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An Experimental Study On Strength & Durability Of Concrete Using Partial Replacement Of Cement With Nano Silica

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Abstract: ***Nano science and technology is a new field of emergence in materials science and engineering, which forms the basis for evolution of novel technological materials. The basic concept behind using nano material which are having large surface area is to improve compressive and flexural strength at early ages when compared with conventional cementitious material. The purpose of this study is to compare the properties of conventional concrete and nano concrete. Strength and durability tests will be carried out. Thus, there is a scope for development nano materials can also pave the path to reduce the cement content in concrete than the conventional mixes while maintaining same strength characteristics, which will lead into the production of 'greener' concrete.***

Index Terms: Nanotechnology; concrete; nano silica; cement paste; cement hydration; C-S-H; mechanical properties; durability properties.

I. INTRODUCTION

Concrete is the most widely used man-made construction material in the world, and is second only to water as the utilized substance on the planet. It is obtained by mixing cementing materials, water and aggregates, and sometimes admixtures, in required proportions. The mixture when placed in forms and allowed to cure hardens into a rock-line mass known as concrete. Nanotechnology is one of the most active research areas that encompass a number of disciplines including civil engineering and construction materials. The most active fields are: electronics, bio-mechanics and coatings. Interest in nanotechnology concept for Portland cement composites is steadily growing. Currently, the most active research areas dealing with cement and concrete are: understanding of the hydration of cement particles and the use of nano-size ingredients such as alumina and silica particles.

There are also a limited number of investigations dealing with the manufacture of nano-cement. If cement with nano-size particles can be manufactured and processed, it will open up a large number of opportunities in the fields of ceramics, high strength composites and electronic applications. This will elevate the status of Portland cement to a high tech material in addition to its current status of the most widely used construction material. Very few inorganic cementing materials can match the capabilities of Portland cement in terms of cost and availability. Basic background information on nanotechnology research, state of the art on use of this technology in concrete, opportunities and challenges are discussed.

The strength and durability and other characteristics of concrete depend upon the properties of its ingredients, on the proportions of mix, the method of compaction and other controls during placing, compaction and curing.

II. LITERATURE REVIEW

Recently nano technology is being used or considered for use in many applications and it has received increasing attention in building materials, with potential advantages and drawbacks being underlined1. At present, a significant number of R&D works dealing with the use of NS in cement based materials are available in the literature. However, there is a limited knowledge about the mechanism by which NS affects the flow properties, setting times, consistency, workability, rheological, micro structural, mechanical properties etc. of cementitious mixes. Furthermore, the literature appear to be contradictory about the influence of NS on the development of such materials.

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Hongjian Du, et al (2014), his study investigated the durability properties of concrete containing nano-silica at dosages of 0.3% and 0.9%, respectively. Due to the nano-filler effect and the pozzolanic reaction, the microstructure became more homogeneous and less porous, especially at the interfacial transition zone (ITZ), which led to reduced permeability. V.R.Rathi, et al (2014), investigated the influence of Colloidal nano SiO2 (CNS) addition along with P-100 grade of fly ash on hydration of cement paste and compressive strength of cement mortar. addition of FA (P-100 grade) in various proportions ranging from 10 to 30 % along with varying dosage of CNS from 1 to 6%.The result revealed that fly ash hydration is accelerated by CNS at early age thus enhancing the early age strength of materials also it was observed that standard consistency of cement paste does not vary much more but by addition of CNS along with fly ash Initial and final setting time get accelerated, also the compressive strength of cement mortar was improved significantly. Sayed Abdel-Baky et al (2013), investigated workability, compressive and flexure strengths. Nano silica particles with size of 19 nm have been used as a cement addition by 1,3,5,7 and 10% by weight of cement content. The study showed that Workability of cement mortar which decreased by increasing the amount of interactive nano silica as long as the inserted nano silica can be interactive with calcium hydroxide resulting from hydration process of cement with water. Compressive and flexural strength of the cement mortar increases proportionally with increasing the amount of nano silica, especially at early ages. Until achieving the optimum percentage, NS at 7%, then decreases due to the decreasing of calcium hydroxide that exhausted in the activation process by 7% nano-silca. Alireza Naji Givi, et al (2010) concluded that the Sio_2 nano-particles blended concrete has higher compressive, flexural and tensile strength at all ages of moist curing in comparison to concrete without Sio_2 nano-particles. Sio_2 nano particles with two different sizes of 15 and 80 nm have been used as a partial cement replacement by 0.5, 1.0, 1.5 and 2.0 wt. %. It was concluded that concrete specimens containing Sio_2 particles with average diameter of 15 nm were harder than those containing 80 nm of particles at the initial days of curing. But this condition was altered at 90 days of curing. Also from the viewpoint of free energy, it can be concluded that the C–S–H gel formation around the particles with average diameter of 15 nm was more at the primary days of curing. This can be as a result of more nucleation sites that causes acceleration in early age strength. On the other hand, the growth probability of C–S–H gel around the 80 nm particles was more at 90 days of moist curing. Ali Nazari, et al (2010) investigated compressive, flexural and split tensile strengths together with coefficient of water absorption of high strength self-compacting concrete containing different amount of SiO2 nanoparticles have been investigated. Strength and water permeability of the specimens have been improved by adding SiO2 nanoparticles in the cement paste up to 4.0 wt. %. SiO2 nanoparticle could accelerate C–S–H gel formation as a result of increased crystalline Ca (OH) 2 amount especially at the early age of hydration and increase the strength of the specimens. In addition, SiO2 nanoparticles are able to act as Nano fillers and recover the pore structure of the specimens by decreasing harmful pores. Several empirical relations have been presented to predict flexural and split tensile strength of the specimens by means of compressive strength at a certain age of curing, all also indicate that SiO2 nanoparticles up to 4 wt.% could improve the mechanical and physical properties of the specimens.Li, et al (2004) showed that with 5% replacement of cement by nS (mean size 15±5 nm), 7- and 28-day compressive strength of mortars were increased by 20% and 17%, respectively, whereas 15% silica fume replacement increased mortar strengths by 7% and 10% compared with those of control Portland cement mortar.

III. CONSTITUENT MATERIALS

CEMENT

Cement is a binding material in concrete which binds the other materials to form a compact mass. Ordinary Portland cement (53 grade as per IS: 12269-2013) is used for the present experimental study.

AGGREGATES

Aggregates are important constituents of concrete. It gives body to the concrete, reduce shrinkage. Aggregate occupy 70 to 80 percent of volume of the concrete. The aggregates combine with the cement and water to produce concrete. Basically there are two types of aggregates, the fine aggregate and the coarse aggregate.

Fine aggregates: Locally available river sand conforming to Grading zone II of IS 383 –1970 was used in the study. Used as a filler. It accounts 60-80% of volume & 70-80 % of weight of concrete and defines concrete dimensional stability. Fine Aggregate passing through less than 4.75 mm was used.

Coarse aggregates: Locally available crushed blue granite stones conforming to graded aggregate of nominal size 20 mm as per IS 383 – 1970 is used. Properties of aggregates have large impact on the strength, durability, workability and economy of concrete.

WATER

Tap potable water available in the laboratory was used for mixing and curing of the concrete.

NANO SILICA

Nano silica is used to density micro and nano structure resulting in improved mechanical properties. Carbon nano fibers act as crack arrester and bridging micro cracks, thus increasing the load carrying capacity. Reduction of porosity, thus resulting in durable concrete. Nano Concrete is represented by "NC".

In this project Nano silica is used. The nano-silica Concrete can be produced in high quantities and for low prices, this in turn makes this concrete suitable for mass concrete. Nano silica will partially replace cement in the mix, which is the most costly and ecofriendly component in concrete. The size of nano silica is 49.7nm.

IV. MIX PROPORTION

S No	% of NS	Cement (kg/m^3)	F.A (kg/m^3)	NS (kg/m^3)	C.A (kg/m^3)
1	0	479	504	0	1142.44
2	1	478.79	504	0.209	1142.44
3	2	478.58	504	0.418	1142.44
4	3	478.37	504	0.627	1142.44
5	4	478.16	504	0.836	1142.44

Table 4.1: Mix Proportion

V. CASTING OF SPECIMENS

MOULD DETAILS

The mould was made up of steel. Cube mould 150 x 150 x 150mm for casting cube test specimens. Cylinder mould 150mm dia and 300mm height for casting cylinder test specimen. Prism mould of 100x100mm cross section and 500mm long for casting flexure test specimens.

CASTING DETAILS OF SPECIMENS

The ingredients of the concrete were weighted as per the design mix and hand mixing was adopted. The fresh concrete were cast in the standard mould for further tests. The specimens were demoulded from the mould after 24 hours and were placed in curing tanks. Further 2% of cement was replaced with nano silica and specimens were casted.

S.No	Name of the test	Size of specimens	Curing period
1.	Cube compressive strength	150x150x150 mm	28 days
2.	Split tensile strength	150mm diameter & 300mm height	28 days
3.	Flexural strength of prism	100x100x500 mm	28 days

Table 5.1: Specifications test specimens (Strength)

S.No	Name of the test	Size of specimens	Curing period
1.	Sulphate attack	100x100x100mm	28 days
2.	Chloride attack	100x100x100mm	28 days
3.	Acid attack	100x100x100mm	28 days

Table 5.2: Specifications test specimens (Durability)

VI. TESTING PROCEDURE

COMPRESSIVE STRENGTH TEST

The concrete cubes of 150mm size were cast for finding the compressive strength. The prepared cubes were cured in water for 28 days. The cured specimens were taken out and dried. After drying, the specimen is loaded using compression testing machine. The compressive strength of concrete cube specimens was investigated by measuring the load and it was calculated by using the equation.

$$f_c = \frac{P}{A}$$

Where, f_c- Compressive strength; P – Load; A - Area of the cube

SPLIT TENSILE STRENGTH

The concrete cylinders of 150mm dia and 300mm height were cast for finding the split tensile strength. The prepared cylinders were cured in water for 28 days. The cured specimens were taken out and dried. After drying, the specimen is loaded using compression testing machine. The split tensile strength of concrete cylinder specimens was investigated by measuring the load and it was calculated by using the equation.

Split Tensile Strength = 0.637P/dL

Where, L – Length; D – Diameter

FLEXURAL STRENGTH TEST

The concrete beam of 100x100x500mm size were cast for finding the compressive strength. The prepared beam were cured in water for 28 days. The cured specimens were taken out and dried. After drying, the specimen is loaded using universal testing machine. The flexural strength of concrete beam specimens was investigated by measuring the load and it was calculated by using the equation,

$$f_{cr} = PL / bd^2$$

Where, f_{cr} - flexural strength; P – Load; b - Measured width; d - Measured depth

DURABILITY TEST

WATER ABSORPTION TEST

After 28 days curing, the specimen was taken out from the curing tank. The specimen were dried for 24 hours. The dried specimens were weighed accurately and noted as dry weight. The dried specimens were immersed in water. Weight of the specimen at pre-determent intervals was taken after wiping the surface with dry cloth. This process was continued not less than 48 hours or up to constant weight is obtained in two successive observations.

% water absorption = $[(w_2 - w_1) / w_1] \times 100$

Where,

w_1= oven dry weight of cubes in grams

w_2= after 24 hours wet weight of cubes in grams

SULPHATE ATTACK TEST

When concrete is exposed to environment containing aggressive chemicals, it leads to deterioration of concrete which can be assessed in terms of loss in weight of concrete. To study the acid resistance of concrete, the cubes of concrete were cured and then immersed in 5% Na_2SO_4 solution up to 28 days. After 28 days immersion, the specimens were taken out and visually observed for the deterioration of the concrete due to sulphate attack. The specimens were weighed once again and the weight is compared with the normal concrete in order to calculate the percentage of loss in concrete.

CHLORIDE ATTACK

A non-porous container is selected and chloride solution has been prepared by adding 5% sodium chloride in water. This solution is stirred well so that all the sodium chloride salts get dissolved in the solution. The initial weights of this cubes are found. Then are they immersed in a chloride solution. After drying the cubes, the change in weight was found.

ACID ATTACK TEST

For acid attack test concrete cube of size 100x100x100mm are prepared. The specimens were cured in curing tank for 28 days. After 28 days all specimens are kept in atmosphere for 2 days for constant weight, subsequently, the specimens are weighed and immersed in 5% sulphuric acid (H_2 SO_4) Solution for 28 days. After 28 days of immersing in acid solution, the specimens are taken out and were kept in atmosphere for 2 days for constant weight. After drying the cubes, the changes in weight were found.

VII. TEST RESULTS

GENERAL

Test results are made in this chapter to determine the Strength and Durability properties of concrete with and without admixtures.

STRENGTH PROPERTIES OF CONCRETE
COMPRESSIVE STRENGTH OF CUBES

The compressive strength of concrete cube was found for the control concrete and the admixtures used concrete. Table 7.1 shows the compressive strength of cubes with and without admixture.27.83,

Mix Id	Compressive Strength (N/mm^2)
CC	26.5
NC	43.7

Table 7.1: The Average Compressive strength of cubes in 28 days

STRESS STRAIN BEHAVIOUR OF CONCRETE

The Conventional and Nano silica 2% Cylinder Specimens were tested to study the Stress Strain behavior of Concrete. And the experimental results are shown in the Table 7.2 and 7.3.

S.No	Load KN	Deformation mm	Stress N/mm^2	Strain no unit
1	20	0.007	1.18	0.00004
2	40	0.016	2.56	0.00008
3	60	0.019	3.29	0.00015
4	80	0.032	4.52	0.00019
5	100	0.045	5.56	0.00025
6	120	0.056	6.87	0.00028
7	140	0.068	7.89	0.00035
8	160	0.075	9.09	0.00038
9	180	0.086	10.20	0.00045

Table 7.2: Stress strain curve for Conventional concrete

Load KN	Deformation mm	Stress N/mm2	Strain no unit
25	0.01	1.52	0.00004
50	0.02	2.95	0.00019
75	0.036	4.56	0.00016
100	0.056	5.89	0.00025
125	0.06	7.56	0.00031
150	0.072	8.23	0.00039
175	0.086	9.34	0.00044

Table 7.3: Stress strain curve for concrete containing NC 2%

SPLIT TENSILE STRENGTH OF CYLINDER

The split tensile strength of concrete cylinder was found the control concrete and admixture used concrete as a replacement of cement.

Mix Id	Split tensile strength (N/mm2)
CC	2.19
NC	2.69

Table 7.4: The Average Split tensile strength of Cylinder in 28 days

FLEXURAL STRENGTH OF PRISM

The flexural strength of concrete prism was found for the control concrete and admixture used concrete as a replacement of cement

Mix Id	Flexural strength (N/mm2)
CC	3.29
NC	5

Table 7.5: The Average Flexural strength of prism in 28 days

DURABILITY PROPERTIES OF CONCRETE RESULTS OF WATER ABSORPTION TEST

Table 7.6 shows the water absorption test results of average % water absorption of concrete cube specimen. ·

Name	Dry weight (g)	Wet weight (g)	% Water of Absorption
CC	2526	2550	0.95
NC	2475	2496	0.84

Table 7.6: Average % Water Absorption

RESULTS OF SULPHATE ATTACK TEST

Table 7.7 shows the sulphate attack test results of average % gain in weight and nano silica used concrete.

Name	Dry weight (g)	Wet weight (g)	% gain in weight
CC	2452	2471	0.78
NC	2455	2469	0.59

Table 7.7: Average % gain of weight in Sulphate Attack Test

RESULTS OF CHLORIDE ATTACK TEST

Table 7.8 shows the chloride attack test results of average % gain in weight and nano silica used concrete.

Name	Dry weight (g)	Wet weight (g)	% gain in weight
CC	2533	2557	0.94
NC	2559	2581	0.88

Table 7.8: Average % gain of weight in Chloride Attack Test

RESULTS OF ACID ATTACK TEST

Table 7.9 shows the Acid attack test results of average % loss in weight and nano Silica used concrete when it is immersed in H_2SO_4 solution.

Name	Dry weight (g)	Wet weight (g)	% loss in weight
CC	2544	2284	10.22
NC	2515	2324	8.64

Table 7.9: Average % loss of weight in Acid Attack Test

VIII. CONCLUSIONS

Based on the results of experimental study the following conclusions are drawn.

- ✓ The compressive strength of concrete is increased by almost 40% by adding 2% nano silica in concrete.
- ✓ The split tensile strength of concrete is increased by almost 15% by adding 2% nano silica in concrete.
- ✓ The flexural strength of concrete is increased by 35% by adding 2% nano silica in concrete.
- ✓ The durability of concrete containing 2% nano silica exhibits better resistance against sulphate attack, chloride attack and acid attack.

The concrete containing nano silica 2% reduces the corrosion when compared to the conventional concrete.

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