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[Tahwia*et al.*, 6(5): May, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

# PROPERTIES OF ULTRA HIGH STRENGTH CONCRETE INCORPORATING NANO-SILICA

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**DOI**: 10.5281/zenodo.800599

## ABSTRACT

The objective of this investigation is to study the effect of nano-silica addition on the fresh and hardened properties of ultra high strength concrete. Nano-silica with 99.8% $SiO_2$ content and particles size of 5 to 20 nm used in concrete mixes as a replacement of silica fume content. The total percentage of silica fume and nano-silica was 20% of weight of binder content. Nano-silica was added in seven percentages (0.5%, 1.0%, 1.5%, 2%, 2.5%, 3.0%, 3.5%) of weight of cementitious materials. The properties of ultra high strength concrete was investigated through twenty seven concrete mixes using nano-silica addition with three different binder content 450, 550, and 650 kg/m$^3$. Nanomaterials have a larger value of the ratio between surface area and volume than other similar particles in larger size , making the nanomaterials more reactive. Slump test, Compacting factor test and Ve-Be time test were used to determine the effect of nano-silica content on the workability of concrete, while compression test, indirect tensile strength test, flexural strength test, modulus of elasticity test and permeability test were carried out to determine the properties of hardened concrete. Also to compare microstructure and nanostructures of concrete with and without nano-silica, scanning electron microscopy was used. The test result showed that the addition of nano-silica as cement replacement could improve the mechanical behavior of ultra high strength concrete. The results showed that the optimum dose of nano-scilica was 2.5% by weight of cementitious materials. Using 2.5% nano-silica can produce ultra-high strength concrete with high workability without segregation. The workability of concrete decreases with the increase in nano-silica content. The use of superplasticizer was necessary in concrete mixes to improve the workability. Results indicated that nano-silica up to 2.5% nano-silica by weight could improve the mechanical and physical properties of ultra high strength concrete.

**KEYWORDS**: Nano-Silica, Ultra High Strength Concrete, Silica Fume, Binder Content

## INTRODUCTION

Concrete is a highly heterogeneous material produced by mixture of finely powdered cement, aggregates of various sizes and water with inherent physical, chemical and mechanical properties. A reaction between the cement and water yields calcium silicate hydrate (C-S-H), which gives concrete strength and other mechanical properties of concrete, as well as some by-products including calcium hydroxide (CH), 'gel pores' etc [1]. In the past several years, improvements have been occurring in concrete technology. Sustainable use of supplementary materials and revolutionary developments in superplasticizer admixtures has facilitated improvements in the mechanical properties and durability of concrete [2, 3]. Today, the challenge is to create a positive image of nanotechnology amongst the public through the media based on understanding, excitement and trust, in addition to personal and societal benefits [4].

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 nanometer, $10^{-9}$m, the properties of the material actually become affected. The precise size at which these changes are manifested varies among materials, but is usually in the order of 100 nm or less[5].

At present, a significant number of works dealing with the use of nano-silica(NS) in cement-paste, mortar, and concrete is available in the literature. The addition of nano-silica to OPC pastes always reduced the mix workability [6-8]. Zaki and Ragab carried out an investigation to study the influence of nano-silica on properties of high performance and self-compacted concrete. they added NS in three percentages (0.5, 0.7 and

1% of weight of cementitious materials. The results showed that 0.5% of NS by weight of cementitious materials gave the higher compressive strength through all ages [9]. Abbas studied the effect of nano-silica addition on properties of normal and ultra-high performance concretes and found that nano-silica concrete requires additional amount of water to maintain the same workability. It was observed through the study that each kilogram of NS added to concrete required 0.4 kilogram of water [10].Amin and abu el-hassan carried out investigation to evaluate the effect of using different types of nano materials on mechanical properties of high strength concrete. They added nano materials (nano silica, Cu-Zn ferrite and Ni ferrite) in five percentages (1%, 2%, 3% ,4%and 5%) of weight of cementitious materials. Results indicated that the optimum dose of nano-silica was 3% by weight and the optimum dose of Cu-Zn ferrite and Ni ferrite was 2% by weight. also, the improving percentage of compressive strength of concrete when NS and nano ferrite was added reaches 21% and 17%, respectively, copared with the control mixes [11]. Ji investigated the water permeability of concrete containing NS and concluded that the microstructures of the nano-silica concrete is more uniform and denser than that of reference concrete[12].
The aim of this study the effect of nano-silica addition on the fresh and hardened properties of ultra high strength concrete. Also, water permeability of concrete incorporating nano silica was investigated. In addition, microstructures and nanostructures of control and nano-silica concrete specimens have been evaluated using scanning electron microscopy (SEM).

## MATERIALS

Ordinary Portland Cement (OPC) type CEM I 52.5 N, produced by El Arish Company was used through this research. Cement tests were carried out as per Egyptian Standard ES 2421/2009.The physical and mechanical properties of the used cement are given in Table 1. The chemical composition of cement used is shown in Table 2. The used silica fume was brought from Sika Company in Egypt. The chemical composition and physical properties of used is shown in Tables 2and 3, respectively, as obtained from the manufacture data sheet. The used nano silica (Silicon Dioxide, 99.8 %) was brought from National Research Center 33 Ad Doqi, Giza. Table 4 shows the physical properties of nano-silica used in this investigation. Figure 1 shows the TEM micrograph of nano-silica. The coarse aggregate used in the experimental work is a crushed dolomite from Ataka Mountain in Suez City with size 4/10 mm. Testing of coarse aggregate was carried out according to Egyptian Standard ES 1109/2008. Table 5 shows the physical properties of the used coarse aggregate. The used fine aggregate was natural siliceous sand. Testing of sand was carried out according to Egyptian Standard ES 1109/2008. Table 6 shows the physical properties of the used sand. A high range water reducer (superplasticizer) of modified polycarboxylates (Viscocrete–3425) was used in this study. The used dosage of superplasticizer was constant in all mixes equals 3.5% of the weight of binder content in each mixes with specific weight of 1.15 and density from 1100 to 1200 kg/m$^3$.

***Table 1 Physical and mechanical properties of used cement CEM I 52.5N***

| Propertiy | Specific surface area (cm$^2$/gm) | Setting Time (min) | | Compressive strength (MPa) | |
|---|---|---|---|---|---|
| | | Initial | Final | 2 days | 28 days |
| Test result | 3750 | 85 | 210 | 22 | 55.8 |
| Limits* | Not less than 2750 | Not less than 45 | - | Not less than | Not less than 52.5 |

*The limits are according to Egyptian Standard ES 4756-1/2013.

***Table 2 Chemical composition of the used cement(OPC) and silica fume(SF)***

| Binder | Oxide | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $Na_2O$ | $K_2O$ | MgO | $SO_3$ |
|---|---|---|---|---|---|---|---|---|---|
| OPC | Content (%) | 22.12 | 5.56 | 3.69 | 62.87 | 0.26 | 0.11 | 2.36 | 0.91 |
| SF | Content (%) | 96 | 0.92 | 1.2 | 1.1 | 0.4 | 0.8 | 0.18 | 0.2 |

***Table 3 Physical Properties of the silica fume****

| Property | Specific surface area (cm$^2$/gm) | Particle size (μm) | Specific gravity | Bulk density (kg/m$^3$) | Color |
|---|---|---|---|---|---|
| Test results | 178,000 | 7.00 | 2.15 | 345 | Light gray |

* By the manufacture data sheet.

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***Table 4. Properties of nano-silica***

| Properties | Particle size (nm) | Surface area ($m^2/gm$) | Density ($kg/m^3$) | Purity (%) | Colour |
|---|---|---|---|---|---|
| Results | 5 to 20 | 160 | 155 | 99.8 | white |

***Table 5. Physical properties of crushed dolomite aggregate used***

| Test | Physical properties of used crushed dolomite aggregate | | | | | |
|---|---|---|---|---|---|---|
| | Specific weight | Bulk Density ($t/m^3$) | Clay and fine dust content % | Coefficient of Impact % | Crushing value % | Absorption % |
| Crushed dolomite | 2.65 | 1.65 | 0.8 | 12.5 | 22.0 | 1.6 |
| Limits* | - | - | Not Less than 3 | Not Less than 30 | Not Less than 30 | Not Less than 2.5 |

* The limits are according to Egyptian Standared ES 1109/2008

***Table 6. Physical properties of used sand***

| Tests | Used sand physical properties | | |
|---|---|---|---|
| | Specific weight | Bulk density ($t/m^3$) | Fineness modulus |
| Sand | 2.55 | 1.70 | 2.95 |

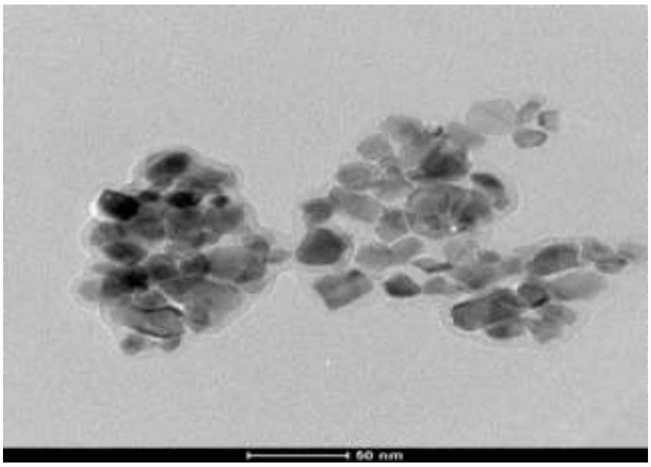

***Figure 1. TEM micrograph of nano-silica.***

## EXPERIMENTAL PROGRAM

To achieve the objectives of this investigation, twenty seven concrete mixes were designed to study the effect of nano-silica on the fresh and hardened properties of ultra- high strength concrete as shown in Table. 2. Nano-silica was added in seven percentages (0.5%, 1.0%, 1.5%, 2%, 2.5%, 3% and 3.5%) of weight of binder content.. Three binders content 450, 550, 650 kg/m$^3$ were chosen in this study. The total percentage of silica fume and nano-silica was 20% of weight of binder content. The percentage of coarse to fine aggregate was 3:2.

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***Table 7. Mixture proportions***.

| Group | Mix No. | Binder content kg/m³ | Cement content ( % ) | SF ( % ) | NS ( % ) | Aggregate | | W/b (%) | SP (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Dolomite (%) | Sand (%) | | |
| I | M1 | 450 | 100 | 0 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M2 | | 80 | 20 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M3 | | 80 | 19.5 | 0.5 | 60 | 40 | 0.23 | 3.5 |
| | M4 | | 80 | 19 | 1.0 | 60 | 40 | 0.23 | 3.5 |
| | M5 | | 80 | 18.8 | 1.5 | 60 | 40 | 0.23 | 3.5 |
| | M6 | | 80 | 18 | 2.0 | 60 | 40 | 0.23 | 3.5 |
| | M7 | | 80 | 17.5 | 2.5 | 60 | 40 | 0.23 | 3.5 |
| | M8 | | 80 | 17 | 3.0 | 60 | 40 | 0.23 | 3.5 |
| | M9 | | 80 | 16.5 | 3.5 | 60 | 40 | 0.23 | 3.5 |
| II | M10 | 550 | 100 | 0 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M11 | | 80 | 20 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M12 | | 80 | 19.5 | 0.5 | 60 | 40 | 0.23 | 3.5 |
| | M13 | | 80 | 19 | 1.0 | 60 | 40 | 0.23 | 3.5 |
| | M14 | | 80 | 18.8 | 1.5 | 60 | 40 | 0.23 | 3.5 |
| | M15 | | 80 | 18 | 2.0 | 60 | 40 | 0.23 | 3.5 |
| | M16 | | 80 | 17.5 | 2.5 | 60 | 40 | 0.23 | 3.5 |
| | M17 | | 80 | 17 | 3.0 | 60 | 40 | 0.23 | 3.5 |
| | M18 | | 80 | 16.5 | 3.5 | 60 | 40 | 0.23 | 3.5 |
| III | M19 | 650 | 100 | 0 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M20 | | 80 | 20 | 0 | 60 | 40 | 0.23 | 3.5 |
| | M21 | | 80 | 19.5 | 0.5 | 60 | 40 | 0.23 | 3.5 |
| | M22 | | 80 | 19 | 1.0 | 60 | 40 | 0.23 | 3.5 |
| | M23 | | 80 | 18.8 | 1.5 | 60 | 40 | 0.23 | 3.5 |
| | M24 | | 80 | 18 | 2.0 | 60 | 40 | 0.23 | 3.5 |
| | M25 | | 80 | 17.5 | 2.5 | 60 | 40 | 0.23 | 3.5 |
| | M26 | | 80 | 17 | 3.0 | 60 | 40 | 0.23 | 3.5 |
| | M27 | | 80 | 16.5 | 3.5 | 60 | 40 | 0.23 | 3.5 |

Binder content: Cement + silica fume + nano silica, SF: Silica fume, NS: Nano silica content as a replacement of silica fume, W/b: Water to binder ratio, , SP: High range water reducer (Viscocrete)

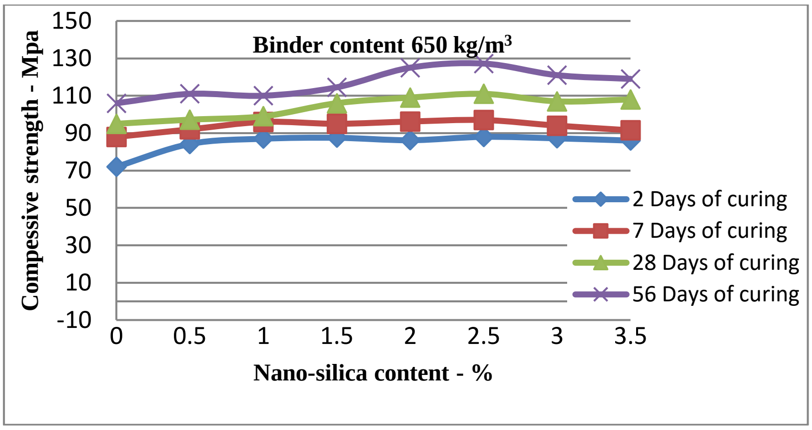


***Figure 2. Effect of nano –silica content on compressive strength of concrete mixes (20 to 27) at different ages***.

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***Mixing procedure***

concrete casting sequence started with mixing coarse aggregate and fine aggregate with cement and silica-fume in a rotary mixer for one minute until they homogenized. Then, the total amount of water containing superplasticizer and nano-silica was mixed by using sonicator for 15 minutes. later, the mixed nano-silica was added to the dry mix and the concrete were and mixing for two minutes.

***Test and specimens***

To determine the fresh and mechanical properties of different mixes, the following tests and specimens were used as follow:

- Slump, compacting factor and Ve-Be time tests of fresh concrete.
- Compression test at 2, 7, 28, 56 days was carried out on 100 mm cubes.
- Splitting test at 56 days was carried out on 150 x 300 mm cylinders.
- Flexure strength at 56 days was carried out on 100 x 100 x 500 mm beams.
- Static modulus of elasticity at 56 days was carried out on 150 x 300 cylinders.
- Water permeability test at 56 days was carried out on 150 x 150 mm cylinders.
- Scanning electron microscopy (SEM) at 56 days was carried out on slides of concrete cubes.

All the test specimens were demolded after 24 hours and then submerged in water tank until the required testing date.

## RESULTS AND DISCUSSION

***1- Fresh concrete properties***

The results of workability tests: slump, compating factor, and Ve-Be time are given in Table 3.

***Table. 8: Fresh properties of concrete mixes***

| Group | Mix No. | Binder content kg/m$^3$ | Cement content ( % ) | SF ( % ) | NS ( % ) | Slump (mm) | Compacting Factor | Ve-Be (sec) |
|---|---|---|---|---|---|---|---|---|
| I | M1 | 450 | 100 | 0 | 0 | 14 | 0.956 | 4.9 |
| | M2 | | 80 | 20 | 0 | 13.5 | 0.95 | 5.1 |
| | M3 | | 80 | 19.5 | 0.5 | 13.5 | 0.948 | 5.5 |
| | M4 | | 80 | 19 | 1.0 | 13 | 0.944 | 5.8 |
| | M5 | | 80 | 18.8 | 1.5 | 12.5 | 0.942 | 5.8 |
| | M6 | | 80 | 18 | 2.0 | 11.5 | 0.935 | 6.0 |
| | M7 | | 80 | 17.5 | 2.5 | 11.5 | 0.93 | 6.1 |
| | M8 | | 80 | 17 | 3.0 | 11 | 0.93 | 6.2 |
| | M9 | | 80 | 16.5 | 3.5 | 9.5 | 0.92 | 6.5 |
| II | M10 | 550 | 100 | 0 | 0 | 18.5 | 0.99 | 3.7 |
| | M11 | | 80 | 20 | 0 | 18 | 0.985 | 3.85 |
| | M12 | | 80 | 19.5 | 0.5 | 17.5 | 0.985 | 4 |
| | M13 | | 80 | 19 | 1.0 | 17.5 | 0.978 | 3.95 |
| | M14 | | 80 | 18.8 | 1.5 | 16 | 0.974 | 4.4 |
| | M15 | | 80 | 18 | 2.0 | 16 | 0.974 | 5.0 |
| | M16 | | 80 | 17.5 | 2.5 | 14 | 0.965 | 5.0 |
| | M17 | | 80 | 17 | 3.0 | 13.5 | 0.945 | 6.0 |
| | M18 | | 80 | 16.5 | 3.5 | 13.0 | 0.94 | 6.1 |
| III | M19 | | 100 | 0 | 0 | 21 | 1.0 | - |
| | M20 | | 80 | 20 | 0 | 18.5 | 1.0 | - |
| | M21 | | 80 | 19.5 | 0.5 | 18.5 | 1.0 | - |
| | M22 | | 80 | 19 | 1.0 | 18 | 0.994 | - |
| | M23 | | 80 | 18.8 | 1.5 | 18 | 0.992 | - |
| | M24 | | 80 | 18 | 2.0 | 17 | 0.983 | - |
| | M25 | | 80 | 17.5 | 2.5 | 15.5 | 0.975 | - |
| | M26 | | 80 | 17 | 3.0 | 15.0 | 0.975 | - |

ISSN: 2277-9655
Impact Factor: 4.116
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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M27 | 650 | 80 | 16.5 | 3.5 | 14.0 | 0.97 | - |

***Slump test***
Figure 1 illustrates the effect of cement content and nano-silica content on concrete slump of the similar mixes. The figure shows that the increasing of cement content lead to increasing in slump of concrete mixes. Similar to SF , the concrete slump was reduced considerably as the percentage of cement replaced by NS increased.

***Compacting factor test***
Figure 2 illustrates the effect of cement content and nano-silica content on concrete compacting factor of the similar mixes. The figure shows that the increasing of cement content caused increasing in compacting factor of concrete mixes, and the increase of nano-silica content cause decreasing in compacting factor of concrete mixes.
*Ve-Be time test*
Figure 3 shows the effect of cement content and nano-silica content on Ve- Be time of the similar mixes. The figure shows that the increasing of binder content leads to decreasing in Ve-Be time of concrete mixes and the increase of nano-silica content causes increasing in Ve-Be time of concrete mixes.

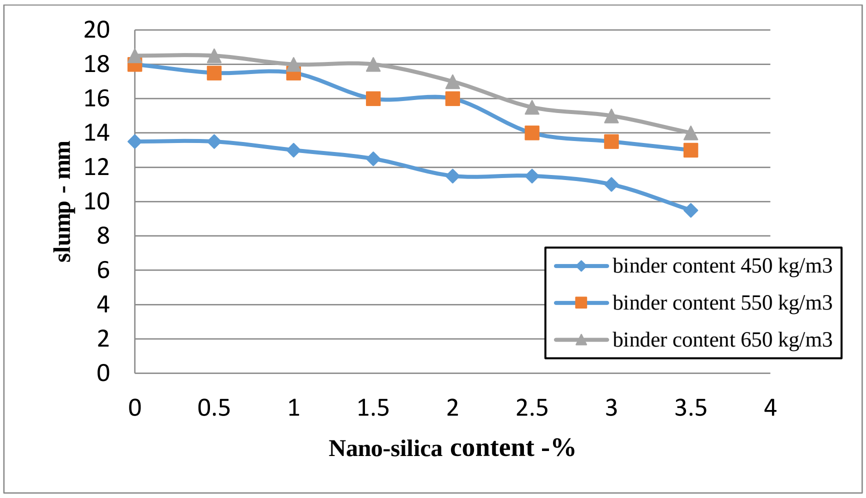


***Figure 3. Effect of cement content and nano –silica content on slump of concrete mixes.***

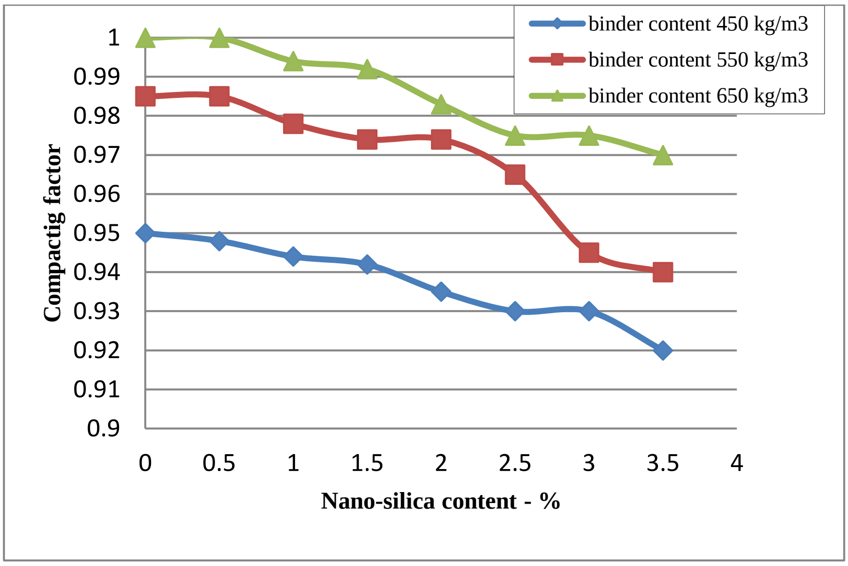


***Figure 4. Effect of cement content and nano –silica content on compacting factor of concrete mixes.***

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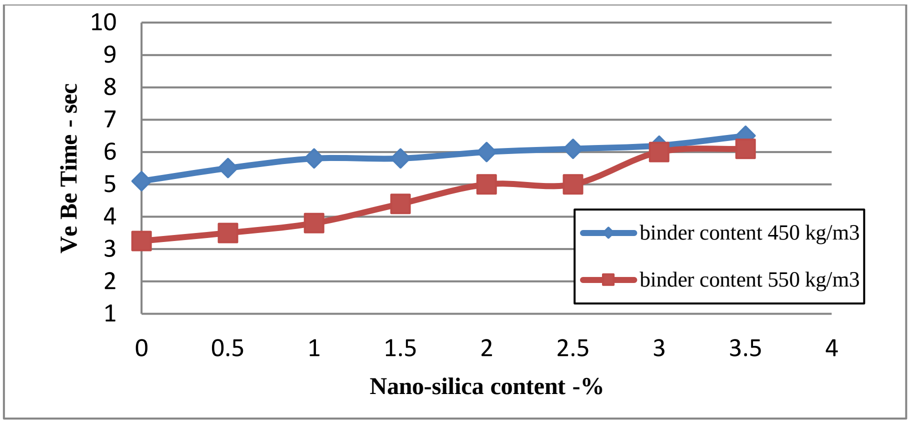


***Figure 5. Effect of cement content and nano-silica content on Ve-Be time of concrete mixes.***

**2- Hardened Concrete Properties**

***Compressive strength***

The compressive strength all concrete mixes at ages of 2, 7, 28 and 56 days of water curing are given in Table 9. The value shown in Table 9 is the average of the result of testing three standard cubes (100 mm). It could be seen that the compressive strength for mix M1 with cement content 450 kg/m$^3$ and M10 with cement content 550 kg/m$^3$ at early ages (2 days) were too close in value, while that of M19 with 650 kg/m$^3$ was increased by 27% more than M1. At 56 days the compressive strength of the mixes M10 and M19 were higher than M1 by 14% and 18%, respectively. The results shows a general trend for strength increases with increasing cement content at all ages. The results shows that the compressive strength increases by adding nano-silica up to 2.5% replacement (M7 , M16 and M25) and then it decreases. The improving percentage of compressive strength reaches about 19% and 25% for cement content 450, 550 kg/m$^3$ and 650 kg/m$^3$, respectively with respect to the control mixes. Figure 2 shows the effect of using nano-silica in the compressive strength with binder content 650 kg/m$^3$. The optimum percentage of nano-silica was 2.5% at all ages of curing as shown in Figure 2. the increase in compressive strength can be due to that fact that CH existing in lime solution react with nano-silica to form additional CSH gel (pozzolanic effect) thereby increasing compressive strength. Also, nano silica particles improve the particle packing density of the cement paste (filling effect). A slight reduction in compressive strength by adding more than 2.5% may be due to the quantity of nano-silica is higher than the amount required to combine with the liberated lime during the process of hydration thus leading to excess silica leaching out and causing a reduction in strength as it replace a part of the cementitious material but does contribute to strength [14]. This results are well corporate to Amin and Abu el-hassan [11] and Nazari [14], but with a different optimum percentage of NS 3% and NS 4%, respectively, which increase compressive strength by 21% and 75%, respectivly.

***Splitting Tensile Strength and Flexural Strength***

The tensile strength is important characteristic for the development of cracking and hence for the prediction of durability concrete. Table 10 shows the splitting tensile strength and the flexural strength of twenty seven concrete mixes at age 56 days. Similar to the compressive strength, the splitting tensile strength and the flexural strength of all nano -silica concrete samples is more than control concrete. In addition, the splitting tensile strength and the flexural strength of all nano -silica concrete samples is increased by adding nano-silica up to 2.5% by weight of binder materials and then it is decreased, although the results of 3.5% replacement are still higher than those of control concrete. Table 10 shows the splitting tensile strength of the different concrete mixes which has improved due to the addition of NS in particular mixtures of M7 , M16 and M25 respectively, show an increase of splitting tensile strength of 41%, 49% and 56%. The higher the splitting tensile strength in nano-silica concrete are due to the rapid consuming of CH which was formed during hydration of portland cement specially at early ages related to high reactivity of nano-silica.

ISSN: 2277-9655
Impact Factor: 4.116
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Flexural strength results are shown in Table 10. Similar to the Splitting tensile strength, the flexural strength of the specimens increases with addition nano-scilica up to 2.5% replacement and then it decreases. Again, The increasing of flexural strength is due to formation of CSH gel from the pozzolanic action for nanopowder with CH which liberated from the hydration process related to the high reactivity of nano-scilica. The improving percentage of flexural strength reaches about 27% (M7) , 37% (M16) and 44 % (M25) for cement content 450, 550 and 650 kg/m$^3$, respectively with respect to the control mixes.

***Modulus of Elasticity***

Table 10 shows the static modulus of elasticity results of group (I) and (II) mixes at age of 56 days. The modulus of elasticity results of nano-silica concrete increases by adding nano-silica up to 2.5% replacment and then it decreases. It means that concrete with nano-scilica particles has greater Stiffness than control concrete without nano particles. The value of stiffness in concrete containing nano-silica are due to the coompactness of the paste bond with aggregates in concrete with nano paticals is greater than that without nano particles[15]. Stres-strain relationship for mix (M7) and (M17) are plotted in Figures 6 and 7. With the addition of nano-silica the improving percentage of modulus of elasticity reaches approximate rate of about 33% (M7) and 30% (M16) for cement content 450 and 550 kg/m$^3$, respectively with respect to the control mixes.

***Table 9. Compressive strength of all mixes.***

| Group | Mix No. | Binder content kg/m$^3$ | Cement content ( % ) | SF ( % ) | NS ( % ) | Aggregate | | Compressive strength MPa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Dolomite ( % ) | Sand ( % ) | 2d | 7d | 28d | 56d |
| **I** | M1 | 450 | 100 | 0 | 0 | 60 | 40 | 60 | 78 | 82 | 87 |
| | M2 | | 80 | 20 | 0 | 60 | 40 | 63 | 81.5 | 85 | 89 |
| | M3 | | 80 | 19.5 | 0.5 | 60 | 40 | 64 | 83 | 93 | 94 |
| | M4 | | 80 | 19 | 1.0 | 60 | 40 | 66 | 85 | 91 | 97 |
| | M5 | | 80 | 18.8 | 1.5 | 60 | 40 | 66 | 85 | 92 | 96 |
| | M6 | | 80 | 18 | 2.0 | 60 | 40 | 67 | 87 | 92.5 | 97.5 |
| | M7 | | 80 | 17.5 | 2.5 | 60 | 40 | 68 | 89 | 94.5 | 102.5 |
| | M8 | | 80 | 17 | 3.0 | 60 | 40 | 66.5 | 87 | 92 | 98 |
| | M9 | | 80 | 16.5 | 3.5 | 60 | 40 | 63 | 85 | 90 | 97 |
| **II** | M10 | 550 | 100 | 0 | 0 | 60 | 40 | 64 | 79 | 90 | 98.5 |
| | M11 | | 80 | 20 | 0 | 60 | 40 | 66 | 84 | 94 | 102.5 |
| | M12 | | 80 | 19.5 | 0.5 | 60 | 40 | 67 | 84 | 95 | 100 |
| | M13 | | 80 | 19 | 1.0 | 60 | 40 | 69 | 86.5 | 96.5 | 104 |
| | M14 | | 80 | 18.8 | 1.5 | 60 | 40 | 70 | 91.5 | 95 | 104.5 |
| | M15 | | 80 | 18 | 2.0 | 60 | 40 | 71 | 94.5 | 99 | 107 |
| | M16 | | 80 | 17.5 | 2.5 | 60 | 40 | 74 | 96 | 105 | 117 |
| | M17 | | 80 | 17 | 3.0 | 60 | 40 | 72 | 95 | 103 | 113 |
| | M18 | | 80 | 16.5 | 3.5 | 60 | 40 | 72 | 93 | 101 | 108 |
| **III** | M19 | 650 | 100 | 0 | 0 | 60 | 40 | 76 | 89.5 | 93.5 | 102.5 |
| | M20 | | 80 | 20 | 0 | 60 | 40 | 80 | 88 | 95 | 106 |
| | M21 | | 80 | 19.5 | 0.5 | 60 | 40 | 84 | 92 | 97.5 | 111 |
| | M22 | | 80 | 19 | 1.0 | 60 | 40 | 87 | 96 | 99 | 110 |
| | M23 | | 80 | 18.8 | 1.5 | 60 | 40 | 88 | 95 | 106 | 114.5 |
| | M24 | | 80 | 18 | 2.0 | 60 | 40 | 89 | 96.5 | 109 | 125 |
| | M25 | | 80 | 17.5 | 2.5 | 60 | 40 | 92 | 97 | 111 | 127.5 |
| | M26 | | 80 | 17 | 3.0 | 60 | 40 | 88 | 94 | 107 | 121 |
| | M27 | | 80 | 16.5 | 3.5 | 60 | 40 | 86 | 91.5 | 108 | 119 |

ISSN: 2277-9655
Impact Factor: 4.116
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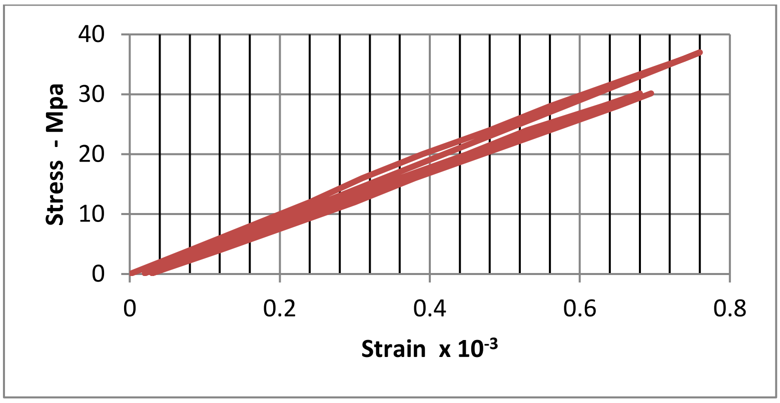


*Figure 6. . Stress- strain of concrete at age 56 days for mix (M7).*

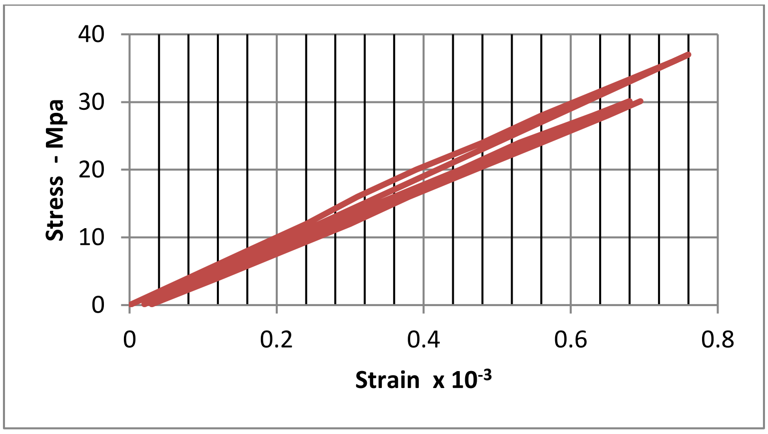


*Figure 7. Stress- strain of concrete at age 56 days for mix (M17).*

***Permeability***

Permeability tests were carried out at the age of 56 days on samples of mixes (M20, M24, and M25) to determine the effect of using 2.5% and 3% nano-silica on the coefficient of permeability of concrete. The coefficient of permeability decreased from 2.53 x $10^{-10}$ for mix ( M20) to 1.64 x $10^{-10}$ for mix (M24), and 1.49 x $10^{-10}$ for mix (M25). So, using nano-silica improve the resistance to water permeability of concrete, due to the microstructure of the nano-silica concrete is more uniform and denser than concrete without nano-silica this results agree with **Shebl et al**.[16]. Nano-silica act as nano filler and improve resistance to water permeability.

***Microstructure and nanostructure characterization***

Scanning electron microscopy was carried out on mixes with and without nano-silica to study the microstructure and nanostructure of the control and ultra-high strength nano- silica concrete. Figure 8 shows SEM micrograph of control sample without SF and NS (M10). It can be seen that the sample have many and microcracks in cement paste, cement particles agglomeration and more CH. Figure 9 shows SEM micrograph of concrete sample with SF and without NS (M11). It can be seen that the sample have dense mixture, less pores and more CSH. Figure 10 shows a more dense and compact mixture (sample M16 with17.5% SF and 2.5% NS). This is due to more formation of CSH gel in presence of nano silica particles and reduction in CH crystals. The nano-silica among the hydrate products prevent CH crystals from growing [17]. In addition, Nano-silica can absorb the CH crystals, and reduce the size and amount of the CH crystals, thus making the interfacial transition zone (ITZ) of aggregates and paste matrix denser. The nano-silica particles can fill pores to increase strength as silica fume does. of the C-S-H gel structure, making binder paste matrix more denser.

From all microstructure it can be seen that M16 which had 2.5% nano-silica act as an active pozolanic material which absorb CH that produced from hydration process to produce additional C-S-H that makes the bond in matrix more strong so improve the mechanical properties as shown Figure 10. SEM study proved that the Nano-silica filled the pores and decreased the content of CH within the hydration products. These effects resulted in the improvement of the mechanical properties of concrete with nanoparticles.

***Table 10. Splitting tensile strength, Flexural strength and Static modulus of elasticity of concrete specimens.***

| Group | Mix No. | Binder content kg/m$^3$ | Cement content ( % ) | SF (%) | NS (%) | Splitting tensile strength (MPa) At age 56 days | Flexural strength (MPa) At age 56 days | Modulus of elasticity (GPa) |
|---|---|---|---|---|---|---|---|---|
| **I** | M1 | 450 | 100 | 0 | 0 | 6.1 | 12.5 | 33.8 |
| | M2 | | 80 | 20 | 0 | 7.1 | 15.7 | 35.1 |
| | M3 | | 80 | 19.5 | 0.5 | 8 | 16.7 | 38 |
| | M4 | | 80 | 19 | 1.0 | 8.5 | 17.1 | 40 |
| | M5 | | 80 | 18.8 | 1.5 | 8.5 | 18.3 | 42 |
| | M6 | | 80 | 18 | 2.0 | 9 | 18.8 | 44 |
| | M7 | | 80 | 17.5 | 2.5 | 10 | 19.8 | 46.7 |
| | M8 | | 80 | 17 | 3.0 | 8.9 | 17 | 44 |
| | M9 | | 80 | 16.5 | 3.5 | 8.6 | 16 | 41 |
| **II** | M10 | 550 | 100 | 0 | 0 | 7.6 | 12.9 | 38.6 |
| | M11 | | 80 | 20 | 0 | 8.1 | 16.1 | 40 |
| | M12 | | 80 | 19.5 | 0.5 | 9.1 | 18.5 | 42 |
| | M13 | | 80 | 19 | 1.0 | 9.5 | 19.1 | 46 |
| | M14 | | 80 | 18.8 | 1.5 | 10 | 20.3 | 48 |
| | M15 | | 80 | 18 | 2.0 | 11 | 21.8 | 50 |
| | M16 | | 80 | 17.5 | 2.5 | 12 | 22 | 52 |
| | M17 | | 80 | 17 | 3.0 | 11 | 20.5 | 49.5 |
| | M18 | | 80 | 16.5 | 3.5 | 10.5 | 19 | 45 |
| **III** | M19 | 650 | 100 | 0 | 0 | 8.02 | 14.6 | - |
| | M20 | | 80 | 20 | 0 | 9.0 | 17.7 | - |
| | M21 | | 80 | 19.5 | 0.5 | 9.8 | 17.8 | - |
| | M22 | | 80 | 19 | 1.0 | 10.5 | 19.3 | - |
| | M23 | | 80 | 18.8 | 1.5 | 12 | 20.2 | - |
| | M24 | | 80 | 18 | 2.0 | 12.5 | 21 | - |
| | M25 | | 80 | 17.5 | 2.5 | 14 | 24 | - |
| | M26 | | 80 | 17 | 3.0 | 13 | 22 | - |
| | M27 | | 80 | 16.5 | 3.5 | 12 | 21 | - |

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

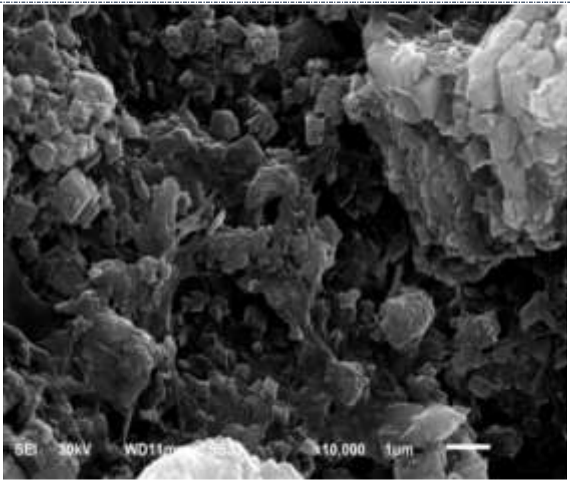

*Figure 8. SEM micrograph of mix M10 after 56 day of curing.*

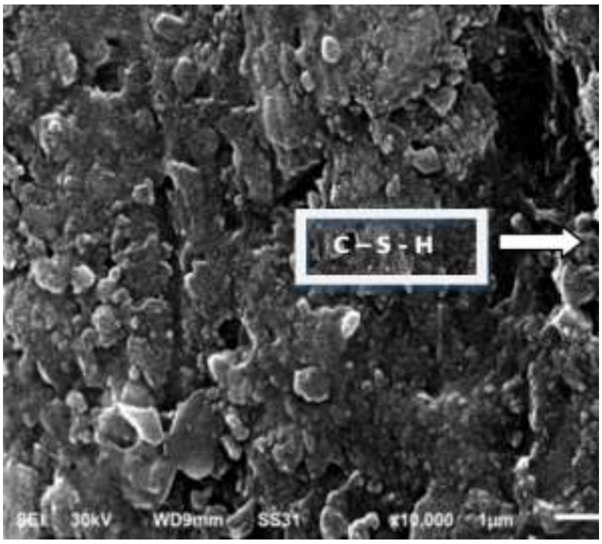


*Figure 9. SEM micrograph of mix M11 after 56 days*

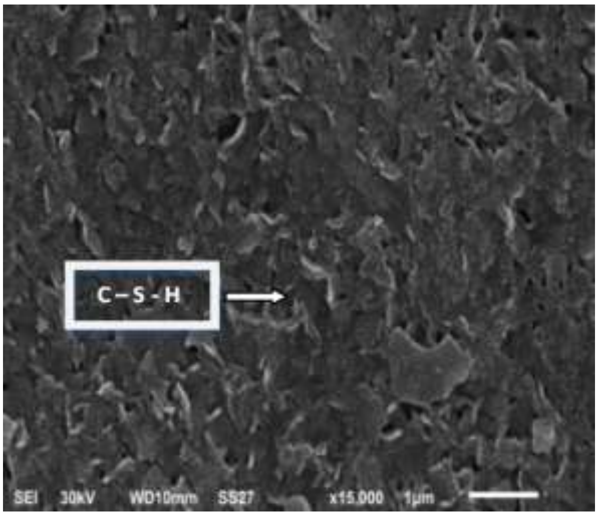


*Figure 10. SEM micrograph of mix M16 after 56 days*

## CONCLUSION

The results and conclusions are summarized as follows:

1. As the percentage of nano-silica is increased up to 2.5% by weight, the compressive strength, the splitting tensile strength, the flexural strength and modulus of Elasticity of Ultra high strength concrete specimens is increased. This is due to formation of an additional C-S-H in presence of nano-silica particles(pozzolanic effect).
2. Increasing the amount of nano-silica more than 2.5% by weight (optimum dose in this study) degrades the mechanical properties.
3. The workability of concrete decreases with the increase in nano-silica content. The use of high range water reducer was necessary in concrete mixes to improve the workability.
4. Nano-silica particles could as nanofiller and fill the voids between cement grains (filling effect) and improve the resistance to water permeability of concrete.
5. The improving percentage of compressive strength of concrete with nano-silica reaches about 19% (for cement content 450 and 550 kg/m$^3$) and 25% (for cement content 650 kg/m$^3$) with respect to the control mixes.
6. With the addition of nano-silica the improving percentage of splitting tensile strength reaches about 41% (M7) , 49% (M16) and 56 % (M25) for cement content 450, 550 and 650 kg/m$^3$, respectively with respect to the control mixes.
7. With the addition of nano-silica the improving percentage of flexural strength reaches about 27% (M7) , 37% (M16) and 44 % (M25) for cement content 450, 550 and 650 kg/m$^3$, respectively with respect to the control mixes.
8. With the addition of nano-silica the improving percentage of modulus of elasticity reaches approximate rate of about 33% (M7) and 30% (M16) for cement content 450 and 550 kg/m$^3$, respectively, with respect to the control mixes. The nano-silica concrete has greater stiffness than concrete without nano-silica.

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## CITE AN ARTICLE

**Tahwia, A. M., Elshikh, M. Y., & Elmetwaly, W. (2017). PROPERTIES OF ULTRA HIGH STRENGTH CONCRETE INCORPORATING NANO-SILICA . *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *6*(5), 678-690. doi:10.5281/zenodo.800599**