# Investigation on Mechanical Properties of Concrete Using Microsilica and Optimised dose of Nanosilica as a Partial Replacement of Cement

**Hemlata Sharma[1], Er.Rishav Garg[2], Er.Devinder Sharma[3], Mirza umar beg[4], Rohit Sharma[5]**

[1]Student of M.Tech (Structures),Department of Civil Engineering, Baddi University, Himachal Pradesh (India).
[2]Associate Professor & HOD, Department of Civil Engineering, Baddi University, Himachal Pradesh (India).
[3]Associate Professor, Department of Civil Engineering, Baddi University, Himachal Pradesh (India).
[4,5]Student of M.Tech (Structures),Department of Civil Engineering, Baddi University, Himachal Pradesh (India)

***Abstract:*** **In this research paper we have studied the mechanical properties of M40 grade concrete by partial replacement of cement with nanosilica, microsilica. The results were obtained for compressive strength, split tensile strength and flexural strength at7days, 28days, 56days and 90days.It was found that the addition of microsilica increases the compressive strength at all levels in comparison to standard mix whereas the strength decreases after attaining a certain percentage. The similar results were also obtained in case of nanosilica but the strength is much higher at the initial ages due to the reaction of unhydrated calcium hydroxide with nanosilica. After certain percentage, the compressive strength decreases with further increases in nanosilica.**

***Keywords:*** **Microsilica, nanosilica, Compressive strength, Split tensile strength, Flexural strength**

## I. INTRODUCTION

Concrete is the one of the most versatile material due to the relentless and continuous demands made on concrete. It is the one's need in present as well as in future. Concrete plays a important role within the style and construction of the nation's infrastructure. The engineering marvels like Roman aqueducts, the Coliseum are examples by Greeks and Romans. Virtually three quarters of the volume of concrete consists of aggregates. The wide use of it in structures, from buildings to factories, from bridges to airports, makes it one in every of the foremost investigated material of the twenty first century. as a result of the fast population explosion and therefore the technology boom to cater to those desires, there's AN imperative got to improve the strength and durability of concrete. Out of the varied materials utilized in the assembly of concrete, cement plays a serious role due its size and adhesive property. But, the use of huge amount o cement is one of the reason of increasing green house effect. So, to provide concrete with improved properties, the mechanism of cement association must be studied properly and higher substitutes to that ought to be prompt. One of the method of reducing the cement content in concrete is the use of chemical admixture and the totally different materials called supplementary cementitious materials or SCMs.

## II. MATERIALS USED AND THEIR PROPERTIES

The materials used to carry out the research work consist of cement, fine and coarse aggregate, microsilica, nanosilica and water.

## III. CEMENT

Ultra tech cement of ordinary Portland cement (OPC) of 43 grade is used which satisfies the requirement of IS 12269-1987.The physical characteristics of cement is given in Table 3.1.

**Table 3.1 Physical Characteristics Of Cement**

| Property | Value |
|---|---|
| Fineness | 278 $m^2$/kg |
| Standard Consistency | 32.0% |
| Initial setting time | 120 min |
| Final setting time | 240 min |
| Soundness Le-Chat expansion | 1.5 mm |
| Compressive strength at 3 days | 33.1 MPa |
| Compressive strength at 7 days | 41.6 MPa |
| Compressive strength at 28 days | 53.7 MPa |

## IV. AGGREGATE

### COARSE AGGREGATES

Locally available coarse aggregate having the size of 10mm and 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. . Physical properties of coarse aggregate are as shown in table 3.2.

**Table 3.2Properties of Coarse Aggregate**

| Sr.No | Characteristics | Values |
|---|---|---|
| 1 | Colour | Grey |
| 2 | Shape | Angular |
| 3 | Maximum Size | 20mm |
| 4 | Specific Gravity | 2.75 |
| 5 | Fineness Modulus | 7.696 |

### FINE AGGREGATE

The fine aggregate used for the work was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The fine aggregate was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and minimum size 150 microns was used. Physical properties of fine aggregate are as shown in table 3.3.

**Table 3.3 Properties of Fine Aggregate**

| Sr.No | Properties | Results |
|---|---|---|
| 1 | Bulk density,kg/m$^3$ | 1625 |
| 2 | Specific gravity | 2.69 |
| 3 | Fineness modulus | 2.95 |
| 4 | Free surface moisture(%) | 2.0 |

### MICROSILICA

The silica fume was used in these experiments conforms to ASTM C 1240 and IS 15388:2003. Microsilica is a extremely fine particle, which exists in powder form. Microsilica has been procured from Orkla India Pvt.Ltd.The physical and chemical requirements of microsilica are as shown in table 3.4and 3.5.

**Table 3.4 Physical Requirements of Microsilica**

| Sr.No | Parameters | Specification | Analysis |
|---|---|---|---|
| 1 | >45 micron | Max.10% | 0.55 |
| 2 | Pozz.Activity Index | Min.105% | 134 |
| 3 | Sp. Surface | Min.15m$^2$/g | 19.5 |
| 4 | Bulk Density | 500-700 kg/m$^3$ | 630 |

**Table 3.5 Chemical Requirements of Microsilica**

| Sr.No | Parameters | Specification | Analysis |
|---|---|---|---|
| 1 | $SiO_2$ | Min.85.0 % | 90.49 |
| 2 | Moisture Content | Max.3.0 % | 0.65 |
| 3 | Loss of Ignition | Max.6.0 % | 1.24 |

### NANOSILICA

Physical characteristics and Chemical Composition of Nanosilica are as shown in Table 3.6and 3.7.

**Table 3.6 Physical Characteristics of Nanosilica**

| Sr.No | Property | Value |
|---|---|---|
| 1 | Average Particle size(nm) | 20 |
| 2 | Density(g/cm$^3$) | 2.4 |
| 3 | Molar Mass(g/mol) | 59.90 |
| 4 | Melting Point(◦c) | 1610 |
| 5 | Boiling Point(◦c) | 2225 |
| 6 | Specific gravity(g/cm$^3$) | 1.31 |
| 7 | Specific Surface(m$^2$/g) | 140 |

**Table 3.7 Chemical Composition of Nanosilica**

| Oxides | $SiO_2$ | C | MgO | CaO | $Al_2O_3$ | FeO | $TiO_2$ | L.O.I |
|---|---|---|---|---|---|---|---|---|
| % by mass | 99.9 | - | - | - | - | - | - | 2.8 |

### WATER

Water is that the one in all the foremost vital ingredient of concrete as a result of it's the potential to mix with cement and forms a binding paste. The paste thus, formed fills up the voids of sand and aggregates and bringing them into close adhesion. The water is the lowest cost component for the production of concrete. Almost any natural water that is fit for drinking and has no undesirable taste or colour is generally used for making concrete. If the quality of water and its chemical composition used in concrete is unknown, then there is a high risk, because it is not known whether the water inside the concrete will cause a benefit or a drawback. The water containing salts, acids, organic matters can affect the setting time, reduce mechanical strength and also increases the risk of corrosion. In general, potable water is suitable for mixing water as per (IS: 456:2000). In this investigation, normal tap water available in the laboratory was used.

**Design of concrete mix**

In the present study, Mix Design for M40 (28 days characteristic compressive strength) grade concrete was prepared as per IS specification BIS: 10262-1982, 2009 with trials.

**Table3.8 Mix proportion of concrete**

| Sr.No | Materials | Quantity in $kg/m^3$ |
|---|---|---|
| 1 | Cement | 400 |
| 2 | Water | 160 |
| 3 | Fine Aggregate | 660 |
| 4 | Coarse Aggregate | 1165 |
| 5 | Water cement ratio | 0.40 |
| 6 | Type of exposure | Moderate |

## V. EXPERIMENTAL PROCEDURE

Specimen casting and curing for production of concrete mixes, initially, controlled mix sample was prepared with the water cement ratio kept as 0.40.The apparatus used generally consist of cube mould (150x150x150 mm), Tamping bar (16 mm diameter and bull-nosed), Steel Float/Trowel and the flexural strength was conducted on beam of size 100x100x500mm and cylinders of 150D×300H mm size were cast in standard moulds. Clean the cube-mould properly and apply oil on inner surface of mould. But no oil should be visible on surface. Fix the cube mould with base plate tightly. No gap should be left in joints so that cement-slurry doesn't penetrate. Place the mould on levelled surface. Place concrete into mould in three layers. Compact each layer by giving 35 blows of tamping bar. Remove excess concrete from the top of mould and finish concrete surface with trowel. Make the top surface of concrete cube even and smooth. Left the mould completely undisturbed for first four hours after casting. After ending undisturbed period, put down casting date and item name on the top of concrete specimen with permanent marker.

After 8 to 10 hours of casting, wrap the cube mould with wetted hessian cloth. Cover the mould's top portion with a polythene sheet so that water doesn't fall on concrete surface. Uncover and remove the cube specimens from mould after 24±½ hours of casting. For removing specimen from mould, first loosen all nut-bolts and carefully remove specimen because concrete is still weak and can be broken.After7days and 28 days of curing take out specimens from water tank and tested. The same procedure was adopted for concrete containing silica fume at (5%, 10%, 15%, and 20%) and finally the mix which gives maximum strength is again mixed with optimized dose of nanosilica by replacing the cement.

**How Microsilica and Nanosilica Works in Concrete**

Micro silica in concrete contributes to strength and durability in two ways: **Pozzolanic effect and Micro filler effect.** The pozzolanic reaction of silica with calcium hydroxide forms more C-S-H gel at final stages. The second function is physical one, because micro-silica is about 100 times smaller than cement. Micro-silica can fill the remaining voids in the young and partially hydrated cement paste, increasing its final density. It has been realized that silica fume by itself, do not contribute to the strength dramatically, it does contribute to the strength property by being very fine pozzolanic material and also creating dense packing and polar filler of cement paste.

OPC+ $H_2O$ → C-S-H (Calcium silicate hydrate) + $Ca(OH)_2$

In the presence of micro silica, the silicon dioxide from the micro silica will react with the calcium hydroxide to produce more aggregate binding CSH as follows:-

$Ca(OH)_2$ + $SiO_2$ + $H_20$ → C-S-H (Calcium silicate hydrate)

The aim of the application of ultra-fine additives like nanosilica in cementitious system is to improve the characteristics of the plastic and hardened material. Micro and nano-scaled silica particles have a filler effect by filling up the voids between the cement grains. With the right composition, the higher packing density results in a lower water demand of the mixture and it also contributes to strength enhancement due to the reduced capillary porosity. Besides this physical effect as obtained by addition, nano-silica has a high pozzolanic reactivity which is much higher compared to silica fume.

**Pozzolanic reaction**

Nano-$SiO_2$+$H_2O$→$H2SiO_4^{2}$

$Ca(OH)_2$+ $H_2O$ → $Ca^{2+}$ +$OH^-$

$H_2SiO_4^{2-}$ +$Ca^{2+}$→ C-S-H

**Designation of Concrete Mixes**

Designation of concrete mixes are given in table 3.9

**Table 3.9 Designation of concrete mixes**

| Designation | Silica fume (%) | Nanosilica (%) |
|---|---|---|
| M0 | 0 | 0 |
| M1 | 5 | 0 |
| M2 | 10 | 0 |
| M3 | 15 | 0 |
| M4 | 20 | 0 |
| M5 | 15 | 1 |

## VI. TEST RESULTS AND DISCUSSION

Result of fresh and hardened concrete with partial substitution of silica fume and optimized content of nanosilica are discussed.

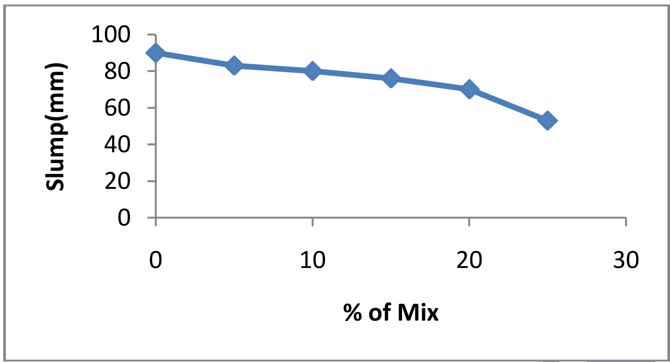
The percentage of silica fume was varied from 0%, 5%, 10%, 15% and 20% .The concrete mix was prepared at optimum content of nanosilica with optimum percentage of silica fume. For each percentage variation of silica fume and nanosilica, three samples were tested and average value was taken.

**WORKABILITY**

The workability of the concrete decreases by adding the silica fume. The workability as measured from slump cone test for control mix was 90mm whereas it decreases gradually by addition of silica fume and lowers to 70mm at 20% addition of silica fume. This decrease in workability was due to small size of silica fume. The workability further decreases by adding even a small amount of nanosilica & it reduces to 53mm with addition 1% nanosilica. This decrease in workability was due to the better packing & better intermolecular forces as the nanosilica acts as filler and also has self adhesive properties leads to decrease in workability.

**Table3.10 Results obtained during slump cone test**

| **Mix** | M0 | M1 | M2 | M3 | M4 | M5 |
|---|---|---|---|---|---|---|
| **Slump(mm)** | 90 | 83 | 80 | 76 | 70 | 53 |



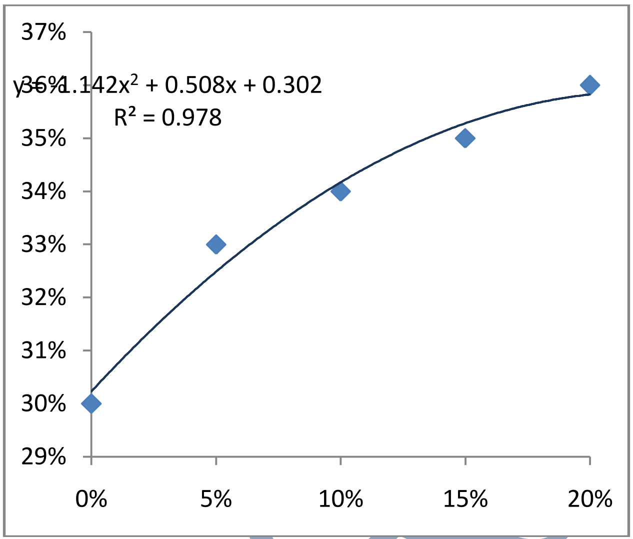

**Workability plot in presence of (MS+NS)**

**CONSISTENCY TEST**

For performing the tests for setting time, soundness and compressive strength of cement, it is essential to fix the quantity of water to be mixed in cement in each case. This test covers the procedure for determining the quantity of water required to produce a cement paste of standard or normal consistency. The consistency of CMS was found to be lower in comparison to all the mixes. Increase in consistency was observed with increases in content of microsilica and found to be maximum for combination of microsilica & nanosilica.

**3.11 Results obtained for consistency**

| **Percentage of silica fume** | **Cement (per/m$^3$)** | **Silicafume( per/m$^3$** | **Normal consistency** |
|---|---|---|---|
| 0% | 350 | 0 | 30% |
| 5% | 332.5 | 17.5 | 33% |
| 10% | 315.0 | 35.0 | 34% |
| 15% | 297.5 | 52.5 | 35% |
| 20% | 280.0 | 70.0 | 36% |
| **% of nanosilica + microsilica** | **Cement per/m$^3$** | **Nanosilica +Microsilica** | **Normal consistency** |
| 1%+15% | 294 | 56 | 38% |




**Consistency plot in presence of MS**

**SETTING TIME**

Reduction in initial and final setting time of paste was observed on addition of microsilica as compared to the control ones. Also, difference between initial setting time and final setting time decreased with increase in microsilica content. The same results were observed on addition with nanosilica but reduction in initial setting time and final setting time was much more as compared to both the mixes.

**COMPRESSIVE STRENGTH**

The compressive strength of the concrete mix was measured at 7 days, 28 days,56 days & 90 days by using compression testing machine on 150 mm cube. The compressive strength was found to increase for all mixes at all days in comparison to control mix. The increase in compressive strength was due to better packing fraction and lesser voids in concrete having silica fume. The increase in compressive strength was mainly due to the enhanced microstructure and improvement in aggregate-paste bond. This improvement in the aggregate/cement bond is due to the conversion of the CH (calcium hydroxide) to CSH (calcium silicate hydrate) in the presence of reactive silica. The compressive strength was found to decrease at 20% addition of silica fume in comparison to 15% addition of silica fume indicating the maximum conversion of CH into CSH only upto 15% and after that the silica fume will act as a free silica and hence hindering the reaction and reducing the strength.

The increase in compressive strength was also observed with addition of nanosilica The maximum value of strength obtained by addition of microsilica i.e.(15%) was again mixed with optimized dose of nanosilica(1%) and the value of the strength obtained is much high as compared to all the mixes. The compressive strength of silicafume concrete and nanosilica concrete at the age of 7days, 28days, 56days, and 90 days is presented in fig3.1and the table3.12.

**Table3.12 Shows the Compressive Strength at various curing ages in(N/mm$^2$)**

| **Mix** | **7Days** | **28Days** | **56Days** | **90Days** |
|---|---|---|---|---|
| M0 | 35.34 | 41.5 | 43.7 | 45.77 |
| M1 | 36.36 | 43.7 | 47.3 | 48.89 |
| M2 | 38.87 | 47.9 | 50.26 | 51.19 |
| M3 | 41.11 | 49.4 | 52.30 | 55.05 |

| | | | | |
|---|---|---|---|---|
| M4 | 40.42 | 48.1 | 51.80 | 53.65 |
| M5 | 45.37 | 55.51 | 59.38 | 61.38 |

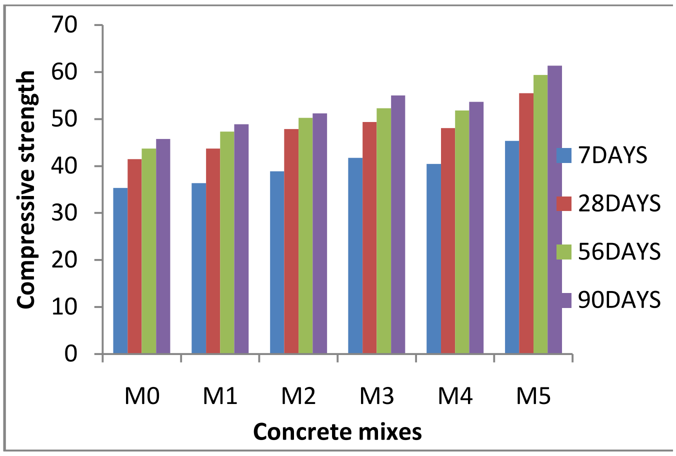



**Figure3.1 Comparison of concrete mixes with increasing curing ages**

**SPLIT TENSILE STRENGTH**

The split strength of the concrete mix was measured at 7 days, 28 days, 56 days & 90 days by using compression testing machine on 150 x 300mm cylinders. The split tensile strength was found to increase for all mixes at all days in comparison to control mix without any additive. The results shows that very high percentages of silica fume did not significantly increase the splitting tensile strength and decrease in split tensile strength was observed beyond 15%. The increase in split tensile strength was also observed with addition of nanosilica. This is due to the better filler effect due to better distribution of particles by the addition of nanosilica. The concrete mix does not exhibit the pozzolanic behaviour by additional silica fume & hence results in reduction of the split tensile strength. The nanosilica makes the concrete denser & with their filler effect enhances the split tensile strength. The split tensile strength increases many fold with the combination of silica fume & nanosilica at optimized content. This may be attributed to the fact that adding silica fume improves dispersion of the nanosilica in the concrete specimens and thereby increase the split tensile strength. The results of silicafume concrete and nanosilica concrete at the curing age of 7days, 28days, 56days&90days are given in the fig3.2 and the table 3.13.

**Table3.13 Shows the split tensile strength at various curing ages (MPa)**

| Mix | 7Days | 28Days | 56Days | 90Days |
|---|---|---|---|---|
| M0 | 2.95 | 3.50 | 3.72 | 4.0 |
| M1 | 3.09 | 3.70 | 3.85 | 4.15 |
| M2 | 3.19 | 3.90 | 3.95 | 4.17 |
| M3 | 3.30 | 3.93 | 4.10 | 4.30 |
| M4 | 3.25 | 3.91 | 4.12 | 4.18 |
| M5 | 4.1 | 4.8 | 4.90 | 5.10 |

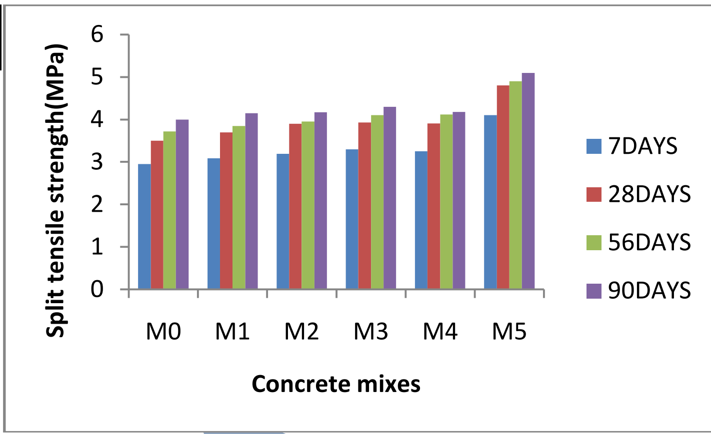



**Figure3.2 Comparison of concrete mixes with increasing curing ages**

**FLEXURAL STRENGTH**

The flexural strength of the concrete mix was measured at 7 days, 28 days,56 days & 90 days by using universal testing machine on standard beams of size(100mmx100mmx500mm).The flexural strength was found to increase for all mixes at all days in comparison to control mix without any additive. The results of silicafume concrete and nanosilica concrete at the curing age of 7days, 28days, 56days &90days are given in the fig3.3 and the table 3.14.

**Table3.14 Shows the flexural strength at various curing ages (MPa)**

| Mix | 7Days | 28Days | 56Days | 90Days |
|---|---|---|---|---|
| M0 | 3.1 | 3.7 | 3.93 | 4.11 |
| M1 | 3.27 | 3.93 | 4.25 | 4.40 |
| M2 | 3.40 | 4.31 | 4.52 | 4.60 |
| M3 | 3.69 | 4.44 | 4.70 | 4.95 |
| M4 | 3.52 | 4.32 | 4.66 | 4.82 |
| M5 | 4.08 | 4.99 | 5.34 | 5.52 |

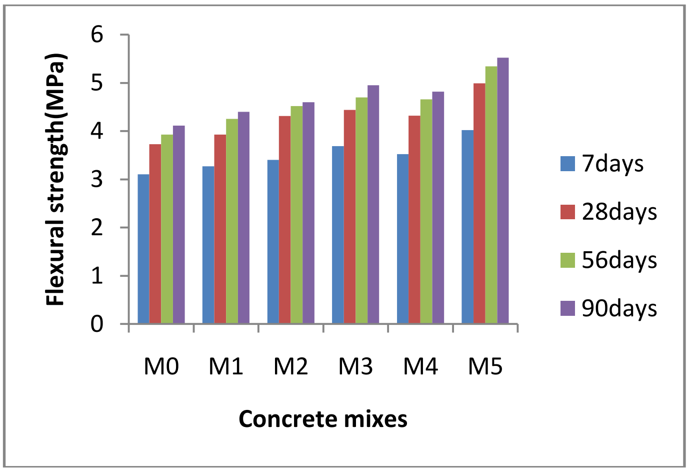



**Figure3.3 Comparison of concrete mixes with increasing curing ages**

## VII. CONCLUSION

- The workability of concrete decreases with addition of silica fume & as well as combination of both nanosilica and microsilica due to the better packing of silica fume & also they act as a filler material.

- The consistency of CMS was found to be lower in comparison to all the mixes. Increase in consistency was observed with increases in content of microsilica and found to be maximum for combination of microsilica & nanosilica.
- Reduction in initial and final setting time of paste was observed on addition of microsilica as compared to the control ones. Also, difference between initial setting time and final setting time decreased with increase in microsilica content. The same results were observed on addition with nanosilica but reduction in initial setting time and final setting time was much more as compared to both the mixes.
- The compressive strength of all the specimens containing silica fume was higher as compared to the mortar mixture without silica fume because of the enhanced microstructure and improvement in aggregate-paste bond which is due to the conversion of the CH (calcium hydroxide) to CSH (calcium silicate hydrate) in the presence of reactive silica. The compressive strength of the specimen containing combination of nanosilica and microsilica was higher in comparison to control as well as microsilica mixes due to self adhesive property of nanosilica. The increase in compressive strength is attributed to the filling of voids within the microstructure by the Nano $SiO_2$ particles that prevent the expansion of $Ca(OH)_2$ crystals. Additionally to that the Nano oxide reacts with calcium hydroxide crystals changing them into C-S-H gel.
- The compressive strength, split tensile strength& flexural strength of concrete mix increases with age but the %age increase in compressive strength varies with the curing ages. The compressive strength, split tensile strength& flexural strength increases with addition of silica fume upto 15% and then decreases and it increases with addition of combination of both microsilica and nanosilica.

## REFERENCES


[1]. A.M. Said, M.S. Zeidan, M.T. Bassuomi and Y. Tian. (2012). Properties of concrete incorporating nano-silica. Construction and Building Materials 36, 838-844

[2]. A.A.Maghsoudi, F. Arabpour Dahooei, "Effect of Nanoscale Materials in Engineering Properties of Performance Self Compacting Concrete", 7th International Congress on Civil Engineering, Tarbiat Modares University, 2005.

[3]. A.Sadrmomtazi, and A.Fasihi—"Influence of Polypropylene fibers on performance of Nano- Si02 incorporated mortar "–Iranian Journal of science and technology –vol-34-2010-pp385-395

[4]. Abdul Wahab, B. Dean Kumar, M.Bhaskar, S.Vijaya Kumar, B.L.P.Swami "Concrete Composites with Nano Silica, Condensed Silica Fume and Fly Ash – Study of Strength Properties" International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May 2013.

[5]. Byung-Wan Jo, Chang-Hyun Kim, Ghi-ho Tae and Jang-Bin Park. (2007). Characteristics of cement mortar with nano-$SiO_2$ particles. Construction and Building Materials 21, 1351-1355.

[6]. Collepardi,M.,Collepardi,S.,Skrap,U.,Troli,R., Optimization of silica fume, Fly ash and Amorphous Nano- Silica in Superplasticized High-Performance Concretes, proceeding of 8 th CANMET/ACI International Conference on fly ash, Silica fume, Slag and Natural Pozzolans in Concrete, SP-221, Las Vegas,USA, (2004), p. 495-50

[7]. Dilip Kumar Singha Roy, Amitava Sil, "Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 8, August 2012

[8]. D. Rodríguez, S. a. Bernal, J. L. Provis, J. Paya, J. M. Monzo, and M. V. Borrachero, "Effect of nanosilica-based activators on the performance of an alkali-activated fly ash binder," Cem. Concr. Cosmpos. vol. 35, no. 1, pp. 1–11, 2013.

[9]. Elahi, "Properties of High Performance Concrete with Supplementary Cementitious Materials Ph. D Thesis University of Engineering & Technology Properties of High Performance Concrete with Supplementary Cementitious Materials," no. December, 2009.

[10]. Heidari, A., and Tavakoli, D. (Sept 2012). A study of mechanical properties on ground ceramic powder concrete incorporating nano $SiO_2$ particles. Construction and Building Materials Vol. 38, 255-264.

[11]. H. Biricik and N. Sarier, "Comparative study of the characteristics of nano silica - , silica fume - and fly ash - incorporated cement mortars," Mater. Res., vol. 2, no. ahead, pp. 15–26, 2014.

[12]. Hui Li, Hui-gang Xiao, Jie Yuan and Jinping Ou. (2004). Microstructure of cement mortar with nanoparticles. Composites: Part B 35, 185-189.

[13]. Ji, Tao. (2005). Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO2. Cement and Concrete Research 35, 1943-1947.

[14]. J. C. Arteaga-Arcos, O. A. Chimal-Valencia, H. T. Yee-Madeira, and S. Díaz De La Torre, "The usage of ultra-fine cement as an admixture to increase the compressive strength of Portland cement mortars," Constr. Build. Mater., vol. 42, pp. 152–160, 2013.

[15]. K. M. Kim, Y. S. Heo, S. P. Kang, and J. Lee, "Effect of sodium silicate- and ethyl silicate-based nano-silica on pore structure of cement composites," Cem. Concr. Compos. vol. 49, pp. 84–91, 2014.

[16]. Kontoleontos, P. E. Tsakiridis, a. Marinos, V. Kaloidas, and M. Katsioti, "Influence of colloidal nanosilica on ultrafine cement hydration: Physicochemical and microstructural characterization," Constr. Build. Mater., vol. 35, pp. 347–360, 2012.

[17]. K. Sridhar and S. B. Vanakudre, "Strength Efficiency Factor for Nano Silica at Different Age," no. 6, pp. 17–20, 2014.

[18]. L. Senff, J. a. Labrincha, V. M. Ferreira, D. Hotza, and W. L. Repette, “Effect of nano-silica on rheology and fresh properties of cement pastes and mortars,” Constr. Build. Mater., vol. 23, no. 7, pp. 2487–2491, 2009.

[19]. Lilkov, I. Rostovsky, O. Petrov, Y. Tzvetanova, and P. Savov, “Long term study of hardened cement pastes containing silica fume and fly ash,” Constr. Build. Mater., vol. 60, pp. 48–56, 2014.

[20]. L. E. Zapata, G. Portela, O. M. Suárez, and O. Carrasquillo, “Rheological performance and compressive strength of superplasticized cementitious mixtures with micro/nano-$SiO_2$ additions,” Constr. Build. Mater., vol. 41, pp. 708–716, 2013.

[21]. M. Heikal, S. Abd El Aleem, and W. M. Morsi, “Characteristics of blended cements containing nano-silica,” HBRC J., vol. 9, no. 3, pp. 243–255, 2013.

[22]. M. Heikal, H. El-Didamony, T. M. Sokkary, and I. a. Ahmed, “Behavior of composite cement pastes containing microsilica and fly ash at elevated temperature,” Constr. Build. Mater., vol. 38, pp. 1180–1190, 2013.

[23]. Mukharjee, Bibhuti Bhusan, Barai and Sudhirkumar V. (2014). Influence of incorporation of nano-silica and recycled aggregates on compressive strength and microstructure of concrete. Construction and Building Materials 71, 570-578.

[24]. Mohammad Reza Zamani Abyaneh, Alireza Mehran,Seyed Mohammad Mahdi Hoseini,(2013).Effect of nanosilica on permeability of concrete and steel bars reinforcement corrosion. Australian Journal of Basics and Applied Sciences, 464-467,2013 ISSN 1991-8178.

[25]. Nilli, M., Ehsani, A. and Shabani, K. (2009). Influence of nano SiO2 and micro silica on concrete performance. Bu-Ali Sina University Iran.

[26]. N. K. Amudhavalli1, Jeena Mathew, “Effect of Silica Fume On Strength And Durability parameters Of Concrete”, International Journal of Engineering Sciences & Emerging Technologies, August 2012. ISSN: 2231 – 6604 Volume 3, Issue 1, pp: 28-35

[27]. P. Hou, S. Kawashima, D. Kong, D. J. Corr, J. Qian, and S. P. Shah, “Modification effects of colloidal nano$SiO_2$ on cement hydration and its gel property,” Compos. Part B Eng., vol. 45, no. 1, pp. 440–448, 2013.

[28]. P. M. Buchanan, R. Weyers, T. Cousins, and C. Roberts-wollmann, “Shrinkage of laterx modified and microsilica concrete overlay mixtures,” 2002.

[29]. Qing Y, Zenan Z, Deyu K, Rongshen C. Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume. ConstrBuild Mater 2007;21(3):539

[30]. R. E. Nuñez, “Performance of Chlorides Penetration and Corrosion Resistance of Mortars with Replacements of Rice Husk Ash and Nano-$SiO_2$,” vol. 10, pp. 332–346, 2015.