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Study and Review of Concrete Grades M 40 & M 50 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. Nano technology finds application in various fields of science and technology. This article presents a critical review of the literature on the influence of nano silica in concrete and its application for the development of sustainable materials in the construction industry and to study the pore filling effect and its pozzolanic activity with cement towards improvement of mechanical properties and durability aspects. Thus, there is a scope for development of crack free concrete towards sustainable construction.

Keywords: ***Nano silica, cement paste, cement hydration, concrete, flowability, mechanical properties.***

INTRODUCTION

Concrete is the most commonly used material in various types of construction, from the flooring of a hut to a multi storied high rise structure from pathway to an airport runway, from an underground tunnel and deep sea platform to high-rise chimneys and TV Towers. In the last millennium concrete has demanding requirements both in terms of technical performance and economy while greatly varying from architectural masterpieces to the simplest of utilities. It is difficult to point out another material of construction which is as versatile as concrete.

Concrete is one of the versatile heterogeneous materials, civil engineering has ever known. With the advent of concrete civil engineering has touched highest peak of technology. Concrete is a material with which any shape can be cast and with any strength. It is the material of choice where strength, performance, durability, impermeability, fire resistance and abrasion resistance are required.

Cement concrete is one of the seemingly simple but actually complex materials. The properties of concrete mainly depend on the constituents used in concrete making. The main important materials used in making concrete are cement,sand, crushed stone and water. The properties of Cement, Sand, crushed stone and water influence the quality of concrete. In addition to these, workmanship, quality control and methods of placing also play the leading role on the properties of concrete.

Compressive strength of concrete comes primarily from the hydration of alite and belite in Portland cement to form C-S-H gel. Alite hydrates rapidly to form C-S-H and is responsible for early strength gain; belite has a slower hydration rate and is responsible for the long term strength improvements.
Alite: $\mathrm{2Ca3SiO5 + 6H2O \rightarrow 3CaO \bullet 2SiO2 \bullet 3H2O + 3Ca(OH)2}$
Belite: $\mathrm{2C2S + 4H2O = C3S2H3 + CH}$

When alite and belite hydrate they produce a by-product, calcium hydroxide (CH), which crystallizes around the aggregate to create a weak zone called the interfacial transition zone (ITZ) [2]. The ITZ is where concrete paste has a higher porosity and lower strength than the surrounding paste and allows the greatest penetration of harmful containments.

HIGH STRENGTH CONCRETE:

High strength concrete is used extensively throughout the world like in the oil, gas, nuclear and power industries are among the major uses. The application of such concrete is increasing day by day due to their superior structural performance, environmental friendliness and energy conserving implications. Apart from the usual risk of fire, these concretes are exposed to high temperatures and pressures for considerable periods of times in the above mentioned industries.

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 40MPa.

High-strength concrete is specified where reduced weight is important or where architectural considerations call for slender structural elements. The high-strength concrete reduces the total amount of material and lower the overall cost of the structure. High-strength concrete columns can hold more weight and therefore be made slimmer than regular strength concrete columns, which allows for more usable space, especially in the lower floors of buildings.

Portland cement concrete is one of the most widely used construction materials. As the demand for concrete as a construction material increases, so also the demand for Portland cement. Nowadays, with the use of high performance concrete (HPC), the durability and strength of concrete have been improved largely. However, due to the restriction of the manufacturing process and the raw materials, some inherent disadvantages of Portland cement are still difficult to overcome. There are two major drawbacks with respect to sustainability.

(1) About 1.5 tonnes of raw materials are needed in the production of every ton of Portland cement, at the same time, about one ton of carbon dioxide (CO2) is released into the environment during the production. Therefore, the production of Portland cement is extremely resource and energy intensive process.

(2) Concrete made of Portland cement deteriorates when exposed to the severe environments, either under the normal or severe conditions. Cracking and corrosion have significant influence on its service behavior, design life and safety.

Several efforts are in progress to reduce the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement.

Fuels and Raw Materials

A cement plant consumes 3–6Gallons of fuel per ton of clinker produced, depending on the raw materials and the process used. Most cement kilns today use coal and petroleum coke as primary fuels and, to a lesser extent, natural gas and fuel oil. Selected waste and by-products with recoverable calorific value can be used as fuels in a cement kiln, replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications. Selected waste and by-products containing useful minerals such as calcium, silica, alumina and iron can be used as raw materials in the kiln, replacing raw materials such as clay, shale and limestone. Because some materials have both useful mineral content and recoverable calorific value, the distinction between alternative fuels and raw materials is not always clear. For example, sewage sludge has a low but significant calorific value and burns to give ash-containing minerals useful in the clinker matrix.

EXPERIMENTAL DETAILS

MATERIALS

CONCRETE

Concrete is a construction material composed of portland cement and water combined with sand, gravel, crushed stone, or other inert material such as expanded slag or vermiculite. The cement and water form a paste which hardens by chemical reaction into a strong, stone-like mass. The inert materials are called aggregates, and for economy no more cement paste is used than is necessary to coat all the aggregate surfaces and fill all the voids.

The concrete paste is plastic and easily moulded into any form or troweled to produce a smooth surface. Hardening beginsimmediately, but precautionsare taken, usually bycovering, to avoid rapid loss of moisture since the presence of water is necessary to continue the chemical reaction and increase the strength. Too much water, however, produces a concrete that is porous and weak. The quality of the paste formed by the cement and water largely determines the character of the concrete. Proportioning of the ingredients of concrete is referred to as designing the mixture, produced as a dense mass which is practically artificial rock, and chemicals may be added to make it waterproof, or it can be made porous and highly permeable for such use as filter beds. An air-entraining chemical may be added to produce minute bubbles for porosity or light weight. Normally, the full hardening period of concrete is at least 7 days. The gradual increase in strength is due to the hydration of the tricalcium aluminates and silicates. The weight of concrete varies with the type and amount of rock and sand. Concrete is stronger in compression than in tension, and steel bar, called rebar or mesh is embedded in structural members to increase the tensile and flexural strengths. In addition to the structural uses, concrete is widely used in precast units such as block, tile, sewer, and water pipe, and ornamental products.

Portland Cement (PC)- 43 grade (OPC – Ultratech Cement) was used in the experimentalinvestigation. It was tested for its physical properties in accordance with Indian Standard specifications. The fine aggregate used in this investigation was clean river sand, passing through 4.75 mm sieve with specific gravity of 2.6. The grading zone of fine aggregate was zone II as per Indian Standard specifications. Machine crushed granite broken stone angular in shape was used as coarse aggregate. The maximum size of coarse aggregate was 20 mm with specific gravity of 2.60. Ordinary clean portable water free from suspended particles and chemical substances was used for both mixing and curing of concrete.

Cement

Cement is a material, generally in powder form, that can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. The most widely used of the construction cements is portland cement. It is a bluish-gray powder obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw material is a mixture of high-calcium limestone, known as cement rock, and clay or shale. Blast-furnace slag may also be used in some cements and the cement is called portland slag cement (PSC). The color of the cement is due chiefly to iron oxide. In the absence of impurities, the color would be white, but neither the color nor the specific gravity is a test of quality.

Fine aggregate

Fine aggregate / sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic materials. Sands that have been sorted out and separated from the organic material by the action of currents of water or by winds across arid lands are generally quite uniform in size of grains. Usually commercial sand is obtained from river beds or from sand dunes originally formed by the action of winds. Much of the earth's surface is sandy, and these sands are usually quartz and other siliceous materials. The most useful commercially are silica sands, often above 98% pure. Beach sands usually have smooth, spherical to ovaloid particles from the abrasive action of waves and tides and are free of organic matter. The white beach sands are largely silica but may also be of zircon, monazite, garnet, and other minerals, and are used for extracting various elements. Sand is used for making mortar and concrete and for polishing and sandblasting.

Sands containing a little clay are used for making moulds in foundries. Clear sands are employed for filtering water. Sand is sold by the cubic yard (0.76 m3) or ton (0.91 metric ton) but is always shipped by weight. The weight varies from 1,538 to1, 842 kg/m3, depending on the composition and size of grain. Construction sand is not shipped great distances, and the quality of sands used for this purpose varies according to local supply.

Coarse aggregate

Coarse aggregate are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone, and trap rock. The last is a term used to designate basalt, gabbro, diorite, and other dark-colored, fine-grained igneous rocks. Graded crushed stone usually consists of only one kindof rock and is broken with sharp edges. The sizes are from 0.25 to 2.5 in (0.64 to 6.35 cm), although larger sizes may be used for massive concrete aggregate. Machine crushed granite broken stone angular in shape was used as coarse aggregate. The maximum size of coarse aggregate was 20 mm and specific gravity of 2.60. Granite is a coarse-grained, igneous rock having an even texture and consisting largely of quartz and feldspar with often small amounts of mica and other minerals. There are many varieties. Granite is very hard and coMPact, and it takes a fine polish, showing the beauty of the crystals. Granite is the most important building stone. Granite is extremely durable, and since it does not absorb moisture, as limestone and sandstone do, it does not weather or crack as these stones do. The colors are usually reddish, greenish, or gray. Rainbow granite may have a black or dark-green background with pink, yellowish, and reddish mottling; or it may have a pink or lavender background with dark mottling. The density is 2,610kg/m3, the specific gravity 2.60, and the crushing strength 158 to 220 MPa.

Silica Fume Definition

The American Concrete Institute (ACI) defines silica fume as "very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon". It is usually a gray colored powder, somewhat similar to Portland cement or some fly ashes.

Fig 2 As-produced silica fume. This is what the material looks like after it is collected

Silica fume is usually categorized as a supplementary Cementitious material. This term refers to materials that are used in concrete in addition to Portland cement. These materials can exhibit the following properties:

- Cementitious — will gain strength when mixed with water

- Pozzolanic and Cementitious — a combination of both properties.

Silica fume is frequently referred to by other names. This manual will use the term silica fume, as adopted by the American Concrete Institute. Here are some of the other names for silica fume:

- Condensed silica fume
- Micro Silica
- Volatilized silica

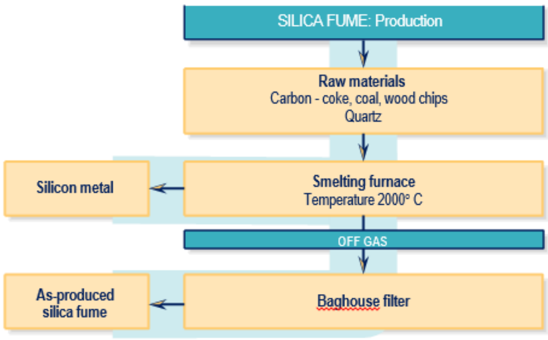
There are several materials that are physically and chemically quite similar to silica fume. These materials may or may not be by-products. Some of these materials may perform well in concrete; however, their cost usually prohibitssuch use.

- Precipitated silica
- Fumed silica
- Gel silica
- Colloidal silica
- Silica flour and silica dust

Production

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys in smelters using electric arc furnaces. These metals are used in many industrial applications to include aluminium and steel production, computer chip fabrication, and production of silicones, which are widely used in lubricants and sealants. While these are very valuable materials, the by-product silica fume is of more importance to the concrete industry.

PRODUCTION OF SILICA FUME



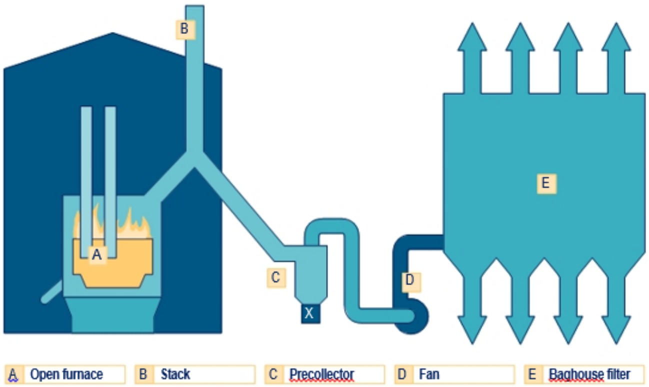


Fig 3. Schematic of a smelter for the production of silicon metal or ferrosilicon alloy. The silica fume is collected in large bags in the baghouse

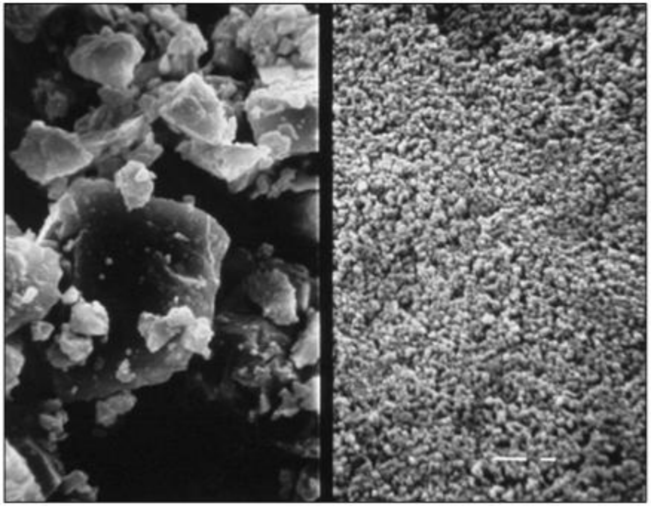


Fig 4 Photomicrograph of Portland cement grains (left) and silica-fume particles (right) at the same magnification. The longer white bar in the silica fume side is 1 micrometer long.

Note that ACI 234R, Guide for the Use of Silica Fume in Concrete, estimates that for a 15 percent silica-fume replacement of cement, there are approximately 2,000,000 particles of silica fume for each grain of Portland cement

Nano Silica

Nanotechnology is the use of very small particles of material either by themselves or by their manipulation to create new large scale materials. The size of the particles, though, is very important because at the length scale of the nano - meter, 10-9m, the properties of the material actually become affected. The precise size at which these changes are manifested varies between materials, but is usually in the order of 100 nm or less.

As people involved in construction, we are very familiar with the concept of getting raw materials, bringing them together in an organized way and then putting them together into a recognizable form. The finished product is a passive machine that does not change or adapt to the surroundings or environment. It works and slowly decays as it is used and abused by the environment and the owners of the project. It gets periodic maintenance but its main goal is to survive the demands made of it until it becomes obsolete and then it is dismantled and discarded to make way for something new. This is our role in society and we have performed it well for hundreds or thousands of years. Construction then is definitely not a new science or technology and yet it has undergone great changes over its history. The industry we see today is the result of a progression in science, technology, process and business.

In the same vein, nanotechnology is not a new science and it is not a new technology either. It is rather an extension of the sciences and technologies that have already been in development for many years and it is the logical progression of the work that has been done to examine the nature of our world at ever smaller and smaller scale.

Nano Technology in Concrete

Nano Technology applied to concrete includes the use of nanomaterials like nano silica, nano fibers etc. By adding the nanomaterials, concrete composites with superior properties can beproduced.Addition of nano silica (nS) in concretes and mortars results inmore efficient hydration of cement. Due to the pozzolanic activity, additional calcium silicate hydrates are formed togenerate more strength and to reduce free calcium hydroxide. This also helps in reducing the cement requirement, nS improvesthe microstructure and reduces the water permeability of concretethus making it more durable. Use of nano silica in HPC and SCCimproves the cohesiveness between the particles of concrete andreduces segregation and bleeding. Concretes with strengths ashigh as 100 MPa with high workability, anti-bleeding propertiesand short de-moulding time can be produced. Nano silica can beused as an additive to eco concrete mixtures.

In the case of eco concrete mixtures, industrial wastes such as flyash, blast furnace slag are used as admixtures at certainpercentages as replacement to cement. Certain problems likelonger setting time, lower compressive strength at higherpercentages can be overcomeby adding nS which improves these properties. Condensed Silica fume (CSF) which is a by-product of metallurgical industrieswhen used as a partial replacement to cement (optimum 10 to 15percent) has been formed to contribute towards strength increaseof concrete in addition to other beneficial properties.

Production of Nano Silica (nS)

Nano materials have atleast one dimension of the order of a nanowhich is 10-9m. For example one strand of DNA is 2nm wide andhuman hair has a diameter of nearly 10-4m. A nano particlebecomes a quantum dot with dimension of the order of 10nm andthis size is so small that jumps in energy levels occur. Nano silicaparticles are of the same size.

There are different methods to produce nS products. Oneproduction method is based on Sol-gel process (organic or waterroute) at room temperature. In this process, the starting materialslike Na2Sio4 and Organo metallics like TMOS/TEOS are added ina solvent and then the pH of the solution is changed reaching theprecipitation of silica gel. The produced gel is mixed and filteredto become a Xerogel. This is further dried and burned ordispersed again with stabilized agent (Na, K, NH3) to produce aconcentrated dispersion (with 20 to 40 % solid content) suitablefor use in concrete. There are other methods like vaporization ofsilica between 1500 to 2000 ºC reducing quartz in an electric arcfurnace, biological method, precipitation method etc.

Benefits of Nano Silica

Addition of nano silica in concretes and mortars results in moreefficient hydration of cement. More strength is developed whichhelps in reducing the cement requirement. Nano silica improvesthe micro structure and makes concrete more impermeable andmore durable. As it produces a dense concrete, compressivestrength is increased. In addition, it reduces segregation andbleeding and is ideal for use in High Performance Concrete(HPC) and Self Compacting Concrete (SCC). Further, when self-compacting concrete is used in the practical construction, theaddition of nS reduces the form work pressure. Addition of nS also contributes in preventing cracking of concrete at early age inthe pavement construction by SCC while using the slip forms

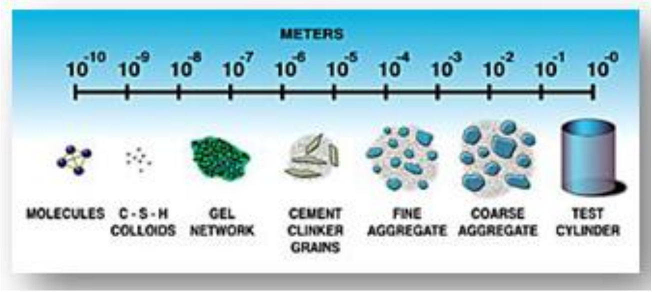


Fig 10 Particle Size Scale

RESULTS

Mix Design for M40 Grade of Concrete

Table No. 10 Mix Design of M40 Grade

Grade Designation	M40
Type of Cement	OPC 43 Grade
Maximum Nominal size of Aggregate	20 mm
Minimum content of Cement	380 Kg/m^3
Maximum Water Cement ratio	0.40
Specific Gravity of Cement	3.15
Specific Gravity of Coarse Aggregate	2.61
Specific Gravity of Fine Aggregate	2.44

Target Mean Strength

$F_{ck}^1 = F_{ck} + 1.65s$

$= 40 + 1.65 * 5$

$= 48.25 N/mm^2$

Calculations of cement content

Water Cement Ratio: 0.40

Water Content: 0.4 * 380

= 152 Litres

Volume of Coarse Aggregate = 0.64 (for Zone II *Table No.3 IS 10262 – 2009*)

Volume of Fine Aggregate = 1 – 0.64 = 0.36

Mix Calculations:

- Volume of Concrete = 1 m^3
- Volume of Cement = $\frac{\text{Mass of Cement x 1}}{\text{Specific Gravity of Cement x 1000}}$

  = (380 / 3.15) * (1/1000) = 0.1206m^3
- Volume of Water = $\frac{\text{Mass of Water x 1}}{\text{Specific Gravity of Water x 1000}}$

  = (152 / 1.0) * (1/1000) = 0.152 m^3
- Volume of All in Aggregates = 1 – [0. 1206 + 0.152]

  = 0.7274 m^3
- Mass of Coarse Aggregate = 0.7274 * 0.64 * 2.61 * 1000

  = 1215.05 Kg
- Mass of Fine Aggregate = 0.7274 * 0.36 * 2.44 * 1000

  = 638.95 Kg

Mix Ratio : 1 : 1.68 : 3.2

Mix Design for M50 Grade of Concrete

Table No. 11 Mix Design for M50

Target Mean Strength

$F_{ck}^1 = F_{ck} + 1.65s$

$= 50 + 1.65 * 5$

$= 58.25 N/mm^2$

Calculations of cement content

Water Cement Ratio: 0.35

Water Content: 0.35 * 430

= 150.5 Litres

Volume of Coarse Aggregate = 0.64 (for Zone II *Table No.3 IS 10262 – 2009*)

Volume of Fine Aggregate = 1 – 0.64 = 0.36

Mix Calculations:

- Volume of Concrete = $1\ m^3$
- Volume of Cement = $\frac{\text{Mass of Cement} \times 1}{\text{Specific Gravity of Cement} \times 1000}$
  = $(430 / 3.15) * (1/1000) = 0.1365\ m^3$
- Volume of Water = $\frac{\text{Mass of Water} \times 1}{\text{Specific Gravity of Water} \times 1000}$
  = $(150.5 / 1.0) * (1/1000) = 0.1505\ m^3$
- Volume of All in Aggregates = $1 - [0.1365 + 0.1505]$
  = $0.713\ m^3$
- Mass of Coarse Aggregate = $0.713 * 0.64 * 2.61 * 1000$
  = 1191 Kg
- Mass of Fine Aggregate = $0.713 * 0.36 * 2.44 * 1000$
  = 626.3 Kg

Mix Ratio : 1 : 1.46 : 2.77

Table No. 26 M40 – Compressive Strength of Cylinders (28 - Days)

S.No.	Combination	Strength (MPa)	Average Compressive Strength (MPa)
1	Controlled Concrete	43.5	44.39
		45.7	
		43.9	
2	Silica Fume 5%	47.6	48.60
		50.1	
		48.1	
3	Silica Fume 10%	51.0	52
		53.6	
		51.5	
4	Nano Silica 1.5% + Silica Fume 5%	51.9	53
		54.6	
		52.5	
5	Nano Silica 1.5% + Silica Fume 10%	55.3	56.43
		58.1	
		55.9	
6	Nano Silica 3% + Silica Fume 5%	49.3	50.32
		51.8	
		49.8	
7	Nano Silica 3% + Silica Fume 10%	50.4	51.41
		53.0	
		50.9	

Table No. 35 Average Compressive Strength for M50

Sample	SF Kg/m3	Colloidal Nano Silica In Lit	Compressive Strength (N/mm2)			
			3 Days	7 Days	28 Days	56 Days
CON	0	0	24.47	38.82	57.67	60.25
NS0/SF5	21	0	25.26	38.96	59.2	63
NS0/SF10	42	0	27.20	40.26	61.4	65.26
NS1.5/SF5.0	21	15.75	28.20	40.89	65.37	67.68
NS1.5/SF10	42	15.75	29.64	44.26	70.24	73.20
NS3.0/SF5	21	31.50	26.25	39.68	62.36	66.24
NS3.0/SF10	42	31.50	27.48	40.58	64.31	67.20

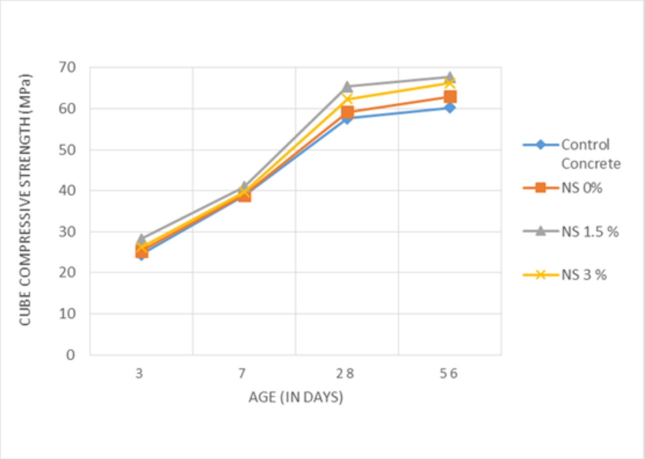


Figure No. Variation of Cube Compressive Strength of M50 Grade Concrete with age for different percentages of Nano-Silica and 5% Micro-silica.

Fig No. 11 Test for Compressive strength of Concrete

Fig No. 12 Test for flexural strength of Concrete

CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn

1. While using the nano silica solution in concrete the original water cement ratio of concrete mix is to be corrected by the amount of water available in nano silica solution.
2. Cement replacement with 10% Silica Fume leads to increase in Compressive Strength, Split Tensile Strength and Flexural Strength.
3. For M40 Grade with Silica Fume 10% the percentage increase in Compressive Strength, Split Tensile Strength and Flexural Strength are 13.21%, 9.5% and 13.75% respectively
4. For M50 Grade with Silica Fume 10% the percentage increase in Compressive Strength, Split Tensile Strength and Flexural Strength are 6.46%, 4.62 % and 5.17 % respectively
5. There is an increase in Youngs Modulus of Concrete for M40 & M50 with Silica Fume 10% is 20.16% and 26.38% respectively higher than Conventional Concrete
6. 1.5 % nano silica appears to be the optimum in the Standard concrete mix like M40 without any admixtures. The highest compressive strength with 1.5 % nano silica and 10% CSF appears to be the optimum in the present blended concrete mixes.
7. For M40 Grade with Nano Silica 1.5% and Silica Fume 10% the percentage increase in Compressive Strength, Split Tensile Strength and Flexural Strength are 19.6 %, 14 % and 19.06 % respectively
8. For M50 Grade with Nano Silica 1.5% and Silica Fume 10%the percentage increase in Compressive Strength, Split Tensile Strength and Flexural Strength are 21.79 %, 15.19 % and 17.3 % respectively
9. There is an increase in Youngs Modulus of Concrete for M40 & M50 with Nano Silica 1.5% and Silica Fume 10% is 50.70 % and 58.88 % respectively higher than Conventional Concrete
10. The Compressive Strength of Cylinders for M40 & M50 with Silica Fume 10% is 17.14% and 11.07 % respectively higher than Convectional Concrete
11. There is an increase in Compressive Strength of Cylinders for M40 & M50 with Nano Silica 1.5% and Silica Fume 10% is 27.12 % and 24.91 % respectively higher than Conventional Concrete

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