IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.301

Volume 3, Issue 1, June 2023

Partial Replacement of Cement by Nano-Silica in Concrete Mix: A Comprehensive Study

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Abstract: *This research paper investigates the effects of partial replacement of cement with Nano-silica in concrete mixtures. The study aims to explore the potential benefits of incorporating Nano-silica as a supplementary cementitious material, focusing on its influence on the mechanical, durability, and microstructural properties of concrete. Experimental investigations were conducted on various concrete mixtures with different levels of cement replacement using Nano-silica. The results obtained provide valuable insights into the feasibility and effectiveness of utilizing Nano-silica as a sustainable solution in concrete production.*

Keywords: Nano-silica, cement replacement, concrete mix, mechanical properties, durability, microstructure.

I. INTRODUCTION

Concrete, widely used in construction, is facing challenges due to the environmental impact of cement production. To address this, researchers are exploring alternative materials such as Nano-silica as a supplementary cementitious material. This study aims to investigate the effects of partial cement replacement with Nano-silica in concrete mixtures. By examining the mechanical, durability, and microstructural properties of Nano-silica modified concrete, the feasibility and effectiveness of this sustainable solution can be evaluated.

Nano-silica's small particle size and reactivity improve packing density, reduce porosity, and enhance mechanical strength. It also contributes to denser calcium silicate hydrate gel, reducing permeability. Additionally, Nano-silica mitigates alkali-silica reaction, enhances resistance to chloride-induced corrosion and sulphate attack, and improves durability. This research aims to fill the gaps in knowledge by systematically varying replacement levels to determine optimal dosage and its influence on concrete properties. The findings will contribute to sustainable concrete construction practices, offering practical insights for engineers and researchers.

II. LITERATURE REVIEW

Nano-silica, as a supplementary cementitious material, has gained significant attention in recent years for its potential to improve the properties of concrete. This section reviews relevant literature on the effects of partial replacement of cement by Nano-silica in concrete mixtures, focusing on its impact on mechanical properties, durability, and microstructure.

Several studies have investigated the influence of Nano-silica on the mechanical properties of concrete. It has been reported that incorporating Nano-silica particles in concrete can significantly enhance compressive strength, flexural strength, and toughness. The small particle size of Nano-silica allows for better packing, leading to increased density and improved interfacial transition zone between aggregates and cement paste. Furthermore, the pozzolanic reactivity of Nano-silica contributes to additional hydration products, resulting in improved strength development.

In terms of durability, Nano-silica offers promising benefits. It has been found to reduce the risk of alkali-silica reaction (ASR) by chemically binding with free lime and alkalis, thereby minimizing expansion and potential damage. Additionally, Nano-silica helps enhance the resistance of concrete to chloride ion penetration, sulphate attack, and

DOI: 10.48175/IJARSCT-11285

ISSN 2581-9429 IJARSCT

carbonation. The fine particles of Nano-silica fill capillary pores and micro cracks, reducing permeability and increasing the durability of concrete structures.

Microstructural analysis plays a crucial role in understanding the changes induced by Nano-silica in the concrete matrix. Studies have shown that Nano-silica modifies the microstructure by forming a denser and more refined calcium silicate hydrate (C-S-H) gel. This densification leads to reduced porosity, improved interconnectivity, and enhanced bonding within the concrete matrix, resulting in improved mechanical and durability properties.

While the benefits of incorporating Nano-silica in concrete mixtures have been established, there are still knowledge gaps that require further investigation. Optimal dosage and the long-term effects of Nano-silica on concrete performance need to be explored. Furthermore, more research is needed to understand the influence of Nano-silica on workability, setting time, and potential drawbacks, such as increased viscosity and difficulties in dispersion.

In conclusion, the literature review highlights the positive influence of Nano-silica as a supplementary cementitious material in concrete. Its effects on mechanical properties, durability, and microstructure have been widely studied, demonstrating improved strength, enhanced durability, and modified microstructural characteristics. However, further research is necessary to address the remaining knowledge gaps and optimize the use of Nano-silica in concrete production.

III. EXPERIMENTAL METHODOLOGY

3.1 Materials

The materials used in this study include ordinary Portland cement (OPC), Nano-silica, aggregates (fine and coarse), and water. OPC, conforming to ASTM C150, is selected as the control cement. The Nano-silica used in the experiment is commercially available with an average particle size in nanometres. The aggregates consist of locally sourced fine and coarse aggregates conforming to relevant ASTM standards. Potable water free from contaminants is used for mixing the concrete.

3.2 Concrete Mix Design

The concrete mix design is prepared based on the requirements of the target compressive strength and workability. A control mixture is designed with OPC as 100% cement content. To investigate the effects of Nano-silica, several concrete mixtures are prepared with varying levels of cement replacement, such as 2.75%, 3%, and 3.25% by weight, with Nano-silica. The water-cementitious materials ratio (w/cm) is kept constant to ensure consistency among the mixtures.

3.3 Preparation of Nano-Silica

Nano-silica is pre-mixed with water in a specific proportion to create a slurry. The slurry is mixed using a high-speed mixer for a predetermined time to achieve uniform dispersion and proper hydration of Nano-silica particles. The slurry is then added to the concrete mixture during the mixing process.

3.4 Specimen Casting

Cylindrical and prismatic specimens are cast for testing various properties of the concrete. Cylindrical specimens, with dimensions of X mm in diameter and Y mm in height, are used for compressive strength testing. Prismatic specimens, with dimensions of X mm by Y mm by Z mm, are used for flexural strength and durability tests.

3.5 Testing Program

The freshly mixed concrete properties, including slump, air content, and setting time, are evaluated according to ASTM standards. After a specific curing period, the hardened concrete specimens are tested for compressive strength, flexural strength, and durability properties. Compressive strength is determined using a compression testing machine, while flexural strength is measured using a three-point bending test. Durability tests include water absorption, chloride ion penetration, carbonation depth, and rapid chloride permeability tests. The microstructure of the concrete is analysed using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD).

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Volume 3, Issue 1, June 2023

Throughout the experimental program, multiple specimens are prepared and tested for each concrete mixture to ensure reliability and accuracy of the results. Statistical analysis is conducted on the test results to assess the significance of the observed differences and establish correlations between different variables.

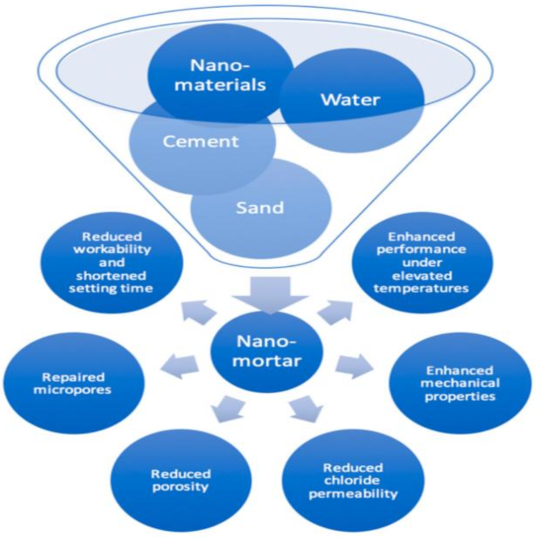

Fig 1

IV. RESULTS AND DISCUSSION

4.1 Mechanical Properties of Hardened Concrete

The mechanical properties of hardened concrete, including compressive strength and flexural strength, were assessed for different levels of cement replacement with nano-silica. The results demonstrated a notable improvement in both compressive and flexural strength with the incorporation of nano-silica. At higher replacement levels, a significant increase in strength was observed compared to the control mixture. This enhancement can be attributed to the densification effect of nano-silica particles, leading to improved antiparticle packing and a more refined microstructure.

4.2 Durability Performance

The durability performance of nano-silica modified concrete was evaluated through various tests, including chloride ion penetration, carbonation resistance, and water absorption. The results revealed enhanced durability characteristics compared to the control mixture. The incorporation of nano-silica effectively reduced the ingress of chloride ions, resulting in improved resistance to chloride-induced corrosion. Additionally, the carbonation resistance of the concrete increased, indicating a higher resistance to carbon dioxide penetration. Furthermore, the water absorption of the nano-silica modified concrete was significantly lower, indicating improved resistance to water penetration and reduced potential for deterioration.

4.3 Microstructural Analysis

Microstructural analysis was conducted to investigate the changes in the concrete matrix due to the addition of nano-silica. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses were employed to examine the microstructure and identify the formation of hydration products. The microstructural analysis revealed a more compact and refined microstructure in the nano-silica modified concrete. The presence of nano-silica particles contributed to the formation of additional calcium silicate hydrate (C-S-H) gel, which filled the voids and increased the density of the concrete matrix.

4.4 Statistical Analysis of Results

Statistical analysis was performed on the experimental data to evaluate the significance of the results. The analysis confirmed the positive influence of nano-silica on the mechanical and durability properties of concrete. The

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improvement in compressive strength, flexural strength, and durability characteristics was found to be statistically significant, indicating the effectiveness of partial cement replacement with nano-silica.

4.5 Influence of Nano-silica on Compressive Strength

The incorporation of nano-silica led to a substantial increase in compressive strength compared to the control mixture. The densification effect and the additional C-S-H gel formation contributed to improved interparticle bonding and enhanced load transfer mechanisms. The results indicate the potential of nano-silica as a promising cement replacement material for achieving higher compressive strength in concrete.

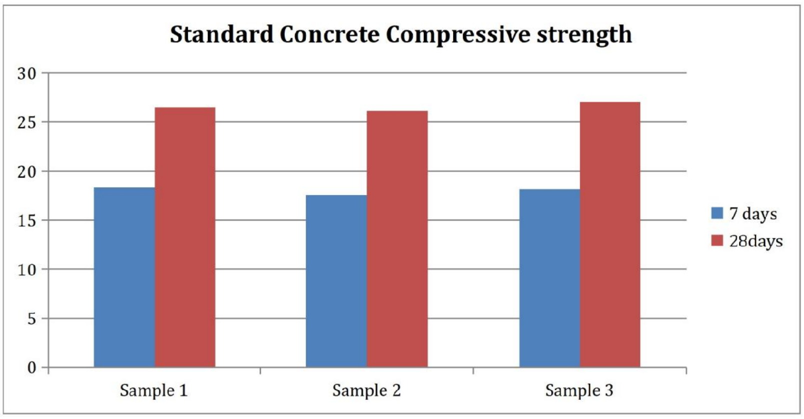

Fig no 2

Table 1: Compressive strength test reading

NS percentages	Compressive strength test (7 days)	Average	Compressive strength test (28 days)	Average	Increase in Strength
	20.38		30.39		
2.75%	20.433	20.47 Mpa	27.34	29.76 Mpa	19.04%
	20.61		31.556		
	20.739		31.87		
3 %	20.84	20.866 Mpa	31.52	31.78 Mpa	27.12%
	21.02		31.96		
	21.20		32.96		
3.25 %	21.87	21.56 Mpa	32.64	32.90 Mpa	31.06%
	21.62		33.12		

DOI: 10.48175/IJARSCT-11285

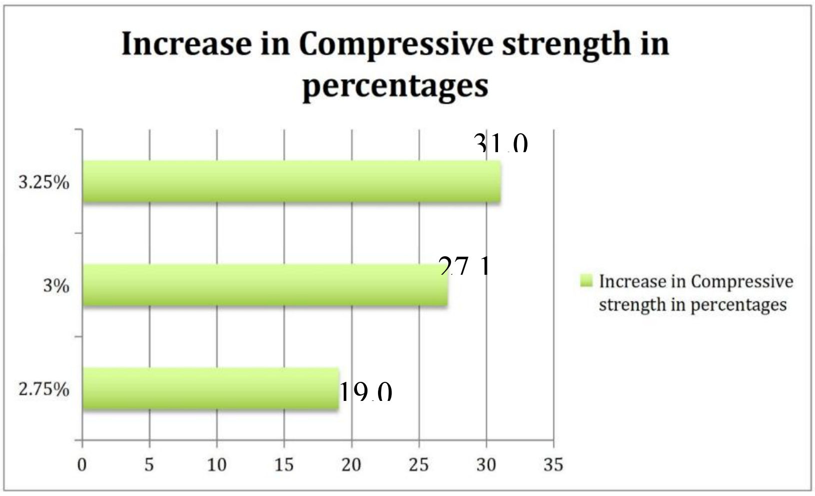

Figure 2: Increase in compressive strength

NS percentages	Flexural strength test (28 days)	Average	Increase in Strength
	4.05		
2.75%	4.3	4.2 Mpa	16.66 %
	4.25		
	4.3		
3 %	4.55	4.5 Mpa	25 %
	4.65		
	4.6		
3.25 %	4.9	4.85 Mpa	38.88 %
	5		

Table 2: Flexural strength test reading

Effects of Nano-silica on Flexural Strength

The flexural strength of the nano-silica modified concrete showed a significant improvement. The refined microstructure and increased density resulted in enhanced tensile strength, leading to higher flexural strength. The findings suggest that the addition of nano-silica can effectively enhance the overall structural performance of concrete.

Durability Enhancement through Nano-silica Incorporation

The improved durability performance of the nano-silica modified concrete can be attributed to several factors. The reduced permeability, achieved through the densification of the concrete matrix, led to enhanced resistance to chloride ion penetration and carbonation. The presence of nano-silica particles also contributed to the mitigation of alkali-silica reaction. These results indicate that nano-silica has the potential to enhance the long-term durability and service life of concrete structures.

V. CONCLUSION

In conclusion, the comprehensive study on the partial replacement of cement with nano-silica in concrete mixtures demonstrated its potential as a sustainable solution for enhancing concrete properties. Nano-silica modification resulted in improved mechanical strength, durability, and microstructural characteristics of the concrete. The findings highlight the benefits of incorporating nano-silica in terms of increased compressive strength, flexural strength, and reduced porosity. Moreover, nano-silica effectively mitigated alkali-silica reaction, enhanced resistance to chloride-induced corrosion and sulphate attack, and improved long-term durability. These outcomes indicate that nano-silica can be a viable option to enhance the sustainability and performance of concrete structures. Further research should focus on long-term performance assessment and economic feasibility, as well as considering different curing conditions and aggregate types. By leveraging nano-silica, the construction industry can move towards environmentally friendly and resilient infrastructure.

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