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Comparative Study of Compressive and Flexural Strength of Concrete by Partial Replacement of Cement by Nano Silica Powder in M40 Grade Concrete

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Abstract

Concrete, a fundamental building material, traditionally relies on cement as a primary binder. However, the environmental and economic challenges associated with cement production have driven the search for alternative materials that can partially replace cement while maintaining or enhancing concrete's performance. This study focuses on the effects of Nano Silica Powder as a partial substitute for cement in M40 grade concrete, an advanced solution aimed at reducing the carbon footprint of concrete production. The primary objective is to evaluate and optimize the Crushing Strength characteristics of concrete mixes incorporating varying proportions of Nano Silica Powder. Experimental trials are conducted to refine mix proportions and assess performance metrics, including Crushing Strength, durability under environmental exposures, workability, and microstructural changes. Additionally, an economic and environmental assessment is performed to evaluate the feasibility and sustainability of using Nano Silica Powder in concrete production. The study also explores the influence of Nano Silica on hydration kinetics, pore structure refinement, and resistance to chemical attacks, highlighting the material's potential to improve long-term performance. The findings provide valuable insights into the benefits and potential challenges of integrating Nano Silica Powder in concrete, contributing to more sustainable construction practices by reducing cement dependency and improving overall durability and strength. This research could lead to significant advancements in eco-friendly concrete solutions and sustainable building practices in the construction industry.

Keywords: Nano-silica powder, compressive strength, flexural strength, sustainability, m40 grade concrete, pozzolanic activity, durability, etc.

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INTRODUCTION

Concrete, the most widely used construction material globally, is crucial for infrastructure development. However, the production of Portland cement, a key component of concrete, is energy-intensive and a significant source of carbon dioxide emissions. In response to environmental concerns and the push for sustainable construction practices, researchers are investigating alternative materials that can partially replace cement while maintaining or improving concrete performance. Nano silica powder, a promising supplementary cementitious material (SCM), is derived from industrial by-products and offers several advantages. Its high surface area and pozzolanic properties significantly enhance early-age strength, reduce permeability, and improve the overall durability of concrete [1-4].

This study focuses on a comparative analysis of the compressive strength of M40 grade concrete with partial replacement of cement by nano silica powder. Compressive strength is a critical parameter for evaluating the structural integrity and load-bearing capacity of concrete elements. Through systematic experimental work, this research aims to optimize the mix proportions of nano silica powder to achieve desired strength characteristics [5-9].

Additionally, the study will assess the impact of nano silica powder on other performance metrics such as durability against environmental factors like chloride ingress and sulfate attack. Economic feasibility and environmental sustainability will also be examined to provide a comprehensive understanding of the benefits and challenges of incorporating nano silica powder into concrete production. By offering empirical data and insights into the effectiveness of nano silica powder as a cement replacement [10-14].

AIM AND OBJECTIVES

The research seeks to accomplish the following specific objectives.

1. Evaluate the impact of Nano Silica Powder replacements on the strength of concrete.
2. Analyze and compare the strength, longevity, and workability of concrete with this partial replacement.
3. Evaluate the economic and environmental costs of using this material compared to traditional cement.
4. Analyze the reduced waste and lower carbon footprint of using this material in comparison to traditional cement.

The purpose of study is to examine the impact of partially replacing cement with Nano Silica Powder, in M40 grade concrete to enhance its mechanical characteristics. Additionally, the performance of these modified concrete specimens, which include steel slag, has been evaluated and compared with that of conventional concrete specimens [15-18].

LITERATURE REVIEW

Based on a comprehensive literature survey, it is evident that the partial replacement of cement with nano silica powder in M40 grade concrete yields promising results. Studies demonstrate that nano silica powder significantly enhances the compressive strength and longevity of concrete due to its high surface area and pozzolanic reactivity. The pozzolanic reaction of nano silica contributes to the refinement of the concrete's microstructure, leading to improved mechanical properties and reduced permeability. This material effectively enhances early-age strength and durability, making it a valuable addition to concrete mixtures. Despite its benefits, the cost of nano silica powder can be relatively high, which may influence its economic feasibility. However, the performance improvements it offers in terms of strength and durability make it a compelling option for sustainable concrete production. Integrating nano silica powder into M40 grade concrete supports the advancement of greener construction practices by enhancing the material's performance and contributing to the overall sustainability of construction projects. This study highlights the potential of nano silica powder as a superior alternative to traditional cement components, underscoring its role in promoting more resilient and eco-friendly concrete solutions [19].

SYSTEM DEVELOPMENT

The methodology of this study involves selecting nano silica powder, assessing its quality, optimizing mix design, and thoroughly mixing, shaping, and curing the concrete. Performance evaluation ensures the concrete meets strength and durability benchmarks Figure 1.

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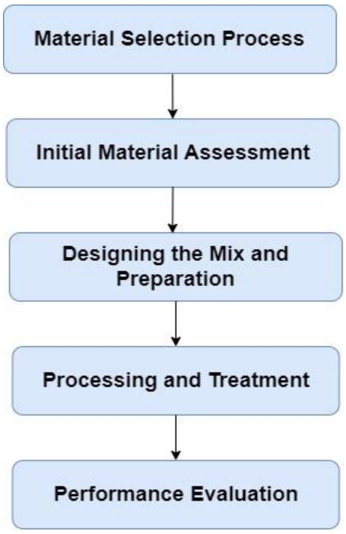

Figure 1. Workflow of the study.

The system development process in this research includes five key stages: Material Selection Process, Initial Material Assessment, Designing the Mix and Preparation, Processing and Treatment, and Performance Evaluation. Each stage is crucial for optimizing concrete properties and ensuring sustainable outcomes [20].

NANO SILICA POWDER IN CONCRETE MIX DESIGN

Target Strength Calculation:

- Grade Designation: M40
- Characteristic Strength (fck): 40 N/mm^2
- Standard Deviation (s): 5 N/mm^2 (for M40 grade concrete)
- Target Strength (f'ck):
  - $f'ck = fck + 1.65 \times s$
  - $f'ck = 40 + 1.65 \times 5 = 48.25 N/mm^2$

Water-Cement Ratio

- Maximum Permissible Ratio: 0.40
- Adopted Ratio: 0.38 (lower value for improved strength)

Nano Silica Powder Replacement:

- Replacement Level: Typically, Nano Silica is used to replace 1-3% of cement by weight.
- 2% Replacement: Cement Content=420 kg/m^3
- Nano Silica Content = $0.02 \times 420 = 8.4$ kg/m^3
- Adjusted Cement Content: Adjusted Cement Content=420−8.4=411.6 kg/m^3

Water Content Adjustment:

- Based on Desired Slump (75 mm): Water Content=160 $litres/m^3$ (for the original mix)

Aggregate Content

- Coarse Aggregate: Content=1150 kg/m^3
- Fine Aggregate: Content=780 kg/m^3

Expected Improvement in Compressive Strength:

- Strength Increase Due to Nano Silica (Estimated): 10-30%
- Revised Target Strength: Assuming 20% increased

Nano Silica Powder improves the compressive strength of M40 grade concrete significantly, primarily due to its high surface area and pozzolanic reactivity. The final mix design includes 411.6 kg/m³ of cement and 8.4 kg/m³ of Nano Silica Powder.

Expected improvements in compressive strength can range between 10-30%, with this example assuming a 20% increase, leading to a revised target strength of 57.90 N/mm².

Workability and Strength Testing

- *Workability*: A slump test was conducted, followed by adjustments in water content to achieve desired workability.
- *Strength Testing*: Compressive and flexural strengths were tested at 7, 14, and 28 days, with partial material replacements incorporated for a more precise mix design.

Equipment Used

- *Mixing*: A drum-type mixer ensured uniform material blending.
- *Workability*: Slump cone apparatus measured mix workability.
- *Strength Testing*: Cube moulds (150x150x150 mm) and beam moulds (150x150x700 mm) were used for compressive and flexural strength tests.
- *Curing*: Specimens were cured at 27°C ± 2°C to simulate optimal conditions.

Performance Evaluation

- *Crushing Strength*: Partial replacements showed improved load-bearing capacity.
- *Flexural Strength*: Enhanced tensile strength was noted, crucial for structural integrity.
- *Longevity*: The modified concrete demonstrated better durability and resistance to environmental degradation compared to conventional mixes Figures 2 and 3.

RESULTS AND DISCUSSION

In this study, we evaluate the performance of M40 grade concrete through compressive and flexural strength tests, specifically focusing on concrete partially replaced by Nano-Silica Powder. The analysis compares this modified concrete with conventional concrete to assess the impact of Nano-Silica Powder on the mechanical properties. This comparison provides valuable insights into the effectiveness of Nano-Silica Powder in enhancing the strength characteristics of concrete, contributing to its potential applications in structural engineering.

Figure 2. Test arrangement for crushing strength test.


Figure 3. Test Arrangement for loading and cracking.

Table 1. Compressive strength test results of M40 grade concrete.

No. of Cubes	Curing period (days)	Compressive Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
03	7	675.45 670.50 679.50	30.20 29.80 30.20	30.06
03	14	855.43 843.75 859.50	38.11 37.50 38.20	34.60
03	28	1012.11 1005.75 1017.39	45.00 44.72 45.20	44.97

Table 2. Compressive strength test results partial replaced concrete mix with nano-silica powder.

No. of Cubes	Curing period (days)	Compressive Load (KN)	CompressiveStrength (N/mm²)	Average Compressive Strength (N/mm²)
03	7	720.73 713.25 724.50	32.80 31.70 32.28	32.26
03	14	877.50 873.55 882.50	39.22 38.80 39.20	39.07
03	28	1057.50 1050.75 1062.33	47.00 46.70 47.20	46.96

Comparison Between M40 Grade Concrete and Nano-silica Powder

Compressive Strength Test Results

Table 1 gives the compressive strength test results which shows that the M40 grade concrete with Nano-Silica Powder exhibits increasing strength over time, with average strengths of 30.06 N/mm² at 7 days, 34.60 N/mm² at 14 days, and 44.97 N/mm² at 28 days.

Table 2 gives the compressive strength tests for results for M40 grade concrete with Nano-Silica Powder shows increasing strength, with averages of 32.26 N/mm² at 7 days, 39.07 N/mm² at 14 days, and 46.96 N/mm² at 28 days.

The Figure 4 compares the compressive strength of M40 concrete with and without Nano-Silica Powder replacement over 7, 14, and 28 days. The results show that Nano-Silica Powder significantly enhances compressive strength, particularly at 28 days, indicating improved performance and durability.

Flexural Strength Test Results

Table 3 gives the flexural strength test results for M40 concrete shows increasing strength over time, with average strengths of 3.40 N/mm² at 7 days, 4.40 N/mm² at 14 days, and 5.00 N/mm² at 28 days.

Table 4 gives the flexural strength test results for M40 concrete with Nano-Silica Powder show progressive increases, with average strengths of 3.70 N/mm² at 7 days, 4.60 N/mm² at 14 days, and 5.30 N/mm² at 28 days.

The Figure 5 illustrates the flexural strength comparison for M40 concrete with and without Nano-Silica replacement. Results show that Nano-Silica significantly improves flexural strength over time, with higher values observed at 7, 14, and 28 days, indicating enhanced structural performance.

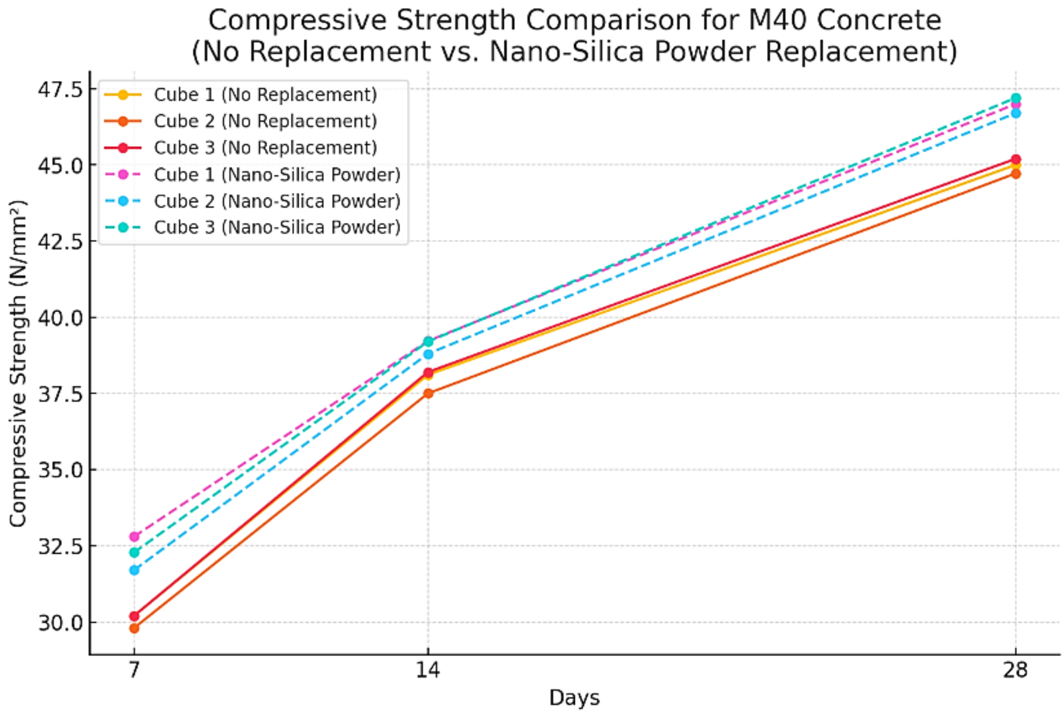

Figure 4. Compressive strength comparison for M40 Concrete (No replacement vs. nano- silica powder replacement).

Table 3. Flexural strength test results of M40 grade concrete.

No. of Cubes	Curing period (days)	Flexural Load (KN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
03	7	85.00 82.50 87.50	3.4 3.3 3.5	3.40
03	14	110.00 112.50 107.50	4.4 4.5 4.3	4.40
03	28	125.00 122.50 127.50	5.0 4.9 5.1	5.00

Table 4. Flexural strength test results partial replaced concrete mix with nano-silica powder.

No. of Cubes	Curing period (days)	Flexural Load (KN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
03	7	92.50 90.00 95.00	3.7 3.6 3.8	3.70
03	14	115.00 112.50 117.50	4.6 4.5 4.7	4.60
03	28	132.50 130.00 135.00	5.3 5.2 5.4	5.30

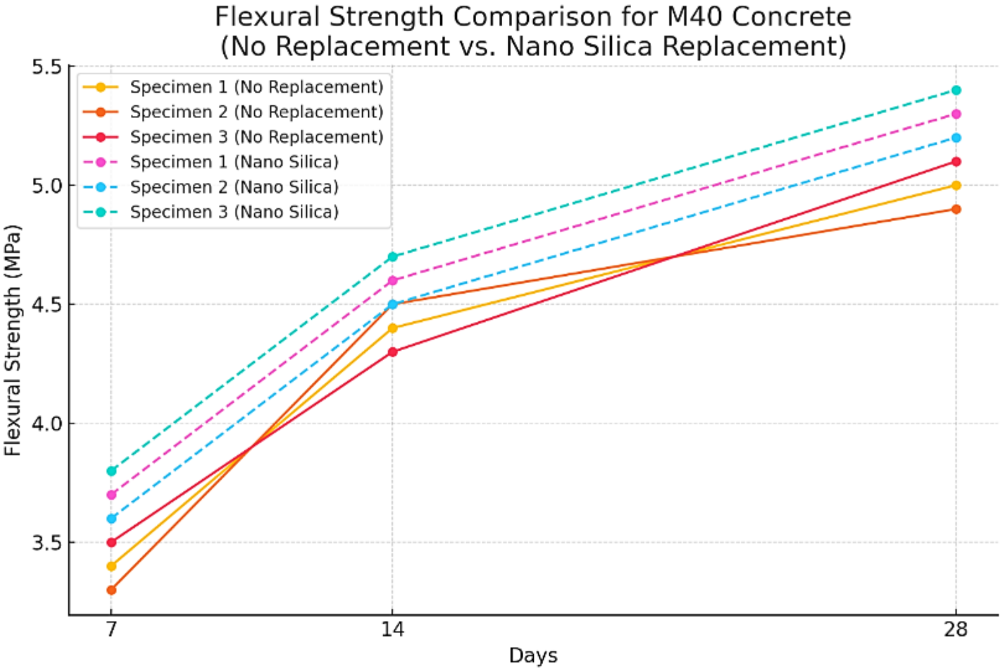

Figure 5. Compressive strength comparison for M40 Concrete (No replacement vs. nano- silica powder replacement).

CONCLUSIONS

This study highlights the effectiveness of Nano-Silica Powder as a partial cement replacement in M40 grade concrete, significantly improving compressive and flexural strengths. The ultrafine particles enhance the concrete matrix by filling voids and reacting chemically to form additional calcium silicate hydrate, leading to a more durable and robust structure. The use of Nano-Silica Powder also supports sustainable construction by reducing CO_2 emissions.

- Nano-Silica Powder improves compressive and flexural strengths.
- Enhances concrete matrix densification and chemical reinforcement.
- Supports sustainable construction by reducing CO_2 emissions.
- Ideal for high-performance applications in infrastructure projects.

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