JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

STUDY OF DURABILITY AND MICROSTRUCTURE PROPERTY OF CONCRETE WITH NANO SILICA WITH FLY ASH

[1]Pawan Pote [1]Nikhil Vatkar [1]Saurabh Burade [1]Adityavikram Lakhotiya
[2]Sudhanshu Pathak, [2]Mahesh Tatikonda,
[1]UG students at D Y Patil College of Engineering
[2]Assistant professor at D Y Patil College of Engineering akurdi, Pune

Abstract

This paper presents the effect of Nano silica (NS) and fly ash on the compressive strength, flexural strength and durability of concretes containing fly ash 20% (by weight) as partial replacement of cement and Nano silica at 1%, 2%, 3% and 4% of replacement of cement. The compressive strength for concretes is measured at 7, 14 and 28 days of curing. The effects of NS in microstructure development studied by SME (scanning electron microscope) and X-ray diffraction (XRD) analysis. Flexural test is carried out on concrete beam at 28 days curing. The fly ash helps in water hydration during the chemical reaction between Nano silica and concrete. Rapid Chloride penetration test (RCPT) is carried out on cement concrete cylinder to assess the short-term chloride ions penetration. The findings demonstrate that using these mineral admixtures improves the qualities of strength and durability.

Key word - **Nano silica, fly ash, Rapid Chloride penetration test (RCPT)**

- ## Introduction

Due to its low cost and high durability, concrete is the most popular building material worldwide. Concrete's primary component is ordinary Portland cement (OPC). Every tonne of cement produced is related with an average of 840 kg of CO2 emissions, and the PC industry is responsible for 7–10% of all anthropogenic CO2 emissions, which contributes considerably to global warming.[9,11,15,16,19,20,22,23,30.] The use of cement in concrete has generated questions about its sustainability. Concrete will be used more and more in the near future due to urbanization and population growth. Annual production of concrete is 20 billion metric tonnes. Environmentalists are worried because about 8% of the world's carbon dioxide emissions come from the production of cement for construction [3].Due to this worry, supplemental cementitious materials (SCMs) have been used to partially replace a significant quantity of OPC in concrete. A vast database of the mechanical and durability qualities of the building materials used in the construction industry is necessary due to the new trend of developing structures utilizing a performance-based design method to achieve enhanced service life under a particular exposure condition [25,32].One of the SCMs that is frequently utilized to partially replace OPC in concrete is fly ash. However, its mass percentage utilization in concrete is just 20% to 25% [1]. Maximizing the usage of fly ash or other SCMs in concrete is the top priority and has been widely explored in light of the aforementioned sustainability. Researchers focused on the partial use of alternative cementitious materials (fly ash, silica fume, slag etc.) to improve the durability and mechanical performance of concrete [11].Currently, the applications of nanotechnology have been gaining popularity in different fields of science and technology [24, 22]. The developments of new materials with new functions or improvements in the properties of existing materials using nanotechnology are new areas of interest in civil engineering [17]. Recent advances in nanotechnology and the accessibility of Nano-silica (NS) have made it possible to use such materials to enhance the characteristics of concrete. Additionally, fly ash and Nano-silica have been combined to improve the early strength of concrete [4]. In addition to the mineral admixtures, the concrete properties can also be improved by the use of Nano-silica that is obtained by recent developments in Nano technology [14]. The use of Nano-silica in OPC concrete was widely investigated and Nano silica takes the greatest attention due to its improved effect on the durability and mechanical performance of OPC concrete [11, 12, and 22]. Utilizing Nano-silica as a substitute for cement leads to cost-effective and sustainable concrete, which lowers the carbon dioxide trail of concrete products[22].Due to an ultrafine size, Nano-particles show unique physical and chemical properties different from those of the conventional materials.[21] Nanoparticles have been found to act as nuclei for the cement phase promoting cement hydration [1,18,33,31]. Nano-silica (NS) has recently been introduced that the high specific surface area can enhance the pozzolanic activity of silica [5, 12, 13, 15, 17, 26, 28, and 35]. It was reported that NS utilization reduces the overall permeability of hardened concrete [14]. Numerous studies have found that larger combinations require more water to make them workable [18].Revealed that Nano-silica could reduce large capillary porosity of concrete, and thus reduce permeability [24]. Nano-SiO2 has been added to polymer to increase strength, flexibility, and aging resistance [28]. The inclusion of NS powder increased the compressive strength more significantly at the early stages in comparison with the other nanoparticle additives. [29, 33, 34]. Initial and final setting times were decreased by 95 and 105 minutes, respectively, when 2% NS by mass was added to cementitious materials [33, 34]. The addition of fly ash leads to higher porosity at short curing time, while nano-SiO2, acting as an accelerating additive, leads to more compact structures, even at short curing times [28]. The rate of cement hydration and reaction appears to be more quickly accelerated by Nano-silica with mean particle sizes of 7 and 12 nm [33, 43]. Water absorption and charge passed in RCPT is also less in the Nano silica (with 6%) [10]. Due to internal and exterior temperature variations, fly ash reduced the overall heat of cement hydration and the occurrence of concrete cracks. Additionally, fly ash promotes matrix compactness by lowering internal capillary pore and water requirement, which also improves impermeability and anti-chloride ion permeability, protecting the steel bar from corrosion [31]. If the Nano-particles were equally scattered, the SEM observations also showed that the Nano-particles were not only working as a filler but also as an activator to promote hydration proofs and to improve the microstructure of the cement paste [18, 21, and 24].The Nano SiO2 concrete can produce Nano crystals gel of C–S–H that can fill up all the micro and Nano pores which were not filled in the plain cement based concrete [1,23]. Nano silica (NS) is one of the silica fines with high potential as cement replacement and as concrete additive. From the other Nano materials, Nano silica is one of the best materials to improve the physical strength, and properties of concrete [23]. There are several drawbacks of replacing OPC with FA i.e. inferior mechanical properties at an early age because of the slow pozzolanic reaction of FA to overcome the shortcoming, nanomaterials with smaller particle size and larger surface area than FA can be used as cementitious additives in concrete [6]. Replacing cement with 15 to 25% fly ash has no significant effects on the compressive strength, flexural strength, and fracture toughness of the mortars at the ages of 28 and 90 days. Higher percentages of the replacement (45 and 55%) have negative effects on these properties [27]. While fly ash is one of the most abundant industrial by-product, its current application in concrete is limited to between 20 and 30 I replacement of the total cement content. Annual worldwide production is approx. 900 million tonnes while annual Australian fly ash production stands at 14.5 million tonnes, which is projected to reach 20 million tonnes in 2025 [9]. Fly ash has been used mainly for mass concrete, utilizing its property of low heat for hydration, development of fluidity and suppression of alkali-aggregate reaction [16, 35]. Usually, replacing cement with fly ash has disadvantages and doesn't produce the desired results. Due to the sluggish polymerization process, mortar with fly ash displayed inadequate strength at the ambient curing temperature. However, incorporating other materials such as nanoparticles can contribute to enhance a better result regarding strength and durability [19]

2. Materials and methods

2.1 materials

Development of cementitious composite employing materials like fly ash and Nano silica is the goal of the current research. Control is compared to the properties of strength and durability. Based on IS 10262:2009, the concrete mix proportions with an M35 strength in compression were created without the use of any additional cementitious elements. While maintaining the discovered optimum concentration of fly ash, nano-silica was altered from 1 to 4% as a partial replacement of cement. Initially, fly ash was a partial replacement in 20%.

Table 1 mix design

materials	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5
Cement(kg/m^3)	400	316	312	308	304
Crush sand (kg/m^3)	955	955	955	955	955
Course aggregate (kg/m^3)	1095	1095	1095	1095	1095
Fly ash (%)	0	20	20	2o	20
Nano silica (%)	0	1	2	3	4

Table 2 cement: chemical property

Cement	Lime saturation	Alumina ratio	Insoluble residue	Magnesia	Sulphuric anhydride	Total chlorides	Total loss of ignition
%	0.8	1.2	1.85	o.85	1.90	0.03	1.79

Table 3 cement: physical property

Specification	Fineness(m2/kg)	Standard consistency (%)	Setting time(mm)		Soundness (le-chart expansion)	Compressive strength 28 days MPa
			initial	final		
%	290	29.5	45	230	1.3	70

Table 4 fly ash chemical properties

Specification	SiO2	AI2O3	Fe2O3	CaO	MgO	SO3	K2O	Na2O	LOI
%	52.50	3.5	30.15	7.4	4.6	2	1.3	0.65	3.9

Table 5 Nano Silica: chemical properties

Specification	SiO2	AI2O3	Fe2O3	CaO	MgO	Na2O	K2O
%	99.00	0.2O	0.30	0.15	O.05	0.1O	0.20

Cement - The typical Portland cement according to IS: 4200 of 53 grade cement was employed in the current study. M35 grade concrete is used in construction. The first and subsequent settings took place at 45 and 230 minutes, respectively. Cement has a specific gravity of 3.14.Fine aggregate—In accordance with IS: 383-1970, Zone-2-compliant fine aggregate was employed. Fine aggregate has a bulk density of 1.45 g/cc. 2.65 was the specific gravity. Coarse aggregate - In accordance with IS: 383-1970, well-graded crushed granite with a nominal size of 20 mm was obtained from a nearby crusher unit. The specific gravity was 2.8 and the bulk density was 1.50 g/cc. Fly ash: In the current experiment, fly ash was used. Its specific gravity and fineness were 2.16 and 326 m2/kg, respectively. It came from the Indian state of Maharashtra's Talegaon AAC Brick Plant. Nano silica - P.H. Gandhi Chemical in Pune, Maharashtra, India, provided the Nano-silica. Nano silica has a specific gravity of 2.17.Potable water was used in accordance with IS: 456-2000. Admixtures of chemicals - MYK 1806

2.2 Specimen preparation and experimental procedures

2.2.1 Cube

For the M35 grade of concrete's compressive strength, a total of 36 cubes of standard size 150 x150 x 150 mm were cast. To achieve the requisite strength, fly ash was substituted for 20% of the cement and Nano silica for 1%, 2%, 3%, and 4% of the cement.

fig.1 – cubes in curing tank

2.2.2 Beam

9 beams totaling 150 x 150 x 750 mm are cast using the provided mix design for the flexural test. To attain the desired strength, replace 20% of the cement with fly ash and 1%, 2%, 3%, and 4% of the cement with Nano silica.

fig.2 – beam

2.2.4 Cylinder

A 150 mm x 300 mm cylinder is cast for a split tensile test using the provided mix design, and To achieve the requisite strength, a total of 5 cylinders measuring 100 x 200 mm were cast for the Rapid Chloride Penetration Test with fly ash replacing 20% of the cement and Nano silica replacing 1%, 2%, 3%, and 4% of the cement, respectively. As indicated in fig. 3, the cylinder was also reduced in size to 50x100 mm for the Rapid Chloride Penetration Test.

fig.3 cylinder for rcpt

Acid resistance of blended cement concrete and the control mix in 3% NaCL and 3 N NaOH4 were tested using the RCPT method after 28 days of curing. In general, as the acid concentration rises, so does the intensity of the attack. Sodium Chloride Solution and Sodium Hydroxide Solution are chosen to test the acid resistance of concrete.

3. Test

3.1 Compressive test

Compressive test is done on concrete cube of size of 150 x 150 x150 mm on UTM of given mix design in table 1 shown in fig. 4

fig. 4 cube testing in utm

3.2 flexural test

Flexural test was done on beam of size 150 x 150 x 750 mm on UTM of given mix design in table 1

fig. 5 beam in utm machine

3.3 split tensile test

Cylinders with a diameter of 50 mm and a length of 300 mm were cast and given varying curing times. For this test, a universal testing equipment with a 1000kn capacity was used. The split tensile strength of concrete was calculated using the formula below at a rate loading of 2.5 kn/sec. The following formula for calculating splitting tensile strength fct is produced using the theory of elasticity.

$$f_{ct} = 2P/(3.14 \times d \times l)$$

P = Peak load
d = diameter of cylinder
L = length of cylinder

3.4 Rapid Chloride Penetration Test

RCPT test was done on cylinder of size 100 x 50 mm cylinder.

Fig. 6 – cylinder of size 50mm x 100mm

4 Testing and result

4.1 XRD Analysis

XRD analysis was done on Nano silica at Savitribai Phule Pune University, Pune, Maharashtra, India

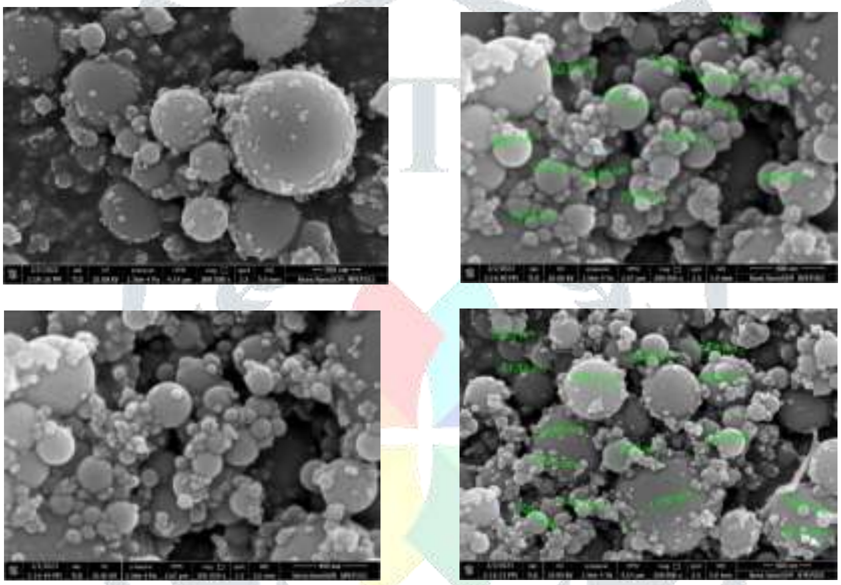

fig. 7 -xrd results

4.2 Scanning electron microscope (SEM) analysis

Scanning electron microscope Test was conducted on Nano silica for fines of SCMs at Savitribai Phule Pune University, Pune, Maharashtra, India

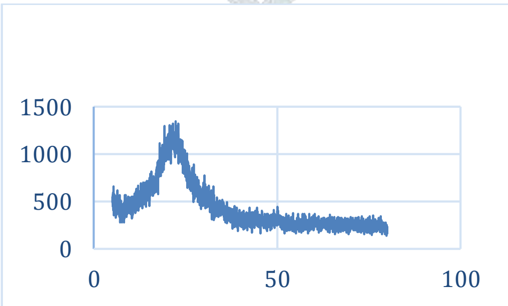

fig 8 - SEM Result

5 Results and discussion

5.1. Effect of Nano silica on compressive strength of cement concrete

The compressive strength of concrete is tested by the cube samples of size (150 mm x 150 mm x 150 mm) in the compression or universal testing machine. The machine should be calibrated as per the Indian standards. This research is to find the effect of Nano-silica ingression on the mechanical properties of conventional concrete. Compressive strength of concrete is carried out on cube of size 150cm x 150cm x150cm at curing of 7days, 14days and 28days. The results show that the addition of Nano silica and fly ash in concrete mix will increase the compressive strength of concrete at fully curing of 28days after adding Nano silica as 1% to 4% and fly ash as 20% replacement of cement

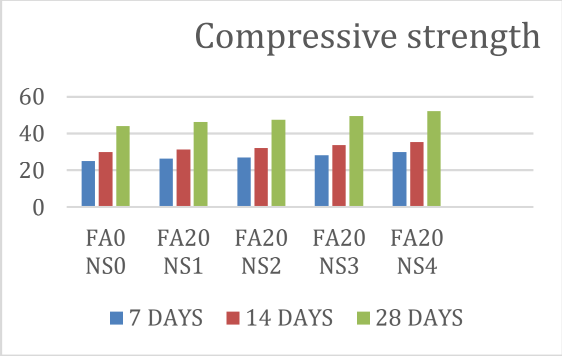

Fig 9 – compressive strength

SPECIMENT	7 DAYS	14 DAYS	28 DAYS
FA0 NS0	25.08 MPa	29.92 MPa	44.00 MPa
FA20 NS1	26.34 MPa	31.42 MPa	46.22 MPa
FA20 NS2	27.06 MPa	32.28 MPa	47.48 MPa
FA20 NS3	28.19 MPa	33.68 MPa	49.46 MPa
FA20 NS4	29.75 MPa	35.50 MPa	52.21 MPa

Table 6 - compressive strength

5.2 Flexural strength

The flexural tensile strength of concrete is tested on the beam specimens. The load is applied in the transverse direction of the beam samples to find the flexural tensile strength of the concrete mix in the flexural testing machine as per Indian standards. Fig. 5 shows the graph between the flexural tensile strength and various mix designs at 7 days, 14 days, and 28 days after the casting. Flexural strength results were found at 7 days, 14 days, and 28 days after casting of mix design specimens

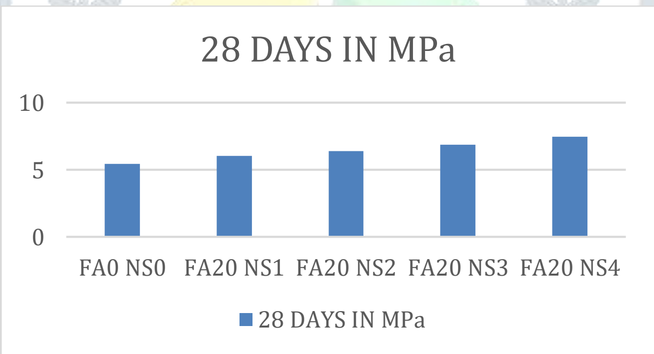

Fig 10 – flexural strength

SPECIMENT	28 DAYS
FA0 NS0	5.45 MPa
FA20 NS1	6.05 MPa
FA20 NS2	6.40 MPa
FA20 NS3	6.85 MPa
FA20 NS4	7.45 MPa

Table 7 flexural test result

5.3 Effect of Nano silica on split tensile strength of cement concrete

Split tensile test was done on concrete cylinder of size 150mm x 300mm

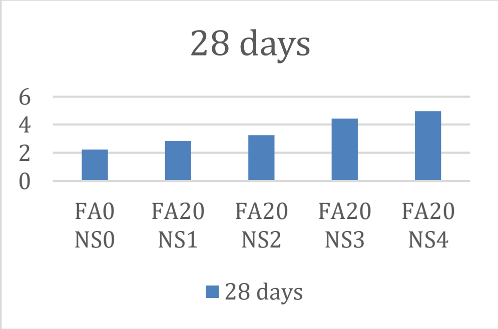

Fig 11 – split tensile test

SPECIMENT	28 days MPa
FA0 NS0	2.25
FA20 NS1	2.85
FA20 NS2	3.25
FA20 NS3	4.45
FA20 NS4	4.95

Table 8 – split tensile test

6 Conclusion

1. 1. Among all of the Nano silica, the 4% Nano silica is the content that exhibits the highest compressive strength after 28 days.
2. The concrete with Nano silica content at 4% exhibit highest flexural strength
3. The partial replacement of cement with Nano silica at 28 days showed greater compressive strength than the other cements.
4. Among all the concrete cylinder for split tensile test the 4% of Nano silica with 20% of fly ash at 28 days of curing show the highest results
5. The use of Nano silica as replacement of cement show good for curing of 28 days of curing
6. The use of nano silica for concrete at lower period of curing show 10-12% low strength results.
7. Fly ash can be used for the hydration of concrete.
8. The Nano silica can reduce the porosity of concrete which can make the concrete more durable.

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