Nano-Silica as Partial Replacement of Coarse Aggregate to Increase the Compressive Strength of Concrete

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Abstract - *Concrete is used in buildings, factories, bridges, pavements, foundations, dams, airports and other structures which makes it one of the most researched material. And the advancement in technology and more population explosion has led to need for improvement in various properties of concrete. The use of nanotechnology in concrete has been helpful in achieving such desired results. Due to the very small size of the particles of nanomaterials, they affect the properties of concrete by altering its microstructure. In this study we have used nano silica of size 235 nm to increase its compressive strength. The tests are conducted by replacing coarse aggregate (by weight) with nano silica of 0.4 %, 0.8 % and 1.2 %. The tests performed are Rebound Hammer Test and Compression Strength Test. Both tests show an increase in early-age compressive strength of 7 days and 14 days as well as overall compressive strength at 28 days. Though the early-age compressive strength results indicate considerable higher increase in compressive strength compared to overall strength*.

***Keywords* -** nano-silica, compressive strength, concrete, microstructure, nanomaterial

1. Introduction

The need to improve properties of concrete is due to the demands produced by massive infrastructures, urbanization and industrialization. To improve the properties of concrete the mechanism of cement hydration has to be studied in detail and better substitutes must be searched. Supplementary cementitious materials are the materials that can be added to concrete to improve its properties. Some of them are used widely like fly ash, rice husk, etc. Nano technology looks very promising approach in improving various properties of concrete. Nanomaterials are very tiny materials. These particles are used in changing the properties of concrete at the microscopic level owing to their very small size. Nano-silica shows pozzolanic nature and has the ability to react with free lime during the cement hydration which leads to improved properties.

2. Literature Review

H. Li et. al. (2004) experimentally investigated the mechanical properties of nano-Fe2O3 and nano-SiO2 cement mortars and found that the 7 and 28 day strength was much higher than for plain concrete. The microstructure analysis shows that the nanoparticles filled up the pores and the reduced amount of $Ca(OH)_2$ due to the pozzolanic reaction.

Tao Ji (2005) experimentally studied the effect of Nano SiO_2 on the water permeability and microstructure of concrete. The findings show that incorporation of Nano SiO_2 can improve the resistance to water of concrete and the microstructure becomes more uniform and compact compared to normal concrete.

M.Nill Jo et. al. (2009) studied the combined effect of micro silica and colloidal nano-silica on the properties of the concrete and found that concrete will attain maximum compressive strength when it contains 6% microsilica and 1.5% nano-silica.

Ali Nazari et.al. (2010) studied the combined effect of Nano SiO_2 particles and GGBFS on properties of concrete. They used nanosilica with 3% b.w.c. replacement and 45% b.w.c. GGBFS, which shows improved split tensile strength.

Surya Abdul Rashid et. al. (2011) worked on the effect of nano-silica particles on both mechanical and physical properties of concrete which shows that binary blended concrete with nano-silica particles upto 2% has significantly higher compressive, split tensile and flexure strength compared to normal concrete.

A.M. Said et.al. (2012) studied the effect of colloidal Nano silica on concrete by blending it with class F fly ash and observed that performance of concrete with or without fly ash was significantly improved with addition of variable amounts of nano silica.

Mukharjee and Barai (2014) studied the compressive strength and characteristics of Interfacial Transition Zone (ITZ) of concrete containing recycled aggregates and nano-silica. An improvement in the compressive strength and microstructure of concrete was observed with the incorporation of nano-silica.

3. Objective Of The Study

The main objective of the research was to have a comparative study of the effect of nano-silica at 0.4%, 0.8% and 1.2% replacement with coarse aggregate on early age compressive strength of concrete at 7 days and 14 days as well as overall compressive strength at 28 days using destructive as well as non-destructive test.

4. Experimental Investigation

Material used:
For M25 grade mix design

1. Cement:
   Portland Pozzolana Cement of grade 53 confining to IS 1489 was used for preparing concrete specimens. The specific gravity of the cement was found to be 3.05. The initial and final setting time was found to be 38 min and 7 hours 40 minutes respectively. And the standard consistency was found to be 30%.

2. Coarse aggregate:
   Locally available crushed coarse aggregate of maximum size of 20 mm was used. Specific gravity of the coarse aggregate was 2.70 and fineness modulus was 6.1.

3. Fine Aggregate:
   Sand is used as fine aggregate which is locally available conforming to zone II and satisfies the requirements according to IS 383-1970. Sieve analysis of the fine aggregate is done. Specific gravity of the fine aggregate was found to be 2.65 and fineness modulus was found to be 2.87.

4. Water:
   Water used in his experiment is tap water, pH of water is found to be greater than 6 and specific gravity of water is taken as 1.0.

5. Nano-Silica:
   The average particle size of nano silica was found to be 235 nm by particle size analyzer. The tamped density of nano silica is 45 g/L and SiO_2 content is equal to 99.8 %.

5. Methodology

For finding the compressive strength cubes of size 150 mm × 150 mm × 150 mm are casted. The fine aggregate and cement are mixed until a thorough blend is formed and then coarse aggregate is added and mixed until it is uniformly distributed. Then water is added and the whole batch is mixed until a homogeneous mix is available to be casted in the moulds and hand compaction is done. The concrete specimens are de-moulded after 24 hours and are kept in water until taken out for testing.

Mix design calculations (as per IS 10262-2019) are given below:

1. Cement=413 kg/m^3
2. Water=186 kg/m^3
3. Coarse aggregate=1155 kg/m^3
4. Fine aggregate=665 kg/m^3

The following tests were conducted as per the Indian codal provisions:

1. Rebound hammer test: Rebound hammer testing is done as per IS 13311(Part 2): 1992. Rebound hammer test is a non destructive test and it can be used for assessing the compressive strength from various graphical co-relations, uniformity, and quality of concrete.
   The plunger of the rebound hammer is pressed against the surface of the specimen and the impact gives a reading noted as rebound number. A number of readings are taken and through graphs and co-relations compressive strength is worked out.
2. Compression test: The compression testing is done afterwards which gives more accurate values. The samples are placed in the universal testing machine. The load is applied gradually at the rate of 140 kg/cm^2/minute until the specimen fails. The maximum load at which it fails is recorded and compressive strength is determined.

6. Experimental Results

In this section we will study the results of the test that have been conducted on the concrete specimen.

COMPARISON OF COMPRESSIVE STRENGTH BY REBOUND HAMMER TEST :

Table 1 Comparison of Equivalent compressive strength at 7 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	22.93	-
2	With 0.4% NS	25.87	12.82 %

3	With 0.8% NS	27.25	18.83 %
4	With 1.2% NS	28.03	22.24 %

Table 2 Comparison of Equivalent compressive strength at 14 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	25.29	-
2	With 0.4% NS	28.23	11.62 %
3	With 0.8% NS	30.38	20.12 %
4	With 1.2% NS	32.54	28.66 %

Table 3 Comparison of Equivalent compressive strength at 28 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	31.76	-
2	With 0.4% NS	32.54	2.45 %
3	With 0.8% NS	35.88	12.97 %
4	With 1.2% NS	37.52	18.13 %

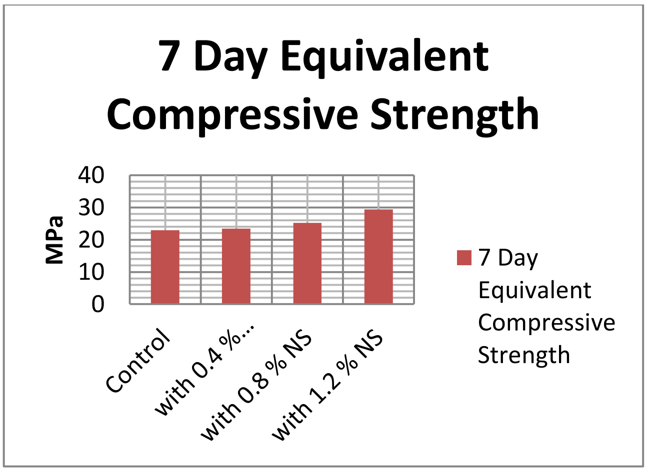

Fig. 1 Equivalent Compressive Strength of control and with 0.4%, 0.8% and 1.2% nano-silica at 7 day with RHT

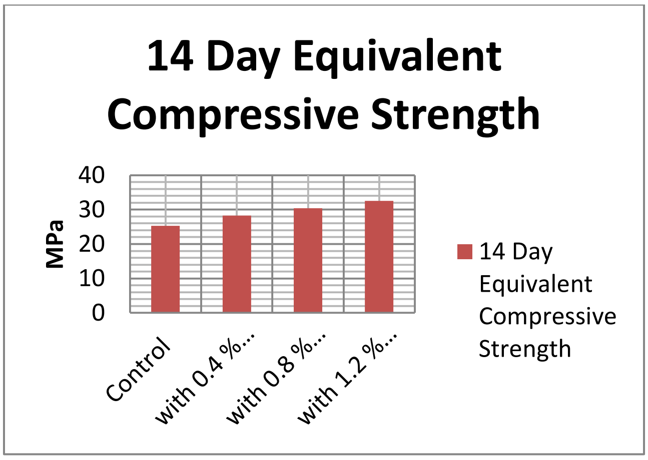

Fig. 2 Equivalent Compressive Strength of control and with 0.4%, 0.8% and 1.2% nano-silica at 14 day with RHT

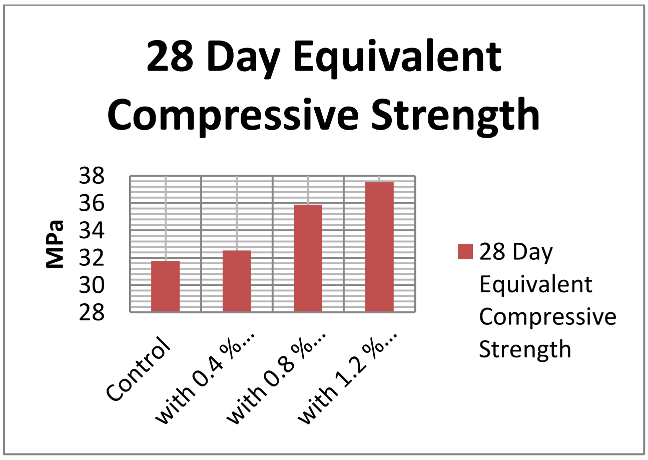

Fig. 3 Equivalent Compressive Strength of control and with 0.4%, 0.8% and 1.2% nano-silica at 28 day with RHT

COMPARISON OF COMPRESSIVE STRENGTH BY UNIVERSAL TESTING MACHINE:

Table 4 Comparison of compressive strength at 7 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	21.27	-
2	With 0.4% NS	23.39	9.96 %
3	With 0.8% NS	25.21	18.52 %
4	With 1.2% NS	29.39	38.17 %

Table 5 Comparison of compressive strength at 14 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	26.06	-
2	With 0.4% NS	29.79	14.31 %
3	With 0.8% NS	31.82	19.60 %
4	With 1.2% NS	35.38	35.76 %

Table 6 Comparison of compressive strength at 28 day test

S.NO	Type of sample	Equivalent Compressive Strength (MPa)	Increase in Strength(%)
1	Control Sample	32.10	-
2	With 0.4% NS	33.88	5.54 %
3	With 0.8% NS	35.75	11.37 %
4	With 1.2% NS	38.80	20.87 %

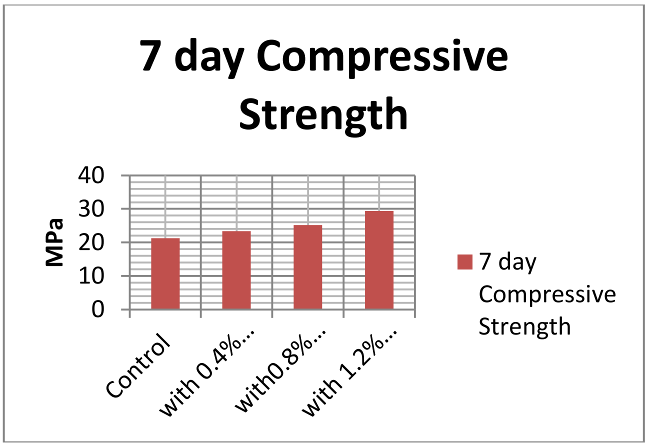

Fig. 4 Compressive Strength of control, with 0.4%, 0.8% and 1.2% nano-silica at 7 days by UTM

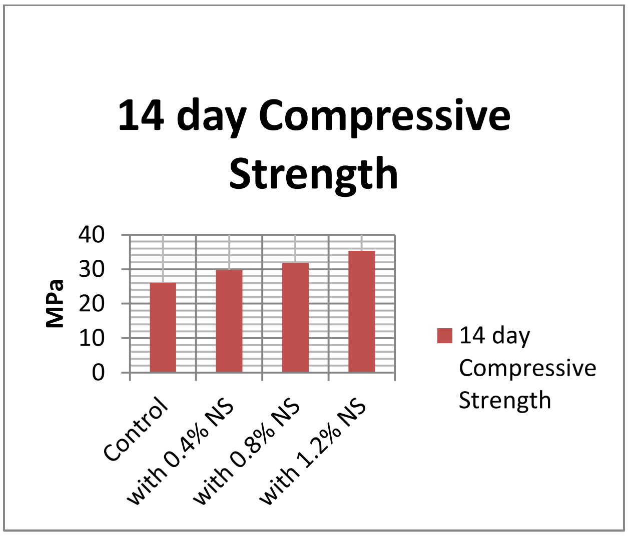

Fig. 5 Compressive Strength of control, with 0.4%, 0.8% and 1.2% nano-silica at 14 days by UTM

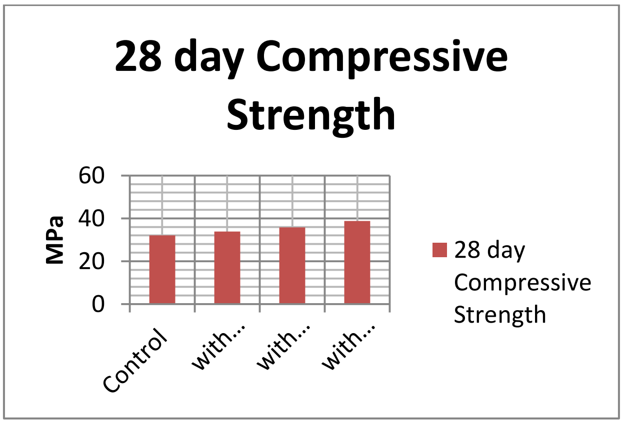

Fig. 6 Compressive Strength of control, with 0.4%, 0.8% and 1.2% nano-silica at 28 days by UTM

Table 7 RELATIVE COMPRESSIVE STRENGTH

S.NO	**Type of sample**	**Compressive strength(MPa)**					
		7 day strength		14 day strength		28 day strength	
		RHT	**CT**	**RHT**	**CT**	**RHT**	**CT**
1	Control Sample	22.93	21.27	25.29	26.06	31.76	32.10
2	With 0.4% NS	25.87	23.39	28.23	29.79	32.54	33.88

3	With 0.8% NS	27.25	25.21	30.38	31.82	35.88	35.75
4	With 1.2% NS	28.03	29.39	32.54	35.38	37.52	38.80

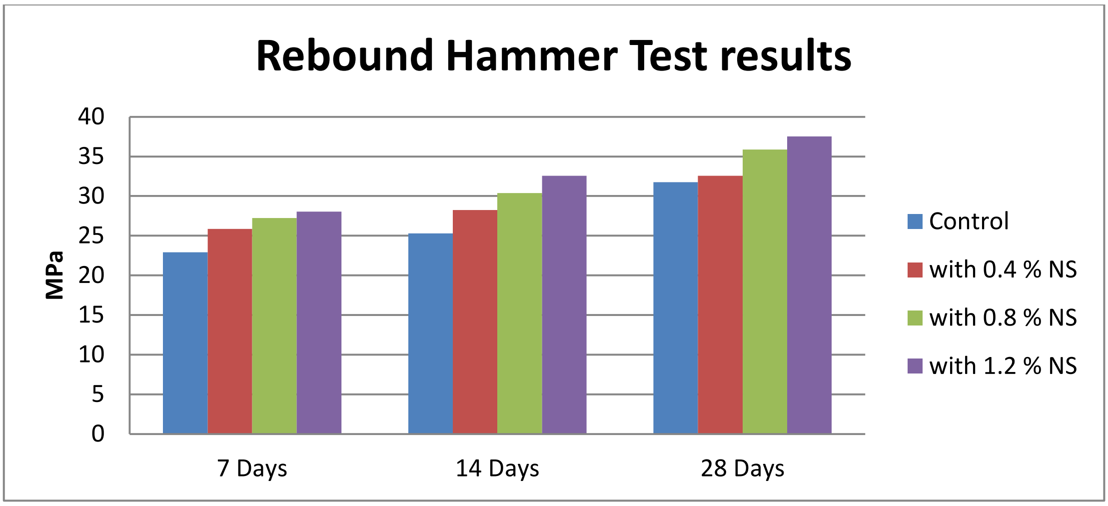

Fig 7 Test Results from Rebound Hammer Test

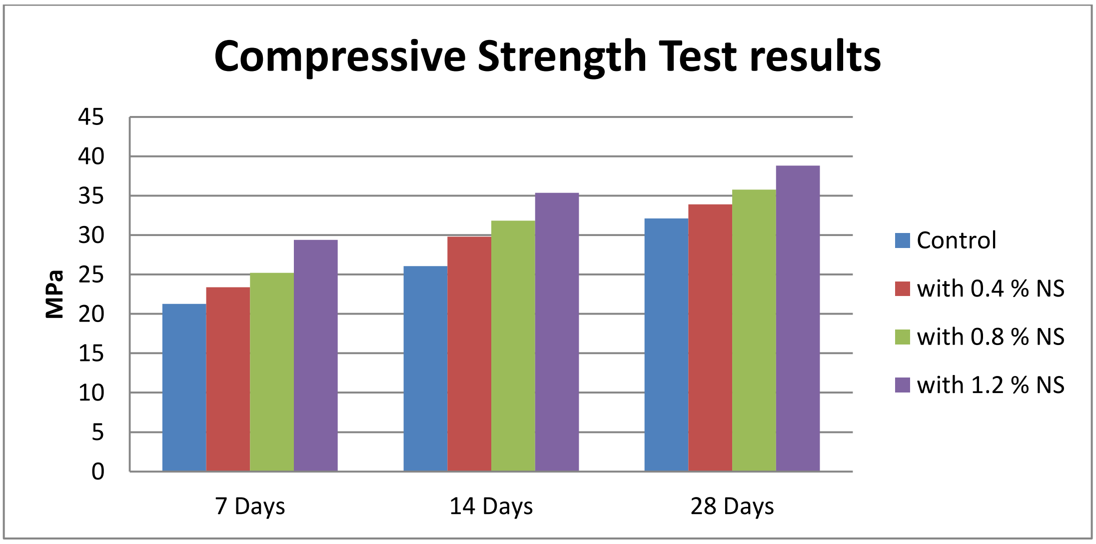

Fig 8 Test Results from Compression Test

7. Conclusions

From the result of the tests performed, the addition of nano-silica leads to the increase in compressive strength of concrete. It can be noted that the early-age strength of samples showed more promising results than the overall compressive strength at 28 days. In this chapter, the detailed conclusions from the test results are discussed as under:

1. The compressive strength observed with Rebound Hammer Test shows a considerable increase when compared to control sample. Following are the conclusions drawn from rebound hammer test:
    a. At 7 days, the sample containing 0.4% nano-silica shows an increase of 12.82%. Similarly, the samples containing 0.8% and 1.2% nano-silica shows an increase of 18.83% and 22.24% respectively.
    b. Similar results were seen at 14 days, with the samples containing 0.4%, 0.8% and 1.2% nano-silica when compared with control sample shows an increase of 11.6 %, 20.12%, 28.66% respectively.
    c. The compressive strength at 28 days also showed promising results with an increase of 2.45%, 12.97% and 18.13%

with the addition of 0.4%, 0.8% and 1.2% nano-silica respectively.

2. Similarly, the results obtained from the compression test by Universal Testing Machine also gave remarkable results. The early age strength at 7 days and 14 days shows a great increase in compressive strength compared to overall strength at 28 days. Following are the conclusions from compression test:
    a. At 7 days, all the samples shows good increase in the compressive strength when compared with control samples. There was a increase of 9.96%, 18.52% and 38.17% with the addition of 0.4%, 0.8% and 1.2% nano-silica respectively.
    b. On the addition of 0.4%, 0.8%, and 1.2% nano-silica there was a remarkable increase of 14.31%, 19.60% and 35.76% respectively.
    c. There was an increase of 5.54%, 11.37% and 20.87% with the addition of 0.4%, 0.8% and 1.2% nano-silica compared to the control sample.

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