An Experimental study on Concrete Containing Nano and/or Micro Silica

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Abstract— **the effect of using Portland cement, nano silica (NS) and /or micro silica on the mechanical and physical properties of concretes containing fine aggregate only is investigated. Two groups divided into five series each have been designed and tested. The first group was containing the nano-silica only, while the second group contained different ratios of nano silica and a constant content of 8 % of silica fume (SF) (by weight) as partial replacement of cement. Water cementations ratio (w/c) of all mixtures was constant and equal to 0.22. The cement content in all series was 800 kg/m3. Commercially available nano silica (NS) was used in the mixture for the partial substitution of cement at ratios of 0, 0.5, 1.0, 2 and 3% by weight. It was found that the addition of nano –silica is significantly enhance compressive, tensile and modulus of elasticity of concrete. From the test results obtained it has been noted that the mix containing 2 % possess significantly improved mechanical properties, furthermore, the group samples of concrete containing binary cementations nano-silica and silica fume showed better results than concrete containing nano silica only.**

Index Terms— Silica, Concrete; Mechanical properties; Binary cementations; High-Performance

I. INTRODUCTION

Nowadays concrete as a building material plays the vital role in the building construction, therefore, it is very important to develop and improve its mechanical and physical properties by improving its component and/or using the new generations of the admixtures and additives. One of the greatest future promising concrete is the Ultra-High-Performance Concrete. UHPC, or Ultra-High-Performance Concrete, is a type of concrete with excellent mechanical and physical properties. It was used especially to overcome the requirements challenges in the particular applications that need high strength and corrosion resistance – marine anchors, piers and seismic structures. UHPC is one of the greatest promising type of concrete, which has been established in 1995 by (Richard, P. and Cheyrezy, M., 1995), [1], and recently defined by (Kay Wille et.al, 2011), [2], as a cement – based concrete with a compressive strength at least equivalent to 150 MPa. Today, the use of UHPC has expanded to cover a wide range of applications requiring its high strength (Zhao and Sun, 2014), [3]. The wide range production of ultra-high performance concrete (UHPC) can be attributed to its material ingredients and mixture proportioning, which leads to denser and relatively more homogeneous particle packing. A database was compiled from various research and field studies around the world on the mechanical and durability performance of UHPC (J.Smith et. al.2014), [4]. Reduction in porosity and therefore, improving the properties of concrete can be achieved by the use of the supplementary cementing material. The combination of partial substitution nano-silica and silica fume are among the most widely used additives to produce this type of concrete with its superior behaviōr and properties. Nano-silica is a highly amorphous material, its use leads to improve the mechanical and durability properties through the following listed mechanism, (Sanchez.F, Sobolev.K. (2010), [5].

1- Using nano-silica leads to reduce the volume of voids occupied by water, thus providing a dense, more homogenous and high permeability resistance matrix.
2- Enhancing the interfacial transition zone is the results of reducing the total voids content due to the production of Calcium-Silicate-Hydrate (C-S-H) gel when the nano-silica reacts with Calcium hydroxide.
3- As a pozzolan, micro silica provides a more uniform distribution and a greater volume of hydration products in this turn forming; as a filler, micro silica decreases the average size of pores in the cement paste. The resulting paste contains more of the strong calcium-silicate hydrates and less of the weak and easily soluble calcium hydroxides than do ordinary cement paste

In the last two decades, the technology of nano-structured material is developing at a surprising speed and will be applied extensively with many materials [Qing, Y., Zenan, Z., Deyu, K., Rongshen, C., 2007], [6]. Micro silica (silica fume) belongs to the category of highly pozzolanic materials because it consists essentially of silica in non-crystalline form with a high specific surface and thus exhibits great pozzolanic activity. A new generations of nano silica has been used around the world and has attracted many researchers from different fields due to its high silicon dioxide content and its Nano-size particles (10-9mm) be able to fill the porosity between cement and micro silica particles (Shaikh and Supit, 2014, Jo et al., 2007,[7]; Shaikh et al., 2014, [8]; Supit and Shaikh, 2013,[9]. Nano silica is a fine amphorous material which t is generally available in the form of an emulsion of colloidal silica. By using Nano silica the binder content may be reduced and also it prevents in early cracking of concrete. Due to its properties nano silica improves the microstructure and makes the matrix more impermeable and more durable. The compressive strength of concrete containing nano silica is increased significantly because nano silica

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addition produces a dense concrete, in addition, it reduces segregation and bleeding (S. Reshma, 2013),[10]. The mechanical and durability properties of concrete are mainly dependent on the gradually refining structure of hardened cement paste and the gradually improving paste–aggregate interface Addition of Nano silica into high-strength concrete leads to an increase of both short-term strength and long-term strength.

The main aims of this experimental study are to investigate the influence of nano and/or micro silica as additives on the mechanical and durability properties of concrete. This research will provide a good platform for future work in this field.

II. MARTIAL AND METHOD

The experimental programme carried out in this study consisted mainly of two stages. The first stage involved the mix design of concrete to ensure the acceptable workability in order to overcome the difficulties when adding the NS. While, in the second stage, the effects of using NS on various properties of plain lower powder concrete were investigated with and without 8% of micro silica.

The experimental programme was conducted to determine the compressive strength, splitting strength, modulus of elasticity and flexural strength at the ages of 14, 28 and 56 days.

A. *Materials*

1) *Cement:*

Cement used in this study was general purpose Type I Portland cement conformed to the Iraqi specification No. 5/1984, [11]. The chemical, physical and mechanical properties are stated in Table 1 and 2 respectively.

2) *Mineral Admixtures*

The chemical compositions and physical characteristics of SF and NS are stated in Tables 1 and 2. The results showed that both SF and NS used in this study are confirmed by the requirements of ASTM C-1240-00, [12].

3) *Chemical Admixture*

A highly efficient new generation of polycarboxylic based High-range Water Reducer Admixture (HRWRA) was used in the mixtures to adjust workability of the fresh concrete. According to ASTM C494 / C494M - 17, [13], this Superplasticizers is classified as type F and G. Table 3 provides the main properties of the superplasticizer.

TABLE I
CHEMICAL PROPERTIES OF PORTLAND CEMENT, SILICA, AND NANO-SILICA

Ingredient %	Portland Cement	Silica fume	Nano silica
CaO	60.72	0.44	-
SiO_2	22.71	88.86	99.8
AL_2O_3	5.54	0.71	-
Fe_2O_3	2.35	1.32	-
MgO	2.27	-	-
SO_3	2.31	0.41	-
K_2O	0.86	1.52	-
Na_2o	0.17	0.45	-
CL	0.0092	-	-
Loss on ignition	2.99	3.11	-

TABLE 2
PHYSICAL CHARACTERISTIC OF PORTLAND CEMENT, SILICA, AND NANO-SILICA

Physical characteristic	Portland Cement	Silica Fume	Nano Silica
Specific surface (m^2/kg)	392	21082	150000
Specific gravity	3.2	2.2	2.2
Initial setting time (min.)	220	-	-
Final setting time (min.)	252	-	-
Volume expansion (mm)	1.0	-	-
28 days compressive strength (MPa)	48	-	-

1. *Fine Aggregate (Sand)*

Natural sand with 1.18 mm maximum size was used as a fine aggregate in this research. Table 4 shows the grading of sand used in this work. The grading of sand is confirmed to Iraqi specification No.45/1984 (zone 1). The sulfate content, the bulk density, specific gravity and the absorption of the sand were 0.07 %, 1500 kg/m3, 2.65, and 1.2 % respectively.

TABLE 3
PROPERTIES OF SUPERPLASTICIZER

Properties	Results
Appearance	Light brown to yellow visco-liquid
Specific gravity at 20ºC	1.095 gm./cm^3
PH-Value	8.0
Alkali content (%)	≤ 1.0
Chloride content (%)	≤ 1.0

TABLE 4
PROPERTIES OF FINE AGGREGATES

Sieve size (mm)	Cumulative passing (%)	Limits of Iraqi Specification No. 45/1984	Cumulative retained (%)
4.75	94	90-100	6
2.36	75.6	65-95	24.4
1.18	54	30-70	46

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0.60	26	15-34	74
0.30	10.8	5-20	89.2
0.15	3.4	010	96.6
Finesse Modules			3.532
SO_3 content = 0.175 % < 0.5 % limits of I.Q.S No.45/1984			

B. Mix proportions

Table 2-5 shows the experimental program and mix proportions used in this study. In total, ten series of mixes divided into two groups, Group 1and Group 2 were considered. The first group was a control mix containing 0% SF and the cement is replaced by NS of 0, 0.5, 1.0, 2.0 and 3.0% by weight respectively, while the second group containing 8% SF and the same replacement of NS used in the first group. To obtain an adequate workability, varying amounts of superplasticizer were used as shown in Table 5. The mix series in Table 5 were classified according to SF and NS dose level. For instance, M8-2 specifies the mixture containing 8% of SF and 2% of NS. Many trial mixes were carried out to find the suitable mix that having the desirable properties in the fresh state, as measured by the flow test according to ASTM C-1437-07.

C. Mix Preparation

All concretes were mixed in a pan mixer using a constant water-to-binder ratio of 0.22. The mix has been prepared in the following sequence steps, dry binder and sand were mixed for about 3 minutes, the mixture was remixed for about 4 minutes after adding a half of the water required for the mix, then, the remaining water and admixture were added into the mixture to premix material for about 4 minutes. Fresh concrete was then cast into the molds. The casting specimens were remolded after 24 hours and then were cured in water until the day before the test date. Three specimens were cast and tested in each group. The types and dimensions of each specimen are shown in the experimental program of each test.

TABLE 5 MIX PROPORTIONS

Series	Mix index	Cement (Kg/m^3)	SF (Kg/m^3)	NS (Kg/m^3)	Water (Kg/m^3)	Superplasticizer (Kg/m^3)	Sand (Kg/m^3)
1	M0-0	800	0	0	200	20.8	1480
	M0-0.5	796	0	4	200	25.0	1480
	M0-1	792	0	8	200	28.6	1480
	M0-2	784	0	16	200	36.0	1480
	M0-3	776	0	24	200	44.2	1480
2	M8-0	736	64	0	200	30.2	1480
	M8-0.5	732	64	4	200	33.4	1480
	M8-1	728	64	8	200	38.0	1480
	M8-2	720	64	16	200	44.8	1480
	M8-3	712	64	24	200	52.2	1480

D. Experiment Procedures

1) Flow Test

Flow of concretes was measured according to ASTM C-1437-07,[14]. The mixes had a flow value that controlled by using an adequate amount of superplasticizer that has been given in table 5.

2) Compressive Strength Test

The compressive strength was measured at 14,28 and 56 days using 50 mm cubes according to ASTM C39 (2003),[15] at a load rating of 0.85 KN/sec. using a digital compressive testing machine of 3000 KN capacity. Each result presented in this paper is the average of three samples.

3) Indirect Tensile Strength

Indirect tensile strength was conducted on 100mm cubical samples at a rating load of 0.2 KN/sec. in accordance with ASTM C496 (2011),[16] at 7, 28 and 56 days. The test was performed on three samples for each mix.

1. Modulus of Elasticity

150 mm cubes at the age 56 days were used to determine the static modulus of elasticity in accordance with ASTM C496 (2010),[17]. In this study, three times the specimens were loaded and unloaded up to 45 % of the ultimate compressive strength capacity. The first set of reading for each specimen was neglected, and the average of the remaining two sets of reading was used to measure the elastic modulus of elasticity.

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III. RESULTS AND DISCUSSIONS

A. *Compressive Strength*

Figures 1 and 2 show the effect of using NS on the compressive strength of the concretes with and without SF. It can be seen that up to 2% replacements of NS, there is a significantly increased in the compressive strength at all ages, beyond this level of replacement strength began decreased, irrespective of SF content. It is also observed that concrete with or without SF had a 56-day strength of 109.6 and 100 MPa respectively. At 56 days a 2% of nano-silica substitution enhanced strength by 4.8 and 9.2% more than the companion control mix, respectively. At 28-days, similarly, the compressive strength improvement for the concretes with and without SF was almost 4.2 and 9 % respectively. Also, it can be noted from figures 1 and 2 that regarding the results obtained at 56-days, the compressive strength value of the mix containing 1% of nano silica and without silica fume (M0-1) was almost equal to that containing 8% of silica fume and zero doses of nano silica (M8-0). It could be observed that the concrete with 8% had a compressive strength of 93.6, 96 and 99.6 MPa at 14,28 and 56 days, respectively (Figure 2), while, the corresponding strength values for the 1% NS concrete were 93.6,96.8 and 99.2 MPa respectively (Fgure3-1-a). This could be attributed to the mechanism of works on concrete. NS was similar to the SF by an improvement in the packing density, particularly providing a dense interface between the pastes and aggregate. However, large quantities of Nano silica beyond 2%, NS in the mixtures, due to agglomerate effect, don't lead to increase the compressive strength of concretes.

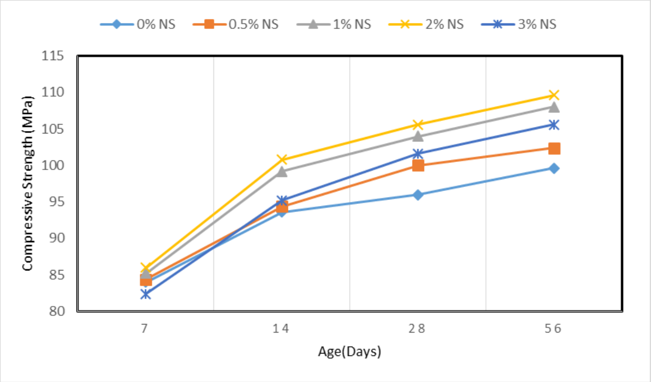

Fig. 1. Compressive Strength Development of Concretes Containing 0%

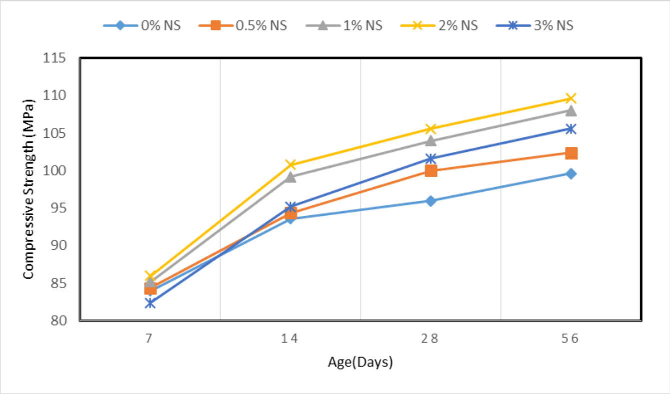

Fig. 2. Compressive Strength Development of Concretes Containing 8% SF

B. *Effect of Superplasticizer on the Flow of Concrete*

Table 5 shows the amount of the superplasticizer necessary to provide the acceptable target workability. It was clear that the superplasticizer demand and NS have a direct relation, so the mix containing NS required a greater amount of superplasticizer than this without especially at higher substitution level. It was observed that the concretes with 1% NS or 8% SF had similar superplasticizer demand as shown in Figures 3 and 4. Indeed the limited strength improvement using NS can also attribute to the fact of superplasticizer demand increasing to obtain a constant workability.

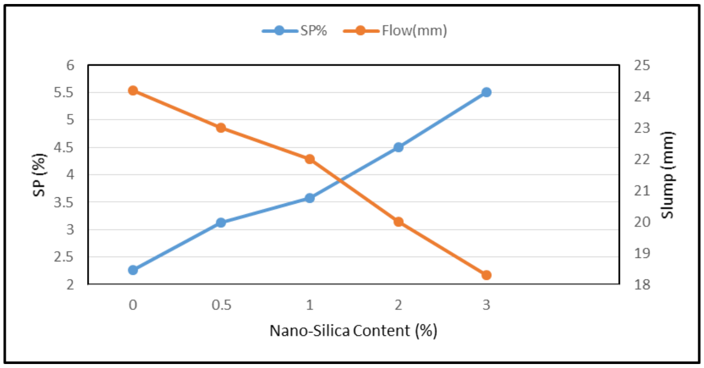

Fig. 3. Effects of NS and SP on the Flow of Concretes Containing 0% SF

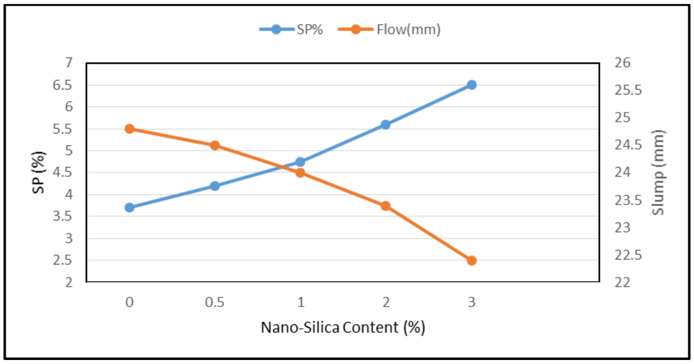

Fig. 4. Effects of NS and SP on the Flow of Concretes Containing 8% SF

C. *Indirect Tensile Strength*

The test results of split tensile strength concrete with various proportions of NS and SF replacement on the indirect tensile strength of concretes at 56 days age are shown in Figure 5. From this figure, it can be seen that the tensile strength increased with the addition of nano-silica up to 2%. Samples with the replacement of 8% FS as well as NS significantly behaved better than concrete samples containing only nano-silica addition. The tensile strength at the age of 56 days and addition of 8% SF and 0.5, 1.0, 2.0 and 3.0% of NS caused an increasing of splitting tensile strength by 6.4, 12.0, 17 and 10.2% respectively. The improving of the splitting strength when adding NS and FS is credited to a denser interfacial transition zone (ITZ) via helps of NS particles. The ITZ became more dense and compact due to the seeding and filling of the pozzolanic action of NS so the development of tensile strength is achieved (Said et al.2012). Moreover, the splitting tensile strength enhancement was limited beyond 2% NS. This can be attributed to the process of hydration such that the amount of silica particles in NS added to the mix was more than the amount required to combine with the other cementation material particles.

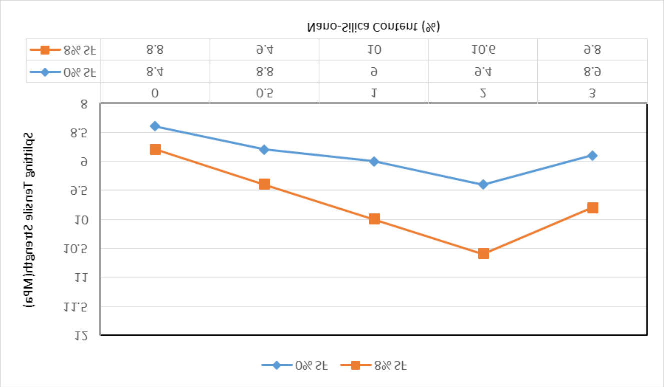

Fig. 5.Effects of NS and FS on Splitting Tensile Strength at 56 Days Age

D. *Modulus of Elasticity*

The test results of the modulus of elasticity of 56 days age concrete with various proportions NS and SF are shown in Figure 4. It can be observed that the modulus of elasticity of concrete increases with nano-silica with or without SF. The modulus of elasticity of concrete attains maximum value at a combination of 2% nano-silica and 8% SF by weight of cement. The increasing tendency took place up to 2% NS content, moreover, beyond 2% the modulus of elasticity is decreased gradually. The increase in the modulus of elasticity of concrete with 2% content is 6 % and 6.8% for concrete with 2%NS and 8%SF content respectively compared with the controlled mixture.

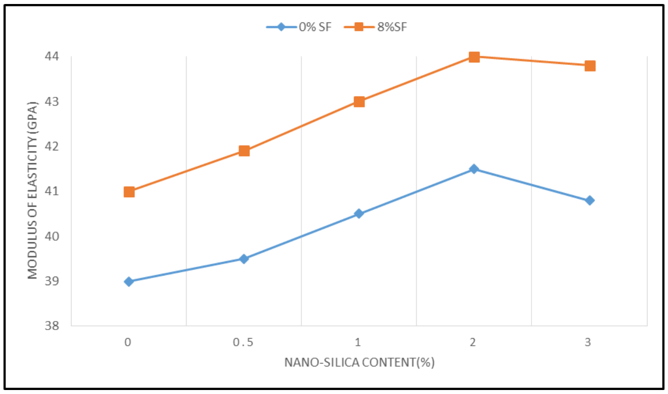

Fig. 6.Effects of NS and FS on the Modulus of Elasticity at 56 Days Age

IV. CONCLUSION

Based on the results obtained from the present experimental study on the effect of nano silica and silica fume on the mechanical properties of concrete, the following conclusions can be conducted.

1- From the results, it can be concluded that by increasing the percentage of nano silica up to 2% the different strength properties are increased, moreover beyond 2% the properties of concrete are decreased gradually.

2- It is observed that concrete with or without SF had a 56-day strength of 109.6 and 100 MPa respectively. At 56 days a 2% of nano-silica substitution enhanced strength by 4.8 and 9.2% more than the companion control mix, respectively. At 28-days, similarly, the compressive strength improvement for the concretes with and without SF was almost 4.2 and 9 % respectively.

3- The tensile strength at the age of 56 days and addition of 8% SF and 0.5, 1.0, 2.0 and 3.0% of NS caused an increasing of splitting tensile strength by 6.4, 12.0, 17 and 10.2% respectively.

4- The effect of 1% nano-silica is almost equal or near to that of 8% of silica fume at 14, 28 and 56 days.

5- Concrete with 1% nano-silica and 8% silica fume had the same superplasticizer demand to get the desirable workability flow.

6-The binary effect of NS with SF had a clear and advance effect on the concrete properties than their individual nanoparticles effect.

In general and based on the results obtained in this study, it could be suggested that using NS with or without silica fume is an attractive technique to enhance the mechanical and durability properties of concrete and improve its performance.

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