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Experimental Study on the Mechanical Properties of Concrete using Micro Silica and Nano Silica - A Step Towards Sustainability

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***Abstract*— The term 'Sustainable' environmentally means "green". The deteriorating environment is driving the worldwide focus on sustainable development. It is to be noted that the largest impact on nature and environment is by the construction industry. Previously, the concern on environment formed a small part of construction development. We know that cement is the main constituent of concrete. Production of large quantity of cement results in increasing CO_2 emissions and the consequence being Greenhouse Effect. In order to overcome the above problems, an attempt has been made to use micro silica and nano silica as partial replacement to cement in concrete.**

Nanotechnology is one of the most promising areas of science. The use of nano materials in concrete is the new revolution. Nanomaterials like nano silica, nano titanium oxide, carbon nano tubes, nano alumina etc. are presently used in concrete in order to modify the strength properties and durability of concrete.

In this experimental investigation, an attempt is made by partially replacing the constituents of concrete with nano silica and micro silica. Later the workability and strength properties of concrete is determined with the use of micro silica (5,10,15%) and nano silica (2.5,5,7.5%) as partial replacement by the weight of the cement.

Keywords—Concrete, Micro silica, Nano silica, workability, strength properties

I. INTRODUCTION

Concrete is the most widely used building material which is a mixture of cement, sand, coarse aggregates and water. The actual cost of concrete is related to cost of materials required for producing a minimum mean strength that is specified by designer of the structures and also depends on the quality control measures. The extent of quality control is often an economical compromise and depends on the size and type of job. Nowadays engineers and scientists are trying to increase the strength of concrete by adding some other cheap and waste materials as partial replacement of cement. Fly ash, micro silica, steel slag etc., are a few examples of the waste materials. These materials are generally byproducts from other industries. For example, fly ash is a waste product from power plants and silica fume is a byproduct resulting from reduction of high purity quartz with coal or coke and wood chips in an electric arc furnace during production of silicon metal or ferrosilicon alloys. These days the whole world is facing a major problem of environmental pollution by these waste industrial materials like as they are dumped as landfills.

To help meeting the sustainable development challenges, the concrete industry developed some environmental friendly concrete technology by the use of supplementary cementing materials, recycling concrete and other materials which will enhance the service life of concrete structures and also a way of saving the environment. With the ever increasing demand and consumption of cement and in the backdrop of waste management, scientists and researchers all over the world are always in quest for developing alternate binders that are environment friendly and contribute towards sustainable ...

II. THE RESEARCH PROGRAM

A set of concrete mixes with partial replacement of cement with micro silica and nano silica were prepared in this experimental study.

Objectives of the present research

The experimental study carried out is to assess the suitability of micro silica and nano silica in manufacturing of concrete. The objectives of the study were:

- To investigate the workability of concrete with micro silica and nano silica as compared with controlled (normal) concrete.
- To investigate the hardened properties like compressive strength, tensile strength of concrete with micro silica and nano silica as compared with controlled (normal) concrete.

III. EXPERIMENTAL DETAILS

A. Materials Used

The materials used in preparing the required proportion of concrete mix are as follows.

Cement

The cement (C) used in this investigation is 53 grade as per IS: 12269 - 2013. The overall quantity of cement required for the investigation was procured in a single lot and stored in the appropriate manner.

Fine Aggregates

Fine aggregates (FA) used was Manufactured Sand (M-Sand) retained on 20 mm and 12.5 mm IS sieves as per the specifications in IS: 383 - 1970 were used.

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Coarse Aggregates

Coarse aggregates (CA) retained on 20mm and 12.5mm IS sieves as per the specifications in IS: 383 - 1970 were used.

Micro silica

Micro silica is a mineral admixture composes of very fine solid glassy spheres of silicon dioxide (SiO_2). Micro silica is a byproduct of the industrial manufacture of ferrosilicon and metallic silicon in high-temperature electric arc furnaces. It changes the rheology and reacts with the cement hydration products to dramatically improve concrete strengths, durability and impermeability, allowing concrete to be used in ways never before possible. For this experimental study, micro silica was purchased from Astraa Chemicals, Chennai.

TABLE I. PHYSICAL PROPERTIES OF MICRO SILICA

Tests	***Results***
Specific Gravity	2.55
SiO_2+ Al_2O_3+Fe_2O_3	96.27%
Form	Ultra-fine amorphous powder
Colour	White
Particle size	<90microns

Nano silica

Nano silica is a new pozzolanic material in the form white amorphous material which has nowadays proven to be better than other pozzolanic materials. It is generally available in the form of colloidal silica. It is believed that by using nano silica it prevents in the early cracking of concrete in the pavement structure. For this experimental work, nano silica was also purchased from Astraa Chemicals, Chennai.

TABLE II. PHYSICAL PROPERTIES OF NANO SILICA

Tests	**Results**
SiO_2	> 99.8
Specific gravity	1.32
Crystalline size	20 nm
Purity percentage	99%
Specific surface	160 m^2/gm
Density	2.12 g/cm^3

B. Experimental Plan

In the present study, Ordinary Portland Cement of 53 grade is replaced with 5%, 10% and 15% micro silica and 2.5, 5, 7.5 for M20 Grade concrete and also a mix with no replacement was produced.

Micro silica and Nano silica is added to concrete by addition at the concrete mixer, along with ordinary cement, aggregates and water. The normal ratios and proportions of aggregates and water to cementitious material in the mix remain unchanged. Mixing times are the same as for ordinary cement.

C. Mix Design and Mix Proportions

The mix design is carried out as per IS: 10262 - 2009. The w/c ratio for the mix was decided based on the slump obtained for the controlled mix for various ratios as shown below.

TABLE III. SLUMP FOR DIFFERENT W/B RATIOS

Trials	***w/b Ratio***	***Slump(mm)***
Trial 1	0.50	55
Trial 2	0.52	97
Trial 3	0.53	105
Trial 4	0.54	125

From the above table, the required slump is obtained in the trial-2 and trial-3. Hence, mix proportion of trial-2 with 0.52 w/b ratio was fixed for controlled concrete.

The trial batch mix proportions are designated as follows:

- CC - Controlled concrete with 0% or no replacement of cement.
- MS 5 - Micro silica concrete with 5% replacement by the weight of the cement.
- MS 10 - Micro silica concrete with 10% replacement by the weight of the cement.
- MS 15 - Micro silica concrete with 15% replacement by the weight of the cement.
- NS 2.5 - Nano silica concrete with 2.5% replacement by the weight of the cement.
- NS 5 - Nano silica concrete with 5% replacement by the weight of the cement.
- NS 7.5 - Nano silica concrete with 7.5% replacement by the weight of the cement.

Mix design for M20 grade concrete and the quantities of the concrete materials are tabulated below.

TABLE IV. MIX PROPORTION OF CONTROLLED CONCRETE

Trials	Controlled Mix
Cement, kg	330
Water, kg/m^3	171.6
Fine Aggregates, kg/m^3	859.32
Coarse Aggregates, kg/m^3	1193.05
w/b Ratio	0.52

Thus, the proportion of the concrete mix with w/b ratio 0.52 is (C:FA:CA) 1:2.60:3.62. The same mix proportion ratio was adopted for the other mixes with partial replacement of micro silica (5%, 10%, 15%) and nano silica (2.5%, 5%, 7.5%).

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Fig. 1. Mix Proportions

Cube specimens of size 150 mm x 150 mm x 150 mm (42 numbers) and cylinders of size 150 mm diameter and 300 mm long (21 numbers) for all the trial mixes were cast and compared against a normal mix with no replacement.

D. Tests and Results

a. Test on Workability

i. Slump Test

Slump test was carried out according to the Indian standards. For the M20 grade concrete, MS concrete and NS concrete.

TABLE V. SLUMP VALUES FOR DIFFERENT PROPORTIONS

Micro Silica (%)	Slump(mm)	Nano Silica (%)	Slump(mm)
0	120	0	120
5	92	2.5	25
10	65	5	0
15	23	7.5	0

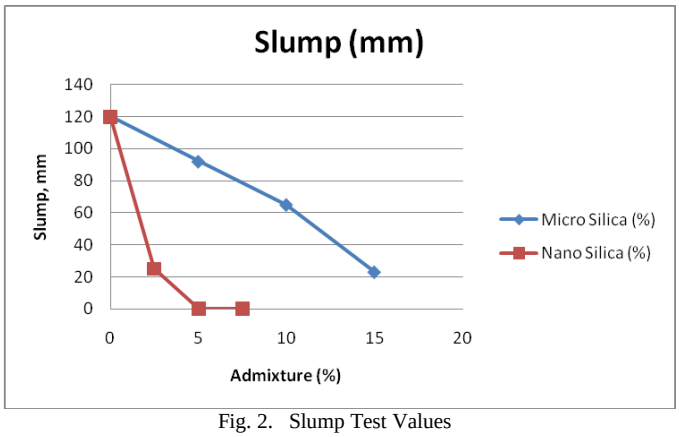

Fig. 2. Slump Test Values

The results shows there is flow reduction with increasing MS and NS percentages in concrete up to 15% and 7.5%. The mixing water was getting exhausted due to the large specific surface area of MS and NS particles.

E. Tests on Hardened Concrete Specimens

All the cast specimens were de-moulded after 24 hours and were placed in a curing tank for a period of 28 days. The specimens were then taken for Strength tests such as Compression and Split Tensile Tests.

All the test results were compared and analysed with that of control mix.

i. Compressive strength test

The Compressive Strength tests was conducted as per **IS: 516 - 1959.** The compressive strength of the cube specimen is calculated using the following formula:

Compressive Strength, $f_c = P/A$ N/mm^2

where P = load at failure in N

A = Area subjected to compression in mm^2

The test results are shown below.

TABLE VI. 28 DAYS COMPRESSIVE STRENGTH, N/MM^2

Micro Silica (%)	*Compressive Strength, N/mm^2*	*Nano Silica (%)*	*Compressive Strength, N/mm^2*
0	29.59	0	29.59
5	33.92	2.5	29.81
10	34.06	5	28.85
15	34.16	7.5	24.24

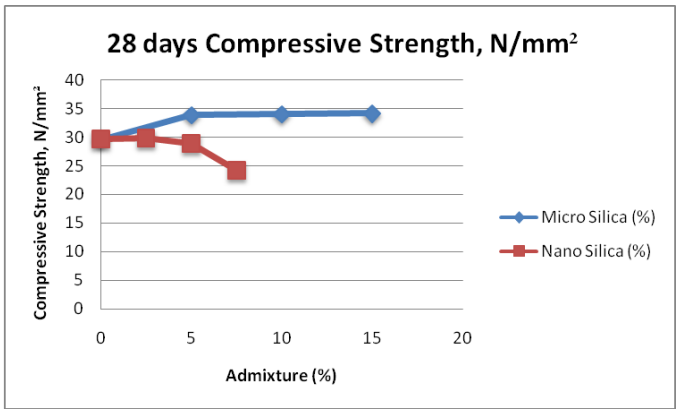

Fig. 3. Compressive Strength of Concrete with varied percentages of Micro Silica and Nano Silica

From the above test results, the compressive strength of M20 grade concrete with partial replacement of cement by 15% MS shows 15.44% increase in strength and that with partial replacement of cement by 2.5% NS shows 11.25% decrease in the strength.

ii. Split –Cylinder Test

It is the standard test, to determine the tensile strength of concrete in an indirect way. This test was performed in accordance with **IS: 5816-1970.**

The formula used to calculate this split tensile strength is as follows:

Split Tensile Strength = $2P/\pi DL$ (N/mm²)

Where P = load at failure in N

D = diameter of the specimen in mm

L = length of the specimen in mm

The test results and the strength variations of MS and NS replacements are illustrated below.

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TABLE VII. 28 DAYS SPLIT TENSILE STRENGTH, N/MM^2

Micro Silica (%)	Split Tensile Strength, N/mm^2	Nano Silica (%)	Split Tensile Strength, N/mm^2
0	2.0	0	2.0
5	2.2	2.5	2.81
10	2.85	5	2.62
15	3.12	7.5	2.58

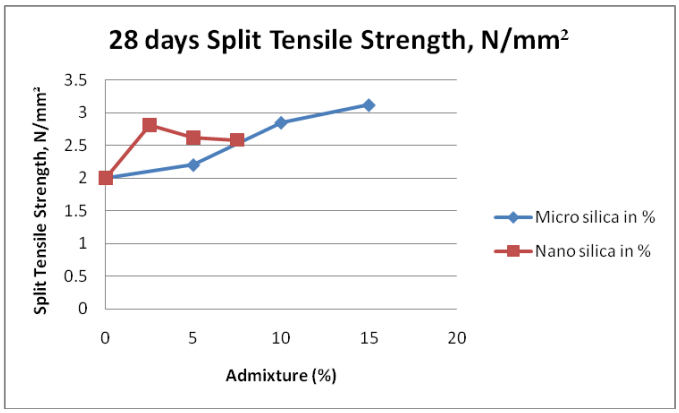

Fig. 4. Split Tensile Strength of Concrete with varying percentages of Micro Silica and Nano Silica

From the above test results, the split tensile strength of M20 grade of concrete with partial replacement of cement by 15% MS shows 0.56% increase in strength and that with the partial replacement of cement by 2.5% NS shows 0.40% increase in strength and gradually decreased with increase in replacement percentages.

IV. CONCLUSIONS

- The study shows that as the content of silicon powder increased after certain limit, its effect on compressive strength decreases. Thus, adding the appropriate content of Micro silica and Nano silica should be given due consideration.
- The workability of concrete with partial replacement of Micro silica and Nano silica which decreased by increasing the amount of micro silica and nano silica. Micro silica and Nano silica absorbs the quantity of mixing water, reducing the workability.
- Addition of silica powder makes concrete sticky hence suitable super plasticizer should be used to achieve required workability.
- Cement replacement up to 15% with MS and 2.5% with NS leads to increasing compressive strength and split tensile strength for M20 grade. Beyond 2.5% of NS, there is decrease in compressive strength and split tensile strength.
- The maximum replacement level of micro silica is 15% and nano silica is 2.5% for M20 grade.
- Until achieving the optimum percentages, NS at 2.5% and MS at 15%, then decreases due to the decreasing of Ca $(OH)_2$ that exhausted in the activation process.

V. FUTURE SCOPE

This research focused on some of the basic physical and chemical properties of micro silica and nano silica as a cement replacement material. However, further studies are required on following issues.

- Workability
- Mechanical properties with the use of chemical admixtures
- Durability
- Working on cost analysis
- Sustainable aspects with use of MS and NS in concrete.

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