IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 4 Ver. VI (Jul. - Aug. 2017), PP 62-72
www.iosrjournals.org

The Hybrid Effect of Micro and Nano Silica on the Properties of Normal and High Strength Concrete

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Abstract **:***Recently, the development in construction field due to nanotechnology materials had a significant inflection on the enhancement of concrete properties. Nano materials had become an important aspect for today's civil engineers. Among the nano materials presently used in concrete, nano-silica provides mechanical strength, impermeability, and durability to concrete. This unique characteristic is attributed to its high pozzolanic nature that gives it the ability to react with the fee-lime during hydration forming an additional C-S-H gel. In the present work, a different content of micro silica and nano silica as partial replacement of cement in Normal and High Strength Concrete mixtures were used. It was concluded that 8% micro silica and 2% nano silica as partial replacements of cement, improved compressive strength and tensile strength of the concrete specimens seriously. In Hybrid NS+SF samples, the cement media was more compact, and the CaOH2 crystals are disappeared, and an almost complete hydration was achieved.*

Keywords: *Nano Silica (NS); Silica Fume (SF); Compressive strength; Split tensile strength; Microstructure.*

Date of Submission: 11-08-2017 Date of acceptance: 25-08-2017

I. Introduction

Nanotechnology is one of the most promising areas of science. The use of nanomaterials in concrete is a new revolution. Nanomaterials are like nano silica, nano titanium oxide, carbon nanotubes, nano alumina, etc. which are presently used in concrete to modify its properties. Recently [1-5], Nano Technology has been introduced in Civil Engineering applications. The mechanical and other properties of concrete are dependent on the micro and nanoscale behavior of the soul component responsible for these properties, calcium silicate hydrate (C-S-H). C-S-H consists of thin layers of solids separated by gel pores filled with an interlayer and adsorbed water. This microstructure of C-S-H makes it fragile in front of moisture and hence shrinkage effect leading to micro-cracks in concrete. Thus, micro and nanomaterials are essential for the engineering of the elements needed to improve mechanical behavior, durability, and sustainability. One of the most used nanomaterials is Nano-Silica (NS) [6]. The advancement made by the study of concrete at the nanoscale has proved that nano silica has better characteristics than silica fume used in conventional concrete. Nano silica is off high pozzolanic nature and has the capability to react with $Ca(OH)_2$ during hydration and forms an additional C-S-H gel which gives strength, impermeability, and durability to concrete.

Nano Silica is catalogized as one of the blending materials capable of improving concrete properties. Nano Silica concrete is stickier than normal concrete and has a better permeability resistance due to its large surface area, [7,8]. Also, The pozzolanic activity of Nano Silica is much better than that of Silica fume [9]. Nano silica consumes $Ca(OH)_2$ crystals and improves the interfacial zone [10]. Fly ash has low initial activity, but pozzolanic activity significantly increases after incorporating little Nano silica [11]. In [12], it was discovered that Compressive strength and strength of mortars with Nano silica particles were all higher than those of mortar containing Silica fume at 7 and 28 days. In [13,14], it was found that adding Nano Silica and Nano Alumina as a partial replacement for cement In pavements subjected to freezing and thawing showed significant improvements in compressive strength and frost resistance. 5% nano-silica (by the weight of cementitious materials) improved the compressive strength of concrete as much as 30%. Also, it was concluded that compressive strength of normal concrete containing nano-SiO2 was higher than that containing the same amount of nano-Al2O3. In [15], the effect of NS on setting time and early strength of concrete and high slag mortar was investigated. It was found that the setting time was reduced by 95 and 105 minutes and the compressive strength increased by 22% and 18% considering three days and seven days respectively when 2%NS was incorporated. It was found that the inclusion of 2%NS was more effective than 1%NS concerning the pores structure of slag cement paste. They also discovered that NS with a particle size of 7-12 nm appeared more efficient than micro SF in increasing the rate of hydration. A microstructure study on the effect of morphological and the textural characteristics of different amorphous nano silica used in concrete was conducted [16]. It was found that the main parameters that influence the final mechanical properties and slump of cement mortars were the specific surface area, the micropore volume and the average size of the primary particles of the silica. Also, it was found in [17] that the fresh concrete and hardened concrete properties such as consistency and setting times were different for NS mixes than SF mixes. NS made cement paste thicker and accelerated the hydration process which improves the bond strength and compressive strength when compared with SF in concrete. In [18], a study was conducted on high strength paste using several NS addition percentages (0%, 0.5%, 1%, 2% and 5%). It was found that the addition of 0.5% to 2% NS caused 20%, 25% strength increases while the demand for water increased in the fresh state. After adding 1% superplasticizer, the water demand was reduced, and strength increased 30-35%. They recorded enlargement in (C-S) crystal size to 1.2 mm at 5%NS, and a denser structure of the nano samples was realized. In [19] a synthesized 2%NS as a partial cement replacement and of diameter [96-120nm] was used in cement/SF paste. Although there was no noticeable improve in final physical and mechanical properties, a significant effect on hardening process during the initial state of hydration was observed. In [20], an investigation on the effect of single and combined Nano Silica, Nano alumina, and Nano Titanium on the properties of self-compacting mortars with fly ash was used within 1%, 3%, and 5% cement replacement ratios. The results indicated that the best result of compressive strength was achieved at 3%NS and a slight decrease was observed at 5%NS. Also, 3%NS gave the lowest absorption value. Jalal, et. al. [21] discussed the effect of a blend of SF and NS on the Microstructure of High-Performance Concrete. The blend showed a compact formation of hydration products and a reduction $Ca(OH)_2$ crystals. At a binder content of 400 kg/m3, the mixture (10%SF+2%NS) gave the best results considering all test ages. Wang, et. al. [22] had realized the important role of NS in hydration reaction of cement at early and at late ages using both mechanical and physical tests, and they concluded that the best results were achieved at 3%NS cement replacement. Abyaneh, et. al. [23] have found that the concrete produced with Micro-SiO_2 and Nano-SiO_2 show higher compressive strength than the concrete which only has Micro-SiO_2 in their mixtures. Specimens with 2% Nano-SiO_2 and 10% Micro-SiO_2 had less water absorption and more electrical resistance. In [24] it was found that 3.8%NS showed a similar flowing and viscosity behavior as reference mix of self-compacting concrete. This percentage, also, gave the best durability indicators. The highest compressive strength was achieved by colloidal NS, while the highest splitting tensile strength was achieved using NS powder. The microstructure investigation showed that NS motivated smaller sizes of C-S-H gel and caused a refinement of the microstructure. In [25], a comparison of NS and Micro Silica effect on the properties of low binder ultra high-performance cementitious composites was made. It was found that the effect of 1%NS is almost equal or near to that of 10% Micro silica (MS) and the use of binary NS and MS had a better performance compared to individual incorporation. They found that the generated plain Ultra High-Performance Concrete with 2%NS gave the highest value of fracture energy. The flexural fatigue performance containing nanoparticles have excellent flexural fatigue performance compared with plain concrete, in particular at high-stress level [26].

II. Materials

2.1. Aggregate

Local materials were used in concrete mixes and tested according to Egyptian Standard Specification (ESS) and American Standard of Testing Materials (ASTM). Dolomite as a coarse aggregate was used with maximum size 10 mm. Fine aggregate used in this research was natural sand and it composed mainly of siliceous material. Table (1) show physical and chemical properties of used aggregate.

Table (1): Physical and Chemical Properties of the used Aggregate

Test	Coarse Aggregate		Sand	
	Results	Specification Limit*	Results	Specification Limit*
Specific gravity	2.61	-	2.64	-
Unit Weight	1.65	-	1.7	-
Materials Finer than no 200 Sieve	1.38	Less than 4 %	1.46	Less than 3 %
Absorption %	2.15	-	-	-
Abrasion (Los Anglos)	14.84	Less than 25 %	-	-
Crushing Value	17.55	Less than 30 %**	-	-
Impact Value	9.2	Less than 30 %	-	-
Chloride content (CL^{-1} %)	0.009	Less than 0.04 %	0.045	Less than 0.06 %
Sulfate content (SO_3 %)	0.031	Less than 0.40 %	0.07	Less than 0.40 %

* ESS No.1109/2002

2.2. Cement

Ordinary Portland cement was tested to assure its compliance with ESS 373-1991. Super-plasticizer was added to keep the slump ranges from 6-10cm. Table(2) show properties of the used cement.

Table (2): Properties of Cement Type (CEM I 42.5 N)

Properties		Measured Values
Fineness (cm^2/gm)		3280
Specific Gravity		3.15
Expansion (mm)		1.2
Initial Setting Time (min)		180
Final Setting Time (min)		230
Compressive strength (N/mm2)	2 days	22.8
	7 days	33.2
	28 days	56
Chemical Compositions	SiO_2	20.32%
	Al_2O_3	5.16%
	Fe_2O_3	3.60%
	CaO	63.43%
	MgO	1.02%
	SO_3	2.22%
	Loss ignition %	1.30%

2.3. Silica Fume and Nano silica

The SF was brought from Sika Egypt in ordinary 5kg batches. According to the manufacturer, it is a dry powder SF additive for concrete and mortars that meet the requirements of ASTM C-1240 and AS/NZ 3582.3/2002. It is a pozzolanic material that consists primarily of fine silicon dioxide particles in a non-crystalline form. SF particles have a diameter of about 1μm.

The NS was brought from Nanotech Egypt. According to the manufacturer, a sequential method has been used to prepare monodisperse and uniform size Silica Nanoparticles using ultrasonication by the sol-gel process. The silica particles were obtained by hydrosis of tetraethyl orthosilicate (TEOS) in ethanol medium. The color of NS was white, powder appearance, spherical shape, and of an average size of 55±8 nm; Fig.(1) and Fig. (2).

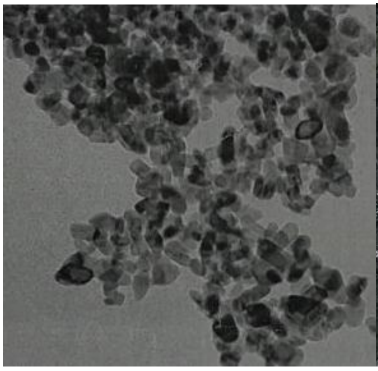


Fig. (1) SF (left) and NS (right)

Fig. (2) TEM of the manufacturer Certificate of Analysis (Nanotech Egypt Co.)

3. Concrete Mixes Proportion

Mix proportions are given in Table (3) .

Table (3): Concrete Mixes Proportion

	Mix No.	NS content %	NS content kg/m³	SF content %	SF content kg/m³	Cement kg/m³	Dolomite kg/m³	Sand	Water lit/m³	Plasticizer kg/m³
Normal Stregnth Concrtete (NSC)	1	0	0	0	0	350	1230	615	192.5	2.45
	2	1	3.5	0	0	346.5	1230	615	192.5	2.45
	3	2	7	0	0	343	1230	615	192.5	3.5
	4	3	10.5	0	0	339.5	1230	615	192.5	5.25
	5	0	0	10	35	315	1230	615	192.5	7.5
	6	1	3.5	9	31.5	315	1230	615	192.5	7.5
	7	2	7	8	28	315	1230	615	192.5	7.5
	8	3	10.5	7	24.5	315	1230	615	192.5	7.5
High Stregnth Concrtete (HSC)	9	0	0	0	0	500	1133	567	200	9
	10	1	5	0	0	495	1133	567	200	9
	11	2	10	0	0	490	1133	567	200	9.25
	12	3	15	0	0	485	1133	567	200	9.25
	13	0	0	10	50	450	1133	567	200	10.5
	14	1	5	9	45	450	1133	567	200	10.5
	15	2	10	8	40	450	1133	567	200	10.5
	16	3	15	7	35	450	1133	567	200	10.5

III. Description Of Tested Specimens And Methods

98 cubes 10x10x10cm and 98 cylinders 10x20cm were cast for compressive strength and splitting tensile strength. Three specimens for each mix of two ages were tested, and their average strength was considered. Concrete was cast vertically in the molds and was mechanically compacted using a table vibrator to ensure the full compaction of concrete inside the forms. The specimens were tested in the civil engineering laboratories located in HTI, 10th of Ramadan, Egypt, using a 2000KN hydraulic compression machine. Tests were completed according to the ASTM C39 standard test method for cylinders. A total of 16 cylinder specimens (25.4 mm diameter and 25.4 mm height) of the mixes were cast during the cast of cubes and cylinders. The mortars of the mixes were selectively used to cast these samples. It were tested at the age of 28 days by scanning electron microscope (Model Quanta 250 FEG (Field Emission Gun) attached with EDX Unit (Energy Dispersive X-ray Analyses), with accelerating voltage 30 K.V., magnification14x up to 1000000 and resolution for Gun.1n); FEI company, Netherlands. The SEM tests were made in The Egyptian Mineral Resources Authority Central laboratories sector, Dokki, Giza, Egypt.

IV. Test Results

4.1 Compressive Strength:

Compressive strength test results of all mixes showed that the coefficients of variation of the three tested specimens for each mix were in the range (3-10 %).

4.1.1 Group of mixes with NS:

The compressive strength results of Normal Strength Concrete (NSC) at both tested ages, 7 and 28 days, are presented in Table(4) and Fig.(3). Considering control specimens and the group of mixes with only NS partial cement replacement, the compressive strength values showed a decrease in 1%NS and 3%NS while it showed an increase in 2%NS. This trend was observed in both 7 and 28 days testing age. At the age of 7 days, compressive strength values were -11.2%, +22.6%, and -11.8% compared to control specimens, with 220.9 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) respectively. At the age of 28 days, compressive strength values were -3.2%, +17%, and -2.1% compared to control specimens, with 280.1 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) respectively. The compressive strength results of High Strength Concrete (HSC) at both tested ages, 7 and 28 days, are presented in Table(5) and Fig.(4). Considering control specimens and the group of mixes with only NS partial cement replacement, the compressive strength values showed an increase in all NS replacement ratios although the highest increase was observed in the 2%NS specimens. The increase was found in both 7 and 28 days testing age. At the age of 7 days, compressive strength values were +5.5%, +20%, and +3.2% compared to control specimens, with 275.4 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) respectively. At the age of 28 days, compressive strength values were +7.4%, +19.1%, and +7.1% compared to control specimens, with 400.5 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) respectively. The best performing mix in the group of mixes containing NS only was the one containing 2%NS regarding both NSC and HSC.

4.1.2 Group of mixes with Hybrid SF and NS:

The compressive strength results of Normal Strength Concrete (NSC) at both tested ages, 7 and 28 days, are presented in Table(4) and Fig.(3). Considering control specimens and the group of mixes with hybrid SF and NS partial cement replacement, the compressive strength values showed an increase in all replacement ratios although the highest increase was observed in the (8%SF+2%NS) specimens. The increase was observed in both 7 and 28 days testing age. At the age of 7 days, compressive strength values were +3%, +23.1%, and +17.5% compared to control specimens, with 200.9 kg/cm2 compressive strength value, for (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) respectively. At the age of 28 days, compressive strength values were +3.5%, +14.6%, and +7.5% compared to control specimens, with 280.1 kg/cm2 compressive strength value, for (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) respectively. The compressive strength results of High Strength Concrete (HSC) at both tested ages, 7 and 28 days, are presented in Table(5) and Fig.(4). Considering control specimens and the group of mixes with hybrid SF and NS partial cement replacement, the compressive strength values showed an increase in all replacement ratios although the highest increase was observed in the (8%SF+2%NS) specimens. This increase was found in both 7 and 28 days testing age. At the age of 7 days, compressive strength values were +17%, +25.4%, and +15.4% compared to control specimens, with 275.4 kg/cm2 compressive strength value, for (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) respectively. At the age of 28 days, compressive strength values were +17.8%, +23.8%, and +16.2% compared to control specimens, with 400.5 kg/cm2 compressive strength value, for (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) respectively. The best performing mix in the group of mixes containing hybrid SF and NS was the one containing (8%SF+2%NS) regarding both NSC and HSC.

The compressive strength values of NSC with (10%SF) were -15.2%, -6.9% compared to control specimens at the age of 7days and 28 days respectively. On the other hand, the compressive strength values of HSC were +9%, +14.9% compared to control specimens at the age of 7days and 28 days respectively.

The results of the NSC mixes showed that the most effective mixes are (0%SF+2%NS) and (8%SF+2%NS). It is clearly that the single 2%NS partial cement replacement gave a very close result of compressive strength enhancement to the hybrid mix (8%SF+2%NS) considering both ages of concrete, 7 and 28 days. However, the hybrid mix (8%SF+2%NS) gave a slightly better value at the early age (+23.1%) and a little lesser value in the late age (+14.6%). It is evident that, for both mixes, the amount of enhancement in the early age is higher than the late age. Also, the results of the HSC mixes showed that the most effective mixes are (0%SF+2%NS) and (8%SF+2%NS). It is clearly that the hybrid mix (8%SF+2%NS) partial cement replacement gave a considerably higher result of compressive strength enhancement than the single 2%NS considering both ages of concrete, 7 days (+25.4%) and 28 days (+23.8%). As noticed in NSC, the amount of enhancement in the early age for both mixes is higher than the late age. These results clearly indicate that the dominant factor in mechanical enhancement is the addition of 2%NS and that the hybrid addition of 8%SF to this NS percentage add considerably to its effect on concrete especially to high strength concrete.

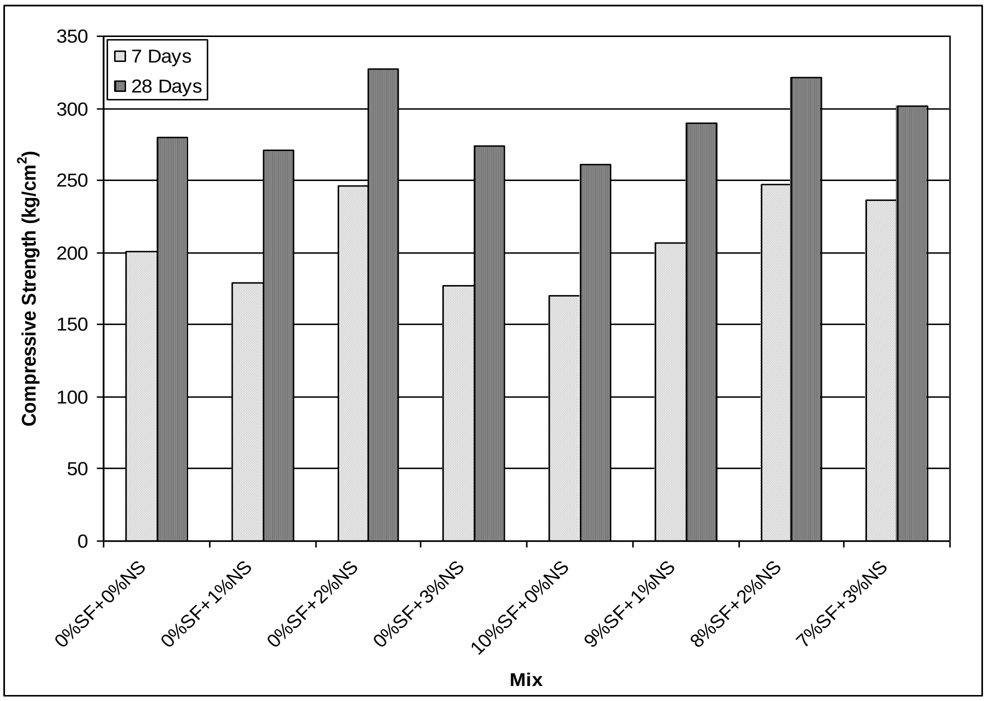


Fig.(3) : The compressive strength (kg/cm^2) of normal concrete

Table (4): Compressive Strength Results of Normal Strength Concrete

cement [kg/m³]	w/c	mix		compressive strength [kg/cm²]			
		mix #	Type	7 days	% from control (%)	28 days	% from control (%)
350	0.55	1	0%SF+0%NS	200.9	0.0	280.1	0.0
350	0.55	2	0%SF+1%NS	178.5	-11.2	271.2	-3.2
350	0.55	3	0%SF+2%NS	246.5	22.6	327.6	17.0
350	0.55	4	0%SF+3%NS	177.2	-11.8	274.2	-2.1
350	0.55	5	10%SF+0%NS	170.3	-15.2	260.8	-6.9
350	0.55	6	9%SF+1%NS	207.1	3.0	289.9	3.5
350	0.55	7	8%SF+2%NS	247.4	23.1	321.1	14.6
350	0.55	8	7%SF+3%NS	236.1	17.5	301.2	7.5

Table (5): Compressive Strength Results of High Strength Concrete.

cement [kg/m³]	w/c	mix		compressive strength [kg/cm²]			
		mix #	Type	7 days	% from control (%)	28 days	% from control (%)
500	0.4	9	0%SF+0%NS	275.4	0.0	400.5	0.0
500	0.4	10	0%SF+1%NS	290.6	5.5	430.2	7.4
500	0.4	11	0%SF+2%NS	330.5	20.0	476.8	19.1
500	0.4	12	0%SF+3%NS	284.3	3.2	428.8	7.1
500	0.4	13	10%SF+0%NS	300.3	9.0	460.2	14.9
500	0.4	14	9%SF+1%NS	322.2	17.0	471.7	17.8
500	0.4	15	8%SF+2%NS	345.5	25.4	495.7	23.8
500	0.4	16	7%SF+3%NS	317.8	15.4	465.2	16.2

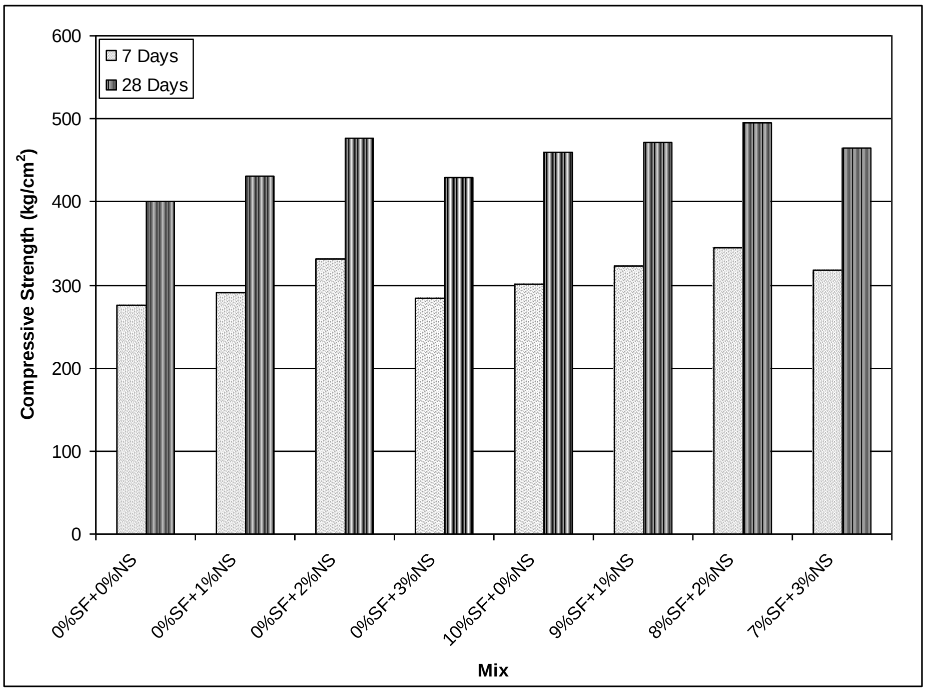


Fig.(4) : The compressive strength (kg/cm²) of high strength concrete

4.2 Split Tensile Strength:

Table (6) and Fig. (5) Show the tensile strength from split test results for NSC at ages of 7 and 28 days. In the group of NS mixes, 2%NS gave the best results with +10.2%, and +7.8% increase over the control mix having a value of 14.2 kg/cm2, and 24.4 kg/cm2 at 7days and 28 days respectively. In the group of hybrid mixes, (8%SF+2%NS) gave the best results with +28%, and +11.1% increase over the control mix at 7days and 28 days respectively. Table (7) and Fig. (6) Show the tensile strength from split test results for HSC at ages of 7 and 28 days. In the group of NS mixes, 2%NS gave the best results with +23.8%, and +17.9% increase over the control mix having a value of 17.5 kg/cm2, and 27.5 kg/cm2 at 7 days and 28 days respectively. In the group of hybrid mixes, (8%SF+2%NS) gave the best results with +15.7%, and +20.6% increase over the control mix at 7days and 28 days respectively. It is implied from these results that the same trend observed in the compressive strength test results concerning 2%NS mix and 2%NS+8%SF mixes for achieving the best enhancement is also realized in split tensile strength test results.

Table (6): Tensile Strength Results of Normal Strength Concrete.

cement [kg/m^3]	w/c	mix		Tensile strength [kg/cm^2]			
		mix #	Type	7 days	% from control (%)	28 days	% from control (%)
350	0.55	1	0%SF+0%NS	14.2	0.0	24.4	0.0
350	0.55	2	0%SF+1%NS	13.5	-5.1	22.8	-6.8
350	0.55	3	0%SF+2%NS	15.7	10.2	26.3	7.8
350	0.55	4	0%SF+3%NS	11.9	-16.2	21.8	-10.7
350	0.55	5	10%SF+0%NS	17.9	25.7	26.4	8.1
350	0.55	6	9%SF+1%NS	17.6	23.5	26.4	8.1
350	0.55	7	8%SF+2%NS	18.2	28.0	27.1	11.1
350	0.55	8	7%SF+3%NS	17.9	25.7	25.4	4.0

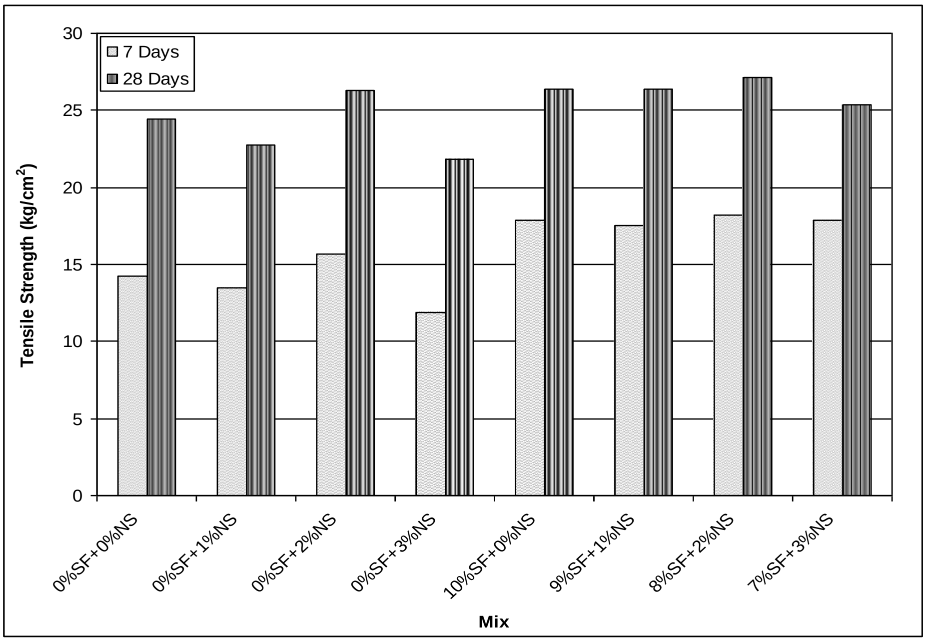


Fig.(5): The tensile strength (kg/cm^2) of normal concrete

Table (7): Tensile Strength Results of High Strength Concrete.

cement [kg/m^3]	w/c	mix		Tensile Strength [kg/cm^2]			
		mix #	Type	7 days	% from control (%)	28 days	% from control (%)
500	0.4	9	0%SF+0%NS	17.5	0.0	27.5	0.0
500	0.4	10	0%SF+1%NS	19.5	11.5	30.8	12.0
500	0.4	11	0%SF+2%NS	21.7	23.8	32.4	17.9
500	0.4	12	0%SF+3%NS	19.9	13.8	30.9	12.5
500	0.4	13	10%SF+0%NS	19.9	13.5	30.4	10.6
500	0.4	14	9%SF+1%NS	19.6	11.7	31.8	15.7
500	0.4	15	8%SF+2%NS	20.3	15.7	33.1	20.6
500	0.4	16	7%SF+3%NS	19.9	13.6	32.0	16.4

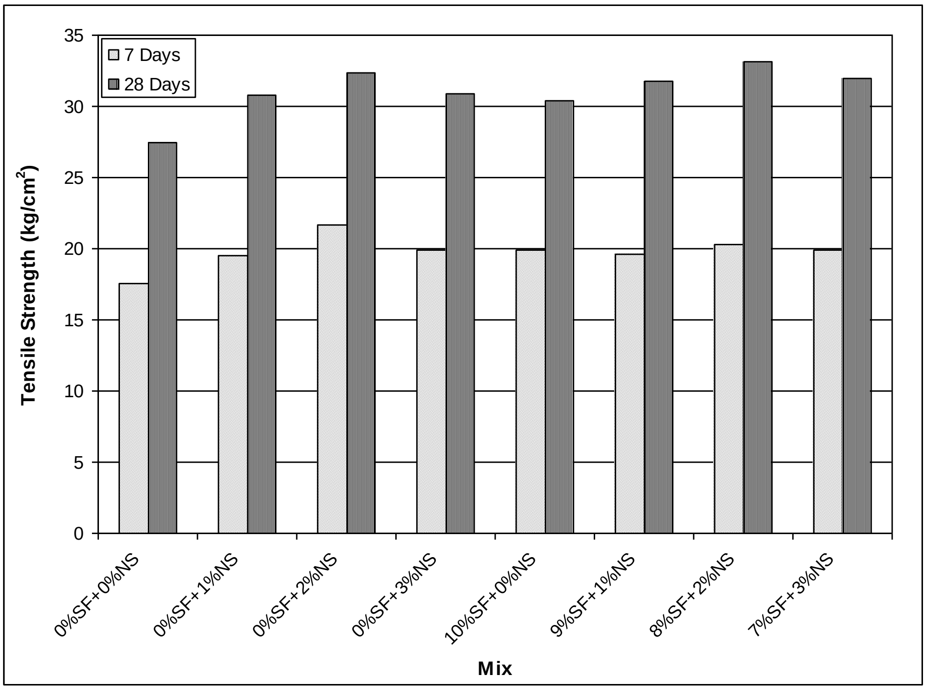
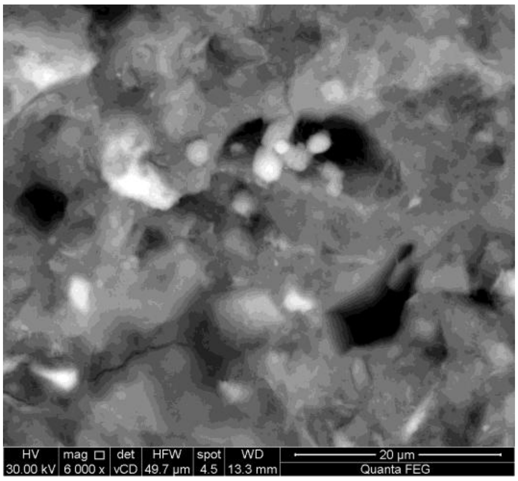


Fig.(6): The tensile strength (kg/cm^2) of high strength concrete

5.3. Microstructure

Figure (7) show the results of SEM of control specimen at the age of 28 days and (0%SF+1%NS) sample and (0%SF+2%NS) sample at 7 and 28 days respectively .

Compared to the samples of NS at 28 days, the morphology of C-S-H in the control specimen was fibrous and noncompact with a large number of micropores. The hydration products structure of the control specimen is different from that of NS samples. Also, it can be seen in the control sample that there is still a built-in CaOH2 crystals that are embedded in and around the pores. On the other hand, in NS samples, the cement media was more compact, and the CaOH2 crystals are disappeared, and an almost complete hydration was achieved . The 7 days 1%NS sample shows some hexagonal flakes of CaOH2 more than those existing in 7 days 2%NS sample and the structure of the cement paste in the first sample is comparatively loose with a considerable number of micropores. In the 28 days, considering NS samples, a residue of hydration action still exist in the sample of 1%NS, but an almost complete hydration product is noticed in the 2%NS sample. It is evident that 2%NS, in the 7 and 28 days, has a structure of C-S-H gel that is denser and finer compared to the sample of 1%NS.



28days-Control

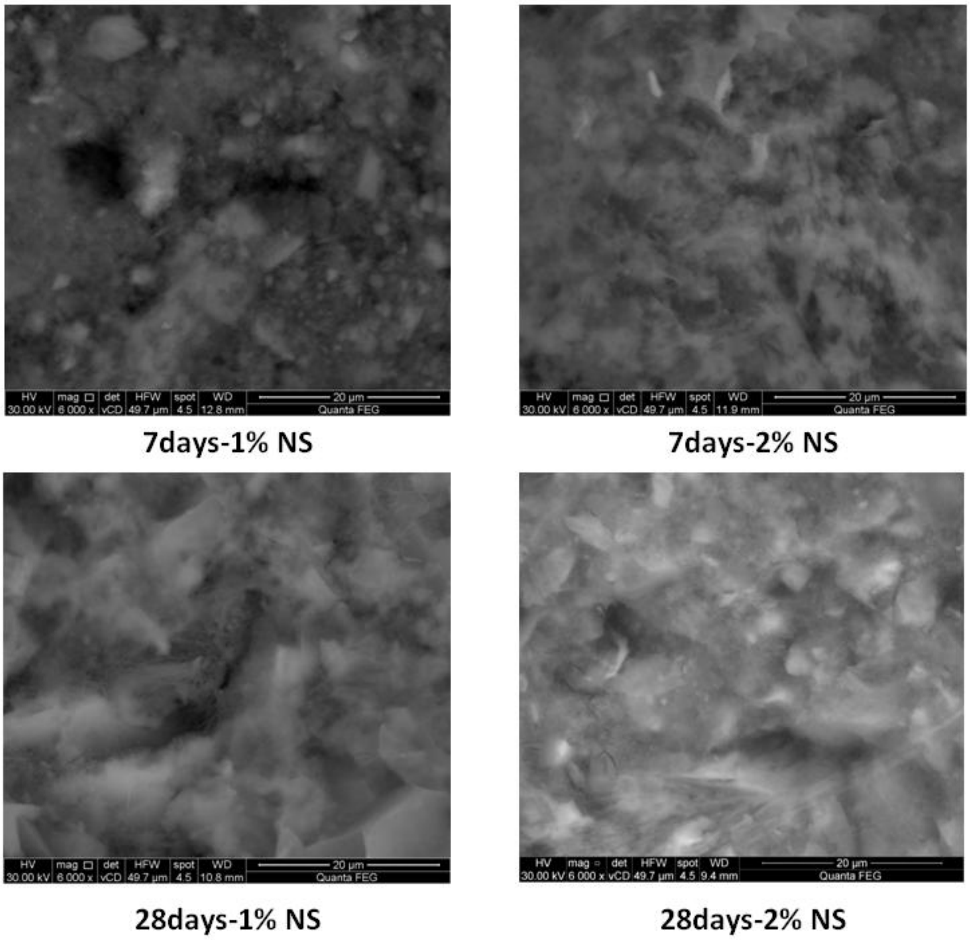


Fig.(7): SEM images of tested Specimens

V. Discussions

Micro silica is of two effects. The first one is a chemical effect due to the pozzolanic action resulted from the reaction of silica with calcium hydroxide (CaOH2) which forms additional calcium silicate hydrate (C-S-H) gel. The new C-S-H gel contributes to an improvement in mechanical strength. The second effect of silica is the physical contribution of it as a filler material which fills the remaining voids in the partially hydrated cement paste leading to an increase in its density and hence its strength and durability. This filling effect is attributed to the specific surface area of micro silica which is 100 times higher than cement powder.

The effect of NS is previously established. It accelerates the cement paste reactions due to its large surface area which works as a nucleation zones for the C-S-H gel precipitants. It was stated that NS needs more water to keep the same workability and plasticizers are required to minimize the effect of agglomeration formation resulted from adsorption of NS of ionic spencies [27]. In [7], the effect of NS on concrete water permeability and microstructure was studied, and the test results showed that NS could reduce water permeability and improve microstructure of hardened concrete. According to [7], the NS has a very high activity due to its galactic specific surface area. It can react with CaOH2 crystals, cement hydration product, quickly and efficiently produce C-S-H gel. This active reaction reduces the size and amount of CaOH2, and C-S-H gel fills the voids to improve the density of the binding paste matrix.

The results of this research indicated that the maximum percentage of NS was 2% and the higher NS percentage, a less mechanical improvement is achieved. The reason for this phenomenon is attributed to that the amount of the NS is greater than the sum of the NS required to react with CaOH2 which leads to an excess of silica leaching out replacing part of the cementitious material without actual contribution or addition to its mechanical strength. The reason for the enhancement in mechanical strength resulted from the addition of 8% SF to the maximum 2% NS is that the micro size of the SF add more contribution as a filler although its function is a secondary rule that follows the primary function of the optimum 2%NS.

VI. Conclusions

Based on experimental results the following conclusions are drawn:

- Considering Normal Strength Concrete, at the age of 28 days, compressive strength values were -3.2%, +17%, and -2.1% compared to control specimens, with 280.1 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) mixes respectively. Compressive strength values were +3.5%, +14.6%, and +7.5% compared to control specimens for mixes (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) respectively. i.e. 2%NS and 8%SF+2%NS gave the best results.
- Considering High Strength Concrete, at the age of 28 days, compressive strength values were +7.4%, +19.1%, and +7.1% compared to control specimens, with 400.5 kg/cm2 compressive strength value, for (0% SF, 1% NS), (0% SF, 2% NS), and (0% SF, 3% NS) mixes respectively. Compressive strength values were +17.8%, +23.8%, and +16.2% compared to control specimens for (9%SF+1%NS), (8%SF+2%NS), and (7%SF+2%NS) mixes respectively. i.e. 2%NS and 8%SF+2%NS gave the best results. However, the hybrid mix was higher than NS mix with 24%.
- 2%NS+8%SF mix achieved the best enhancement in split tensile strength test results. The percentage increase in split tensile strength is +11.1% and +20.6% for high strength concrete at the age of 7 days and 28 days respectively.
- In NS samples, the cement media was more compact, and the CaOH2 crystals are disappeared, and an almost complete hydration was achieved.
- The mix 2%NS, in the 7 and 28 days, has a structure of C-S-H gel that is denser and finer compared to sample of 1%NS.

Acknowledgements

The authors would like to thank the administration of the Higher Technological Institute (HTI), 10th of Ramadan City, Egypt, for providing possibilities in testing laboratories for conducting the practical program.

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