How Nano-Silica addition can change Ultra High Strength Properties

Mohamed Y.Elshikh[1] , Ahmed M.Tahwia[2] , Walid Elmetwaly[3]

Abstract - The present paper intends to investigate How Nano-Silica addition can change Ultra High Strength Properties. The emergence of nanotechnology in concrete industry has made great changes in many of the concrete properties. nano-silica with 99.8% Sio_2 content and average particles size 12 nm used in concrete mixes as a replacement of silica fume content, the percent of silica fume and nano-silica together was 20% of total binder content. To produce ultra high strength concrete, the water to binder ratio used in all mixes was (0.23%) with high range water reducer was used by percent 3.5%.The constructed concrete samples with (0.5%, 1.5%, 2.5%, 3.0%) nano-silica content and two different binder content 550, and 650 kg/m^3 were experimented. compression test, indirect tensile strength test, and flexural strength test were carried out in this investigation. Also to compare microstructure of concrete with and without nano-silica, scanning electron microscopy was carried out. The compressive strength of block samples of 10x10x10 cm^3 were evaluated in duration 7, 28 and 56 days. the tensile strength of cylinder samples 15cm diameter and 30 cm length were tested after 56 days. The flexural strength test was carried out on 10 x 10 x 50 cm^3 beams. the result of compressive strength experiment showed that Using 2.5% nano-silica with 17.5% silica fume increase the compressive strength by percent 12.9%, and 20% for 550, and 650 kg/m^3 binder content respectively at age 56 days. the indirect tensile strength and flexural strength increase with increase in nano-silica content.

Keywords: Nanotechnology, Nano-Silica, Ultra High Strength Concrete, Silica Fume, Binder Content.

1. Introduction

In the past several years, improvements have been occurring in concrete technology. Sustainable use of supplementary materials and progress developments in superplasticizer admixtures have facilitated improvements in the mechanical properties and durability of concrete [1]. Ultra high strength concrete (UHSC) is characterized by extraordinary mechanical properties (high compressive and tensile strength, large E-modulus) and has excellent durability properties regarding corrosion of concrete and reinforcement (Low permeability against liguids and gases. Ultra high strength concretes (UHSC) have an ultra-dense micro-structure, giving advantageous waterproofing and durability characteristics. UHSC is generally characterized by its high silica fume content, very high cement content and very low water to binder ratio.

In contrast to other technologies, nano-technology is much less well-defined and well-structured. Nano, which comes from the Greek word for little, indicates a billionth. One nanometer is a billionth of a meter, that is, about 1/80,000 of the diameter of a human hair. Nanotechnology can best be considered as a catch all description of activities (any application of science and technology) at the nanometer scale that have applications in the real world. Definition of nanotechnology varies but it generally refers to understanding and manipulation of issue on the nanoscale, say, from 0.1 nm to 100 nm [2, 3].

Nanotechnology is one of the most active research areas, the meaning of ‘‘nanotechnology’’ varies from field to field and country to country and is widely used as a ‘‘catch all’’ description for anything very small, nanotechnology is commonly defined as the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions. Nano sized particles have a high surface area to volume ratio, Fig.1, providing the potential for tremendous chemical reactivity [4].

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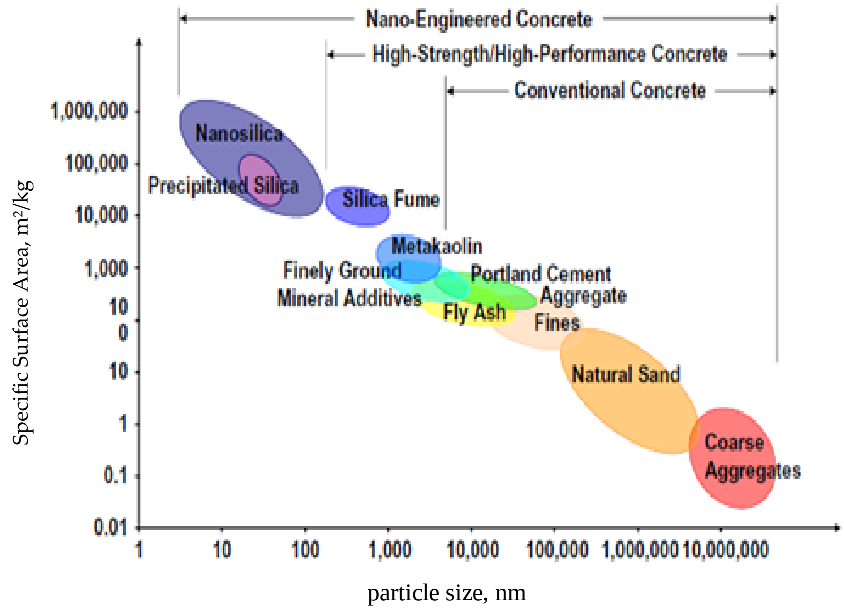

Fig.1. Particle size and specific surface area related to concrete materials.

Nano silica is the most abundant material that makes the earth. It has the chemical composition of Si02 which is similar to a diamond structure. It is a white and crystal-formed material. Nano silica is one of the most applied nanoparticles in concrete. It is a new pozzolanic material which is in water in a solid or liquid form. In the concrete industry, nano-silica is one of the most famous materials that determine viscosity and filling state of the concrete. nano silica is made up of bullet-formed particles with diameter less than 100 nanometer, or dry powder particles, or particles which could be dispersed in the liquid. The researchers pay attention to nano silica as one of the products of nanotechnology that plays an important role as a very active pozzolan in the concrete. Adding nano particles of concrete could maintain its strength during physical and chemical reactions and also compress the particles.

At present, a significant number of works dealing with the use of nano-silica in cement-paste, mortar, and concrete is available in the literature. The addition of nano-silica to OPC pastes always reduced the mix workability, [5]. So nano-silica concrete requires addition amount of superplasticizer to maintain the same workability level [6]. Compressive and tensile strength of the concrete increases with adding the nano-silica [7].

2. Experimental Procedure

2.1 Properties of Materials

Commercially available ordinary Portland cement (CEM I 52.5 N) confirming to the egyptian standard specification (ES 4756-1/2007) was used through this research. The silica fume used was a very fine by-product powder obtained sika company in Egypt having a specific gravity of 2.15. The used nano silica (sio2, 99.8 %) was brought from National research center 33 Al- Behous, Ad Doqi, Giza Governorate. Table. 1 show the properties of nano-silica used in this investigation. (Photo. 1) show the TEM micrograph of nano-silica.The coarse aggregate used in the experimental work is a crushed dolomite from Ataka in suez city with size 4/10 mm confirming to the egyptian standard specification (ES 1109-1/2008). The used fine aggregate was natural siliceous sand has a fineness modulus of 2.95. a superplasticizer admixture (viscocrete – 3425) was used, 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, density from 1100 to 1200 kg/m3.

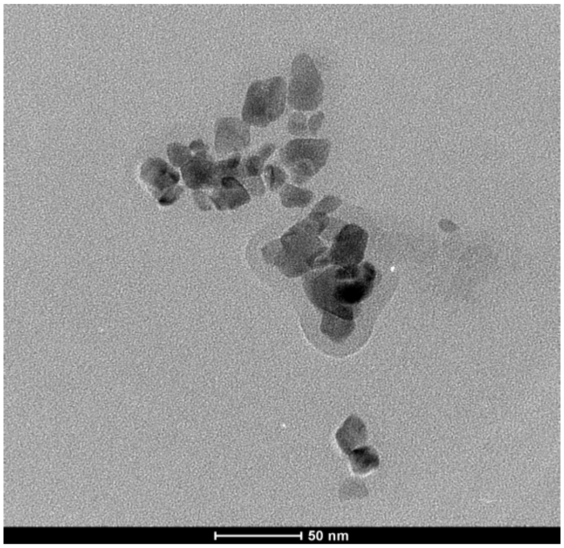

Photo. 1: TEM micrograph of nano-silica.

Table.1: Properties of Nano-Silica

Properties	Result
Particle size (nm)	12
Surface area (m^2/gm)	160
Density (kg/m^3)	155
Purity (%)	99.8

2.2 Experimental Program

To achieve the objectives of this investigation eighteen concrete mixes were designed to study the effect of nano-silica on the strength of ultra-high strength concrete as shown in Table. 2. So, a high-range water reducer with a high dosage was used to reduce the water to binder ratio without reducing the workability of fresh concrete. The nano-silica was used as addition by percentages 0.5%, 1.5%, 2.5%, and 3% of binder contents. Two binder content 550, 650 kg/m3 were chosen in this study. also silica fume was used with percent up to 20% of binder content. The percent of coarse to fine aggregate was 3:2.

Table. 2: Mixture Proportions.

Group	Mix No.	Binder content kg/m3	Cement content (%)	S.F. (%)	N.S. (%)	Aggregate(100%) (dolomite%)+(sand%)		W/b (%)	S.P (%)
						Dolomite (%)	Sand (%)		
I	1	550	100	0	0	60	40	0.23	3.5
	2		80	20	0	60	40	0.23	3.5
	3		80	19.5	0.5	60	40	0.23	3.5
	4		80	18.5	1.5	60	40	0.23	3.5
	5		80	17.5	2.5	60	40	0.23	3.5
	6		80	17	3.0	60	40	0.23	3.5
II	7	650	100	0	0	60	40	0.23	3.5
	8		80	20	0	60	40	0.23	3.5
	9		80	19.5	0.5	60	40	0.23	3.5
	10		80	18.5	1.5	60	40	0.23	3.5
	11		80	17.5	2.5	60	40	0.23	3.5
	12		80	17	3.0	60	40	0.23	3.5

Binder content: Cement + silica fume + nano silica.
S.F: Silica fume content as addition to cement.
N.S: Nano silica content as a replacement of silica fume.
W/b: Water to binder ratio.
S.P: High range water reducer (viscocrete)

3. Mixing procedure

- the cement, coarse aggregate, fine aggregate and silica-fume were dry mixed in arotary mixer for 30 sec.
- adding super plasticizer and nano-silica to the total amount of water and mixing them by using sonicator for 15 minutes.
- adding the mixed nano-silica in step (2) to the dry mix in step (1) and mixing for two minutes.

4. Test and specimens

The prepared concrete samples have to determine the strength of different mixes, the following tests and specimens were used as follow:

- Compression test at 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.
- Scanning electron microscopy (SEM) at 56 day was carried out on slides of concrete from 100 mm cubes.

5. Testing Results

5.1 Compressive strength

The most common of all tests on hardened concrete is the compressive strength test, because many, though not all, of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the importance of the compressive strength of concrete in structural design. Table. 3 gives the result of compressive strength at different ages for (twelve) concrete mixes of group I, and II. As mentioned before, it is aimed to study the effect of nano-silica contents with different cement contents and with presence of silica fume on compressive strength.

Table. 3: Result of compressive strength for all mixes.

Group	Mix No.	Binder content kg/m^3	Cement content (%)	S.F. (%)	N.S. (%)	Aggregate		Compressive strength Mpa		
						Dolomite (%)	Sand (%)	7d	28d	56d
I	1	550	100	0	0	60	40	79	90	98.3
	2		80	20	0	60	40	84	94.1	102.3
	3		80	19.5	0.5	60	40	84	95	100
	4		80	18.5	1.5	60	40	91.3	95	104.3
	5		80	17.5	2.5	60	40	94.5	103	115.5
	6		80	17	3.0	60	40	96.1	105	117
II	7	650	100	0	0	60	40	89.5	93.2	102.5
	8		80	20	0	60	40	88	95	106
	9		80	19.5	0.5	60	40	92	97.2	111
	10		80	18.8	1.5	60	40	95	106	114.5
	11		80	17.5	2.5	60	40	97	111	127.2
	12		80	17	3.0	60	40	94	107	121

The value shown in Table. 3 is the average of the result of testing three standard cubes (100 mm). the compressive strength were determined at ages 7, 28, and 56 days. the compared mixes have the same aggregate grading, the same water to binder ratio (0.23), and the same superplasticizer content (3.5%). Fig. 2 show comparison between the compressive strength for mixes 2 to 6 at ages 7, 28, 56 days which have percentages of nano-silica 0%, 0.5%, 1.5%, 2.5%, and 3.0% as a replacement of silica fume. After 7 days the compressive strength increase from 84 Mpa of mix (2) to 96.1 Mpa for mix (6) which contain 3.0% nano-silica. the percent of increase was about (14.4%). After 28 day the increase in compressive strength was (11.6%), and at 56 days the compressive strength increase from 102.3 for mix(2) to 117 for mix (6) by percent of increase about (14.4%).

Also, Table. 3 and Fig. 3 show the effect of using nano-silica in the compressive strength with constant binder content 650 kg/m^3. The optimum percentage of nano-silica which affect the maximum increase in compressive strength was 2.5% at all ages of curing .

The percentages of increase were 10.2%, 16.85%, and 20% after 7, 28, and 56 days of curing. and there is a slight reduction in compressive strength when increasing nano-silica more than 2.5%. this reduction in compressive strength could be explained by the weakness in concrete pore-structure due to decreasing the distance between nanoparticles associated with increasing content of nano- particles, and also Ca $(OH)_2$ crystal cannot grow up enough due to limited space and the crystal quantity is decreased, which leads to decreasing the ratio of crystal to strengthening gel and consequently the shrinkage and creep of cement matrix increased.

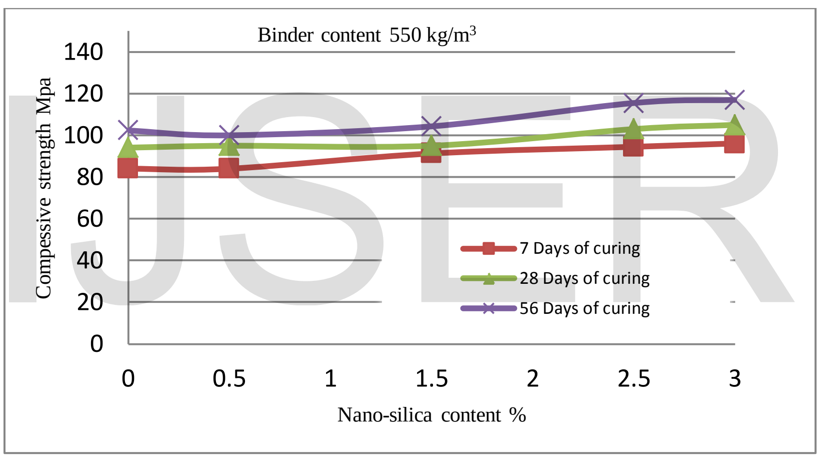

Fig. 2. Effect of nano –silica content on compressive strength of concrete mixes (2 to 6) at different ages.

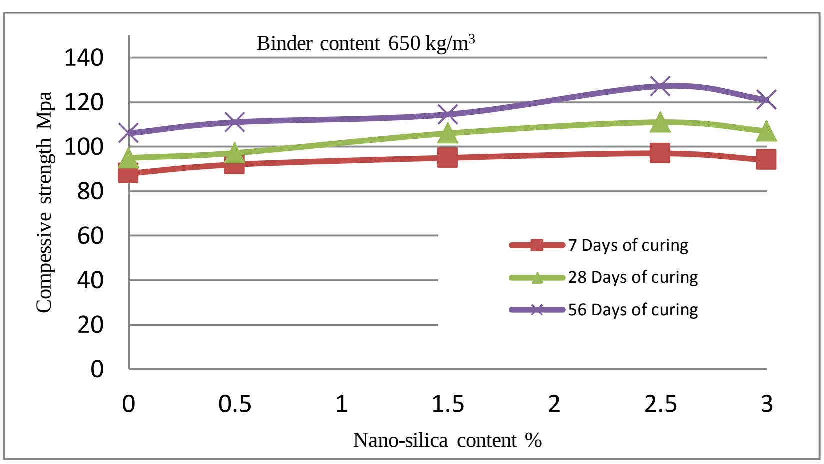

Fig. 3. Effect of nano –silica content on compressive strength of concrete mixes (8 to 12) at different ages.

5.2 Splitting Tensile Strength

Concrete is not normally designed to resist direct tension, the knowledge of tensile strength is of value of estimating the load under which cracking will develop. Splitting tensile test of the cylinder-concrete specimens give more reasonable tensile strength estimation than the direct tensile test or the modulus of rupture test. The tensile strength is important characteristic for the development of cracking and hence for the prediction of durability concrete. Table. 4 shows the results of splitting tests of (twelve) concrete mixes at age 56 days.

Table. 4: Result of splitting tensile strength, Flexural strength, Static modulus of elasticity tests.

Group	Mix No.	Binder content kg/m^3	Cement content (%)	S.F. (%)	N.S. (%)	Indirect tensile strength (Mpa) At age 56 days	flexural strength (Mpa) At age 56 days
I	1	550	100	0	0	7.6	10.9
	2		80	20	0	8.96	12.2
	3		80	19.5	0.5	9.08	13.5
	4		80	18.8	1.5	9.76	14.3
	5		80	17.5	2.5	9.87	15.1
	6		80	17	3.0	10.0	14.8
II	7	650	100	0	0	8.02	12.6
	8		80	20	0	9.3	13.7
	9		80	19.5	0.5	9.43	14.31
	10		80	18.8	1.5	10.26	16.2
	11		80	17.5	2.5	10.74	17.46
	12		80	17	3.0	10.81	17.55

As shown in Table. 4, and Fig. 4, mixes with binder content 550 kg/m^3 and 650 kg/m^3 show that the increase in nano silica content caused increase in the splitting tensile strength of concrete. The tensile strength increase from 8.96 Mpa for (mix 2) to 10.0 Mpa for (mix 6) for binder content 550 kg/m^3, and for binder content 650 kg/m^3, the increase in nano-silica caused increase in splitting tensile strength, but the percent 3% nano-silica not cause high increase in tensile strength than 2.5%. The tensile strengrh increase from 9.3 Mpa for (mix 8) to 10.81 for (mix 12).

In general, the increase in nano-silica content cause increase in splitting tensile strength, because of increasing CSH product from the pozzolanic action for nano Powder with CH which produced from the hydration process. Since increasing CSH lead to increase in pond strength between cement paste and aggregate surface (ITZ).

5. 3 Flexural Strength

As shown in Table. 4, and Fig. 5, the flexural strength increase from 12.2 Mpa for (mix 2) to 15.1 Mpa for (mix 5) which had 2.5% nano-silica by percent of increase 23.8%, but the flexural strength decrease when increase nano-silica content than 2.5% for binder content 550 kg/m^3.

Also, for 650 kg/m^3 binder content, the increase in nano-silica content caused increase in flexural strength. The percent of nano-silica content which caused the best flexural strength was 3%. The strength increase from 13.7 Mpa for (mix 8) to 17.55 Mpa for (mix 12).

The results were logically agree with compressive strength and tensile strength results. As a result of increasing CSH, and improving in the microstructure of concrete, when using nano-silica, the flexural strength increased.

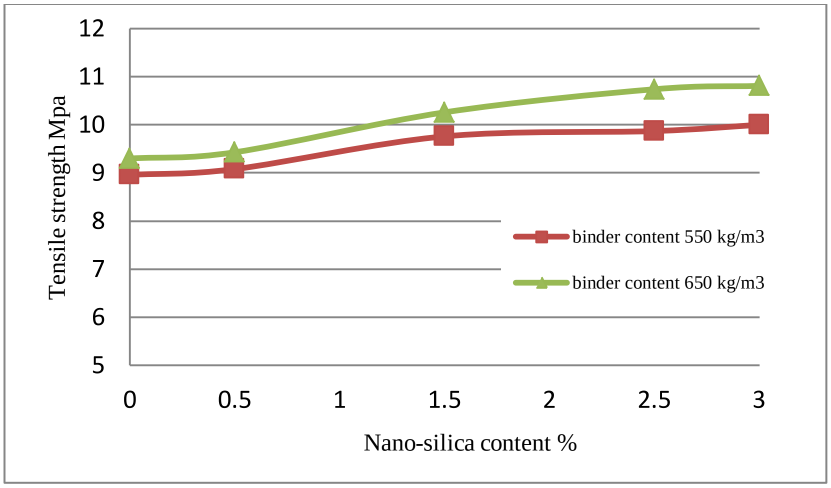

Figure. 4: Effect of nano-silica content on the the splitting tensile strength.

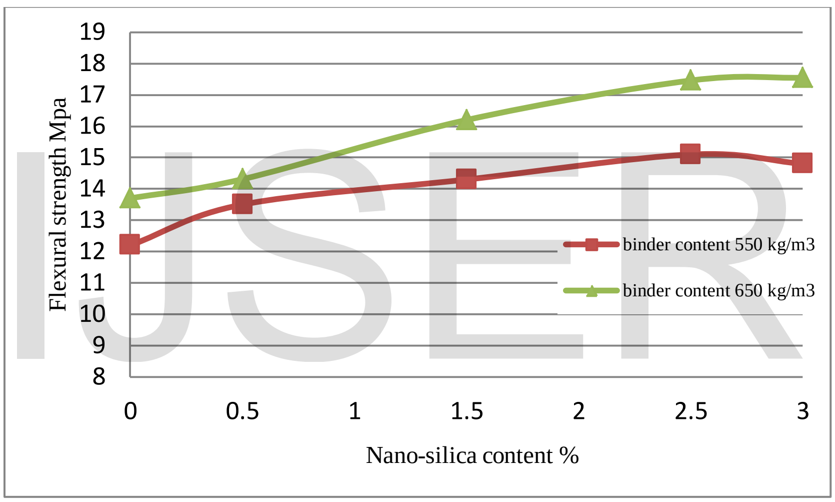

Fig. 5. Effect of nano-silica content on the the flexural strength.

5.4 Scanning electron microscopy SEM

Scanning electron microscopy was carried out on mixes with and without nano-silica to verify the mechanism of nano-silica on the properties of ultra high strength concrete. The specimens were cut down directly from the concrete cubes. When a material with high specific surface is added to cement or concrete, it acts as the micro-filler of the cement particles, which can reduce the amount of water that filled in the void of the blending materials. However, replacing cement with a high specific surface material would increase the wettable surface area and the amount of water adsorbed [8]. Additions nano-silica was found to improve hydration behavior and caused differences of the microstructure of hardened concrete. Photos. 2 shows SEM micrograph of mix 8 (had 20% silica fume and 0% nano-silica). It can be seen that calcium silicate hydrate C-S-H in isolation surrounded and connected with many needle-hydrate, but there are many $Ca(OH)_2$ crystals and there are many pores and cracks.

On the other hand, Photos. 3, and shows mixes contained nano-silica 1.5%, and 18.5% silica fume, it can be seen that the concrete become more denser, but some cracks still found. The nano-silica particles can fill the voids of the C-S-

H gel structure, making binder paste matrix more denser. it can be seen that mixes 11 and 12 which had 2.5%, and 3.0% nano-silica respectively give high denser concrete. the nano-silica among the hydrate products prevent $Ca(OH)_2$ crystals from growing [9]. In addition, nano-silica can absorb the $Ca(OH)_2$ crystals, and reduce the size and amount of the $Ca(OH)_2$ crystals, thus making the interfacial transition zone (ITZ) of aggregates and paste matrix denser. as shown in Photos. 4, and 5.

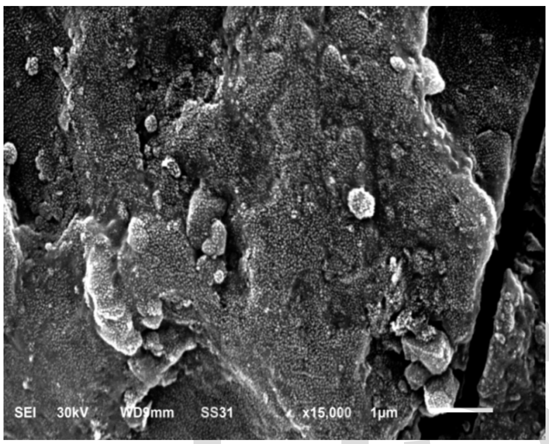

photo.2: SEM micrograph of mix 8 after 56 day of curing.

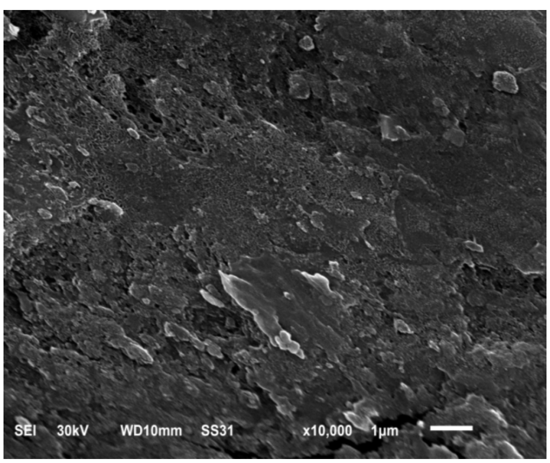

photo.3: SEM micrograph of mix 8 after 56 day of curing.

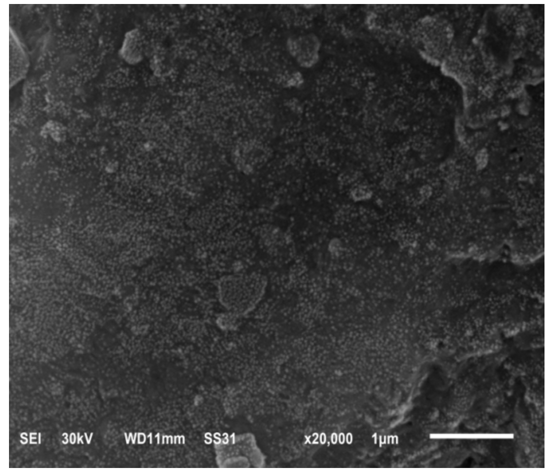

Photo.4 : SEM micrograph of mix 11 after 56 day of curing.

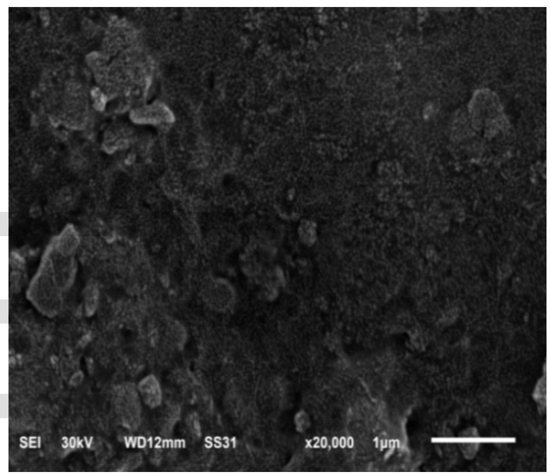

Photo.5 : SEM micrograph of mix 12 after 56 day of curing.

6. Conclusions

The results and conclusions are summarized as follows:

- The effect of nano-silica on the properties of hardened concrete not appears clearly at early ages.
- Mixes with 3% nano-silica and 17% silica fume as a replacement of cement content showed the optimum compressive strength of concrete for 550 kg/m3 binder content at 28, and 56 days, and for 650 kg/m^3 binder content Mixes with 2.5% nano-silica and 17.5% silica fume showed the optimum compressive strength.
- Using 2.5% nano-silica with 17.5% silica fume increase the compressive strength by percent 12.9%, and 20% for 550, and 650 kg/m^3 binder content respectively at age 56 days.

- Using 3.5% nano-silica increase the indirect tensile strength by percent 13.8%, and 17.1% for 550, and 650 kg/m^3 binder content.
- The increase in nano-silica content lead to increase in the indirect tensile strength, the flexural strength and modulus of elasticity until 3%.

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