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# REDUCING POROSITY AND INCREASING STRENGTH OF CONCRETE THROUGH THE INCORPORATION OF SILICA FUME AND NANO-SILICA: EXPERIMENTAL INVESTIGATION AND CHARACTERIZATION

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## Abstract

The paper discusses experiments conducted to examine the effects of nano-SiO2 on concrete properties. The results showed that adding nano-SiO2 improved the compressive strength and reduced porosity of the concrete. However, beyond a certain concentration, the benefits reached a plateau. Flexural strength also increased with nano-SiO2, The addition of nano-SiO2 reduced capillary absorption, indicating improved water resistance. Overall, while nano-SiO2 showed some improvements, and further research is needed to optimize concrete mix designs

**Keywords:** Silica Fume, Nano Silicon Dioxide, Porosity.

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## Introduction

### 1.1 Overview

Nanotechnology is a burgeoning field of engineering that focuses on the manipulation of particles ranging from 1 to 100 nanometers (nm) in size (Farokhzad, OC, & Langer, R., 2009). Coined by Norio Taniguchi of Tokyo University of Science in 1974 (Taniguchi, N.ib., 1974), nanotechnology finds its primary applications in semiconductors through techniques like thin film deposition. The production of nanomaterials involves processes such as deformation, consolidation, and separation of raw materials at the molecular or atomic level. Nanotechnology plays a pivotal role in various fields including medicine, agriculture, engineering, military applications, computing, and astronomy.

Several noteworthy applications of nanotechnology have already made significant impacts, such as the utilization of nanoparticles in sunscreens, personal hygiene products, antibacterial socks, and lipsticks. In the realm of drug delivery, nanotechnology has revolutionized the development of many drugs, including chemotherapy. It enables precise targeting of cancer cells and reduces the side effects associated with conventional administration methods (Farokhzad, O.C., and Langer, R., 2009).

Nanomaterials are now integrated into fabrics to enhance performance and durability. For instance, materials as small as 2nm and nanofibers are incorporated into waterproof and water-resistant clothing. The increased surface area-to-volume ratio of nanoparticles enhances their reactivity in chemical and biological processes. Metal nanoparticles, for example, prove effective in groundwater purification due to their superior efficacy compared to larger particles. Carbon nanoparticles possess exceptional strength, contributing to the durability of buckyballs, nanotubes, and even soft protective jackets (Coyle, S. et al., 2007).

Moreover, nanomaterials play a vital role in the creation of silicon surfaces, utilizing techniques like thin-film deposition, which are essential for producing mirrors, sensor components, and airbag electrical circuits. They are also instrumental in the manufacturing of microelectromechanical systems (MEMS) and individual chips, offering advantages such as smaller sizes and lower costs compared to traditional materials. MEMS serves as the foundation for nanoelectromechanical systems (NEMS) (Liu, G., 2009).

However, it is important to note that nanoparticles have been associated with various health concerns, including lung diseases. Their minute size allows them to penetrate the lungs, posing risks to respiratory health. Additionally, nanoparticles have the potential to damage DNA and organs, indicating that the body may not readily tolerate new substances (Maynard, A).

#### 1.1.1 Concrete

Researchers are actively exploring the use of nanomaterials to enhance the durability and strength of various materials, particularly in conjunction with Portland cement (PC). PC is a key component of concrete and is produced by crushing and burning lime, concrete, and clay. Concrete has a long history of use, dating back to ancient civilizations such as the Babylonians, Egyptians, and Romans. Over time, advancements and improvements have been made through experimentation and trial and error (InterNACHI, 2018).

Concrete is typically composed of cement, sand, gravel, and water. To alter its chemical composition and enhance its properties, small particles known as additives are incorporated. These additives play a crucial role in improving the performance, strength, and, most importantly, durability of concrete. Commonly used mineral additives include pozzolan, silica, and fly ash. These additives exhibit pozzolanic properties, contributing to reduced permeability, lowered production costs, increased concrete strength, and enhanced hardness.

Water-reducing agents: Water-reducing agents can reduce the water content in concrete by 15% to 30% after the mixing process. They have a rapid action and are typically added to the ready-mix concrete on-site. Superplasticizers, a type of water-reducing agent, have a short lifespan and tend to lose their effectiveness within an hour (Gharpedia, 2018).

Air entrainment: Air entrainment involves creating air pockets within the concrete matrix. This improves the concrete's ability to withstand water expansion without sustaining damage, thereby enhancing its durability.

Silica fume (SF): Silica fume can be mixed with cement or used as a substitute. When combined with cement, it increases the porosity and compressive strength of concrete. However, the use of silica fume may require additional water compared to using cement alone (Toutanji, H.A. and El-Korchi, T., 1995).

Fly ash (FA): Fly ash is an additive that exhibits pozzolanic properties when added to concrete. Its incorporation offers several advantages, including improved performance in fresh and hardened conditions, enhanced durability, and plasticity of the concrete. Additionally, fly ash reduces the water requirement for plastic concrete (Marthong and Agrawal, 2012, p. 1990).

Furthermore, when discussing nanoparticles, it's important to note that they are particles smaller than 100 nm. Various methods, such as Cary-5E spectrometry, BET (Brunauer-Emmett-Teller) method, and transmission electron microscopy, can be used to determine their size and distribution. Smaller nanoparticles tend to have a finer and more filler-like nature (Maiyalagan, T. et al., 2006). . (See figure 1.)

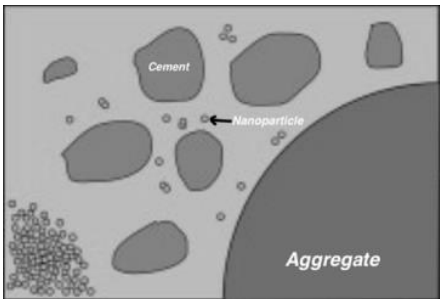

Fig 1. Size of nanoparticles compared to cement and aggregate

Using the values in the tables below, the ratios of the amounts to be used in concrete preparation should be adhered to to obtain best results.

Table 1. Recommended Dosages of Mineral Admixtures Materials for High Strength

| S. No | Mineral Admixtures | Percentage by Mass of Total Cementitious Materials |
|---|---|---|
| 1 | Fly ash | 15 - 30 |
| 2 | Ground granulated blast furnace slag | 25 - 50 |
| 3 | Metakaoline | 5 - 15 |
| 4 | Silica fume | 5 - 10 |

Table 2 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine

| S. No | Nominal Maximum Size of Aggregate (mm) | Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate | | |
|---|---|---|---|---|
| | | Zone I | Zone II | Zone III |
| 1 | 10.0 | 0.56 | 0.54 | 0.52 |
| 2 | 12.5 | 0.58 | 0.56 | 0.54 |
| 3 | 20 | 0.68 | 0.66 | 0.64 |

Table 3 Chemical compositions of PC and SF [Effect of Silica Fume on the Properties of Self-Compacted Light Weight Concrete]

| Chemical composition of silica fume and Portland cement | | |
|---|---|---|
| Chemical composition | PC (%) | SF (%) |
| CaO | 63.35 | 2 |
| SiO2 | 19.85 | 95.5 |
| Al2O3 | 4.85 | 1.7 |
| Fe2O | 3.7 | 0.4 |
| SO3 | 3.12 | - |
| MgO | 2.34 | 0.1 |
| Na2O | 0.22 | - |
| K2O | 0.76 | - |
| Compound (%) | | |
| C3S | 47.55 | |
| C2S | 27.3 | |
| C3A | 9.4 | |
| C4AF | 10.65 | |

### 1.1.2 Size of Nano Particles

Nanoparticles play a crucial role in preventing water penetration into concrete by reducing pore volume and increasing concentration within the material. This ability stems from their unique characteristics and properties.

The presence of nanoparticles in concrete leads to a reduction in pore volume, which means there are fewer open spaces or voids for water to enter. By decreasing the pore volume, nanomaterials restrict the movement of water molecules, thus inhibiting water ingress.

Additionally, nanoparticles enhance the concentration of the concrete mixture. When incorporated, they contribute to the formation of a denser and more compact structure. This increased concentration further hinders water penetration into the concrete.

Overall, the use of nanomaterials in concrete effectively reduces pore volume, making the material more resistant to water ingress. This improvement in water resistance is a significant benefit provided by nanotechnology in the construction industry , alsothe use of nanotechnology in concrete improves its water resistance by reducing pore volume and increasing concentration. This advancement in the construction industry helps enhance the durability and longevity of concrete structures, offering significant benefits in terms of sustainability and maintenance.

## Literature References

This research study aims to examine the impact of nano-silica on both porosity and strength in concrete. Previous research on the subject has been limited, particularly in exploring the combination of nano-silica with silica fume and its effect on porosity. Silica, in the form of silicon oxide nanoparticles (nano-SiO2), is abundantly available in the earth's crust and possesses desirable mechanical and chemical properties such as strength and porosity. This has led to its widespread use in various industries.

Table 2. 1 property of quartz and fused silica [Materials and structures]

| Material | Quartz | Fused Silica |
|---|---|---|
| Density (g/cm3) | 2.65 | 2.2 |
| Thermal Conductivity (Wm-1 K) | 1.3 | 1.4 |
| Thermal expansion coeff (10-6K-1) | 12.3 | 0.4 |
| Tensile Strength (MPa) | 55 | 110 |
| Compressive Strength (MPa) | 2070 | 690-1380 |
| Poisson’s Ratio | 0.17 | 0.165 |
| Fracture Toughness (MPa) | - | 0.79 |
| Melting Point (°C) | 1830 | 1830 |
| Modulus of Elasticity (GPa) | 70 | 73 |

Studies conducted by Supit, S. W. M. and Shaikh, F. U. A. have demonstrated the addition of silica-based materials, including fly ash, consolidated sand concrete, ceramic sand, and glass refractories, resulting in increased strength and reduced porosity.

Goltermann, P. et al. discussed the concept of high packing density and void content minimization, which led to low cement consumption, low porosity, and low shrinkage, contributing to high-performance concrete mixes.

Haruehansapong, S. et al. found that adding nano-silica to cementitious pastes increased compressive strength and reduced porosity. Berra, M. et al. observed an increase in compressive strength of 30% after three days and 22% after 28 days of curing when nano-silica was added. The bond strength and flexural strength were also enhanced proportionally. Proper adjustment of superplasticizer and water ratios is necessary to prevent cracking and self-desiccation when adding nano-silica.

Jalal, M. et al. investigated the durability of high-strength self-compacting concrete containing silica fume and nano-silica, considering factors such as water absorption, chloride penetration, and electrical resistivity. The addition of these admixtures resulted in reduced chloride ion penetration and water absorption, improving the resistance to corrosion.

Givi, A. N. et al. examined the effects of different sizes of nano-SiO2 particles (80 nm and 15 nm) on flexural strength, tensile strength, and compressive strength in binary blended concrete. The study found that specimens with a diameter of 15 nm exhibited higher strength in the initial curing period, while the 80 nm particles demonstrated greater Calcium-Silicate-Hydrate (C-S-H) gel formation after 90 days.

When incorporating nano-SiO2 into the concrete mix, the dispersion of nanoparticles and their settling within the mixture play significant roles in determining the qualities and properties of the resulting concrete. Proper attention should be given to mixing procedures to ensure effective dispersion of the nanomaterial.

Further research is recommended to explore additional effects, such as acidity, sulphate resistance, corrosion, and carbonation. Moreover, optimization studies on nanoparticles relative to other ingredients in concrete are suggested for future investigation.

## Summary

The article discusses the field of nanotechnology and its applications in various industries, focusing on its impact on concrete. Nanotechnology involves manipulating particles ranging from 1 to 100 nanometers in size. It has found applications in medicine, agriculture, engineering, military, computing, and astronomy.

In the realm of drug delivery, nanotechnology has revolutionized the development of drugs, allowing for precise targeting of cancer cells and reducing side effects. Nanomaterials are also integrated into fabrics to enhance performance and durability, and they play a role in manufacturing silicon surfaces, mirrors, sensor components, and microelectromechanical systems (MEMS).

However, it is important to consider the potential health risks associated with nanoparticles, including lung diseases and organ damage. Despite these concerns, nanoparticles are being explored to enhance the durability and strength of materials, particularly in concrete. Additives such as fly ash, silica fume, and water-reducing agents are commonly used to improve the properties of concrete.

Nanoparticles reduce pore volume and increase concentration in concrete, making it more resistant to water ingress. This improvement in water resistance enhances the durability and longevity of concrete structures. The article also references various studies that demonstrate the positive effects of nano-silica on porosity and strength in concrete.

Further research is recommended to explore additional effects and optimize the use of nanoparticles in concrete

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