# INFLUENȚA NANO SILICEI ASUPRA CARACTERISTICILOR DE REZISTENȚĂ A BETONULUI DE ÎNALTĂ PERFORMANȚĂ
# BEHAVIOUR OF NANO SILICA ON STRENGTH CHARACTERISTICS OF HIGH PERFORMANCES CONCRETE

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***In the present scenario of emerging concepts of nano materials and micro technologies, researchers are investigating how and what nano materials can be used to improve different characteristics of conventional concrete. With increase in trend towards the wider use of concrete for prestressed concrete and high rise buildings there is a growing demand concrete with higher strength. In the present research, the effect of nano silica on high performance concrete has for been studied. Nano silica is an ultrafine airborne material with spherical particles less than 20 nm in diameter, the average being about 15 nm. Concrete mixes prepared by replacing portland cement with nano silica at 1%, 1.5%, 2%, 2.5%, 3% with curing age of 28 days. The mechanical tests like- compressive strength, flexural strength, modulus of elasticity, splitting tension test and rapid chloride permeability test of high performance concrete were studied. The micro analyses were studied using scanning electron microscope and energy dispersive spectroscopy to know the effect of nano silica on high performance concrete. The experiment result shows that, at 3% of nano silica has better mechanical properties, voids were also reduced because of that denser matrix was formed in the high performance concrete.***

***Keywords***: *Nano silica, Silica fume, Mechanical strength, SEM, EDS*

## 1. Introduction

With increasing amount of research being diverted to nano level, Nano technology has gained major attention with its potential uses of particle. Nano scale, which is $10^{-9}$ meter sized particle, proves its improved properties with the same chemical composition as that of from the conventional grain size materials. Integration of nano materials with traditional building materials results in new kinds of materials which could possess outstanding and significant properties that can be applied in the construction of skyscrapers, long span or civil infrastructure systems. The nano scale of particles can result in dramatically improved or different properties from conventional grain sized materials with similar chemical composition [1, 2]. Due to the nano filler effect and the pozzolanic reaction, microstructure became more homogeneous and less porous, especially at the interfacial transition zone, leading to reduced permeability [3, 4]. It was shown that nano silica is pozzolanic and improves the strength and durability of concrete. It also has complex effects on hydration of cements. Nano silica not only influences the rate of hydration, but also reacts with the hydration products. It consumes calcium hydroxide in concrete and forms more calcium silicate hydrates [5 - 11].

## 2. Experimental program

### *2.1. Materials*

The cement used was Ordinary Portland Cement 53 grade corresponding to ASTM type I cement with a specific gravity of 3.15 g/cc was used in concrete mixtures [17, 20]. Natural river sand having a specific gravity 2.6 was used. Crushed, angular, graded coarse aggregates of normal size 12.5 mm and specific gravity of 2.71 were used in the investigation [19]. The commercial superplasticizer (SP) and potable water were employed for mixing. Silica fume from Elkem Group of Companies, Mumbai was used. Nano silica material was supplied by SIGMA ALDRICH (Bharatesh Bhat) Bangalore, the average particles size 15nm (XRD) and 99.5% of $SiO_2$ content.

### *2.2 Mix proportions and test specimens*

In this study, mixtures proportioned M 70 grade concrete is used. Mix proportions and test program are summarized in Table 1. A cast iron mould was used to cast specimens. The effect of casting position was believed to be minimal in terms of bleeding and segregation of concrete due to low water cement ratio used in the mix. Proper arrangement was made to prevent deformation or bulging of the mould during compaction. The concrete was placed in three layers and was

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Table 1

**Mix proportions (kg/m³)**

| Name of specimen | Cement | Fine Aggregate | Coarse Aggregate | Fly ash | % weight fraction | | Slump (mm) | Compaction factor (mm) |
|---|---|---|---|---|---|---|---|---|
| | | | | | NS | SF | | |
| MB | 389 | 622 | 1078 | 118 | - | - | 89 | 0.93 |
| $MBSV_1$ | 385.1 | 622 | 1078 | 118 | 1 | - | 90 | 0.91 |
| $MBSV_2$ | 385.1 | 622 | 1078 | 118 | - | 1 | 89 | 0.93 |
| $MBSV_3$ | 383.16 | 622 | 1078 | 118 | 1.5 | - | 92 | 0.92 |
| $MBSV_4$ | 383.16 | 622 | 1078 | 118 | - | 1.5 | 90 | 0.93 |
| $MBSV_5$ | 381.22 | 622 | 1078 | 118 | 2 | - | 93 | 0.91 |
| $MBNV_1$ | 381.22 | 622 | 1078 | 118 | - | 2 | 90 | 0.92 |
| $MBNV_2$ | 379.27 | 622 | 1078 | 118 | 2.5 | - | 92 | 0.90 |
| $MBNV_3$ | 379.27 | 622 | 1078 | 118 | - | 2.5 | 89 | 0.93 |
| $MBNV_4$ | 377.33 | 622 | 1078 | 118 | 3 | - | 92 | 0.91 |
| $MBNV_5$ | 377.33 | 622 | 1078 | 118 | - | 3 | 90 | 0.93 |

internally compacted through table vibration. The slump value was maintained for all the mixtures as 87 ± 5 mm and compaction factor 0.92 ±0.03 with help to good workability of concrete. The experiment consisted of casting and testing 325 mechanical strength and 42 specimens micro analysis including 115 cubes of 150 mm x150 mm x150 mm size, 70 cylinders of 100 mm x 50 mm size, 70 prisms of 100 mm x100 mm x 400 mm size and 70 cylinders of 150 mm x 300 mm size for silica fume (SF) and nano silica (NS) modified high performance concrete (HPC).

## 3. Mechanical Strength Result and Discussion

### *3.1 Compressive Strength*

For Figure 1, According to code IS 516-1959, tests were performed for curing age of 28 days for all ratios from 0% to 3%. From the tests, significant improvement was observed for specimens with silica fume and nano silica as their replacement while the control specimens showed no improvement. On adding nano silica as the replacement, it was found that the compressive strength was improved by 43.25% when compared to silica fume. Silica fume showed 12.19% improvement for the same percentage of weight fraction. The improvement in compressive strength may be due to formation of C-S-H gel [1, 2 and 5], the effects of using different types of nano material on mechanical properties of high performances concrete results shows that compressive strength is increased by the formation of C-S-H gel. This gel is formed calcium hydroxide compounds existing in lime solution reacting with nano particles in their surface areas. Similarly [9 and 14], studied the mechanical and durability properties of high strength concrete containing macro-polymeric and polypropylene fibers with nano silica and silica fume. Results shows that efficiency of bridging micro cracks are higher because of polypropylene which consequently improve the mechanical strength.

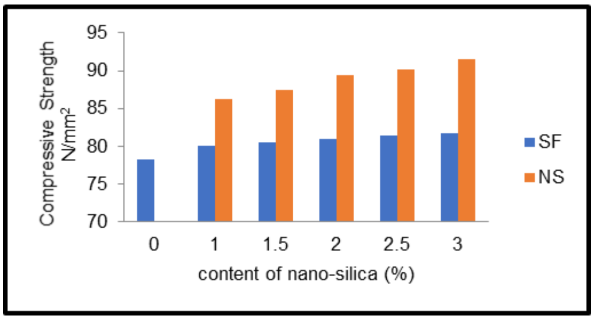


Fig. 1 - Compressive Strength at 28 days.

### *3.2 Flexural Strength*

According to ASTM-C78, Flexural strength test was conducted. For every 1kN, the deflection was found by using Linear Variable Differential Transformer. The value for strain arrived by using LVDT for was control specimens, specimens with silica fume and nano silica as their replacement. Replacement of cement with silica fume ensured flexural strength improvement of 8.62% at 28 days while replacement of the same amount of cement with nano silica improved flexural strength by 17.46% for the same ages. [15], Comparison of experimental result obtained shows that the strength of the concrete admixed with nano silica was substantially higher than the strength of the concrete with silica fume [16]; the usage of nano silica with reduced water cement ratio improves its transition zone. Thus, for the same percentage replacement of cement with nano silica, flexural strength improved consistently over silica fume. Figure 2 clearly shows the variation of flexural strength of nano concrete for 28 days.

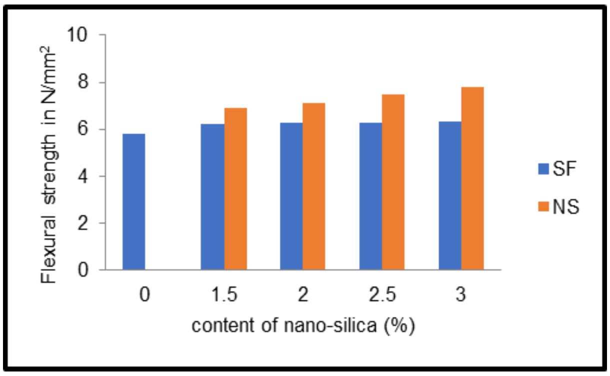


Fig. 2 - Flexural Strength at 28 days.

### 3.3 Modulus of Elasticity

The test was performed as per ASTM C 469 - 02 in a universal testing machine. Then load was applied continuously without any shock at a rate 140 kg / sq cm / min, when extensometer reading was taken. From the graph, it may be noted that as the % of nano silica and silica fume increases the modulus of elasticity of nano silica also increases. Figure 3 clearly shows variations in the modulus of elasticity for NS and SF at different ages. Replacement of cement with silica fume ensured modulus of elasticity improvement by 9.75% at 28 days, while replacement of the same amount of cement with nano silica improved modulus by 20.13% at the same age. Authors [4 and 18] investigated that the modulus of elasticity will increase to a certain percentage and then decrease. This is due to the fact that concrete with nano material attains greater stiffness than the concrete without nano material. This value of stiffness is because of the compactness of the past bond with the aggregates. Mechanical strengths greater for high strength concrete with nano silica than the without nano silica may be specified reported author by [9, 25]. Thus, for the same percentage of cement replacement with nano silica, modulus of elasticity improved consistently over silica fume.

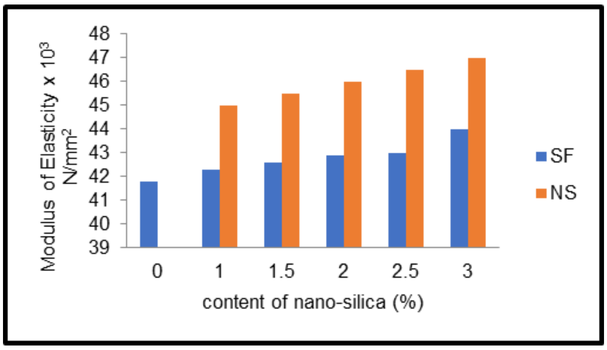


Fig. 3 - Modulus of elasticity of NS and SF at 28 days

### 3.4 Splitting Tensile test

The specimens were tested in compression testing machine of 3000 kN capacity. According to ASTM C 496; the load was applied at a rate of 140 kg / sq cm / min. From the results obtained in Figure 4, it is seen that all concrete specimens with nano silica as the replacement increased in indirect tensile strength when compared to specimens with silica fume as replacement. This shows that the strength of the concrete was increased with the increase of nano silica content. Strength improvement of nano silica concrete compared to silica fume concrete with curing age of 28 days was 4.65 - 28.56%. This improvement is because of the more efficient bridging effect across the crack width. The strength can also be attributed by the enhanced bond between aggregates and hydrated cement as investigated by [21]. This is obtained by converting calcium hydroxide to calcium silicate hydrates in the presence of silica. Split tensile strength of concrete increases with the increase in nano material as reported by [22 and 23].

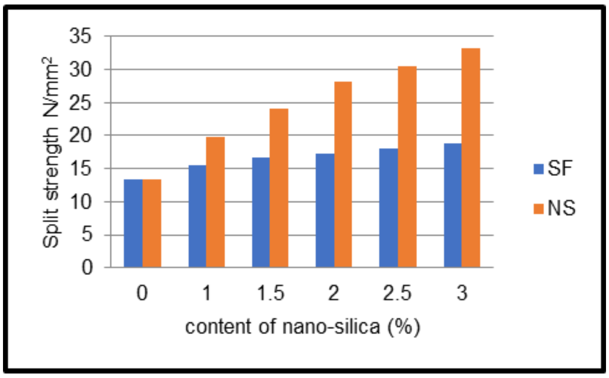


Fig. 4 - Splitting Tensile strength of NS and SF at 28 days.

### 3.5 Rapid Chloride permeability Test

According to the ASTM C 1202, the rapid chloride permeability is low for all specimens and the coulomb passing is between 1000 to 2000.The rapid chloride permeability test of concrete mixtures is shown in Figure 5 at 28 days. The results indicate that the lowest coulombs absorption coefficient belongs to SF and NS when compared to control specimen. This indicates that incorporation of nano silica and silica fume is an efficient way to lower permeability. The RCPT coulombs absorption rate decreased to the lowest, when 1% to 3% nano silica was used in concrete. It seems that when silica fume was used at a high value in the mixture, a slight increase in coulombs absorption coefficient was observed, which is attributed to the agglomeration effect of nano silica in concrete. An overall evaluation of the RCPT coulombs indicates that nano silica concrete specimens with 3% weight friction exhibit lower absorption capacity. [8,11 and 23] showed that addition of nano silica reduces the chloride penetration due to identified microstructure and refined pore structure. Concrete exhibits more resistance to chloride permeability with reduction in coulombs value up to 2% nano silica. Thus, concrete with nano silica proves to be better than concrete containing silica fume.

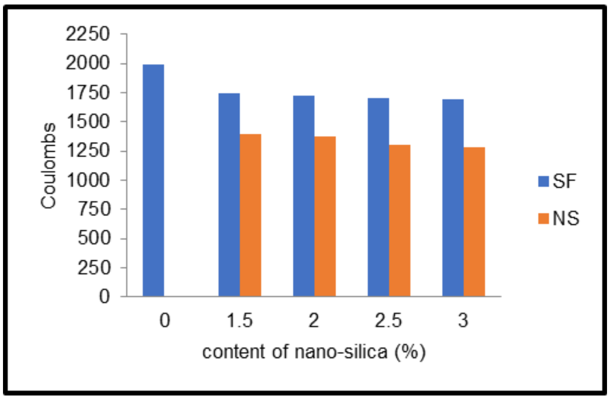


Fig. 5 - RCPT of NS and SF at 28 days.

## 4. Micro Structures analysis

### *4.1 Scanning Electron Microscope (SEM)*

Magnification-5X has been carried out for all types of specimens, ie control specimens, specimens with nano silica and silica fume as replacement to check the crystal formation that would take place inside the concrete. With this magnification process, the distance between the particles can be found. Here, the distance between two particles was found out for control specimens, specimens with nano silica and specimens with silica fume. Nano silica and silica fume was added to concrete at different percentage. The strength for control specimens was lower. This happens because of the voids present in huge amountis shown in figure 6. For a particular surface area nano silica was added at all weight friction with the outcome that strength was moderate, and voids present were comparatively less to that of the control specimens and specimens with silica fume. The strength of

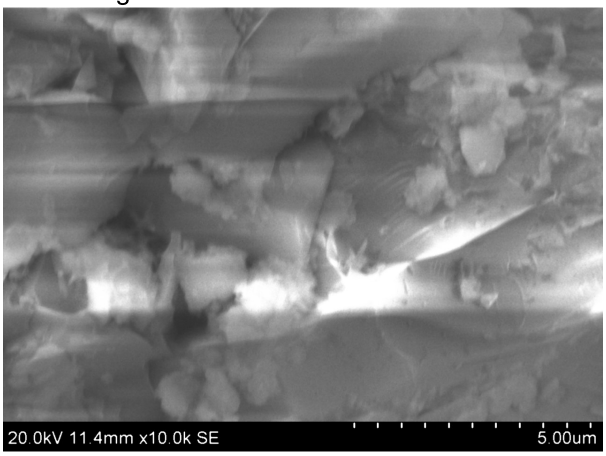


Fig. 6 - SEM Micrographs of MB.

silica fume concrete was also lower. There is great reduction in voids at 5 µm level as the volume fraction of nano silica increases from 2.5 % and 3 % in Figure 8 and Figure 10. This reduction is higher compared to the same volume fractions of silica fume specimens. Authors [1, 24 and 26] experimentally studied the effects of nano silica with pore structures, where the results show the unique shape of nano silica with hydration of cement to form the calcium silicate hydrate, as detected by the SEM images with improved topographical surface area. In Figure 8 and Figure 10, at 5 µm levels, the topographical surface is very dense compared to the silica fume, as the molecules occupy more voids leading to great improvement in the mechanical strength of nano silica specimens compared to silica fume specimens at high volume fractions of 2.5% and 3%.

### *4.2 Energy Dispersive Spectroscopy (EDS)*

Energy Dispersive Spectroscopy is used in conjunction with the scanning electron microscope providing chemical analysis in areas as small as 1 nm in diameter and is shown in Figures 7 to 11. The EDS detector collects the entire spectrum at once, while the wavelength detector acquires the spectrum sequentially. EDS provides quantitative details of the chemical analysis as well as a map of element distribution. Image is monochrome as they reflect the electron or X- ray from the specimen's interaction. EDS is produced when a specimen is bombarded by high energy electrons. The X-ray energy levels is displayed as the number of counts at each energy interval and appear as a set of peaks on a continuous background in $MBNV_5$; the positions of the peak are characteristic of a particular element and so identifications are made by examination of peak positions and relative intensities. The X-ray signal can be used for spectrum analysis to determine what elements are present in the area. From the obtained values, it is inferred that the number of atoms increases due to an increase in nano silica

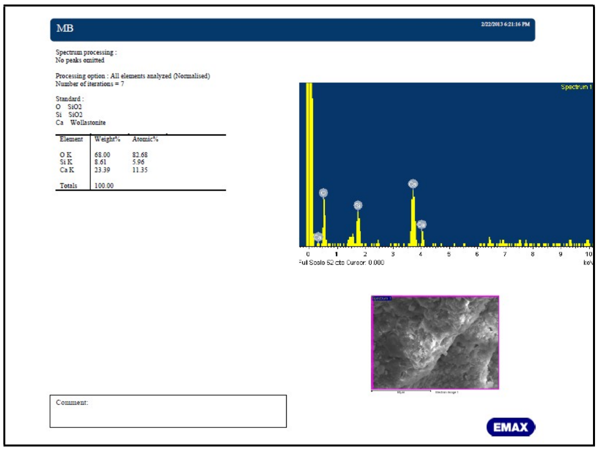


Fig. 7 - EDS analysis of MB

Fig. 8 - SEM Micrographs of $MBSV_5$

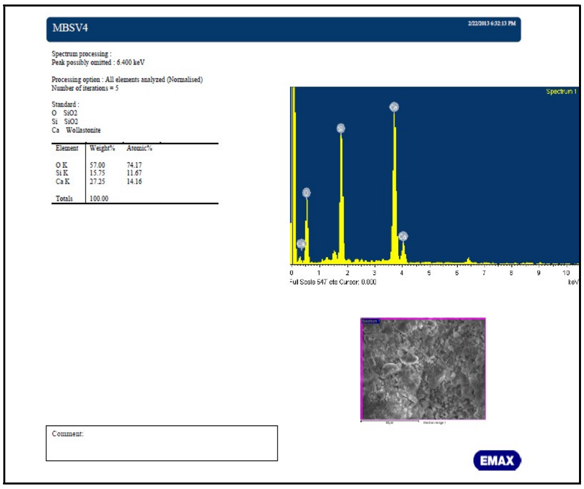


Fig. 9 - EDS analysis of $MBSV_5$

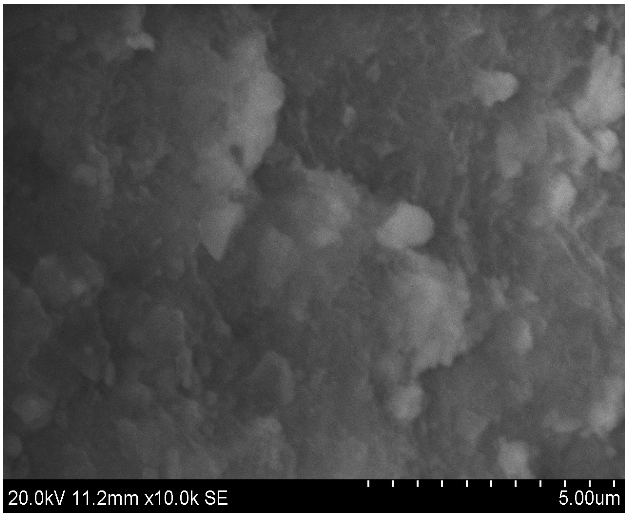


Fig. 10 - SEM Micrographs of $MBNV_5$

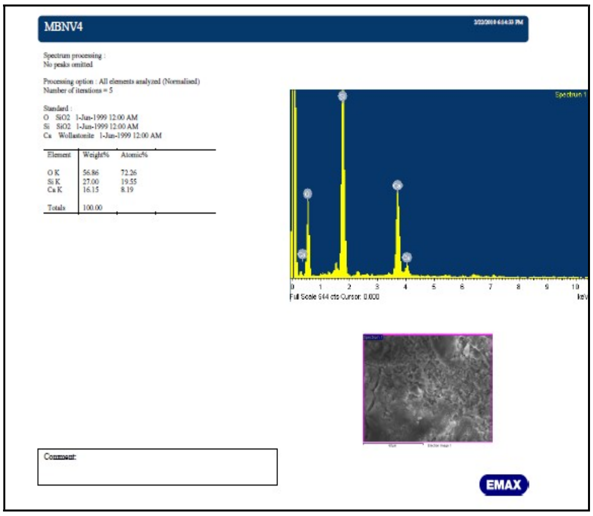


Fig. 11 - EDS analysis of $MBSNV_5$

content in concrete; Figure 11 shows clearly that the surface area of nano silica is uniformly distributed due to the hydration process which improves the mechanical strength and durability of nano silica compared to the silica fume concrete. The strength of concrete is enhanced with the use of nano silica as it will fill the pores[13]. Nano silica takes part in hydration process for the generation of C-S-H gel in reaction with Ca (OH) 2 thereby increasing the strength.

## 5. Conclusions

1. The compressive strength of concrete improved with the addition of nano silica (NS) and Silica fume (SF) over control conditions at all ages. But nano silica showed greater compressive strength than silica fume. The compressive strength of concrete increases with nano silica at 28 days of curing is 38.72% higher compared to silica fume (SF) concrete.

2. Flexural Strength improved with the addition of nano silica and silica fume to high performance concrete, for 28 days. The percentage improvement was 17.46 for nano silica, where as for silica fume it is 8.62%.

3. The indirect tensile strength for nano silica and silica fume is higher compared to the control specimen for all ages. In nano silica, indirect tensile strength in high performance concrete was 4.65%, but in silica fume variation is less compared to nano silica, which is 3.55%.

4. Increase in concrete strength is the most important advantage of using nano particles. When particles are uniformly distributed in concrete, nano particles fill cement pores, and act as a core which sticks strongly to hydrated concrete. Due to its intense activity, cement hydration is rapid and concrete strength increases.

5. Scanning Electron Microscope (SEM) studies show that nano particles are uniformly distributed and that the microstructure of concrete improved. Chemical characterization of nano silica and silica fume in high performance concrete using Energy Dispersive Spectroscopy (EDS) indicates a good pattern of C-H-S and peak values of NS. The number of atoms in silica fumes and nano silica is higher than that of the control specimen. The

results show that the percentage increase in surface area in nano $SiO_2$ is 41.87% and that of silica fume is 5.12%. It was further concluded that nano silica had lower voids than silica fume.

6. The overall conclusion was that nano materials behaved as a filler to improve concrete microstructure leading to a denser morphology.

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