Experimental investigation of the effect of Nano-silica on the mechanical properties of concrete

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Abstract. Construction Industry is one of the leader in deterioration of environment. The production of cement consumes large quantities of raw materials, energy, heat and releases greenhouse gases. This paper focuses to minimize the use of cement in the production of concrete. Concrete cubes and cylinders were prepared with 0, 2, 4 and 6% nano-silica and cured. Mechanical properties such as compressive strength, Split tensile strength, Flexural Strength and Sulphate attack of concrete were obtained and compared with conventional concrete for 7 days, 14 days and 28 days curing. The test results show 4% of nano-silica in concrete increases the Compressive and Split tensile strength of concrete.

Keywords: Nano-silica, Compressive strength, Split tensile strength, Concrete, Flexural Strength, Sulphate attack

1. Introduction

In construction industry the use of high strength concrete has increased to a large extent. The strength of the concrete can be increased by adding additives and admixtures exhibiting similar characteristics as that of cement. Nano sized particles contribute to the technological advancements. Nano particles are added to the concrete whose properties influence the strength characteristics of concrete. Nano silica is an additive which is used in concrete. The unique properties of nano silica in the nano scale impart higher mechanical and durability properties than conventional concrete. The very fine nano silica fills the pores of the concrete matrix increasing the binding strength of concrete. Nano silica also enhances the production of calcium silicate hydrate during hydration process which contributes to the improvement in strength and durability. The nano fillers reduce the porosity of concrete and increase the early pozzolonic strength to the concrete. This paper attempts to study the optimum percentage of nano silica that provides optimum mechanical properties of concrete incorporating Nano-Silica.

The addition of nano silica in the concrete and its strength behavior has been reported by many researchers. Hongjian Du et al., (2014) investigated the durability properties of concrete containing nano silica and reported that at early stages of hydration nano silica incorporated concrete exhibited higher pozzolonic reaction. This showed the early increase in compressive strength. SEM analysis depicted that pore sizes were homogeneous resulting in lesser rate of water and chloride ion penetration. Based on the study investigated by Anjusha and Bindhu (2014) compressive strength, flexural strength, split tensile strength and modulus of elasticity improved with 2% addition of nano
silica. The impact strength also showed an improvement. The durability studies with the addition of nano silica showed improvement towards the sulphate resistance and water absorption [2]. The nano silica has a pore filling effect and pozzolonic activity of nano silica with cement towards improvement of mechanical property and durability characteristics, this is stated by Maheswaran et al (2013). Jonbi et al., (2012) on the investigation of incorporating nano silica along with silica fume in concrete reported that the percentage on nano silica to be incorporated in concrete should not be more than 10%. Based on the inference from SEM analysis it is observed that nano silica readily react with calcium hydroxide to produce new forms of calcium silicate hydrate which leads to improvement in strength and durability [4].

The effect of nano silica for the chemical composition, mechanical characterization and chloride permeability was studied by Gopinath et al., (2012). It was concluded after investigation that nano silica on hydration reduced the development of calcium hydroxide indicative of the formation of calcium silicate hydrate gel. Compressive strength was observed to be increased with addition of nano silica. The addition of 2% by weight of nanosilica with 50% GGBS reported an increase of compressive strength by 18% and the setting time also showed variation when compared to slag concrete [6].

2. Materials
Concrete was cast with Ordinary Portland cement 53 grade in accordance to IS 12269-1987., natural river sand with fraction passing through 4.75mm sieve and retained on 60micron sieve was used. 20mm coarse aggregate was used for the study. Nano silica of particle size 50nm is used. The specific gravity of nano silica is determined as 1.03. Super plasticizers confined to IS9103-1999 was used. M30 grade of concrete was designed as per IS 10262-2009, with mix ratio of 1:1.61:2.68 and the water cement ratio of 0.45 was adopted for this study.

3. Experimental Procedure
Compression tests were carried out for conventional concrete and for concrete with varying percentages of nano silica (2%, 4%, 6%) as partial replacement of cement. The tests were done in accordance with IS 516-1999 standards conducted on concrete specimen size 150mm x 150mm x 150mm. The specimens were tested respective to their days in compression testing machine.

3.1. Split Tensile Strength
Cylinder specimens of 150 mm diameter and 300 mm length were prepared with designed mix concrete for varying percentages of nano silica and split tensile this tests were carried out in accordance with IS 516-1999.

3.2. Flexural Strength Test
Flexural tests were done with specimen size of 500x100x100 in accordance to IS 519-1999. The specimen testing should be done with two rollers of 38mm diameter and specimen placed along lines spaced 13.3 cm apart. The line of fracture measured on the center line of the specimen

3.3. Sulphate Resistance Test
An experimental study was undertaken to evaluate the relative chemical resistance of concrete made with 4% of nano silica to the following solution; 1% H2SO4, 1% HCl and 5% ammonium sulphate. Ammonium sulphate was used for sulphate resistance determination. Acid resistance study was conducted using sulphuric acid and hydrochloric acid. Time taken for 25% weight loss of the specimen fully submerged is taken as a criterion for failure. Concrete cube specimen of 150mm were used for testing and specimens were subjected to alternate wetting and drying process for a 15 days interval. The weight loss of the specimens is determined in terms of percentage.

4. Results and Discussion
4.1. Compressive Strength Test
The cube specimens were tested for their compressive strength. Nano silica incorporated concrete with 2%, 4% and 6% by weight of cement has been casted for compression tests in compression testing
machine. It is inferred that the compression strength increases till 4% replacement of nano silica and then drops down. The pozzolonic action of nano silica within the pores of matrix, accelerates the hydration and increases the strength of concrete. Calcium silicates formation during hydration process reduces the generation of cracks and exhibits the increase in strength. The increase in addition of the nano silica does not participate in the strength increase after 4% because excess formation of calcium silicates does not contribute to the improved strength. Table 1 shows the compressive strength of concrete specimens for 7, 14 and 28 days.

Table 1. Compressive strength of 7, 14 & 28 days having different proportion.

| % of Nano Silica | 7 DAYS (N/mm²) | 14 DAYS (N/mm²) | 28 DAYS (N/mm²) |
|------------------|---------------|----------------|----------------|
| Conventional Concrete (0 %) | 21.62 | 26.72 | 32.35 |
| 2 % | 22.08 | 27.08 | 34.23 |
| 4 % | 24.64 | 29.23 | 36.81 |
| 6 % | 22.13 | 27.98 | 35.12 |

4.2. Split Tensile Strength
To evaluate the tensile strength of concrete the cylindrical samples were tested for their split tensile strength as per IS 5816:1999. Table 2 reports the 7, 14 and 28 days Split tensile strength with respect to varying percentages of nano Silica in the concrete specimens. It is inferred that tensile strength of nano silica incorporated specimens increase and it is higher than conventional concrete.
Table 2. Split Tensile strength of 7, 14 & 28 days having different proportion.

| % OF NANO SILICA | 7 DAYS (N/mm²) | 14 DAYS (N/mm²) | 28 DAYS (N/mm²) |
|------------------|----------------|----------------|----------------|
| Conventional Concrete (0 %) | 2.35 | 2.64 | 2.80 |
| 2 % | 2.47 | 2.70 | 2.94 |
| 4 % | 2.67 | 2.79 | 3.15 |
| 6 % | 2.40 | 2.61 | 2.98 |

Figure 2. Split Tensile Strength of concrete

4.3. Flexural Strength of Concrete

The Prism samples were tested for their flexural strength. Table 3 reports the flexural specimen at 4% shows maximum flexure strength.

Table 3. Flexural Strength of 7, 14 & 28 days having different proportion.

| % OF NANO SILICA | 7 DAYS (N/mm²) | 14 DAYS (N/mm²) | 28 DAYS (N/mm²) |
|------------------|----------------|----------------|----------------|
| Conventional Concrete (0 %) | 2.46 | 3.13 | 3.48 |
| 2 % | 2.50 | 3.21 | 3.52 |
| 4 % | 2.55 | 3.34 | 3.55 |
| 6 % | 2.52 | 3.29 | 3.50 |
4.4. Sulphate Attack Test

The specimens of size 100mmx100mmx100mm were tested and the dried weight of the specimen before and after sulphate attack is taken. It can be observed from the test that the average weight loss for nano silica incorporated specimen is less compared to conventional concrete.

Table 4. Sulphate attack test for 40% nano silica concrete.

| Mix ID                      | Initial weight (Weight after 28 days) | Final weight (After 3 days immersion in MgSO₄) | % of Weight loss |
|-----------------------------|---------------------------------------|-----------------------------------------------|-----------------|
| Conventional concrete       | 8.678                                 | 8.240                                         | 5.04            |
| 2% Nano Silica              | 8.646                                 | 8.242                                         | 4.67            |
| 4% Nano Silica              | 8.652                                 | 8.247                                         | 4.68            |
| Concrete made with 4% of Nano silica | 8.435                                 | 8.128                                         | 3.63            |
|                             | 8.457                                 | 8.154                                         | 3.58            |
|                             | 8.402                                 | 8.198                                         | 3.43            |

5. Conclusion

Based on experimental research for Concrete made with 4% of Nano silica is used as partially replacement of cement and the harden properties of compressive strength, flexural strength and split tensile strength of concrete was tested at 7 days, 14 days and 28 days.

The test results shows that the use of 4% of Nano silica in concrete, its increase the compressive strength, split tensile strength and also increase in the flexural strength of concrete as compared with conventional concrete.

The durability test are to be conducted on concrete made with 4% of Nano silica, its shows greater resistance against chemical attach as compared with conventional concrete. The following benefits are drawn when the Nano silica used in concrete,

- Concrete with high initial and final compressive and tensile strengths.
- Concrete with good workability.
- Cessation of super plasticizing utilization
- Cessation of silicosis risk
- Accelerates the hydration.
- Better bond between aggregates and cement paste.
- Improves the toughness, shear, tensile strength and flexural strength of concrete

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