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Mechanical and Flexural Behavior of High Performance Concrete Containing Nano Silica

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Abstract: This research work presents the role of nano silica (NS) on properties of high performance concrete. This study evaluates the influence of nano silica in three percentages (1%, 2%, 3 %,) by weight of cement. Several tests including mechanical properties and flexural test were performed to understand the influence of nano silica on behavior of concrete. It was determined that Portland cement replaced with 3% by weight with nano silica could accelerate C-S-H gel structure at early stage of hydration. In return this increases water permeability resistance of concrete specimens and acts as filler material that enhances micro structure as well as activator to promote pozzolanic activity and this will pave the way for producing good quality concrete.

Key words: Nano silica, concrete, Flexural strength, Compressive strength

I. INTRODUCTION

High performance concrete (HPC) refers to concrete mixture constituents which posse's high durability and strength when compared to conventional concrete. The compressive strength may vary between 20 N/mm^2 to 200 N/mm^2. The use of some mineral and chemical admixtures like silica fume, GGBS and water reducing agents enhances the strength and durability factor to a greater extent. Significantly addition of nano particles such as nano silica in small dosages can significantly improve the resistance to water permeability. Concrete is most broadly adopted construction material in construction industry. Usage of nano material has gained vast attention with its budding use of nano particle. Cement substitute materials, also known as mineral admixtures which can fill the pores inside the matrix, act as pore fillers as well as pozzolanic materials which improve microstructure properties and density of hardened cement mixture and which inturn increases the strength and durability properties of concrete [9]. The high performance concrete includes better workability, higher strength and stability in volume which allow constructors to use in high rise buildings with more durable at comparable cost [11]. Usage of water reducing agent and addition of mineral admixture in cement matrix plays vital role in producing high performance concrete [10]. Concrete mixes will achieve good density and high workability when high efficiency water reducing admixtures are used.

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This will help to control slump loss [20].

Investigations of Vivek et al. [12] resulted that high performance concrete containing higher volume fraction of nano silica showed increase in flexural strength. Cement was substituted by nano silica in three different percentages (5%, 10%, 15%). The increase in flexural strength was marginal and it was found and specimen containing higher order replacement of nano silica is effective in maintaining structural integrity. Mohamed amin et al. [23] found that optimum dosage of nano silica by 3% weight improves the compressive property of concrete by 21% comparing the nominal specimen and with addition of nano silica, splitting tensile property of concrete also increases 44% compared to control specimens. Flexural and compressive strength of concrete also increased comparing to those without addition of nano Silica. Among the types of nano materials existing, nano silica is the commonly used material and research from past revealed that performance of concrete is generally improved by addition of nano silica. [7, 13, 18, 19, 21]. Nano silica is bound to have larger surface area which accelerates hydration process and pozzolanic activity [13, 22, 28]. The results from Scanning electron microscope (SEM) revealed that a densification in interfacial transition zone (ITZ) was accomplished that combination of nano silica with super plasticizers could improve compressive strength of concrete [1]. The findings of Alireza khaloo et al. [3] proved that 1.5% replacement of nano silica for cement resulted in increase in electrical resistivity and SEM results showed that coarser nano silica resulted in improved high performance concrete matrix and a denser microstructure also developed. Chithra et al. [26] deliberated the properties of concrete containing 2% nano silica. Results showed higher compressive and tensile properties compared to concrete specimens without nano material. Alireza Naji Givi et al [4] found that nano silica with normal diameter of 15 nano meter with maximum limit up to 2% addition can develop early strength of concrete. Inclusion of nano particle in concrete can lead to new rheological properties. Nano silica replacement can develop mechanical and a durability property of concrete and makes compact microstructure and thereby increases permeability characteristics [25, 27]. The prime objective of this research is to study importance of using nano silica as replacement for cementitious materials in conventional concrete and this paper presents the mechanical and flexural properties of high performance concrete containing Nano silica.

II. METHODOLOGY

The first step in this study is to determine the properties of cement, Fine aggregate, Coarse aggregate which are used for concrete. It is proposed to vary Nano silica content in concrete from 0% to 3% by total weight of cement.

In addition Super plasticizer of 0.9% by weight of cement is added in all proportions. To study the mechanical properties like compressive strength, Tensile strength concrete cubes of size 15 cm x 15 cm x 15 cm and cylinders with a size 15 cm x 30 cm were cast and tested after 28 days of curing. The experimental results are compared with the recommendations given by ACI 209 ASTM TYPE 1[2].Moreover to study the flexural behavior of Reinforced Concrete beams with nano silica, beams of size 10cm x 15 cm x 150 cm were cast and tested under load at one third points.

III. EXPERIMENTAL PROGRAM

A. Materials

Ordinary Portland cement of 53 grade confirming to IS: 12269-1987 [15] was used. Test on cement were conducted as per IS 4031-1988 [18]. Fine aggregate passing through 4.75 mm IS sieve confining to grading zone III of IS: 383-1970 [17, 16, 24] was used. Crushed stone with a maximum size of 20 mm were used [6]. CONPLAST SP430 (G) complies with IS: 9103:1999 [20] types 'F' with specific gravity of 1.2 was used as a water reducing agent. Pure Nano- Silica was collected and its properties are tested in manufactured company.

B. Specimen Preparation

Concrete cubes of size 15 cm x 15 cm x 15 cm and cylinders with a size 15 cm x 30 cm was prepared for testing compressive strength and tensile strength respectively. In this present work M70 grade of concrete mix was used. To evaluate workability of concrete standard test with actions described with Indian standards BIS 1199-1959 [5, 8] are conducted. Cast iron mould was used to cast specimens and all specimens were filled in concrete with three layers and table vibrator was used to compact the specimens in each layer. Nano particles were mixed with water or super plasticizer in order to distribute the particles evenly. Nano silica was stirred with water or super plasticizer for 1 to 3 minutes at high speed until nano particles have been completely dissolved. After 24 hours of air curing specimens are demoulded and transferred to curing tank. After curing, the specimens were tested in compression testing machine having capacity of 2000kN.

C. Mix proportions

In this current investigation M70 grade of mix was used. For each mix proportion nano silica was replaced from 0% to 3% by weight of cement. Thus four mixes were designed as per IS 10262 – 2009 [14]. The details of the mix proportion is arrayed in Table.I

Table.I Mix Proportion

S.No	Mix Specification	Cement	Fine aggre gate	Coarse aggregate	Fly ash	Percentage wt fraction of Nano silica	Percentage of Super plasticizer	Slump (mm)	Compaction factor
1	CS	390	620	1080	120	0	0.9	89	0.9
2	NS1	386.1	620	1080	120	1	0.9	90	0.91
3	NS2	382.2	620	1080	120	2	0.9	92	0.92
4	NS3	378.3	620	1080	120	3	0.9	92	0.93

IV. RESULTS AND DISCUSSION

A. Compressive strength

Figure 1 shows the enhancement of compressive property for M70 grade of concrete with addition of nano silica from 0% to 3 %. The maximum compressive strength of 88.7 MPa was obtained for the specimen NS 3 which is 12.3 % higher than the control specimen. Further for NS1 and NS2, the compressive strength is 5.7% and 7% higher respectively when compared to the control specimen. The enhancement of compressive strength is due to the favorable surface physical characteristic that improves the bond between nano silica, fine aggregate and cement paste up to 3 % of nano silica by cement weight. The compressive strength of concrete can be evaluated from following equation (1) as recommended by ACI 209 ASTM TYPE 1[2] with time. The correlation of measured compressive strength and computed compressive strength is shown in Table II.

$$f_{cm}(t) = f_{c28}\left(\frac{t}{4+0.85\,t}\right) \quad (1)$$

Where f_{cm} (t), is the mean compressive property at the age of t days and f_{c28} is mean compressive property at 28 days.

Table.II correlation of measured compressive property and computed compressive Property

Mix Designation	Experimental compressive Property (MPa)	Theoretical compressive property (ACI 209 (Type 1)) (MPa)	Correlation between Experimental to computed Theoretical property
	28 days	28 days	
CS	79	79.5	0.99
NS 1	83.5	84.1	0.99
NS 2	84.5	85.1	0.99
NS 3	88.7	89.3	1.00

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The compressive property of all substitutions was obtained at the ages of 28 days and their strength are shown Figure.1.From the results obtained, it was observed that concrete specimens containing higher order replacement of nano silica exhibited higher strength than control specimens.

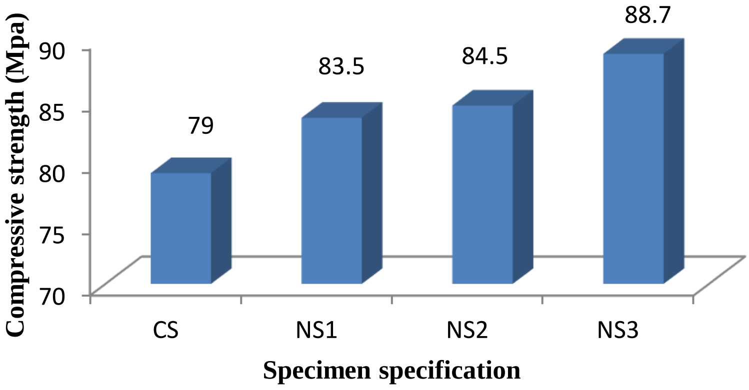

Figure 1. Compressive strength at 28 days

The measured compressive properties for the M70 grade of concrete is compared with the computed compressive strength using Equation (1) as per ACI 209 ASTM TYPE 1[2] .From the Table. II. it is obvious that the correlation between experimental compressive property go in hand with theoretical compressive strength.

B. Split tensile strength

From Figure 2, the split tensile strength of 3.61 MPa was obtained for the specimen NS3 which is about 28.9% higher than the control specimen. Similarly split tensile strength for NS1 and NS2 are 13.21% and 23.5% respectively when related to the control specimen. This improvement is because of the more efficient bridging effect across the crack width. The correlation of measured split tensile strength and computed split tensile property as per equation(2) is shown in Table III and From Table.III it is clear that maximum accuracy of correlation is obtained for NS 2 and NS 3. The correlation for CS and NS 1 between measured and computed was found to be 0.83 and 0.93 respectively which is within ± 20% accuracy

$$f_{st(t)} = 0.85(f_{ck})^{0.315} \quad (2)$$

Wheref_{st}(t), is the mean split tensile strength at the age of t days and f_{ck} is mean compressive property at 28 days.

Table.III Correlation of measured split tensile strength and computed split tensile strength

Mix Designation	Experimental Split tensile strength (MPa)	Theoretical Split tensile (ACI 209 (Type 1)) (MPa)	Correlation between Experimental to Theoretical Split tensile strength
	28 days	28 days	
CS	2.80	3.36	0.83
NS 1	3.17	3.43	0.93
NS 2	3.46	3.44	1.00
NS 3	3.91	3.49	1.00

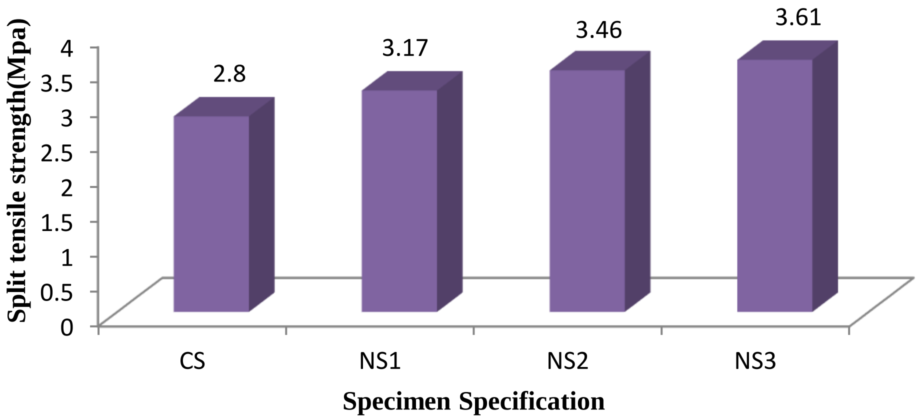

Figure.2. Split tensile strength at 28 days

C. Flexural behavior of Reinforced concrete beams:

Four reinforced concrete beams of size 10cm x 15 cm x 150 cm were cast and tested for load at one third points. Details of beam geometry and flexural reinforcement locations are shown in Figure 3. Reinforced Concrete beams were tested with monotonic load at one third points till failure for this investigation. One control beams were used as a comparison for the remaining three. Reinforced Concrete beams were subjected to flexural test on a simply supported span of 1100 mm with loads at one third points in Universal Testing Machine of 1000 kN capacity. A hydraulic jack with 1000 kN capacity was used to provide a controlled linear loading with 2 kN increment and at each stage and corresponding mid span deflection was recorded with help of dial gauge of least count of 0.01 mm / division. The load cell having a capability of 50 T was used to measure the load applied. The crack initiation due to flexure was carefully noted and corresponding load and deflection were recorded. The nature of failure of the specimen was noted. The test results of RC beam which are tested under load at one third points are arrayed in Table.IV

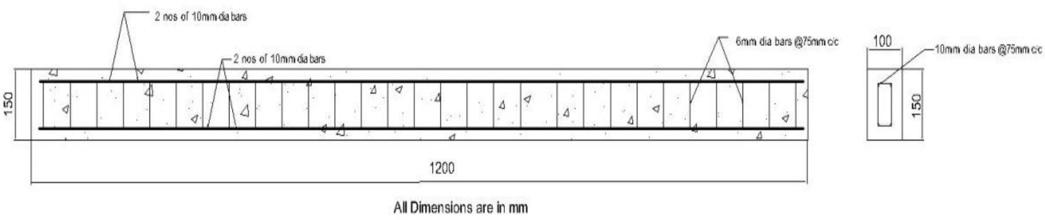

Figure 3. Flexural reinforcement of RC beam

- ***Load Deflection behavior***

From the Figure 4 it is obvious that load deflection curve is linear up to first crack load. The load deflection history for all beams was noted. From the load vs. deflection curves, it was noted that the flexural behavior of beams containing 3% nano silica behaved in a superior way when compared with corresponding control specimen.

Table.IV Test results of RC beam

Mix Designation	First crack load (kN)	Ultimate load (kN)	Energy absorption (kNmm)	Ductility factor
CS	28	69.0	429.9	2.44
NS 1	30	74.3	448.0	2.90
NS 2	30	84.2	462.5	3.33
NS 3	34	92.5	483.4	3.54

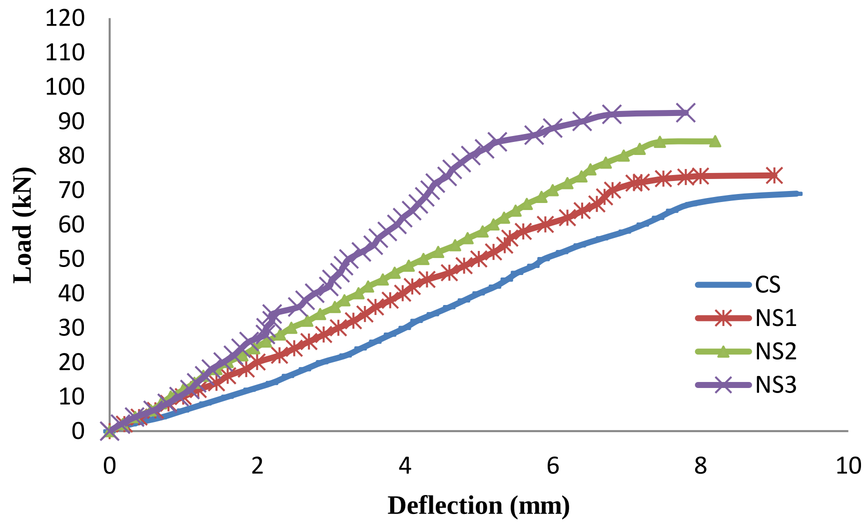

Figure.4 Load vs Deflection behaviour

- ***First Crack Load***

Static load at one third point was applied on all beams and at each increment of load, deflection was noted. The observed load was recorded at initial crack of all the beams and shown in the Figure.5. In control beam, CS initiation of crack took place at a load of 28 kN. In beam NS1 initiation of crack took place at a load of 30 kN which is lower than beam NS2 in which crack initiation starts at 30 kN. Similarly, in beam NS3 initiation of crack take place at a load of 34 kN, In the case of reinforced concrete beams 3% of nano silica the first crack load was found to be increased by 8 % for NS1 and NS2, 21 % for NS3 with reference to control beam CS

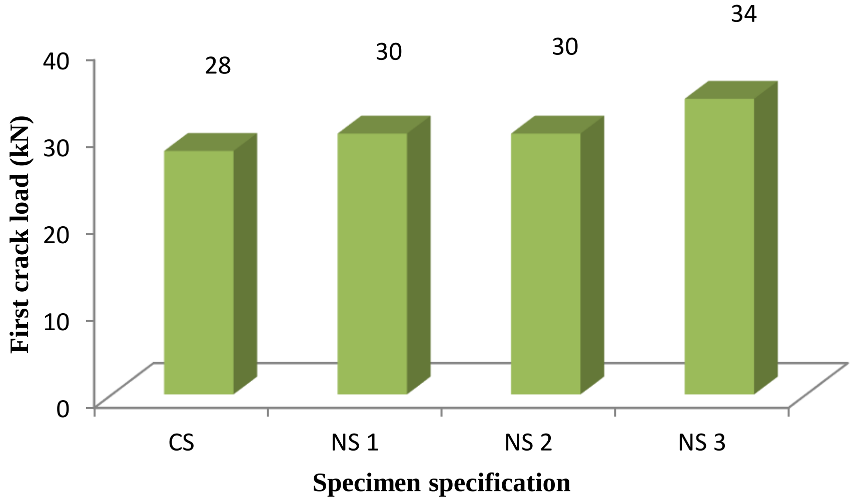

Figure.5 First crack load

- ***Ultimate Load***

The load carrying capacity of Reinforced concrete beam was recorded and is shown in Figure.6 .It was noted that all the beams replaced with nano silca had the higher load carrying capacity compared to the control beam CS. In control beam, ultimate failure took place at a load of 69kN. In beam NS1 ultimate load was 74.3 kN, which is lower than beam NS2 in which ultimate load was about 84.2 kN. Similarly, in beam NS3 ultimate failure took place at a load of 92.5 kN. Similarly, the ultimate load was increased by 7.61 % for NS1, 22 % for NS2, 34 % for NS3, with reference to control beam CS.

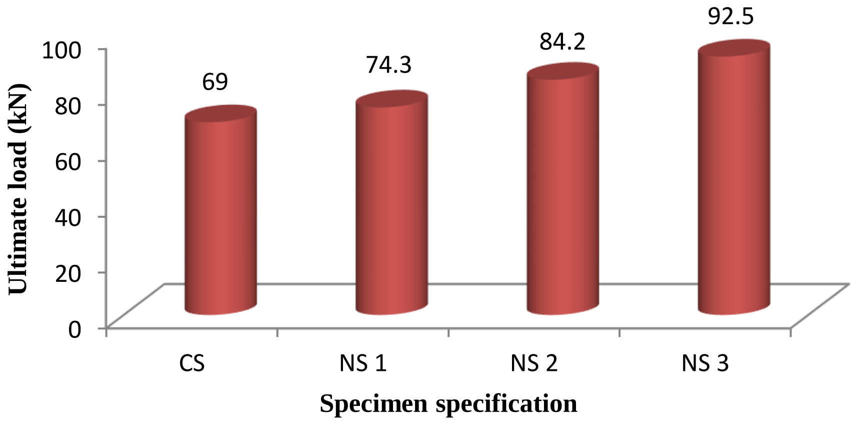

Figure.6. Ultimate load

- ***Energy absorption***

Energy absorption is the area under the load deflection curve. Figure.7 shows the variation in energy absorption capacity of RC beams. The RC beams with nano silica exhibits an increase in energy absorption capacity with reference to control specimen. The energy absorption capacity was found to have increased by4% for NS1, 7.5% for NS2, 12.41% for NS3 as that of control specimen.

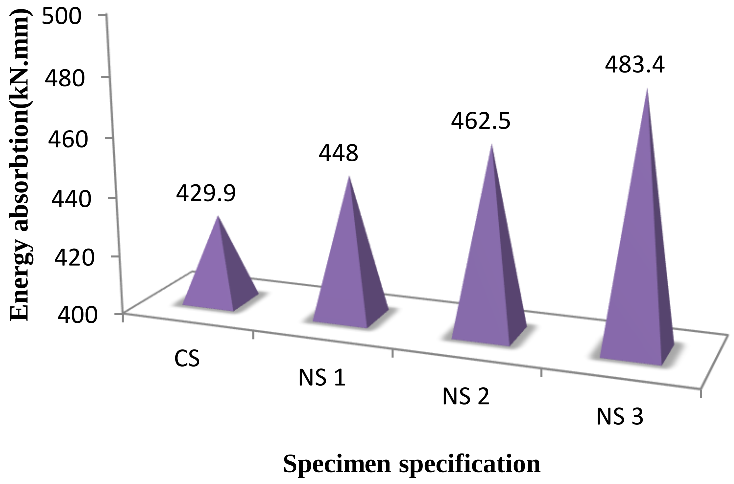

Figure.7 Energy Absorption

- ***Ductility Ratio***

Ductility ratio is the total deflection to the deflection at elastic limit. Figure.8 shows the variation in ductility factor. The ductility ratio of Reinforced concrete beams with Nano silica varies from 2.44 to 3.54. The ductility factor was found to have increased by 18.8% for NS1, 36.4% for NS2, 23% for FB03 and 45% for NS3 as that of control specimen CS.

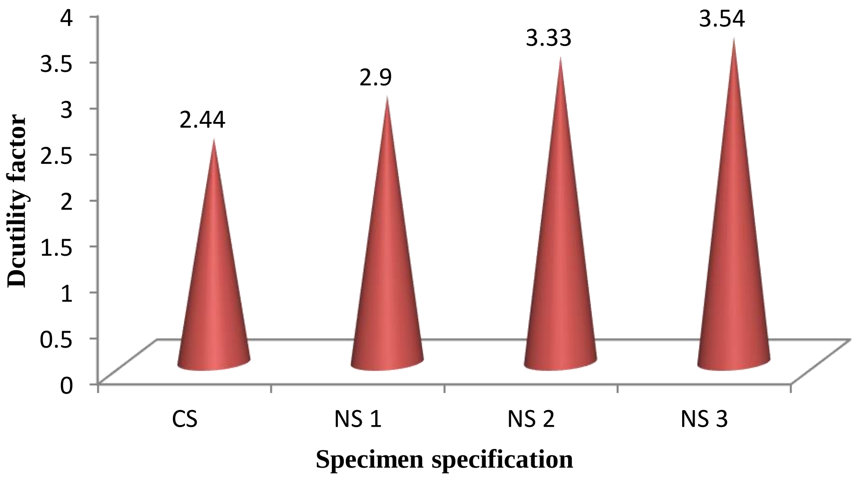

Figure.8 Ductility factor

- ***Crack Pattern***

Flexural failure was observed for all specimens. Cracks were observed to originate at the soffit of the beams below the load point, propagating across the beam for the specimen CS and RC beams with Nano Silica. The introduction of Nano Silica altered the cracking behavior of Reinforced Concrete beam.

V. CONCLUSIONS

Based upon the experimental investigation the following conclusion were drawn

1. The addition of Nano particles of Sio_2 can improve the compressive and tensile properties of concrete.
2. The increase in properties depends upon the addition on Nano Silica content.
3. Mechanical properties were found to be maximum for concrete mix containing 3% of Nano silica.
4. The correlation of Experimental results and Computed results were found to be good.
5. The first crack load and Ultimate load was found to be maximum for RC beam with 3% addition of Nano Silica content.
6. Similarly the Energy absorption, ductility ratio was found to be high for RC beam containing higher order replacement of Nano Silica.

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7. Addition of Nano Silica acts as a packing material to improve the concrete microstructure and results in reduction of crack width.
8. From the overall discussion it is concluded that there is strength enhancement in compressive strength, Tensile strength and Flexural behavior of concrete with 3% addition of Nano silica and which is the optimum percentage addition of Nano silica in the concrete.

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