diverse proportions of Silica Nano Particles present within the corresponding concrete mix formulations.

Furthermore, the study extends its focus to the specific proportions of Silica Nano Particles in Concrete Mix, utilizing a meticulously crafted mix design based on IS10262:2019 standards for grade M35 concrete. The ensuing results from this experimental investigation are encapsulated in Table 2, presenting the mix design proportions and offering a succinct overview of the composition variations corresponding to the distinct SNP nomenclatures. This structured nomenclature system and the accompanying mix design details contribute to a nuanced understanding of the interplay between Silica Nano Particles and concrete properties, offering insights into the optimization of concrete for enhanced structural performance in civil engineering applications.

Table 2 Mix Design Proportion for Test Samples as per IS10262:2019 & IS456:2000

| SNP % | Silica Nano Particles (kg/m ³) | Cement (kg/m ³) | Fine Aggregate (kg/m ³) | Coarse Aggregate (kg/m ³) | Water (kg/m ³) | Admixture (kg/m ³) | W/C Ratio |
|-------|--|-----------------------------|-------------------------------------|---------------------------------------|----------------------------|--------------------------------|-----------|
| SNP 0 | 0 | 346 | 661.67 | 1253.68 | 155.6 | 3.46 | 0.45 |
| SNP 3 | 10.38 | 335.62 | 661.67 | 1253.68 | 155.6 | 3.46 | 0.45 |
| SNP 4 | 13.84 | 332.16 | 661.67 | 1253.68 | 155.6 | 3.46 | 0.45 |
| SNP 5 | 17.3 | 328.7 | 661.67 | 1253.68 | 155.6 | 3.46 | 0.45 |

3. RESULTS AND DISCUSSION

Table 3 and Figure 1 distinctly present the findings derived from compressive strength tests conducted on cube specimens. The data reveals a conspicuous improvement in compressive strength, specifically a notable 28% augmentation, discerned at the 7-day interval in concrete subject to a 3% replacement of cement with silica nanoparticles.

This empirical evidence underscores the consequential influence of silica nanoparticles on the mechanical attributes of concrete, offering crucial insights into the efficacy and feasibility of such composite materials in construction applications.

The decrement in compressive strength observed at silica nanoparticle (SNP) concentrations of 4% and 5% is ascribed to the agglomeration of nano-sized silica particles. This phenomenon curtails nucleation sites, impeding the initiation of the pozzolanic reaction, thereby explicating the observed decline in compressive strength.

The experimental design aligns with scientific rigor, employing cube specimens and meticulous testing protocols. These findings contribute substantively to the burgeoning knowledge base concerning the nuanced interplay of nano-materials in cementitious matrices and provide a foundation for further exploration in optimizing concrete performance.

Table 3 comparison for compressive strengths of 7-days at various percentages

| SNP (%) | 7 Days Strength (Mpa) | Increase in Strength (%) |
|---------|-----------------------|--------------------------|
| 0 | 23.79 | — |
| 3 | 30.45 | 28 |
| 4 | 28.17 | 18.41 |
| 5 | 26.46 | 11.22 |

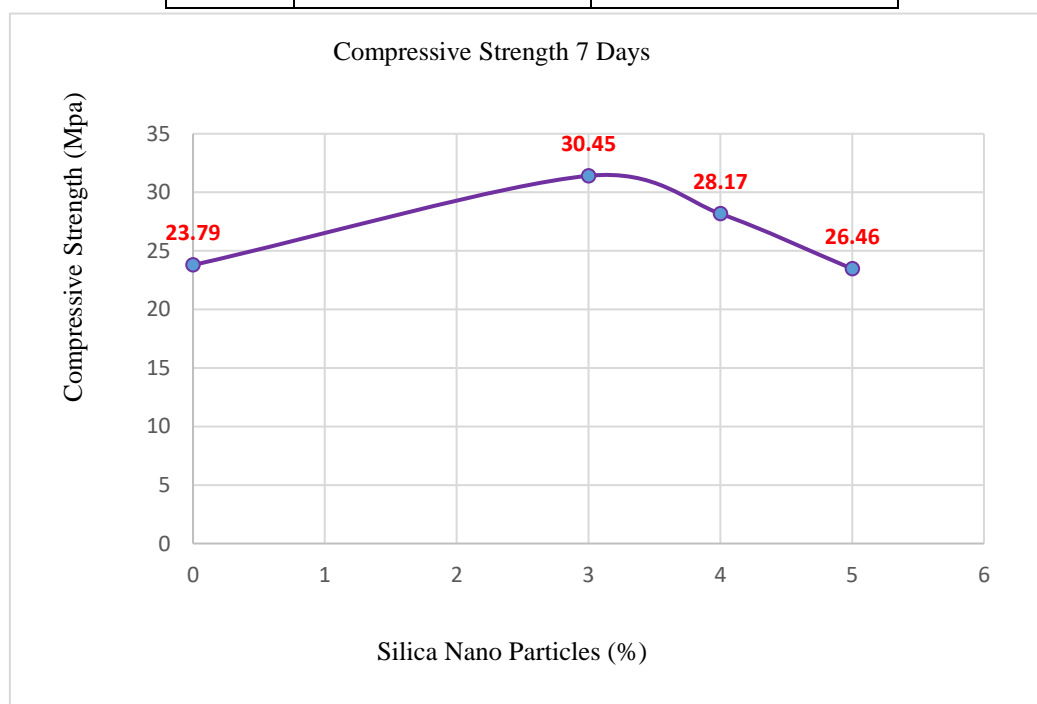


Figure 1 compressive Strength 7-days VS SNP percentage

Table 4 and Figure 2 succinctly present outcomes derived from compressive strength evaluations conducted on cubic specimens. The tabular data elucidates a conspicuous enhancement in compressive strength, signifying an approximate 30% amplification, notably discernible at the 28-day juncture in concrete samples subject to a 3% substitution of cement with silica nanoparticles. This empirical evidence underscores the discernible impact of silica nanoparticles on the mechanical characteristics of concrete, providing invaluable insights into the operational aspects and viability of such composite materials in the domain of construction applications.

The reduction in compressive strength observed at 4% and 5% concentrations of silica nanoparticles (SNP) is attributed to the agglomeration of nano-sized silica particles. This phenomenon hampers nucleation sites, consequently impeding the initiation of the pozzolanic reaction, elucidating the observed decline in compressive strength. This intricate interplay between nanoparticle concentration and compressive strength underscores the nuanced complexities inherent in optimizing the performance of concrete incorporating silica nanoparticles.

The experimental approach adopted in this study adheres to M30 grade concrete, as per mix design IS10262:2019, offering a methodical exploration of the effects of varying silica nanoparticle concentrations on compressive strength, durability, and microstructure. Utilizing advanced instrumentation techniques such as Scanning Electron Microscopy (SEM) enhances the examination of surface morphology and micropores, providing a comprehensive understanding of the concrete's enhanced durability. This research contributes valuable insights, paving the way for the advancement of cement concrete properties and offering a promising trajectory for sustainable and resilient construction practices in civil engineering applications.

Table 4 comparison for compressive strengths of 28-days at various percentages

| SNP % | 28Days Strength (Mpa) | Increase in Strength (%) |
|-------|-----------------------|--------------------------|
| 0 | 36.50 | – |
| 3 | 52.16 | 30.02 |
| 4 | 41.19 | 12.85 |
| 5 | 39.44 | 8.05 |

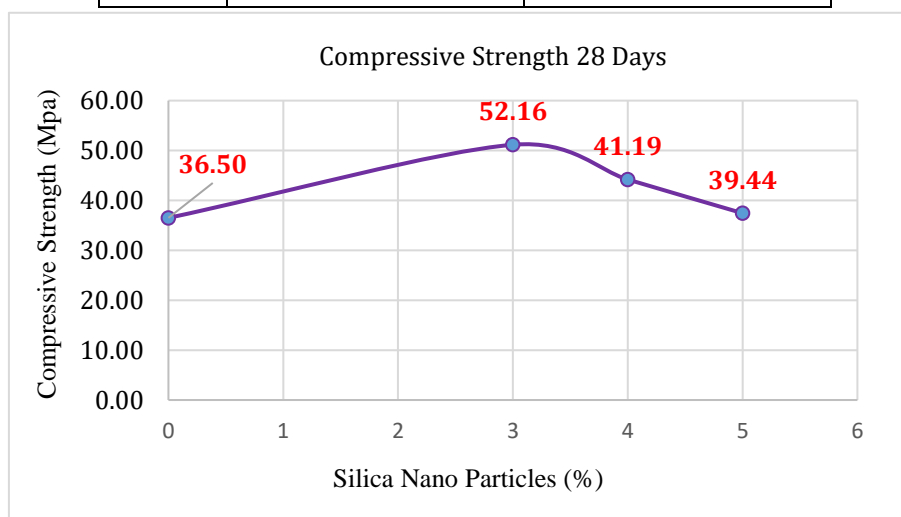


Figure 2 compressive Strength 28-days VS SNP percentage

The investigation into the surface morphology of concrete samples, employing Scanning Electron Microscopy (SEM), constitutes a critical facet of this study. SEM is utilized to discern the microstructure of the concrete surface, offering high-resolution images that enable a comprehensive analysis of the material. Through SEM imaging, the pores present in the concrete matrix are examined, allowing for the determination of their sizes and distribution. The addition of nano-silica particles to the concrete mix contributes to the creation of a denser matrix. The enhanced denseness in the hardened concrete is a result of the pozzolanic reactivity and nucleation effects induced by the nano-silica particles. These particles facilitate the formation of additional Calcium-Silicate-Hydrate (C-S-H) gel, resulting in a more compact and durable concrete structure. The inhibition of pore coarsening and the refinement of microstructural features contribute to the observed improvements in compressive strength and durability. This reinforced matrix, characterized by a reduced pore network, fortifies the concrete against environmental factors, rendering it less susceptible to deterioration caused by weathering phenomena. Consequently, the integration of nano-silica in concrete presents a viable strategy for achieving resilient and sustainable construction materials in civil engineering applications.

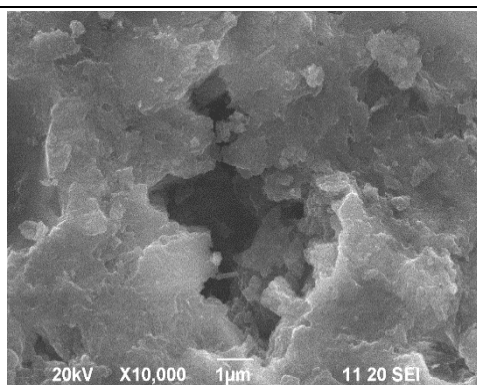


Figure 3 SEM Image for SNP 0%

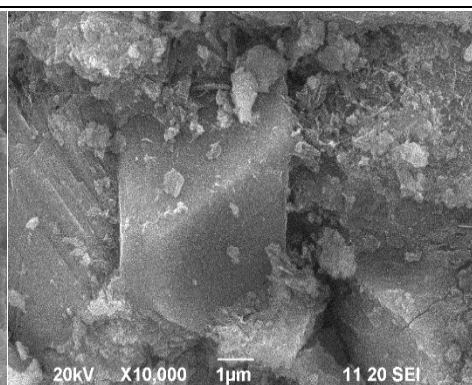


Figure 4 SEM Image for SNP 3%

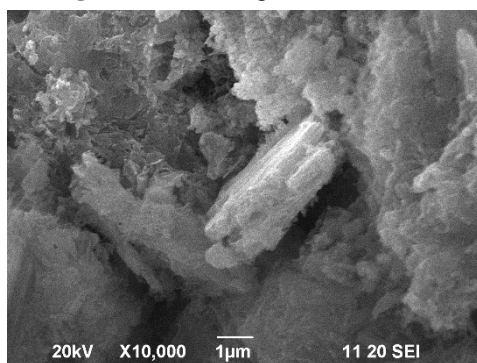


Figure 5 SEM Image for SNP 4%

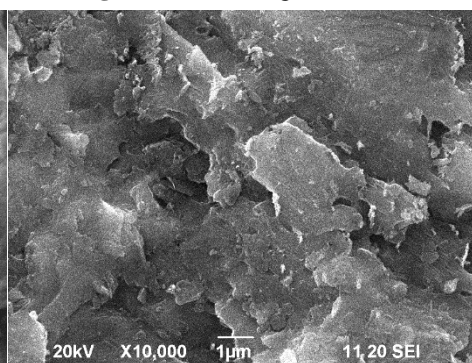


Figure 6 SEM Image for SNP 5%

The SEM images appended herewith vividly depict that the substitution of 3% of cement with silica nanoparticles (SNP) in figure 3 results in a notably denser surface morphology. SEM analysis elucidates the densification of the concrete matrix through observable surface characteristics. A more compact concrete structure, as evidenced by SEM, indicates heightened resistance to deterioration and weathering phenomena. Specifically, the SEM-derived insights substantiate that the incorporation of SNP at the specified concentration contributes to the enhancement of concrete density, thereby imparting superior durability to the material. This empirical evidence underscores the potential for employing SNP as a strategic additive in cement formulations to achieve resilient and enduring concrete structures, thereby advancing the efficacy of construction materials in civil engineering applications.

4. CONCLUSION

In conclusion, this research establishes that the judicious inclusion of nano-silica particles at a concentration of 3% substantially augments the compressive strength of concrete, substantiated through rigorous testing. The empirical results emphasize the practicality of employing such concrete formulations in retrofitting and repair applications. The refined composition exhibits superior structural performance, indicative of its potential to contribute to sustainable and resilient infrastructure development. This scientific investigation advances our comprehension of nano-material-enhanced concrete, laying a solid foundation for future progress in construction materials and methodologies, especially in retrofitting and repair initiatives. The integration of nano-silica particles in the study demonstrates a conspicuous nucleation effect, prompting additional pozzolanic reactions within the cementitious matrix. This phenomenon significantly contributes to the intensified generation of calcium silicate hydrate (C-S-H) gel, ultimately resulting in a noteworthy enhancement in compressive strength. The expounded mechanism underscores the effectiveness of nano-silica particles as a strategic additive in cement formulations, providing a promising pathway for optimizing material properties in the domain of concrete technology. These findings contribute valuable insights into the nuanced interactions at the nanoscale, guiding future efforts aimed at advancing the performance and sustainability of construction materials. The SEM micrographs provided herein conspicuously illustrate that the replacement of 3% of cement with silica nanoparticles (SNP), as depicted in figure 3, induces a conspicuously more condensed surface morphology. SEM examination elucidates the consolidation of the concrete matrix through discernible surface attributes. The discernibly more consolidated concrete structure, as discerned through SEM, signifies heightened resilience against degradation and atmospheric weathering phenomena. Notably, the SEM-derived observations validate that the infusion of SNP at the designated concentration substantiates the augmentation of concrete density, thereby conferring superior durability to the material.

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