

Experimental Investigation on Concrete with Nano Silica and Polyvinyl Alcohol Fiber

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Abstract: This experimental study investigates the combined effect of Nano Silica (NS) and Polyvinyl Alcohol (PVA) fiber in M30 grade concrete. Nano Silica owing to its ultrafine particle size and high pozzolanic reactivity acts as a micro-filler and accelerates the formation of calcium silicate hydrate (C-S-H) gel thereby refining the pore structure and improving compressive strength. PVA fibers with their high tensile strength and excellent bonding properties, bridge micro-cracks and enhance ductility and toughness of the concrete matrix. In this study Nano Silica was used as a partial replacement for cement at 1%, 2%, and 3% by weight, while PVA fiber was added as 0.5% by volume of concrete. The specimens were tested for compressive strength, split tensile strength, and flexural strength at 7 and 28 days of curing.

Keywords: Concrete, Nano Silica, Polyvinyl Alcohol, Fiber

1. Introduction

1.1 General

Environmental preservation and responsible usage of resources are currently the main challenges facing sustainability. Cement manufacture is precise and are crucial factor for the maximum CO₂-formation. It is reliable for approximately 5%–8% of the carbon produced worldwide. Many by-products were assessed as a substitution for cement. The better the pozzolanic properties possessed by the material, the higher the opportunity to effectively replace the cement. In response to growing environmental concerns and the global push toward sustainable development, there is an increasing focus on identifying and incorporating alternative materials that can partially or wholly replace conventional cement in construction. Sustainable construction practices are guided by three primary pillars: environmental sustainability, economic feasibility, and social responsibility. Within this context, the present study investigates the partial replacement of cement with Nano Silica, a high purity amorphous silica powder, and the incorporation of Polyvinyl Alcohol Fiber as an admixture in concrete.

The objective of this research is to evaluate the mechanical characteristics of concrete modified Nano Silica and Polyvinyl Alcohol Fiber, with the aim of promoting innovative and sustainable practices in civil engineering materials.

1.2 Nano Silica

Nano Silica, (nanosilica or SiO₂ nanoparticles) refers to silica particles with a nanometer-scale size, typically ranging from 1 to 100 nanometers. Due to its high surface area, excellent mechanical properties, and ability to interact at the molecular level, nano silica is widely used in various engineering and scientific applications. In the field of civil engineering, it is especially valued for its potential to enhance mechanical strength, durability, and other performance characteristics of composites and materials. One of the key characteristics of nano silica is its high reactivity and pozzolanic behavior, especially when used in cement-based or composite materials. It can fill microvoids in matrices, leading to a denser microstructure, and it actively reacts with calcium hydroxide in cementitious systems to form additional calcium silicate hydrate (C-S-H), thereby improving strength and durability.

1.3 Polyvinyl Alcohol Fiber

PVA fiber is a synthetic, high-strength fiber known for its excellent chemical stability, strong adhesion to cement matrices, and superior resistance to alkali environments. Unlike other synthetic fibers, PVA provides both mechanical and chemical bonding within a composite system. Compared to steel fibers, PVA fibers offer corrosion resistance, finer crack control, and enhanced ductility. Their hydrophilic surface also allows better interaction with cementitious matrices, making them ideal for Engineered Cementitious Composites (ECC).

1.4 Literature Review

1.Hosseini, Nematian Jelodar, Rahmat Mandandoust "Experimental Investigation on the Mechanical Characteristics of Cement-Based Mortar Containing Nano-Silica, Micro-Silica, and PVA Fiber" (8 September 2022)- ResearchGate

This study investigates the mechanical properties of cement-based repair mortar enhanced with Nano-Silica (NS), micro-silica (SF), and polyvinyl alcohol (PVA) fibers, used individually (single), in pairs (binary), and all together (ternary). A total of 28 mix designs and 112 specimens were tested for compressive and flexural strengths using standard methods (ACI 318 and BS EN 1015-11). Results showed that the optimal single-mode mix was 10% silica fume (SF10), improving flexural and compressive strength by 27% and 48%, respectively. In binary mode, the best performance was achieved with 2% NS and 8% SF (NS2SF8), showing a 24% increase in flexural and 49% in compressive strength. For the ternary mode, a mix with 0.75% PVA and 10% SF (PVA0.75SF10) was most effective, though the improvements were lower—3.5% in flexural and 4.6% in compressive strength. Overall, binary combinations offered the most significant enhancements.

2.Haibin Yang "Effects of nano silica on the properties of cement-based materials" - (may 2021) -ScienceDirect

Nowadays, many nanomaterials such as graphene oxide (GO), carbon nanotubes (CNTs), Nano Silica (NS) etc. have been introduced to improve the microstructures and performances of cement-based materials (CBM). Compared with other nanomaterials, NS has attracted much attention because of its pozzolanic reaction with calcium hydroxide (CH) to form calcium-silicate-hydrate (C-S-H) gel. Although several review papers have been published, the breadth and depth of literature coverage on NS and its effects on CBM is insufficient. This paper is aimed to keep researchers abreast of the latest research in the field. In particular, the influence of NS on CBM properties including workability, setting time, hydration characteristic, calcium leaching, porosity, mechanical strengths, and durability is critically reviewed. It is believed that this review paper will not only arouse new ideas to promote practical application of NS in construction materials but also provide some constructive guidance for similar research in the future.

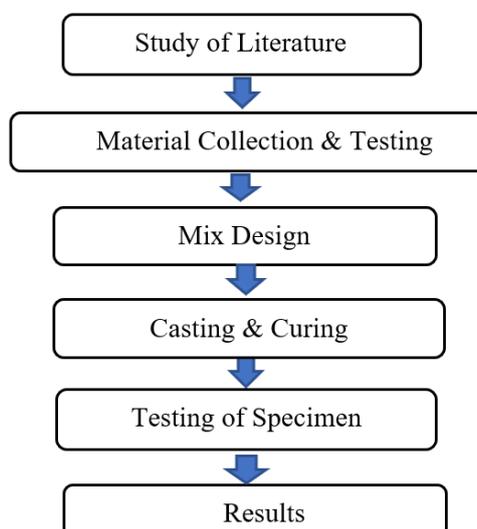
3.Weiliang Xie, Jiajian Chen "Workability and Mechanical Properties of PVA Fiber-Limestone Fine Cementitious Composite" (19 November 2024) - ResearchGate

Cement-based materials are the most widely used building materials and have two main problems: low flexural/tensile strength and low sustainability. To solve these two problems at the same time, the strategy of the utilization of fillers as cement paste replacement and utilization of fiber was proposed. Mixes with varying PVA fiber and LF were produced for workability and mechanical properties measurement and analysis. The results showed that the addition of PVA fibers reduced the flowability and bonding, while the addition of LF similarly reduced the flowability but enhanced its bonding. Both effects on strength showed an increase and then a decrease. An analysis of microstructure and chemical composition demonstrated that the addition of PVA fiber and/or LF first decreased the porosity, and a further addition increased the porosity. The mixes with 0.2% fiber content showed fracture failure mode, while the mixes with 0.4–0.6% fiber content showed the pulling out of failure mode. A mix with 0.2% fiber content and 10% LF content exhibited concurrent workability and mechanical properties.

1.5 Objective

- To investigate the effect of Nano Silica and PVA fibers as partial replacements of cement on the mechanical and properties of concrete.
- To design mix proportions with varying percentages of Nano Silica and PVA fibers to identify the optimum replacement level.
- To evaluate the mechanical properties such as compressive strength, split tensile strength, and flexural strength of modified concrete.
- To compare the performance of Nano Silica–PVA blended concrete with that of conventional M30 grade concrete.
- To assess the sustainability benefits of using Nano Silica and PVA fibers as cement replacements in terms of reduced cement consumption and improved service life.

1.6 Methodology



2. Experimental Investigation

For the experimental investigation, concrete specimens were cast in the form of cubes, cylinders, and prisms with standard dimensions. The cube specimens were prepared with a size of $150 \times 150 \times 150$ mm for compressive strength evaluation. Cylindrical specimens of 150 mm diameter and 300 mm height were cast to assess the tensile strength characteristics. In addition, prism specimens measuring $100 \times 100 \times 500$ mm were prepared to study the flexural behavior of the concrete. In this study, Nano Silica was used as a partial replacement for cement at 1%, 2%, and 3% by weight, while PVA fiber was added as 0.5% by volume of concrete. Each test was carried out on three specimens for each mix proportion and the average value was taken as the representative result. These tests provided a comprehensive understanding of how Nano Silica and PVA fibers influence the mechanical performance of concrete.

3. Results

The results section presents the outcomes of strength tests conducted on the cast specimens, including cubes, cylinders, and prisms. Compressive strength tests were performed on cube specimens, split tensile strength tests on cylindrical specimens, and flexural strength tests on prism specimens to evaluate the mechanical behaviour of the concrete. The measured strength values obtained for conventional concrete and Nano Silica and PVA Fiber modified concrete at different replacement levels are reported and compared.

3.1 Compressive Strength Test Results

Percentage of replacement of Nano Silica	Compressive Strength (N/mm ²) -7 days	Compressive Strength (N/mm ²) -28 days
0	21.61	32.25
1	25.13	35.90
2	28.84	38.97
3	27.31	37

Tab 1 Compressive Strength Test Results

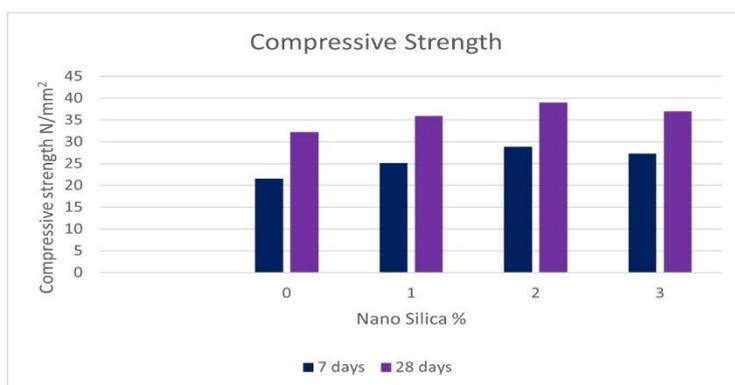


Fig 1 Compressive Strength Test -Graph

3.2 Split Tensile Strength Test Results

Percentage of Replacement of Nano Silica (%)	Split Tensile Strength (N/mm ²) -7 days	Split Tensile Strength (N/mm ²) - 28 days
0	2.33	2.84
1	2.76	3.30
2	2.96	3.45
3	2.88	3.37

Table 2 Split Tensile Strength Test Results

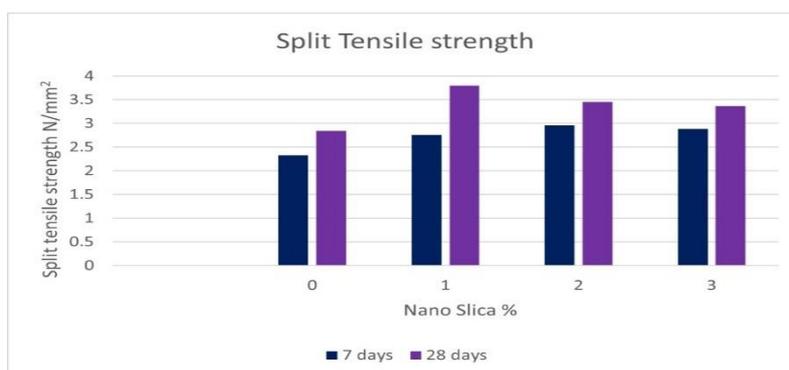


Fig 2 Split Tensile Strength Test- Graph

3.3 Flexural Strength Test Results

Percentage of Replacement of Nano Silica (%)	Flexural Strength (N/mm ²) -7 days	Flexural Strength (N/mm ²) - 28 days
0	3.25	3.97
1	4.04	4.82
2	4.32	5.03
3	4.21	4.25

Table 3 Flexural Strength Test Results

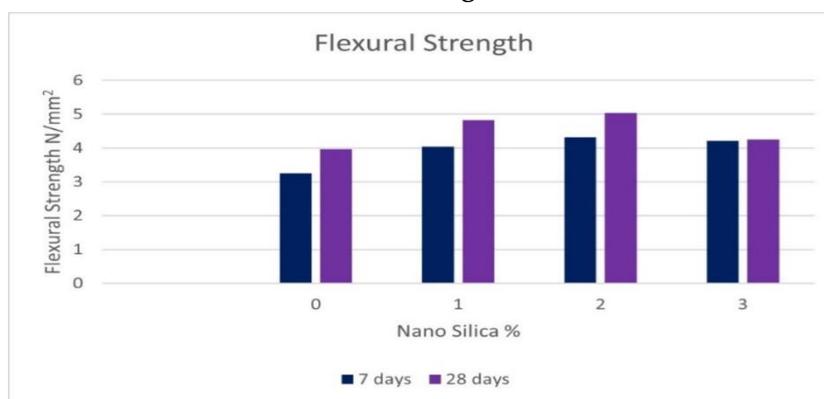


Fig 3 Flexural Strength Test – Graph

4. Conclusion

The study concludes that the combined use of Nano Silica and PVA fiber leads to a high-performance concrete, suitable for advanced construction applications requiring superior strength and crack resistance. The experimental results revealed that the inclusion of Nano Silica significantly increased the compressive strength up to 2% replacement, beyond which the strength slightly reduced due to particle agglomeration. The addition of PVA fiber improved tensile and flexural performance by enhancing crack resistance. The optimum mechanical properties were obtained at 2% Nano Silica and 0.5% PVA fiber, showing notable improvement in overall performance compared to conventional M30 concrete.

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