STUDY OF COMPRESSIVE STRENGTH OF CONCRETE WITH EFFECT OF NANO SILICA

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ABSTRACT: The application of nanotechnology in concrete has added a new dimension to the efforts to improve its properties. Nanomaterials, by virtue of their very small particle size can affect the concrete properties by altering the microstructure. This study concerns with the use of nano silica of size 236 nm to improve the compressive strength of concrete. An experimental investigation has been carried out by replacing the cement with nano silica of 0.3%, 0.6% and 1% b.w.c. The tests conducted on it shows a considerable increase in early-age compressive strength and a small increase in the overall compressive strength of concrete. The strength increase was observed with the increase in the percentage of nano silica. The FESEM micrographs support the results and show that the microstructure of the hardened concrete is improved on addition of nano silica.
Keywords: concrete, nano silica, compressive strength, microstructure

I. INTRODUCTION

The increased use of cement is essential in attaining a higher compressive strength. But, cement is a major source of pollution. The use of nanomaterials by replacement of a proportion of cement can lead to a rise in the compressive strength of the concrete as well as a check to pollution. Since the use of a very small proportion of Nano SiO_2 can affect the properties of concrete largely, a proper study of its microstructure is essential in understanding the reactions and the effect of the nanoparticles. The existing papers show the use of admixtures in concrete mix. In the present study, no admixture has been used in order to prevent the effect of any foreign material on the strength of the concrete. This study is an attempt to explain the impact of a nano-silica on the compressive strength of concrete by explaining its microstructure.

The main objectives of the present study are as mentioned below:

- To study the effect of nano-silica on the compressive strength of concrete.
- To study the microstructure of the hardened cement concrete
- To explain the change in properties of concrete, if any, by explaining the microstructure.

II. EXPERIMENTAL SETUP METHODS

Mix Design

The mix design for M25 grade of concrete is described below in accordance with Indian Standard Code IS: 10262-1982.

TARGET STRENGTH FOR MIX PROPORTIONING:

Characteristic compressive strength at 28 days: f_{ck} = 25 MPa Assumed standard deviation (Table 1 of IS 10262:1982): sd = 4 MPa

Target average compressive strength at 28 days: $f_{target} = f_{ck} + 1.65sd$ =31.6 Mpa

SELECTION OF WATER-CEMENT RATIO:

From Table 5 of IS: 456-2000, maximum water-cement ratio = 0.50 To start with let us assume a water-cement ratio of 0.43

SELECTION OF WATER CONTENT:

Maximum water content per cubic metre of concrete (refer Table 2 of IS: 10262- 1982): W_{max} = 186L (for 50 mm slump).

Since, the slump was less than 50 mm, no adjustment was required.

CALCULATION OF CEMENT CONTENT:

Mass of water selected per cubic metre of concrete = 186 kg.

Mass of cement per cubic metre of concrete = 186/0.43 = 433 kg.

Minimum cement content = 300 kg/m^3 (for moderate exposure condition, Table 5 of IS 456:2000)

Maximum cement content = 450 kg/m^3 (Cl. 8.2.4.2 of IS 456:2000) So, the selected cement content is alright.

PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT:

Volume of coarse aggregate per unit volume of total aggregate (Table 3 of IS: 10262-1982) = 0.64

(This is corresponding to 20 mm size aggregate and Zone III fine aggregate for water-cement ratio of 0.50) As the water-cement ratio is lowered by 0.05, the proportion of volume of coarse aggregate is increased by 0.01 (ref. Table 6 of IS: 10262-1982)

Corrected volume of coarse aggregate per unit volume of total aggregate = (0.64+0.014) = 0.654 Volume of fine aggregate per unit volume of total aggregate = 1-0.654 =0.346

MIX CALCULATIONS

Volume of concrete = 1 m^3

ii. Volume of cement = 433/(3.01×1000) = 0.144 m^3

Volume of water = 186/1000 = 0.186 m^3

Volume of all aggregates = 1-0.144-0.186 = 0.67 m^3
v. Mass of coarse aggregate = 0.654×0.67×2.72×1000 = 1192 kg
vi. Mass of fine aggregate = 0.346×0.67×2.65×1000 = 614 kg

MIX PROPORTION:
For a batch of 6 cubes of 150mm side, the volume of concrete required
= $(0.15)^3$×6×1.2 = 0.024 m^3 (taking into account 20 % extra for losses) Cement required = 0.024x433 = 10.4 kg

Fine aggregate required = 0.024x614 = 14.7 kg Coarse aggregate required = 0.024x1192 = 28.6 kg Water required = 0.024x186 = 4.5 kg

Preparation of Test Specimen
For conducting compressive strength test on concrete cubes of size 150 □150 □150 mm are casted. A rotary mixture is used for thorough mixing and a vibrator is used for good compaction. After successful casting, the concrete specimens are de-moulded after 24 hours and immersed in water for 28 days maintaining 27 □□1^0 C. Fig. 3.3 shows some concrete specimen casted in laboratory.

Fig. 3.3 (a): concrete cubes casted in the mould

Fig. 3.3 (b): concrete cubes after de-moulding Fig. 3.3: (a) and (b) shows some concrete specimen cast in laboratory

Compressive Strength Test
The compressive strength of specimens is determined after 7 and 28 days of curing with surface dried condition as per Indian Standard IS: 516-1959. Three specimens are tested for typical category and the mean compressive strength of three specimens is considered as the compressive strength of the specified category.

Ultrasonic Pulse Velocity (UPV) Test
It is a non-destructive testing technique (NDT). The method consists of measuring the ultrasonic pulse velocity through the concrete with a generator and a receiver. This test can be performed on samples in the laboratory or on-site. The results are affected by a number of factors such as the surface and the maturity of concrete, the travel distance of the wave, the presence of reinforcement, mixture proportion, aggregate type and size, age of concrete, moisture content, etc., furthermore some factors significantly affecting UPV might have little influence on concrete strength. Table 3.4 shows the quality of concrete for different values of pulse velocity. The images of the UPV Testing Machine used in the laboratory is shown in Fig. 3.4.

Table 3.4: Criteria for quality of concrete

PULSE VELOCITY	CONCRETE QUALITY
>4000 m/s	Excellent
3500-4000 m/s	Very Good
3000-3500 m/s	Satisfactory
<3000 m/s	Poor

RESULT ANALYSIS
EXPERIMENTAL RESULTS
UPV Test Results:
Fig 4.1-4.8 show UPV test results for specimen for 7 day and Fig 4.5-4.8 show UPV test results for specimen for 28 day.

Table 4.1: UPV Test for control specimen for 7 day

7-DAY TEST RESULT			
Sample No.	**Weight (kg)**	**Velocity (m/s)**	**Time (µs)**
1	8.10	4678	32.2
2	8.34	4702	31.9
3	8.36	4777	31.4

Table 4.2: UPV Test for specimen with nano-silica 0.3% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	**Weight (kg)**	**Velocity (m/s)**	**Time (µs)**
1	8.18	4491	33.4
2	8.22	4491	33.4
3	8.24	4386	34.2

Table 4.3: UPV Test for specimen with nano-silica 0.6% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.26	4630	32.4
2	8.08	4630	32.4
3	7.98	4702	31.9

Table 4.4: UPV Test for specimen with nano-silica 1% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.24	4491	33.4
2	8.14	4360	34.4
3	8.30	4559	32.9

Table 4.5: UPV Test for control specimen for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.42	4808	31.2
2	8.36	4854	30.9
3	8.14	4777	31.4

Table 4.6: UPV Test for specimen with nano-silica 0.3% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.06	4673	32.1
2	8.32	4732	31.7
3	8.22	4854	30.9

Table 4.7: UPV Test for specimen with nano-silica 0.6% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.18	4702	31.9
2	8.24	4777	31.4
3	8.22	4777	31.4

Table 4.8: UPV Test for specimen with nano-silica 1% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Velocity (m/s)	Time (µs)
1	8.30	4658	32.2
2	8.30	4702	31.9
3	8.28	4808	31.2

Compressive Strength Test Results

*Compressive Strength = (52 × 9.81 × 1000) ÷ (150 × 150) = 22.67 MPa

Table 4.9: Compressive Strength of control specimen for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.10	52	22.67 *
2	8.34	68	29.65
3	8.36	61	26.59
Mean			26.30

Table 4.10: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.18	67	29.21
2	8.22	71	30.95
3	8.24	52	22.67
Mean			27.61

Table 4.11: Compressive Strength of specimen with nano-silica 0.6% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.26	66	28.77
2	8.08	72	31.39
3	7.98	76	33.14
Mean			31.1

Table 4.12: Compressive Strength of specimen with nano-silica 1% b.w.c for 7 day

7-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.24	77	33.57
2	8.14	79	34.44
3	8.30	82	35.75
Mean			34.59

Table 4.13: Compressive Strength of control specimen for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.42	84	36.62
2	8.36	84	36.62
3	8.14	75	32.70
Mean			35.31

Table 4.14: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.06	66	28.78
2	8.32	88	38.37
3	8.22	88	38.37
Mean			35.17

Table 4.15: Compressive Strength of specimen with nano-silica 0.6% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.18	83	36.19
2	8.24	80	34.88
3	8.22	88	38.37
Mean			36.48

Table 4.16: Compressive Strength of specimen with nano-silica 1% b.w.c for 28 day

28-DAY TEST RESULT			
Sample No.	Weight (kg)	Load (tonne)	Compressive Strength (MPa)
1	8.30	88	38.37
2	8.30	93	40.55
3	8.28	93	40.55
Mean			39.82

III. COMPARISON OF RESULTS

Comparison of Compressive Strength Results

The change in compressive strength for the blended sample (in %) for 7 and 28 day is shown in Table 4.17 and Table 4.18 respectively. A graphical representation of this result is shown in Fig.
4.1 and Fig. 4.2. The change in compressive strength from 7 day to 28 day is shown in Fig 4.3.

Table 4.17: Comparison of compressive strength for 7 day

7-DAY RESULTS	STRENGTH (MPa)	INCREASE IN STRENGTH (%)
CONTROL	26.30	-
NS 0.3% b.w.c	27.61	4.98
NS 0.6% b.w.c	31.10	18.25
NS 1% b.w.c	34.59	31.52

NS= Nano SiO_2 Table 4.18: Comparison of compressive strength for 28 day

28-DAY RESULTS	STRENGTH (MPa)	INCREASE IN STRENGTH (%)
CONTROL	35.31	-
NS 0.3% b.w.c	35.17	-0.39
NS 0.6% b.w.c	36.48	3.31
NS 1% b.w.c	39.82	12.77

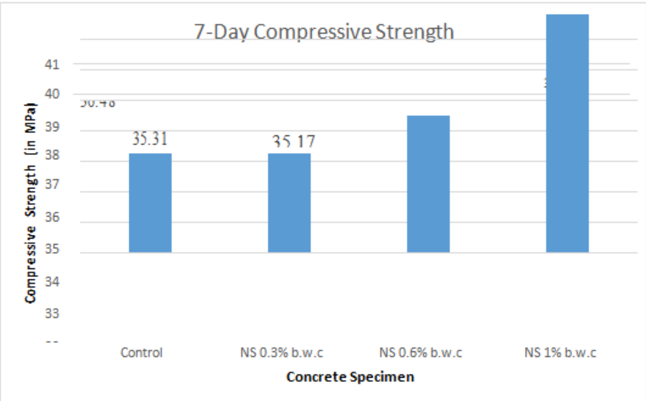

Fig. 4.1: 7-day compressive strength of four specimen

IV. CONCLUSION

From the test results, the SEM micrographs and the relative chemical composition of the specimen a number of conclusions can be drawn. These conclusions are justified in the next section. The conclusions drawn are:

- From the compressive strength results, it can be observed that increase in compressive strength of concrete is observed on addition of a certain minimum quantity of Nano SiO_2. The increase in strength is maximum for NS 1% b.w.c and least for NS 0.3% b.w.c.
- On addition of Nano SiO_2 there is a substantial increase in the early-age strength of concrete compared to the 28 day increase in strength.
- The UPV test results show that the quality of concrete gets slightly affected on addition of Nano SiO_2 but the overall quality of concrete is preserved.
- The FESEM micrograph shows a uniform and compact microstructure on addition of Nano-SiO_2.

DISCUSSION

- The increase in compressive strength can be attributed to the filling of voids in the microstructure by the Nano SiO_2 particles which prevents the growth of $Ca(OH)_2$ crystals. In addition to it the nano silica reacts with calcium hydroxide crystals converting them into C-S-H gel. The reduction in the $Ca(OH)_2$ content is the reason for increase in compressive strength of concrete.
- $Ca(OH)_2$ crystals are present in the Interfacial Transition Zone (ITZ) which is between the aggregates and the hardened cement paste. Nano SiO_2 reacts with these crystals and decreases their concentration, hence, strengthen the ITZ. Due to lesser concentration Nano SiO_2 are consumed in the reaction and hence the increase in strength is inhibited with time.
- A study of relevant papers show that concrete blended with Nano SiO_2 sets quicker compared to normal concrete. Since, the mix design is carried out without the aid of supper- plasticizers, the mix dried up fast which affected the compaction of the mix using mechanical vibration. Lumps of the mix could be seen during the mixing of concrete. With increase in percentage of Nano SiO_2 the compaction gets tougher. This is the reason for degradation in its quality. It is advisable to use superplasticizers with nano silica.
- The Nano SiO_2 added to the mix filled up the pores in between the C-S-H gel, hence, making the microstructure more compact and uniform.

SCOPE FOR FUTURE RESEARCH

Although a lot of work has been carried out involving the use of nano silica in concrete, a proper understanding has not been developed. In future, the size effects of nano silica can be studied in detail. A detailed study of the microstructure at specific intervals throughout a year can give a very good idea about the reactions taking place in the concrete. Looking at the price of the nano silica new methods can be designed for its production at a low cost.

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