EXPERIMENTAL & COMPARATIVE STUDY OF COMPRESSIVE STRENGTH OF CONCRETE WITH THE USE 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.*

***Key Words*: Cement, Concrete, Nano Silica, Compressive Strength, Microstructure**

1.0 INTRODUCTION

“Concrete is the most bountiful resource on Earth. " Therefore, concrete is the second most consumed material on Earth after water. Concrete is the material of present as well as future. The wide use of it in structures, from buildings to factories, from bridges to airports, makes it one of the most investigated material of the 21st century. Due to the rapid population explosion and the technology boom to cater to these needs, there is an urgent need to improve the strength and durability of concrete. Out of the various materials used in the production of concrete, cement plays a major role due its size and adhesive property. So, to produce concrete with improved properties, the mechanism of cement hydration has to be studied properly and better substitutes to it have to be suggested. Different materials known as supplementary cementitious materials or SCMs are added to concrete improve its properties. Some of these are fly ash, blast furnace slag, rice husk, silica fumes and even bacteria. Of the various technologies in use, nano-technology looks to be a promising approach in improving the properties of concrete.

1.1 CEMENT- Composition and Hydration

Cement can be described as a crystalline compound of calcium silicates and other calcium compounds having hydraulic properties (Intht). The four major compounds that constitute cement (Bogue’s Compounds) are Tricalcium silicate, abbreviated as C_3S, Dicalcium silicate (C_2S), Tricalcium aluminate (C_3A), Tetracalcium aluminoferrite (C_4AF) where C stands for CaO, S stands for SiO_2, A stands for Al_2O_3 and F for Fe_2O_3. Tricalcium silicate and dicalcium silicate are the major contributers to the strength of cement, together constituting about 70 % of cement. Dry or anhydrous cement does not have adhesive property and hence cannot bind the raw materials together to form concrete. When mixed with water chemical reaction takes place and is referred to as ‘hydration of cement’. The products of this exothermic reaction are C-S-H gel and $Ca(OH)_2$. Calcium hydroxide has lower surface area and hence does not contribute much to the strength of concrete. On hydration of cement aluminates a product is formed known as ettringite, which has needle like morphology and contributes to some early strength of concrete. C-S-H gel refers to calcium silicate hydrates, making up about 60 % of the volume of solids in a completely hydrated cement paste. It has a structure of short fibres which vary from crystalline to amorphous form. Owing to its gelatinous structure it can bound various inert materials by virtue of Van der Waal forces. It is the primary strength giving phase in cement concrete.

1.2 NANOMATERIALS- Use in Concrete

Nanomaterials are very small sized materials with particle size in nanometres. These materials are very effective in changing the properties of concrete at the ultrafine level by the virtue of their very small size. The small size of the particles also means a greater surface area (Alireza Naji Givi, 2010). Since the rate of a pozzolanic reaction is proportional to the surface area available, a faster reaction can be achieved . Only a small percentage of cement can be replaced to achieve the desired results. These nanomaterials improve the strength and permeability of concrete by filling up the minute voids and pores in the microstructure. The use of nanosilica in concrete mix has shown results of increase in the compressive, tensile and flexural strength of concrete. It sets early and hence generally requires admixtures during mix design. Nano-silica mixed cement can generate nano-crystals of C-S-H gel after hydration. These nano-crystals accommodate in the micro pores of the cement concrete, hence improving the permeability and strength of concrete.

1.3 OBJECTIVE OF THE STUDY

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.

2.0 METHODOLOGY

2.1 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.

2.2 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. Table2.1 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. a ,b.

Table 2.1: 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

2.3 Other Tests

Some other tests performed were using Field Emission Scanning Electron Microscope (FESEM) and using Particle Size Analyser (PSA). Since these tests were performed by technical experts, these are not explained here and only the results are presented in the next topic.

Fig. (a): UPV Test apparatus

Fig. (b): UPV Test of concrete specimen
Fig. (a) and (b) shows UPV Test performed in laboratory

3.0 RESULT AND DISCUSSION

It includes results from compressive strength test, UPV Test and FESEM. The results are supplemented with graphs in order to have a better analysis of the results.

3.1 UPV Test Results:

Fig 3.1-3.8 show UPV test results for specimen for 7 day and Fig 3.5-3.8 show UPV test results for specimen for 28 day.

Table 3.1: UPV Test for control specimen for 7 day

7-DAY TEST RESULT			
SampleNo.	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 3.2: UPV Test for specimen with nano-silica 0.3% b.w.c for 7 day

7-DAY TEST RESULT			
SampleNo.	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 3.3: UPV Test for specimen with nano-silica 0.6% b.w.c for 7 day

7-DAY TEST RESULT			
SampleNo.	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 3.4: UPV Test for specimen with nano-silica 1% b.w.c for 7 day

7-DAY TEST RESULT			
SampleNo.	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 3.5: UPV Test for control specimen for 28 day

28-DAY TEST RESULT			
SampleNo.	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 3.6: UPV Test for specimen with nano-silica 0.3% b.w.c for 28 day

28-DAY TEST RESULT			
SampleNo.	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 3.7: UPV Test for specimen with nano-silica 0.6% b.w.c for 28 day

28-DAY TEST RESULT			
SampleNo.	Weight(kg)	Velocity(m/s)	Time(μs)
1	8.18	4702	31.9
2	8.24	4777	31.6
3	8.22	4770	31.4

Table 3.8: UPV Test for specimen with nano-silica 1% b.w.c for 28 day

28-DAY TEST RESULT			
SampleNo.	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

- **Comparison of UPV Test Results**

From the UPV test results, we find that the quality of concrete is very good. The 28-day quality is better than the 7-day quality. The control specimen are found to have better quality compared to the blended concrete specimen.

3.2 Compressive Strength Test Results

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

= 22.67 MPa

Table 3.9: Compressive Strength of control specimen for 7 day

7-DAYS TEST RESULT			
SampleNo.	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 3.10: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 7 day

7-DAYS TEST RESULT			
SampleNo.	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 3.11: Compressive Strength of specimen with nano-silica 0.6% b.w.c for 7 day

7-DAYS TEST RESULT			
SampleNo.	**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			31.10

Table 3.12: Compressive Strength of specimen with nano-silica 1% b.w.c for 7 day

7-DAYS TEST RESULT			
SampleNo.	**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 3.13: Compressive Strength of control specimen for 28 day

28-DAY TEST RESULT			
SampleNo.	**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 3.14: Compressive Strength of specimen with nano-silica 0.3% b.w.c for 28 day

28-DAY TEST RESULT			
SampleNo.	**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 3.15 Compressive Strength of specimen with nano-silica 0.6% b.w.c for 28 day

28-DAYS TEST RESULT			
SampleNo.	**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 3.16: Compressive Strength of specimen with nano-silica 1% b.w.c for 28 day

28-DAYS TEST RESULT			
SampleNo.	**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

- **Comparison of Compressive Strength Results**

The change in compressive strength for the blended sample (in %) for 7 and 28 day is shown in Table 3.17 and Table 3.18 respectively. A graphical representation of this result is shown in Fig. (c) and Fig. (d) .The change in compressive strength from 7 day to 28 day is shown in Fig (e).

Table 3.17: 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 3.18: 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

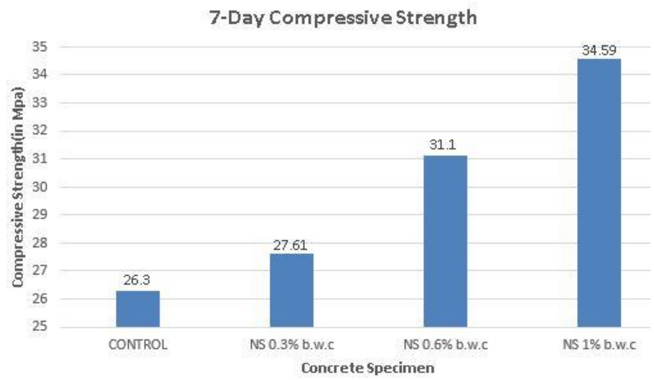

Fig. (c) : 7-day compressive strength of four specimen

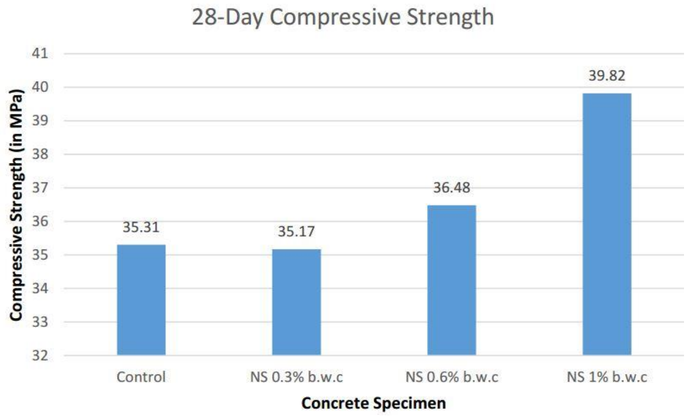

Fig. (d) : 28-day compressive strength of four specimen

Fig. (e): Change in compressive strength of four specimen from 7 day to 28 day

3.3 Field Emission Scanning Electron Microscope (FESEM) IMAGES

The FESEM micrographs for the four specimens are shown below from Fig (f)- (g). Two different magnification has be chosen for the purpose of comparison.

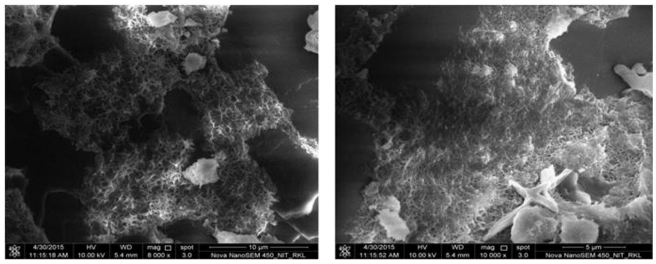

Fig. (f): FESEM image of control specimen with different Magnification

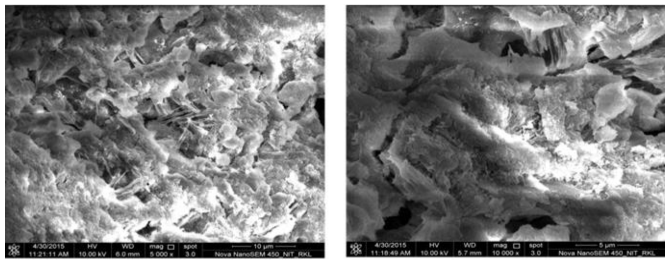

Fig. (g): FESEM image of specimen with Nano SiO_2 0.3% b.w.c

with different magnification

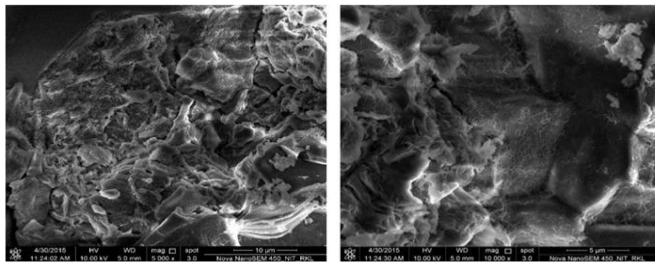

Fig. (h) : FESEM image of specimen with Nano SiO_2 0.6% b.w.c with different magnificaton

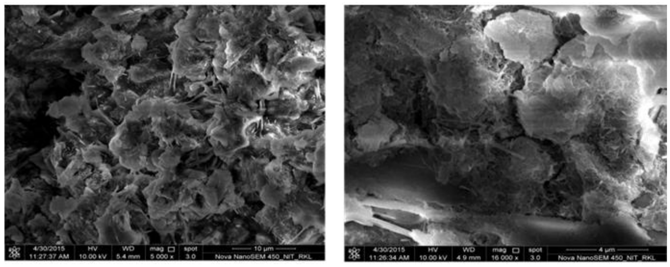

Fig. (i) : FESEM image of specimen with Nano SiO_2 1% b.w.c with different magnificaton

- **Comparison of FESEM micrographs**

Fig. (f) shows the FESEM micrograph of concrete specimen without nano-silica (NS). In this figure it can be clearly seen that the C-S-H gel is scattered with lots of empty spaces in between the lumps. The lumps can be $Ca(OH)_2$ which weakens the Interfacial Transition Zone (ITZ) hence affecting the strength. The microstructure looks to contain mainly amorphous substances.

Fig. (g) shows the FESEM micrograph of concrete specimen with NS 0.3% b.w.c. Here we can see a better packed microstructure but again large lumps of possibly $Ca(OH)_2$ crystals surrounded connected by needle like structures are found which is generally seen in plain concrete. The NS particles occupying the pores in C-S-H gel gives the compact structure but are not sufficient in amount to react with $Ca(OH)_2$ and produce C-S-H gel.

Fig. (h) shows the FESEM micrograph of concrete specimen with NS 0.6% b.w.c. A uniform microstructure with very little void can be seen. The absence of $Ca(OH)_2$ crystals indicates that NS has reacted with $Ca(OH)_2$ and converted it into C-S-H gel.

Fig. (i) shows the FESEM micrograph of concrete specimen with NS 1% b.w.c. The microstructure is very dense and many crystalline lumps can be observed. These lumps indicates the agglomeration of Nano SiO_2 particles which make the structure crystalline and hence enhances the strength.

4.0 CONCLUSIONS

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:

(i) 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 SiO2. The increase in strength is maximum for NS 1% b.w.c and least for NS 0.3% b.w.c.

(ii) On addition of Nano SiO2 there is a substantial increase in the early-age strength of concrete compared to the 28 day increase in strength.

(iii) The UPV test results show that the quality of concrete gets slightly affected on addition of Nano SiO2 but the overall quality of concrete is preserved.

(iv) The FESEM micrograph shows a uniform and compact microstructure on addition of Nano-SiO_2.

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