

An Experimental Study on Improving Mechanical Properties of Concrete Using Nanoparticles

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Abstract- This publication summarizes an experimental investigation on improving the mechanical properties of concrete using nanoparticles such as nano-silica, nano-alumina, and nano-titania. The study focused on enhancing compressive strength, split tensile strength, flexural strength, and durability of M30 grade concrete. Different percentages of nanoparticles including 1%, 2%, and 3% were incorporated into concrete mixes and tested after 7, 14, and 28 days of curing. The results demonstrated that nanoparticles significantly improve concrete performance, particularly at 2% dosage where the maximum strength enhancement was observed. The research confirms that nanoparticle-based concrete can be used in modern infrastructure for improved strength, durability, and sustainability.

I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world. It is extensively used in buildings, bridges, dams, highways, and industrial structures because of its high compressive strength and availability. However, conventional concrete has limitations such as low tensile strength, brittleness, crack formation, and permeability issues.

To overcome these limitations, researchers have introduced nanotechnology into construction materials. Nanotechnology involves the use of particles with dimensions between 1 and 100 nanometers. Due to their extremely small size and high surface area, nanoparticles exhibit enhanced chemical and physical properties.

When nanoparticles are added to concrete, they improve hydration reactions, fill microscopic pores, and strengthen the bond between cement paste and aggregates. Nano-silica, nano-alumina, and nano-titania are among the most commonly used nanoparticles in concrete technology.

These nanoparticles improve strength, durability, and crack resistance while reducing porosity and permeability.

II. OBJECTIVES OF THE STUDY

The major objectives of the study were:

- To investigate the influence of nanoparticles on concrete properties.
- To improve compressive strength of concrete.
- To enhance split tensile strength and flexural strength.
- To determine the optimum percentage of nanoparticle addition.
- To evaluate the durability and microstructural improvements in concrete.
- To compare the behavior of normal concrete and nano-modified concrete.

The study aimed to develop high-performance concrete suitable for sustainable and durable infrastructure applications.

III. LITERATURE REVIEW

Several researchers have studied the use of nanoparticles in concrete. Nano-silica has been identified as the most effective nanoparticle because of its high pozzolanic activity. It accelerates cement hydration and increases calcium silicate hydrate gel formation, resulting in higher strength.

Li et al. (2004) reported that nano-silica increased compressive strength by approximately 25–30%. Jo et al. (2007) observed improved microstructure and reduced pore size in nano-modified concrete. Senff et al. (2009) found that nanoparticles reduce workability because of their high surface area.

Nano-alumina improves early-age strength and chemical resistance, while nano-titania provides self-cleaning and photocatalytic properties. Although many studies have been conducted, there remains a need for comparative investigations and optimization of nanoparticle dosage under practical conditions.

IV. MATERIALS USED

The experimental investigation used the following materials:

Cement:

Ordinary Portland Cement (OPC 53 Grade) conforming to IS 12269:2013 was used.

Fine Aggregate:

River sand conforming to Zone II grading as per IS 383:2016 was used.

Coarse Aggregate:

Crushed stone aggregate of 20 mm maximum size was used.

Water:

Potable water with neutral pH was used for mixing and curing.

Nanoparticles:

- Nano-silica (SiO_2)
- Nano-alumina (Al_2O_3)
- Nano-titania (TiO_2)

The nanoparticles possessed extremely fine particle size and high reactivity, making them suitable for improving concrete performance.

V. MIX DESIGN AND METHODOLOGY

M30 grade concrete was selected for the study with a water-cement ratio of 0.45. The concrete mixes were prepared by partially replacing cement with nanoparticles in different proportions.

Mix Variations:

- M0 – Control Mix (0% nanoparticles)
- M1 – 1% nanoparticles
- M2 – 2% nanoparticles
- M3 – 3% nanoparticles

Concrete specimens were prepared in the form of cubes, cylinders, and beams for testing compressive strength, split tensile strength, and flexural strength respectively.

The specimens were cured for 7, 14, and 28 days before testing. Standard IS code procedures were followed for specimen preparation, curing, and testing.

Care was taken to ensure uniform mixing and proper dispersion of nanoparticles to avoid agglomeration.

VI. EXPERIMENTAL RESULTS

The experimental results showed significant improvement in mechanical properties due to the addition of nanoparticles.

Compressive Strength:

At 28 days, the compressive strength of the control mix was 35 MPa, while the 2% nanoparticle mix achieved 45 MPa, representing an increase of approximately 28%.

Split Tensile Strength:

The split tensile strength improved from 3.2 MPa in conventional concrete to 4.5 MPa in the 2% nanoparticle mix, showing nearly 40% improvement.

Flexural Strength:

Flexural strength increased from 4.5 MPa to 6.0 MPa with the addition of nanoparticles.

The maximum improvement was observed at 2% nanoparticle dosage. Beyond this level, strength slightly decreased due to particle agglomeration and poor dispersion.

VII. DISCUSSION

Nanoparticles improved the performance of concrete through several mechanisms. They filled micro-pores and voids within the concrete matrix, resulting in denser and stronger concrete.

Nanoparticles also accelerated cement hydration and increased the formation of calcium silicate hydrate gel.

The improved microstructure reduced permeability and crack propagation. Nano-modified concrete exhibited better resistance to cracking and gradual failure behavior compared to normal brittle concrete.

However, the addition of nanoparticles reduced workability because of their high surface area and water absorption characteristics. Therefore, the use of superplasticizers is recommended for practical applications.

VIII. ADVANTAGES AND APPLICATIONS

Nanoparticle-based concrete offers several important advantages:

- Improved compressive, tensile, and flexural strength.

- Enhanced durability and reduced permeability.
- Better resistance to chemical attack and cracking.
- Reduced maintenance and repair costs.
- Sustainable construction due to reduced cement consumption.

Applications of nanoparticle concrete include:

- High-rise buildings
- Bridges and flyovers
- Marine structures
- Pavements and highways
- Smart infrastructure systems
- Industrial floors and precast structures

The use of nanotechnology can significantly improve the lifespan and performance of infrastructure.

LIMITATIONS AND FUTURE SCOPE

The study was limited to laboratory-based experimental investigations and short-term curing periods. Long-term durability tests such as freeze-thaw resistance, chemical exposure, and marine environment performance were not investigated.

Future research should focus on:

- Long-term durability studies.
- Hybrid nanoparticle combinations.
- Large-scale field applications.
- Advanced SEM and XRD analysis.
- Economic feasibility analysis.
- Optimization of nanoparticle dispersion

methods.

Further studies can help in commercial implementation of nanoparticle-based concrete technology.

CONCLUSION

The study confirmed that nanoparticles significantly improve the mechanical and durability properties of concrete. Among all mixes, the 2% nanoparticle dosage produced the best performance in terms of compressive strength, tensile strength, and flexural strength.

Nano-silica proved to be the most effective nanoparticle due to its high pozzolanic activity and ability to improve the microstructure of concrete. Although workability decreased with increasing nanoparticle content, the problem can be solved using suitable chemical admixtures.

The research demonstrates that nanotechnology has great potential in the field of civil engineering and can contribute to the development of sustainable, durable, and high-performance infrastructure.