

Experimental Investigation On Reinforced Concrete Beam 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. In this study, the structural behaviour of reinforced concrete beams were studied through load-deflection testing. The behaviour of conventional concrete beam was compared with beam containing Nano Silica and Polyvinyl Alcohol fibers to evaluate the influence of the modified concrete on structural performance, crack development, and deformation characteristics. Nano Silica was used as a partial replacement for cement at 2% by weight, while Polyvinyl Alcohol fiber was added as 0.5% by volume of concrete. In addition, the performance of the modified concrete was evaluated through various durability tests to assess resistance against environmental effects. Microstructural characteristics of the material were examined using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis to understand the morphology and elemental composition.

Keywords: Nano Silica, Polyvinyl Alcohol Fiber, Reinforced Concrete Beam, Compressive Strength, Flexural Strength, Durability Tests, Microstructural Analysis, Load-Deflection Behavior, Crack Resistance, M30 Grade Concrete

1. Introduction

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 replaced 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.

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

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).

2. Literature Review

1. Naser Rahmani, Anil Kumar Kannauzia, Sulfuric acid, Sulphate, and Alkali resistance of Self compacting concrete, JETIR April 2018, Volume 5, Issue 4

The resistance to sulphuric acid solution was measured by means of the weight loss of the mortar cubes. The weight loss is considered as a function of time. As expected, the sulphuric acid resistance of mortars improved with increasing the replacement level of volcanic ash. This improvement of acid resistance was higher at early ages and decreased with increasing the immersion time. Beyond 28 days of exposure, slight improvements in the sulphuric acid resistance have been found.

2. Hossein, Nematian Jelodar, Rahmat Mandandoust "Experimental Investigation on the Mechanical Characteristics of Cement-Based Mortar Containing Nano-Silica, Micro-Silica, and PVA Fiber" Processes, Vol 10, 1814 (8 September 2022)

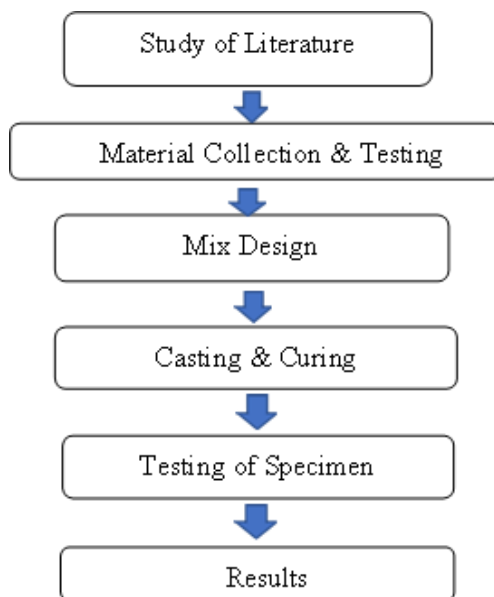
This study evaluated the mechanical performance of cement-based repair mortar modified with Nano-Silica (NS), Silica Fume (SF), and PVA fibers in single, binary, and ternary combinations. A total of 28 mix designs and 112 specimens were tested for compressive and flexural strength. Among single mixes, 10% silica fume (SF10) gave the best results, increasing flexural and compressive strength by 27% and 48%. In binary mixes, NS2SF8 showed the highest improvement with 24% higher flexural and 49% higher compressive strength. In ternary mixes, PVA0.75SF10 performed best, with smaller improvements of 3.5% and 4.6%. Overall, binary combinations produced the most effective strength enhancement.

3. Mounika Naidu G, Rathna chary M, Experimental study on concrete for sulphuric acid resistance using silica fume, ground granulated blast furnace slag and volcanic ash, IJCRT, Volume 6, Issue 15 April 2018

The resistance to sulphuric acid solution was measured by means of the weight loss of the mortar cubes. The weight loss is considered as a function of time. As expected, the sulphuric acid resistance of mortars improved with increasing the replacement level of volcanic ash. This improvement of acid resistance was higher at early ages and decreased with increasing the immersion time. Beyond 28 days of exposure, slight improvements in the sulphuric acid resistance have been found.

Objective

- To evaluate the mechanical strength of conventional and nano silica with polyvinyl alcohol fiber modified concrete and determine the optimum mix of modified concrete.
- To analyse the microstructural characteristics using SEM and EDX techniques to understand the densification and bonding mechanisms.
- To study the durability properties of conventional concrete and nano silica with polyvinyl alcohol fiber modified concrete.
- To study the flexural behaviour of conventional beam and nano silica with polyvinyl alcohol fiber modified concrete beams.
- To compare the overall structural performance of modified concrete with conventional under similar loading conditions.

Methodology**3. Experimental Investigation****Strength study**

All tests were done with reference to IS 516 (Part1/Section1):2021. The tests conducted on cubes, cylinders and prisms are

- 1) Compressive strength test
- 2) Split tensile strength test
- 3) Flexural strength test.

Microstructural analysis

Microstructural analysis, using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray spectroscopy (EDX) is a standard technique for evaluating the physical morphology and chemical composition of materials at the micro- and nano-scale.

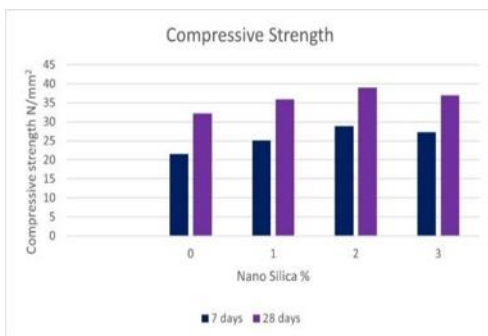
Durability test

S.NO	TESTS CONDUCTED ON CUBES	SPECIMEN SIZE
1.	Acid resistance test	100 x 100 x 100 mm cubes
2.	Sulphate resistance test	100 x 100 x 100 mm cubes
3.	Water absorption test	100 x 100 x 100 mm cubes
4.	Sorptivity test	100 mm diameter x 50 mm thickness discs

4. Results

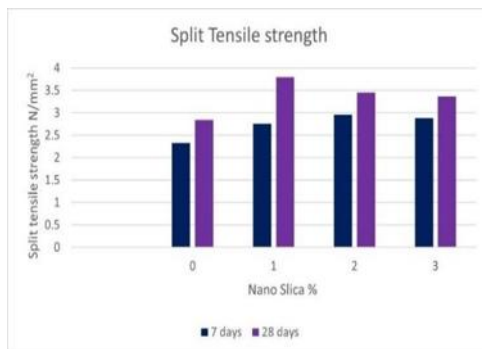
Compressive Strength Test Results

Mix ID	Compressive strength in N/mm^2	
	7 DAYS	28 DAYS
NS 0%	21.61	32.25
NS 1%	25.13	35.90
NS 2%	28.84	38.97
NS 3%	27.31	37



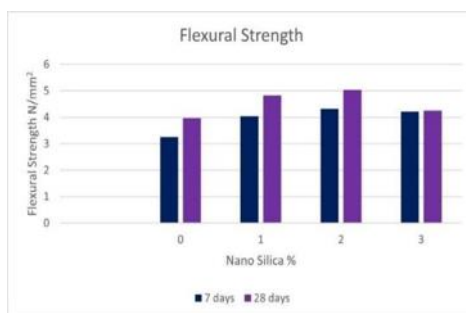
Split Tensile Strength Test Results

Mix ID	Split Tensile strength in N/mm^2	
	7 DAYS	28 DAYS
NS 0%	2.33	2.84
NS 1%	2.16	3.30
NS 2%	2.96	3.45
NS 3%	2.88	3.37



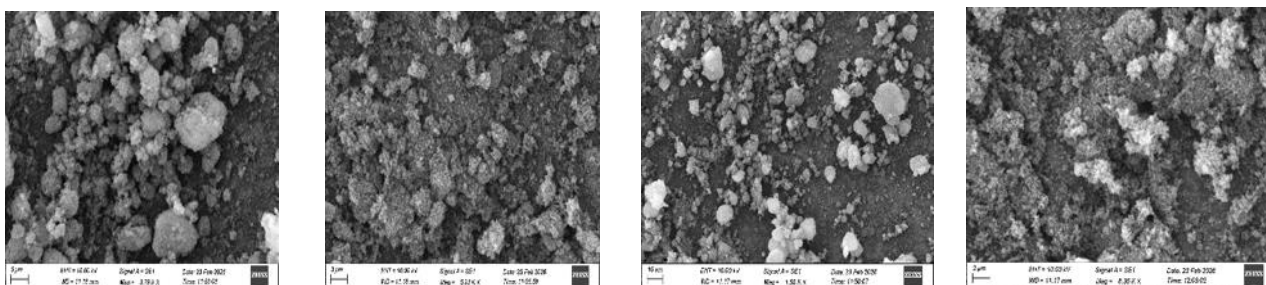
Flexural Strength Test Results

Mix ID	Flexural strength in N/mm ²	
	7 DAYS	28 DAYS
NS 0%	3.25	3.97
NS 1%	4.04	4.82
NS 2%	4.32	5.03
NS 3%	4.21	4.25



Microstructural Analysis Results SEM

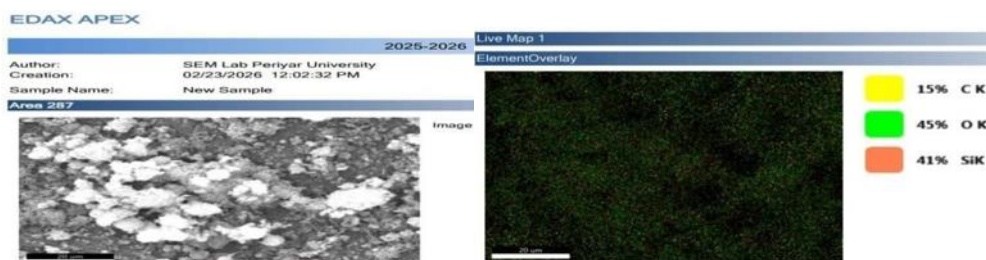
Analysis

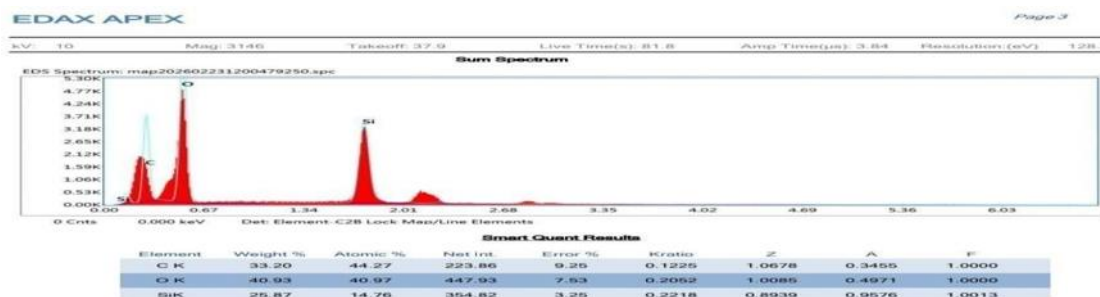


Interpretation from SEM Analysis

The microstructural characteristics of the nano-silica sample were analysed using Scanning Electron Microscopy. The SEM images show that the Nano Silica particles are extremely fine and mostly spherical to irregular in shape. The micrographs reveal the presence of agglomerated clusters, which occur due to the high surface energy and strong interparticle attraction of nanoparticles. The images also indicate a rough surface texture and porous morphology, which contribute to a high specific surface area. This characteristic improves the pozzolanic activity of nano-silica and helps in filling micro-voids in cement matrices, thereby enhancing the strength and durability of cementitious composites.

EDX Analysis





Interpretation From EDX Analysis

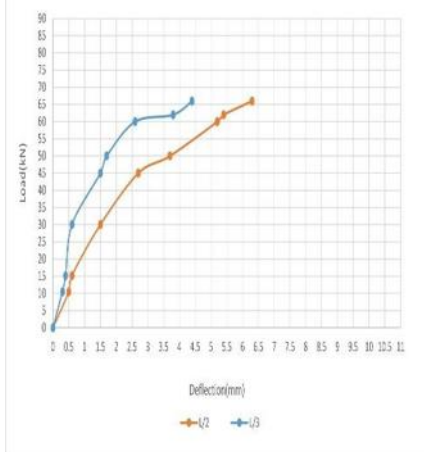
The EDX analysis of the nano-silica sample confirms the presence of the major elements silicon (Si), oxygen (O), and carbon (C). The quantitative results show approximately 40.93% oxygen, 25.87% silicon and 33.20% carbon. The strong peaks of Si and O in the EDX spectrum indicate the presence of silicon dioxide (SiO₂), confirming the nano-silica composition. The carbon peak may be attributed to carbon coating during SEM preparation or minor environmental contamination. Elemental mapping also shows a uniform distribution of silicon and oxygen throughout the sample, indicating good dispersion of nano-silica particles. This confirms the suitability of nano-silica for improving the microstructure and durability of cementitious composites.

Durability Test Results

The durability performance of M30 concrete incorporating nano silica (NS) as a partial cement replacement and PVA fibers as an additive was evaluated through acid resistance, sulphate resistance, water absorption, sorptivity, and residual compressive strength tests. The modified concrete exhibited improved mechanical and durability characteristics compared to conventional concrete. In the acid resistance test using HCl solution, the conventional concrete showed an average weight loss of 2.73% and 5.13% after 15 and 30 days, respectively, whereas the NS + PVA concrete showed lower weight losses of 1.47% and 2.87%, indicating superior acid resistance. Similarly, under magnesium sulphate exposure, the conventional concrete recorded weight gains of 1.09% and 2.37%, while the modified concrete exhibited lower gains of 0.68% and 1.36% at 15 and 30 days, respectively, demonstrating improved sulphate resistance. Water absorption results also confirmed enhanced durability, where the conventional concrete showed absorption values of 2.01% and 4.05%, compared to 1.01% and 2.99% for NS + PVA concrete at 15 and 30 days, respectively. The modified concrete further exhibited lower sorptivity values and higher residual compressive strength after chemical exposure. The improved performance is attributed to the pore refinement and densification caused by nano silica along with the crack-bridging action of PVA fibers, which collectively reduced permeability and enhanced resistance against aggressive environmental conditions.

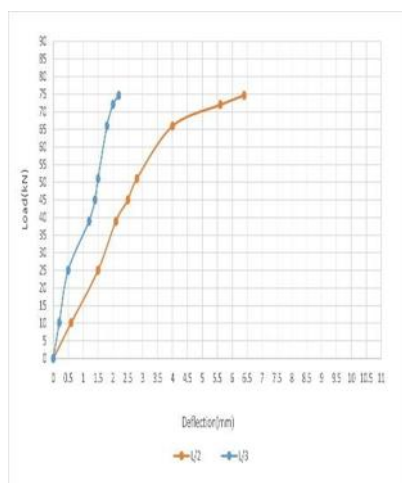
Flexural Behaviour Test Results of Reinforced Concrete Beams Results of 0% Nano Silica with Polyvinyl Fiber Beam (Conventional)

LOAD (kN)	Deflection at L/2 (mm)	Deflection at L/3 (mm)	Remarks
0	0	0	
10.5	0.5	0.3	
15.2	0.6	0.4	First crack
30	1.5	0.6	
45	2.7	1.5	
50	3.7	1.7	
60	5.2	2.6	
62	5.4	3.8	
66	6.3	4.4	Ultimate load



Results of 2% Nano Silica With 0.5% Polyvinyl Alcohol Fiber Beam

LOAD (kN)	Deflection at L/2 (mm)	Deflection at L/3 (mm)	Remarks
0	0	0	
10.1	0.6	0.2	
25	1.5	0.5	First crack
39	2.1	1.2	
45	2.5	1.4	
51	2.8	1.5	
66	4	1.8	
72	5.6	2	
74.7	6.4	2.2	Ultimate load



Parameter	0% NS with PVA	2% NS with 0.5% PVA
First crack	15.2 kN	25 kN
Crack width	3mm, 4mm	1mm, 2mm
Ultimate load	66 kN	74.7 kN
Max. deflection	6.3 mm	6.4 mm

Crack Pattern



The conventional beam experienced flexure–shear failure. The development of a major diagonal crack in the shear span indicates that shear stresses governed the final failure. The conventional beam showed relatively brittle behaviour with fewer cracks and sudden failure.

The modified beam exhibited flexure–shear failure. The presence of nano-silica densifies the cement matrix, while PVA fibers bridge the cracks and delay crack propagation, resulting in higher load-carrying capacity, increased deflection, and improved ductility compared with the conventional beam.

5. Conclusion

The addition of nano-silica and PVA fibers improved the mechanical performance of concrete compared to conventional concrete. At the ultimate stage, the conventional beam reached a load of 66 kN with a deflection of 6.3 mm, whereas the modified beam carried a higher ultimate load of 74.7 kN with a deflection of 6.4 mm. This demonstrates that the modified beam has greater load-carrying capacity. For the same load level of 66 kN, the modified beam showed a lower deflection of 4 mm, while the conventional beam showed 6.3 mm. This indicates that the modified beam possesses higher stiffness and better resistance to deformation under service loads. The crack width in the modified beam was smaller and cracks were more distributed, whereas the conventional beam showed wider and fewer cracks. Durability test results indicated that NS–PVA concrete retained higher strength after exposure, demonstrating improved durability. Microstructural analysis (SEM and EDX) confirmed that nano-silica produced a denser cement matrix, contributing to improved strength and durability. Overall, nano-silica and PVA fiber modified concrete showed better strength, crack resistance, ductility, and durability, making it suitable for high-performance structural applications.

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