**EFFECT OF NANOSILICA INCORPORATION ON THE WORKABILITY AND MECHANICAL PROPERTIES OF CONCRETE**

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**ABSTRACT**

Nanosilica (NS) has emerged as a promising additive in concrete technology due to its ability to enhance mechanical performance and durability. This study investigates the impact of nanosilica incorporation on the workability and mechanical properties of concrete. Nanosilica particles, with their high surface area and pozzolanic reactivity, improve the microstructure of the cementitious matrix. However, their inclusion reduces workability due to increased water demand and particle agglomeration. To counteract this, superplasticizers were employed in varying dosages. Experimental results show that while the slump and flow values decrease with increasing NS content, compressive strength, flexural strength, and tensile strength exhibit significant improvement. The enhanced mechanical properties are attributed to the densification of the interfacial transition zone (ITZ) and the accelerated hydration process facilitated by nanosilica. An optimum dosage of NS was identified to balance workability and strength. The findings underscore the potential of nanosilica as a supplementary cementitious material for developing high-performance concrete with enhanced sustainability.

**INTRODUCTION**

Concrete is one of the most widely used construction materials in the world, valued for its strength, durability, and versatility. However, the growing demand for high-performance and environmentally sustainable concrete has led researchers to explore the use of advanced materials to enhance its properties. Among these materials, nanosilica (NS) has emerged as a promising additive due to its unique characteristics and potential to significantly improve concrete performance.

Nanosilica is a nanostructured material with extremely small particle size and a high specific surface area, which makes it highly reactive. When incorporated into concrete, nanosilica can accelerate the hydration process and improve the formation of calcium silicate hydrate (C-S-H), the main binding component in cement. Additionally, nanosilica fills the microvoids in the concrete matrix, particularly in the interfacial transition zone (ITZ), leading to a denser and more durable structure. These benefits translate into enhanced compressive strength, tensile strength, and overall durability.

Despite these advantages, the use of nanosilica also presents challenges. Its small particle size and high reactivity can reduce the workability of concrete by increasing water demand and promoting particle agglomeration. This creates a need to carefully balance nanosilica dosage and often requires the use of superplasticizers to maintain adequate flow and slump in concrete mixtures.

This study focuses on examining the effects of nanosilica incorporation on the workability and mechanical properties of concrete. By exploring the balance between improved strength and reduced workability, this research aims to provide insights into optimizing nanosilica dosage for practical applications in construction.

**HISTORY**

The use of supplementary materials to enhance the properties of concrete dates back centuries, with natural pozzolans, such as volcanic ash, being used in ancient Roman structures. These materials contributed to the remarkable durability of Roman concrete, which has stood the test of time. Over the years, the construction industry has continually sought ways to improve concrete performance, particularly with the development of modern high-performance and sustainable concretes.

Early studies on nanosilica in concrete focused on its chemical reactivity and its ability to enhance hydration, producing more calcium silicate hydrate (C-S-H) and reducing porosity in the interfacial transition zone (ITZ). By the mid-2000s, researchers had begun to recognize its potential to significantly improve the compressive and tensile strength of concrete, as well as its durability against chemical attacks and environmental degradation.

As understanding of nanosilica’s benefits grew, challenges such as its tendency to agglomerate and its impact on workability emerged. This led to the development of techniques to disperse nanosilica effectively and optimize its dosage in concrete mixtures. The use of superplasticizers and other additives became common to address these challenges, paving the way for nanosilica to become a viable component in high-performance concrete.

**CEMENT-COMPOSITION AND HYDRATION**

**Cement is the key binding material in concrete, made by heating a mixture of limestone and clay to form clinker, which is then ground into a fine powder. The main components of Portland cement are tricalcium silicate (C₃S), dicalcium silicate (C₂S), tricalcium aluminate (C₃A), and tetracalcium aluminoferrite (C₄AF).**

**C₃S is responsible for early strength development by reacting quickly with water, while C₂S contributes to long-term strength through slower reactions. C₃A reacts rapidly and releases heat, requiring gypsum to control its reaction. C₄AF has a minor role in strength but affects the cement’s color.**

**When water is added, cement undergoes hydration, forming calcium silicate hydrate (C-S-H) and calcium hydroxide (CH). These compounds bind the materials together, giving concrete its strength. Hydration occurs in stages, starting with an initial reaction, followed by a dormant period, setting, and finally hardening.**

**This process determines the concrete’s strength and durability. Enhancing hydration with materials like nanosilica can refine the structure and improve performance.**

**NANOMATERIALS-USE IN CONCRETE**

Nanomaterials are increasingly used in concrete to improve its mechanical properties, durability, and sustainability. These materials operate at the nanoscale, significantly influencing the microstructure of the concrete matrix.

1. Nanosilica (NS): Nanosilica is the most commonly used nanomaterial in concrete. It enhances strength and durability by filling microvoids, refining the interfacial transition zone (ITZ), and accelerating cement hydration.

2. Nano-Titanium Dioxide (Nano-TiO₂): This material is often used for its photocatalytic properties. It helps concrete surfaces stay clean by breaking down organic pollutants and offers self-cleaning and air-purifying benefits.

3. Carbon Nanotubes (CNTs): CNTs improve the tensile strength, crack resistance, and flexibility of concrete. They also enhance the electrical conductivity, making concrete suitable for advanced applications like smart infrastructure.

4. Nanoclays: These materials improve workability, reduce permeability, and enhance the durability of concrete by controlling moisture movement within the mix.

5. Graphene and Graphene Oxide: Graphene-based materials enhance the strength and durability of concrete. They also improve thermal and electrical conductivity, making concrete more versatile.

**COMPRESSIVE STRENGTH TEST**

The compressive strength test is one of the most important tests to evaluate the performance of concrete. It measures the ability of concrete to withstand axial loads without failure. The test is typically conducted on concrete cubes or cylinders that are cured for a specified period, usually 28 days, to allow for optimal hydration.

To conduct the test, the sample is placed in a hydraulic press, and a gradually increasing load is applied until the specimen fractures. The maximum load sustained by the sample is recorded, and the compressive strength is calculated by dividing the load by the cross-sectional area of the specimen.

Compressive strength is a key indicator of the concrete’s quality and is directly related to its mix design, material properties, and curing conditions. Higher compressive strength usually means stronger, more durable concrete, which is essential for structural applications**.**

**FRACTURE BEHAVIOUR**

Fracture behavior in concrete refers to how the material responds to stress beyond its elastic limit, leading to cracking and failure. Concrete is generally strong in compression but weak in tension, which makes it prone to cracking under stress. When concrete experiences a load that exceeds its tensile strength, microcracks form and propagate, eventually leading to larger cracks and structural failure.

The fracture process in concrete is complex and influenced by factors like the mix design, type of aggregates, curing conditions, and the presence of additives such as fibers or nanomaterials. Fracture behavior can be characterized by crack initiation, crack propagation, and the final failure. Understanding these mechanisms is crucial for designing more durable and crack-resistant concrete structures.

Incorporating materials like fibers or nanomaterials can improve the fracture toughness of concrete, helping to control crack propagation and enhance the material's overall performance under load.

**RATE OF HYDRATION**

The rate of hydration refers to how quickly the chemical reactions between cement and water occur after mixing. It is a crucial factor in determining the setting time and early strength development of concrete. Initially, hydration is rapid, especially for compounds like tricalcium silicate, which releases heat and forms calcium silicate hydrate (C-S-H) and calcium hydroxide.

As the hydration progresses, the rate slows down, with dicalcium silicate continuing to react more slowly over time, contributing to the long-term strength of the concrete. The rate of hydration can be influenced by factors like temperature, water-to-cement ratio, and the presence of accelerators or retarders.

Understanding and controlling the rate of hydration is important for ensuring proper curing, preventing early cracking, and achieving the desired strength and durability in concrete.

**MICROSTRUCTURE**

The microstructure of concrete refers to the arrangement and interaction of its components at the microscopic level. It plays a key role in determining the material's strength, durability, and overall performance. The main components of concrete—cement, aggregates, and water—combine during hydration to form a dense network of calcium silicate hydrate (C-S-H) gel and other hydration products that bind the material together.

At the micro level, the interfacial transition zone (ITZ) between the cement paste and aggregates is critical. A weak ITZ can compromise the overall durability and strength of the concrete. The presence of fine pores and microcracks within the paste can also affect its mechanical properties.

By modifying the microstructure through additives like nanosilica or fibers, the density and homogeneity of the material can be improved, leading to better strength, lower permeability, and enhanced resistance to environmental factors.

**EFFECT OF SIZE AND TYPE OF NANOSILICA AND MIXING**

The size and type of nanosilica (NS) used in concrete can significantly affect its properties. Nanosilica particles have a high surface area, which enhances the cement hydration process by providing more sites for chemical reactions. Smaller nanoparticles generally have a more significant impact on improving strength and durability because they fill the voids in the concrete's microstructure more effectively, leading to a denser and stronger matrix.

Different types of nanosilica, such as fumed silica or precipitated silica, vary in their reactivity and surface characteristics. Fumed silica, for example, is highly reactive and can contribute more to the development of early strength, while precipitated silica might provide longer-term benefits by enhancing the microstructure over time.

How nanosilica is mixed into the concrete is also crucial. Proper dispersion of nanoparticles is necessary to avoid agglomeration, which can reduce their effectiveness. This often requires the use of superplasticizers or advanced mixing techniques to ensure that the nanosilica is evenly distributed throughout the mix. Well-dispersed nanosilica improves the concrete's overall performance, enhancing both workability and mechanical properties.

**FUTURE SCOPE**

1. Optimized Mix Designs

Development of cost-effective and eco-friendly concrete mixtures incorporating Nano silica.

Exploration of hybrid nanoparticles to enhance performance further.

2. Sustainability

Use of Nano silica to reduce cement content in concrete, lowering carbon emissions.

Integration with recycled materials to promote circular construction practices.

3. Enhanced Durability

Investigation of Nano silica's impact on long-term durability under aggressive environments like marine, freeze-thaw, and sulfate attack conditions.

4. Industrial Applications

Adoption of Nano silica in ultra-high-performance concrete (UHPC) for infrastructure requiring superior strength and durability.

Application in 3D printing concrete to improve printability and structural integrity.

5. Nanotechnology Advancements

Exploration of advanced Nano silica formulations with controlled particle size and surface modifications for tailored properties.

Development of multifunctional Nano silica-based additives for self-healing and thermal insulation.

6. Standardization and Scalability

Establishment of standards for Nano silica use in construction.

Scaling up production and reducing costs for widespread adoption.

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