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Investigation of Using Nano-silica, Silica Fume and Fly Ash in High Strength Concrete

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ABSTRACT
This study aims to investigate the performance of hardened high strength concrete cast using Nano-silica, silica fume and fly ash. Experiments were conducted by substituting cement by weight with Nano-silica, silica fume or fly ash with ratios of 5 %, 10% and 15% and compared to a control mix. This study generally proposes a sustainable solution to produce durable concrete that could have useful application in the construction industry. Based on the results obtained, the hardened properties of concrete improved depending on the type of supplementary cementious materials. Test results showed that adding the suggested types is effective to improve concrete strength. Adding Nano-silica has a great influence on concrete properties. Increasing the dosage over 5.0% affects badly on strength.

***Keywords**:* High strength concrete; Nano-silica; silica fume; fly ash.

1. INTRODUCTION

In the present day, concrete is the most widely-used construction material in the world [1]. The construction industry uses concrete to a large extent. Roughly 35 billion tons used [2]. Due to the great development in the construction industry concrete has developed to keep pace with evolving and requirements of industry, one of the developed concrete is the high strength concrete "HSC". It is used for concrete mixture which has high strength, high workability, high durable, high density, low permeability and resistance to chemical attack as compared to normal strength concrete [3, 4]. High strength concrete "HSC" is often considered a relatively new material; it is improved over years due to the development of concrete additives such as water reducers (plasticizers and super-plasticizers). Definition of the minimum strength value for high-strength concrete varies with time and geographical location depending on the availability of raw material and the technical Know-how, and the demand from the industry [5]. Mechanical properties of HSC are sensitive to the type of coarse aggregates and curing techniques [6]. The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied loads. HSC can be obtained for some different special concrete types such as self-compacted concrete, self-curing concrete and recycled aggregate concrete [7, 8, 9].

By using fly ash, silica fume or other pozzolanic materials which are the most commonly used as mineral admixtures in high-strength concrete and ultra-high strength concrete. These materials impart additional strength to the concrete by reacting with Portland cement hydration products to create an additional C-S-H gel, the part of the paste responsible for concrete strength [10]. Addition of silica Nano particles has important implications for the hydration kinetics and the microstructure of the paste such as (a) an increase in the initial hydration rate, (b) an increase of the amount of C-S-H gel of the paste through pozzolanic reaction, (c) reduction of porosity, (d) improvement in the mechanical properties of the C-S-H gel itself (e.g., greater alumina-content, longer silicate chains) [11]. Nano-Silica, as well as silica fume, is a highly reactive pozzolan and could consume calcium hydroxide (CH) to form secondary C-S-H [12]. Chemically, Nano-silica addition increases the pozzolanic reactivity when compared to the silica fume [13, 14].

Silica is the common name for materials composed of silicon dioxide (SiO_2) and occurs in crystalline and amorphous forms. SF is also known as micro silica, condensed silica fume, volatilized silica or silica dust [15]. The American concrete institute defines silica fume as "Very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon". It is a grey coloured powder, similar to Portland cement or fly ash. SF is a very fine powder consisting mainly of spherical particles or microspheres, with a mean diameter of about 0.15 microns, with Avery high specific surface area (15,000–25,000 m^2/kg). Each microsphere is on average 100 times smaller than an average cement grain [16].

Fly ash, another popular pozzolan, can improve concrete properties such as workability, durability, and ultimate strength in hardened concrete [17]. Fly ash (FA) is a fine-grained solid material having a particle size range of 0.2–200 lm. The range of particle size of any given FA depends largely on the fineness of the pulverized coal and the type of flue Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies [18]. It is a fine powder resulting from the combustion of powdered coal - transported by the flue gases of the boiler and collected in the Electrostatic Precipitators [19]. Fly ash is a fine powder resulting from the combustion of powdered coal - transported by the flue gas scrubbing systems [20]. Millions of tons of fly ash produced each year due to the massive consumption of coal [21]. Physical properties of fly ash may vary depending on the nature of coal; rank, mineral matter chemistry and mineralogy, furnace design, furnace operation and method of particulate control, while chemical properties are less dependent on those factors [22]. Fly Ash (FA) as a supplementary cementitious material (SCM) increases the sustainability of concrete by decreasing CO_2 emissions from cement production. The addition of fly ash leads to higher porosity at a short curing time [23]. When fly ash is mixed with Portland cement and water, it generates a product similar to that formed by cement hydration, but having a denser microstructure that is less permeable [24]. The strength development of FA concrete, particularly that containing Class F fly ash, is slow compared to normal concrete that is not suitable for many applications where early strength is required, such as repairs and rapid construction [25]. Whereas, concretes containing SF are thought to be more susceptible to plastic shrinkage than any other type of concrete, particularly in structures with large surface areas [26].

In this research, the influence of using NS, SF or FA with high strength concrete with the compressive, tensile, flexure and bond strengths of concrete after different ages, 7, 28 and 56 days, will be studied and evaluated.

2. RESEARCH SIGNIFICANCE

Using pozzolanic additives improves concrete characteristics. Changing the pozzolanic additive type changing its effects on concrete. This research aims to study the effects of using different types of pozzolanic additives to obtain structural high strength concrete. The main variables at this investigation are; additive type *(fly ash, silica fume, and Nano-silica)* and an additive ratio *(5%, 10%, and 15%)* of the cement weight. The outputs of this research are experimental results that the researchers can use it to judge and use this type of concrete.

The innovation in this research is the comparative study of the properties and the behaviour of the pozzolanic additives used and their ratios in high strength concrete mixes.

The importance of this research is to provide sufficient data for the researchers and engineers that concerns in using high strength concrete "HSC" and the effects of using different pozzolanic additives to improve it.

3. EXPERIMENTAL PROGRAM

Materials

In the present work, Ordinary Portland Cement (OPC) of "CEM I 42.5 N" was used. The properties of the cement used were illustrated in Table 1. Basalt rock stones crushed using cone crusher having maximum size 12.5 mm was used as coarse aggregate. Natural siliceous sand from Naga Hammadi quarries, Qena governorate, was used as fine aggregates. The particle size distributions of fine aggregate and coarse aggregate are shown in Fig. 1 and the properties of aggregates were illustrated in Table 2. The properties of aggregates obtained in the laboratories of the Arab Contractors Company and it is characteristics satisfy the E.S.S. 1109/2008 and the Egyptian Code for Concrete Design E.C.P. 203/2018.

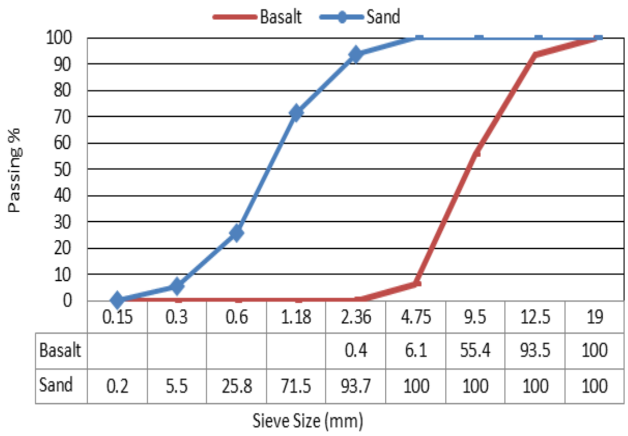

Figure 1- The particle size distribution of fine and coarse aggregate

Tap water was used in this investigation for the mix and cure of concrete mixes. High range water reducer as a super plasticizer was used to improve concrete workability. It obtained from the SIKA Company under a commercial name of Sika ViscoCrete®-3425.

Fly ash and silica fume as pozzolanic admixtures were obtained from SIKA Company. Nano-Silica of a crystalline silica particles (in Nano-size) synthesis of top-down techniques in which the large particles convert to small one. Silica used was obtained from Quartz mineral with silica more than 98.9% come from red sea quartz mining. The Ball milling technique was used to prepare Crystalline Silica Nano particles with multi-steps procedures. Particle size of Nano-silica lies between (40 to 140 nm), but the most particle sizes of Nano-silica distribution is about 80 nm as shown in Fig. 2.

To obtain Nano-silica properties, XRD tests, TEM image and SEM image were performed. XRD for mineral identification showed that 99.0% of the sample is composed of SiO2 as shown in Fig. 3. XRD pattern illustrated synthesis of Nano-quartz without any impurities during the synthesis process as shown in Fig. 4. XRD data illustrated a high crystallinity of Nano-quartz with hexagonal lattice structure. Crystal size measuring using XRD data was 22.7 nm. Raman shift curve illustrated the finger print Raman shift curve for quartz mineral without any additional peaks for other was associated minerals, which indicate to the high purity of Nano-quartz. However, there are three very characteristic peaks at 127.57, 205.32 and 464.16 cm^{-1} and 10 weak peaks at 263,354, 383.18, 384.92, 694.58, 795, 806, 1022, 1085 and 1160 cm^{-1} as shown in Fig. 4. TEM image (Fig. 5), shows the spherical shape of quartz Nano particles. The agglomeration and concentration were well sorted. SEM image (Fig. 6) showed the 3D spherical shape of quartz Nano particles.

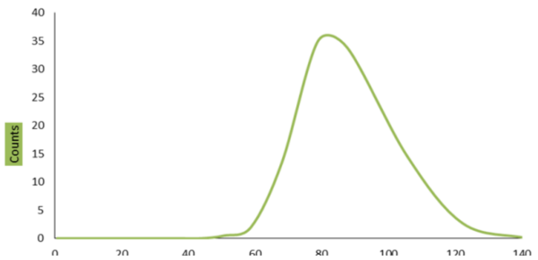

Figure 2- Particle size distribution of silica Nano particles

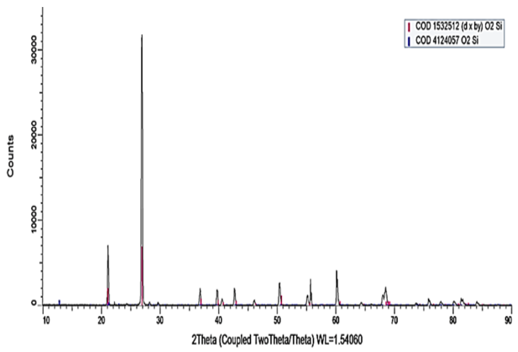

Figure 3- Mineral identification of silica Nanoparticle

Table 1- The properties of the cement used

Test description	Test results	E.S.S. limits
Specific gravity	3.15	--
standard consistency w/c %	27%	--
Setting time (Vicat) Initial Final	hr : min 2 : 30 8 : 50	E.S 2421-1/2005 Not less than 60 min. Not more than 10 hr.
Fineness of cement	7%	Not more than 10%
Com. strength 2 days 28 days	 18.4N/mm^2 44.7N/mm^2	E.S 2421-7/2006 10 N/mm^2 (42.5-62.5) N/mm^2
Size stability (mm)	1.0 mm	E.S 2421-1/2005 (Not more 10 mm)
Loss of burning	3.02%	E.S 5325/2006 (Not more 5%)
Insoluble substances	1.670	E.S 5325/2006 (Not more 5%)

Table 1-continued The properties of the cement used

Sulfate content (SO3)	2.470	E.S 5325/2006 (Not more 3.5%)
Chloride content	0.034	E.S 5325/2006 (Not more 0.1%)

Table 2- The properties of properties of the fine and coarse aggregate used

Test description	Sand	Basalt
Volume weight	1.74 t/m^3	1.64 t/m^3
Specific gravity	2.65	2.81
Fineness modulus	3.1	-----
The ratio of fine materials	0.8	0.5 %
Chloride content	0.036 %	0.008%
Sulfate content (SO3)	0.18 %	0.059%
Organic impurities	Nothing	Nothing
Aggregate impact value	------	10.75
Aggregate crushing value	------	16.33 %

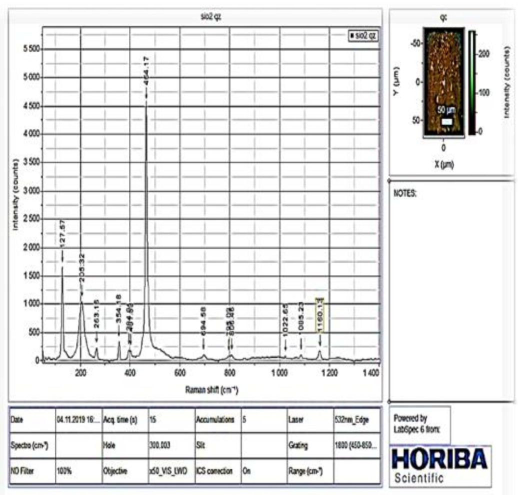

Figure 4- Raman shift shows the chemical composition of the sample consists mainly of SiO_2

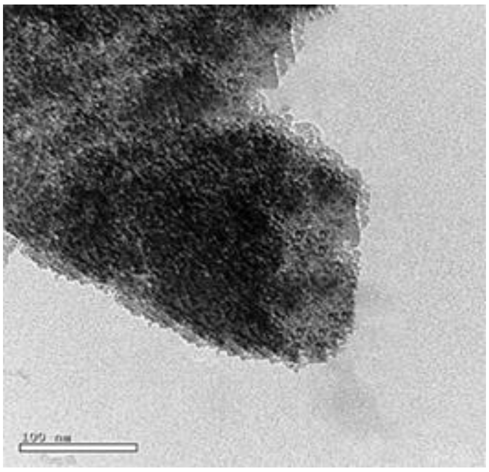

Figure 5- TEM image of Nano-quartz

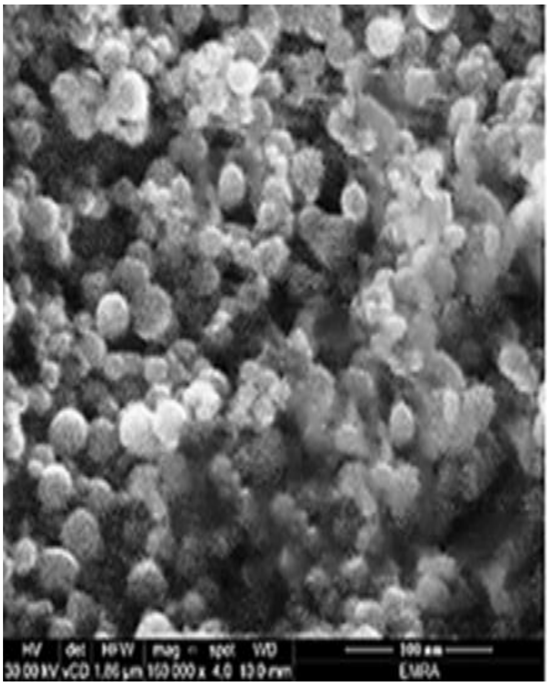

Figure 6- SEM image of Nano-quartz

All Nano-silica experiments were done in Egypt Nanotechnology Centre at Cairo University, El-Sheikh Zayed city. We use the following instruments in testing:

1. Nano Sight (NS500) Instrument (Malven, UK) was used to analyze the particle size and zeta potentials for the obtained Nano particles.
2. XRD for mineral identification carried out by Bruker company model D8 (including reflectometry, high-resolution diffraction, in-plane grazing incidence diffraction (IP-GID), small angle X-ray scattering (SAXS), as well as residual stress and texture investigations).
3. Study surface area and pore volume using surface area and pore size analyzer model Nova Touch LX2 manufacture by Quanta Chrome Company made in the USA.
4. Raman spectrometer, which show 2D and 3D confocal images showed the shape of particles with different color (every color refer to one of chemical composition consist of materials) and its Raman shift determine the chemical composition with three different laser source 325 nm, 532 nm and 785nm.
5. AFM (Atomic Force microscope) Model 5600LS manufactured by Agilent Technology Company.

Concrete Mixes

In this study, high strength concrete was designed based on ACI 211-4R 93 guidelines by using excel sheet. The chosen concrete mix of HSC used is obtained based on research conducted by (Annadurai and Ravichandran, 2014) [27]. Totally ten mixes were used, the first was a control mix without any cement replacement. Three mixes were cast using silica fume (5%, 10%, or 15% as a replacement of cement weight). Three mixes were cast using Fly ash (5%, 10%, or 15% as a replacement of cement weight) and three mixes were designed with Nano-Silica quantities 5%, 10%, or 15% as a replacement of cement weight), the Proportions of concrete Mixes used are shown in Table 3. The specimens demolded after 24 hours and kept curing until the day of the test. The experimental program is shown in Fig. 7; all tests were carried out according to Egyptian Standard Specifications (E.S.S.).

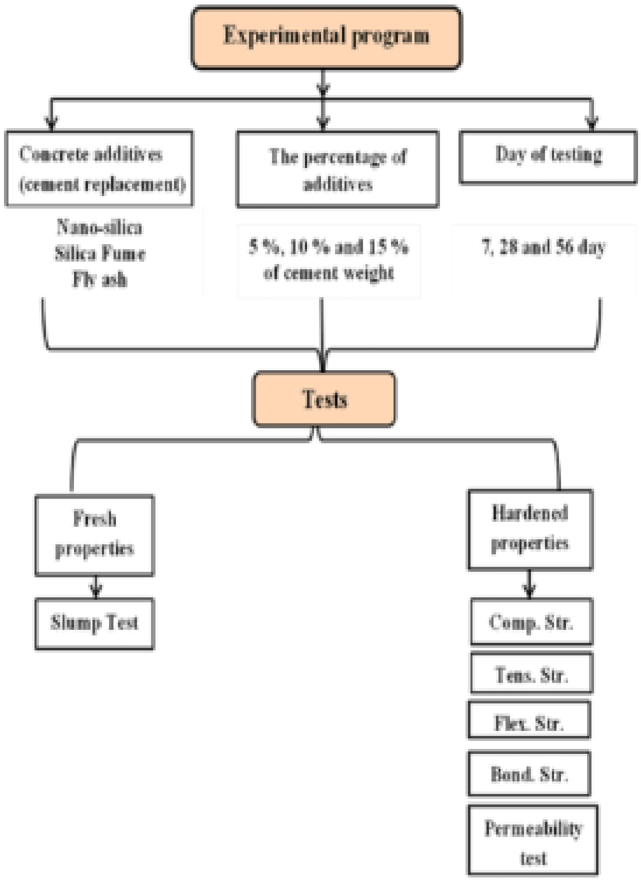

Figure 7- The flow chart of the experimental program

Table 3- Proportion of concrete mixes used (stage 1 – conventional water curing)

<table>
<tr><th rowspan="3">Mix code</th><th colspan="8">Components (kg)</th><th colspan="5">Tested samples</th></tr>
<tr><th rowspan="2">C</th><th rowspan="2">W</th><th rowspan="2">F.A</th><th rowspan="2">C.A</th><th rowspan="2">Viscocrete</th><th colspan="3">Cement replacement</th><th rowspan="2">Compressive strength</th><th rowspan="2">Tensile strength</th><th rowspan="2">Flexure strength</th><th rowspan="2">Bond strength</th><th rowspan="2">Permeability test</th></tr>
<tr><th>Type</th><th>Percentage %</th><th>Weight</th></tr>
<tr><td>B1</td><td>512</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>--</td><td>--</td><td>--</td><td rowspan="10">9 Cubes 15*15*15 cm for each Mix.</td><td rowspan="10">6 cylinders 15 * 30 cm for each Mix.</td><td rowspan="10">6 beams 10*10*50 cm for each Mix.</td><td rowspan="10">6 cubes 15*15*15 cm for each Mix.</td><td rowspan="10">1 cube 20*20*12 cm for each Mix.</td></tr>
<tr><td>NS1</td><td>486</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td rowspan="3">Nano-Silica</td><td>5</td><td>25.6</td></tr>
<tr><td>NS2</td><td>460</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>10</td><td>51.2</td></tr>
<tr><td>NS3</td><td>435</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>15</td><td>76.8</td></tr>
<tr><td>SF1</td><td>486</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td rowspan="3">Silica Fume</td><td>5</td><td>25.6</td></tr>
<tr><td>SF2</td><td>460</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>10</td><td>51.2</td></tr>
<tr><td>SF3</td><td>435</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>15</td><td>76.8</td></tr>
<tr><td>FA1</td><td>486</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td rowspan="3">Fly Ash</td><td>5</td><td>25.6</td></tr>
<tr><td>FA2</td><td>460</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>10</td><td>51.2</td></tr>
<tr><td>FA3</td><td>435</td><td>163</td><td>673</td><td>1174</td><td>2.56</td><td>15</td><td>76.8</td></tr>
</table>

Test specimens

The specimens used in this study were categorized into five standard groups of samples. Concrete cubes 15 x 15 x 15 cm to determine the compressive strength of concrete mixes. Cylinders with 15 cm diameter and 30 cm height were used to determine the tensile strength of concrete mixes. Prisms with a square section of 10 cm side length and 50 cm total length were used to determine the flexural strength of concrete mixes. Concrete cubes 15 x 15 x 15 cm were used to determine the bond strength of concrete mixes. Permeability tests were conducted by using cubes with dimensions of 20 x 20 x 12 cm to study the penetration depth of water under pressure in concrete.

Table 4- Slump values of different mixes

Mixes: Supplementary cementious materials	Ratio	Code	Slump Value *(mm)*
Control mix	0	C.M.	200
Nano-Silica	5%	NS1	125
	10%	NS2	90
	15%	NS3	70
Silica-Fume	5%	SF1	200
	10%	SF2	165
	15%	SF3	135
Fly-Ash	5%	FA1	250
	10%	FA2	230
	15%	FA3	210

4. RESULTS AND DISCUSSION

Fresh Properties of Concrete Mix

The Fresh concrete properties represented in the slump values were conducted for all concrete mixes to show the variation of using different supplementary cementious materials (Nano-silica, Silica-fume, and Fly-ash) with different ratios. The results are shown in Table 4. The slump value decreases as increasing the dosages of Nano-silica, Silica-fume and Fly-Ash. Also, it shows that the flowability of concrete mixes contains Nano-silica is lower than concrete mixes contain Silica-fume. Concrete mixes with fly-ash show high slump values. That may be led to segregation in concrete. So, reducing the super plasticizer dosage with using fly-ash is recommended.

As the fineness of supplementary cementious materials increases, the surface area becomes larger which requires more water for hydration or for workability. Using different supplementary cementious materials requires a different dosage of chemical admixtures.

Mechanical Properties

The main studied mechanical properties are compressive, splitting tensile, flexural, bond strengths and permeability test. The results are shown in Table 5. and Figs. 8. to 12. Results obtained from the compressive strength test are plotted graphically as reported in Fig. 8. The compressive strength of the control mixture compared to the other concrete mixtures to show the impact of using different supplementary cementious materials with different ratios. The concrete mixture with 5% fly ash content show a little increase in compressive strength by about 0.2% after 28 days and 3.3% after 56 days than the control mixture, while the concrete mixture with 10% fly ash content decreased by about 16% than the control mixture, and the concrete mixture with 15% fly ash content decreased by about 19% than the control mixture. The decrease of compressive strength may cause due to constant w/cm, that fly ash require reducing water content by approximately 3% for each 10% fly ash compared to similar mix without fly ash [28]. The delay of the hydration process for the specimens with fly ash.

At early ages, the compressive strength of fly ash concrete is less than the control mixture. Concrete with high percentages of fly ash can be used in situations where strength is not important economy is required. The decrease of compressive strength may cause due to constant w/cm, that fly ash require reducing water content by approximately 3% for each 10% fly ash compared to similar mix without fly ash That is in agreeing with other researches [29, 30, 31].

The concrete mixture with 5% silica fume content show an increment in compressive strength by about 4.0% after 28 days, with increasing silica fume ratios up to 10% the compressive strength increased by about 9.7% after 28 days. While the concrete mixture with 15% silica fume content increased by about 6.4% than the control mixture, but it is less than the concrete mixtures with 10% silica fume. Silica fume increases the concrete properties by two ways: first, its small particles act as a filler for the spaces between cement and aggregate particles. Second, SF reacts with CH to produce a greater solid volume of C–S–H gel, tends to an additional reduction in capillary porosity during hydration. This result is matched with (Saini and Nayak, 2019) [32]. The concrete mixture with 5% Nano-silica content show an increment in compressive strength by about 9.7% after 28 days than the control mixture. While concrete mixture with 10% Nano-silica content show an increment in compressive strength by about 7.3% after 28 days than the control mixture, although it is less than that mix with 5% Nano-silica. While concrete mixture with 15% Nano-silica content show an increment in compressive strength by about 5.1% after 28 days compared to the control mixture. Nano-silica increases the compressive strength and enhance the mechanical properties of concrete, this can be attributed to the reaction of silica with calcium hydroxide (pozzolanic reaction) resulted from cement hydration besides the formation of C–S–H gel. Also, the high specific surface of NS enables it to do very well. Where the compressive strength decreases with the increasing Nano-silica ratio, but it is still greater than the control mix compressive strength. That was explained as follows: as the quantity of SiO_2 Nano-particles added to the mix is greater than that needed to syndicate with the liberated lime through the hydration process, the extra silica, which does not contribute to concrete strength, replaces portions of the CMs materials and thus decreased the strength. When the NS percentage is large, the weak zone in concrete increases then compressive strength decreases. This decrease is owing to the agglomeration and defects generated in the dispersion of NS particles this result is matched with (Sharaky et. al., 2019) [33].

Results obtained from the tensile strength test are plotted graphically as reported in Fig. 9. The tensile strength of the control mixture compared to the other concrete mixtures to show the impact of using different supplementary cementious materials with different ratios. The concrete mixtures containing fly ash have higher tensile strength than control mixture, the tensile strength decreases with increasing fly ash. The concrete mixtures with 5%, 10%, and 15% of fly ash content show an increment in tensile strength by about 13%, 10% and 5%, respectively after 28 days compared to the control mix. The concrete mixtures with 5%, 10% and 15% silica fume content show enhancement in tensile strength by about 18%, 27% and 17%, respectively compared to the control mix after 28 days. When using Nano-silica in concrete mixes as 5%, 10% and 15% of cement content, an enhancement in tensile strength by about 62%, 53% and 32%, respectively were obtained compared to the control mixture after 28 days. Better split tensile strengths were obtained in the concretes blended with nanoparticles in comparison to the control concrete. . The strength increases may be attributed to the pozzolanic reaction and filler effect of nanosilica and the reason for the reduced strength improvement at later ages may be due to lack of proper dispersion of the nanosilica particles and the lack of formation of calcium hydroxide at later ages for the pozzolanic reaction of unreacted silica fume. This result is matched with (Ganesh, R. Murthy, S. Kumar, M. S. Reheman and Iyer, November 2015) [34].

Table 5- The test results of hardened properties of concrete mixes

Mix Code	Compressive Strength *(MPa)*			Tensile Strength *(MPa)*			Flexural Strength *(MPa)*			Bond Strength *(MPa)*			Permeability test *(mm)*
	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days	28 days
C.M	50.3	60.78	61.8	2.67	3.31	4	6.28	7.31	8.91	21.22	25.46	27.58	9
FA1	50.7	60.9	63.87	3.19	3.76	4.1	6.37	10.3	10.53	22.28	26.34	29.7	36
FA2	46.6	50.76	56.3	3.1	3.65	3.89	6.51	10.1	10.18	18.1	20.16	25.46	26
FA3	43.1	48.77	54.87	3	3.5	3.89	6.52	9.05	9.36	17.5	20.00	23.34	15
SF1	52.5	63.4	66.6	3.3	3.92	4.53	8.196	9.11	9.88	28.6	38.2	38.2	0
SF2	55.9	66.5	67.95	3.83	4.22	4.66	9.66	9.81	10.44	28.6	40.32	42.44	4
SF3	55.1	64.7	66.16	3.89	3.89	4.11	9.62	9.74	10.23	27.58	39.38	41.44	8
NS1	63.4	66.74	67.6	5.01	5.38	5.38	10.8	11.5	12.46	38.1	40.32	41.8	0
NS2	60.8	65.23	65.91	4.88	5.09	5.28	8.11	8.77	8.78	33	35.01	36.8	0
NS3	59.2	63.87	64.1	4.01	4.38	4.48	8	8.68	8.68	30.91	33.95	34.8	8

Results obtained from the flexural strength test are plotted graphically as reported in Fig. 10. The flexural strength of the control mixture was compared to the other concrete mixtures to show the impact of using different supplementary cementious materials with different ratios. The concrete mixtures containing fly ash have higher flexural strength than control mixture, but the flexural strength decreases with increasing fly ash content. The concrete mixture with 5%, 10% and 15% fly ash content show an increment of flexural strength by about 41%, 38% and 23%, respectively after 28 days than the control mixture. The concrete mixtures with 5%, 10% and 15% of silica fume content show enhancement of flexural strength by about 24%, 34% and 33%, respectively than the control mixture after 28 days. While concrete mixtures with 5%, 10% and 15% of Nano-silica content show enhancement of flexural strength by about 57%, 19% and 18%, respectively than the control mixture after 28 days.

Results obtained from the bond strength test are plotted graphically as reported in Fig.11. The bond strength of the control mixture compared to the other concrete mixtures to show the impact of using different supplementary cementious materials with different ratios. The concrete mixtures containing 5% of fly ash have higher bond strength than control mixture. The bond strength decreases with increasing fly ash. The concrete mixture with 5% fly ash content show an increment in flexure strength by about 35% after 28 days compared to the control mixture. As used 10% and 15% of fly ash content there is a decrease in bond strength by about 20% and 21%, respectively after 28 days compared to the control mixture. The concrete mixtures with 5%, 10% and 15% silica fume content show enhancement in bond strength by about 50%, 58% and 54%, respectively than the control mixture after 28 days. While concrete mixtures with 5%, 10% and 15% Nano-silica content show enhancement in bond strength by about 58%, 37% and 33%, respectively than the control mixture after 28 days.

Results obtained from the permeability test are plotted graphically as reported in Fig. 12. The permeability test expressed by the penetration depth of water in concrete samples. The penetration depth decrease with increasing fly ash content and all concrete mixtures containing fly ash have a higher penetration depth than the control mixture. The penetration depth increases with the increasing silica fume content and all concrete mixtures containing silica fume have a lower penetration depth than the control mixture. The best samples showed in permeability test are represented by 5% and 10% Nano-silica concrete mixtures and 5% silica fume concrete mixtures that its value is zero (no penetration of water in the concrete). The penetration depth of the concrete mixtures containing 10% silica fume as a replacement of cement decreased by about 55% than the control mixture after 28 days.

Generally, high strength concrete "HSC" requires a higher quality of the materials used so it is preferred to use fine aggregates with a high value of fineness modulus and clear of fine materials and the type of coarse aggregate is very important in high strength concrete and has a great influence on the concrete strength. High strength concrete requires a low w/c ratio, so the use of superplasticizer enhances the main fresh and hardened concrete properties and decrease water content in concrete mixture. The strength of concrete varies accordingly the cement grade and its chemical composition.

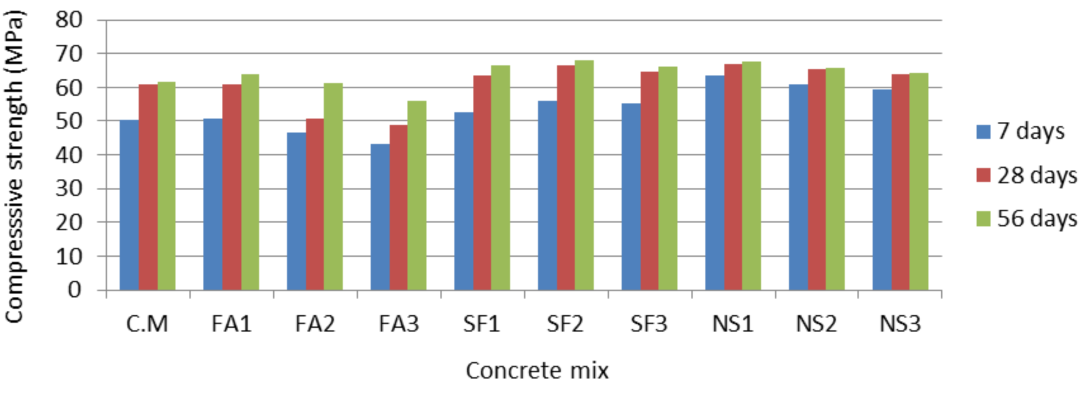

Figure 8- Compressive strength of HSC using different ratios (5%, 10%, and 15%) of fly ash, silica fume and Nano-silica compared to control mix at 7, 28 and 56 days

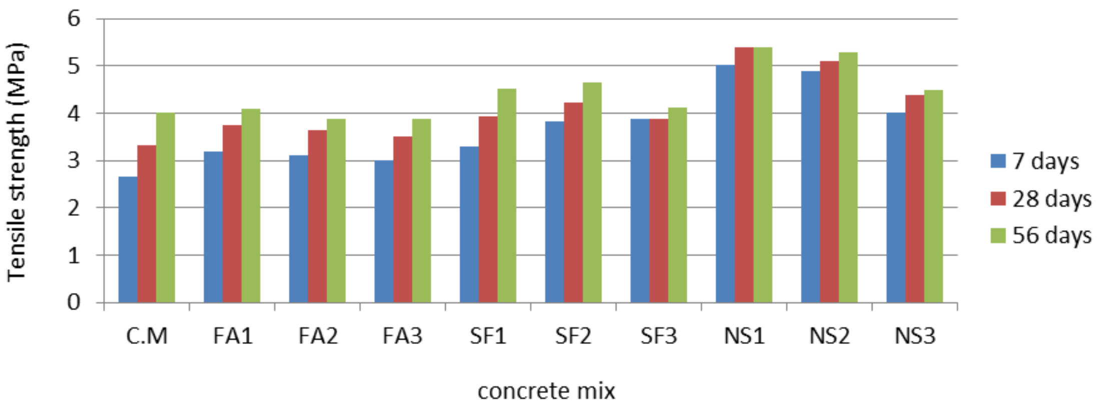

Figure 9- Tensile strength of HSC using different ratios (5%, 10%, and 15%) of fly ash, silica fume and Nano-silica compared to control mix at 7, 28 and 56 days

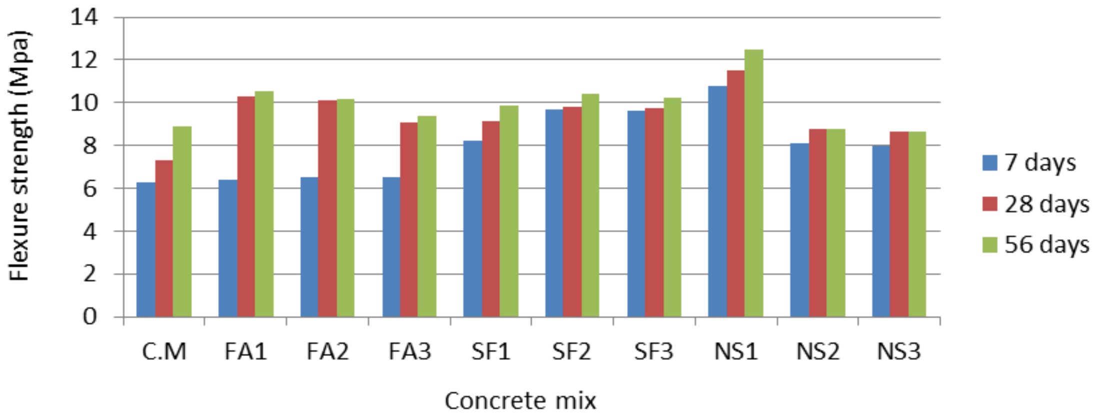

Figure 10- Flexure strength of HSC using different ratios (5%, 10%, and 15%) of fly ash, silica fume and Nano-silica compared to control mix at 7, 28 and 56 days

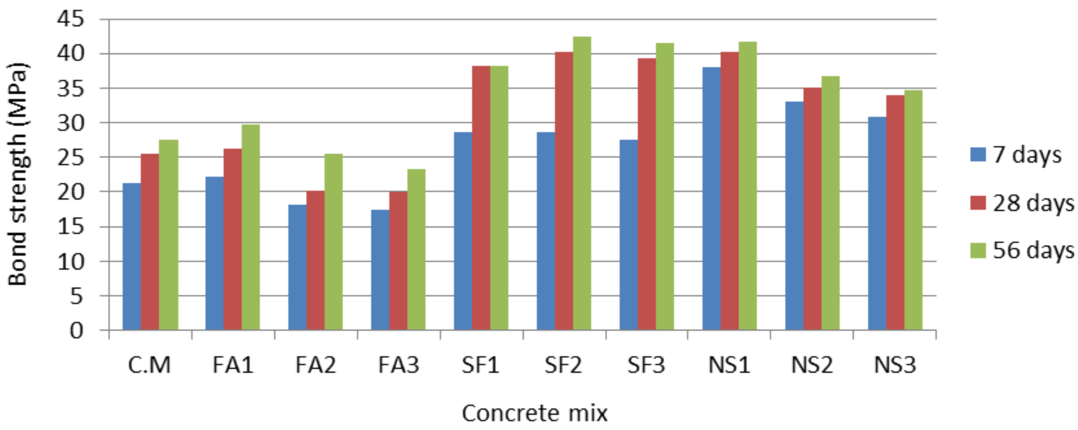

Figure 11- Bond strength of HSC using different ratios (5%, 10%, and 15%) of fly ash, silica fume and Nano-silica compared to control mix at 7, 28 and 56 days

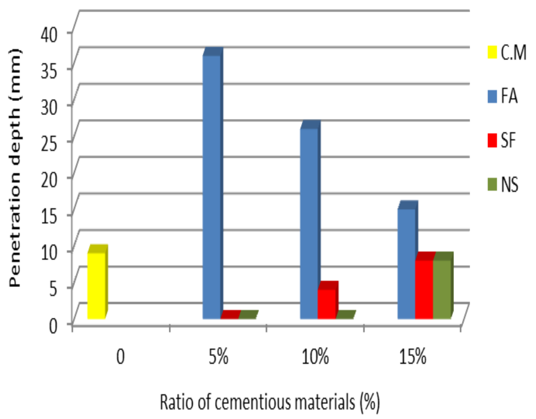

Figure 12- Permeability of HSC using different ratios (5%, 10%, and 15%) of fly ash, silica fume and Nano-silica compared to control mix after 28 days

5. CONCLUSIONS

The main conclusions based on the results of this study can be summarized as follows:

1. Slump values decrease with the increasing of supplementary cementious materials. Slump values decrease in concrete mixes with Nano-silica than that with silica fume and fly ash due to its large surface area.
2. Using silica fume and Nano-silica improves the main properties of high strength concrete.
3. The compressive strength of fly ash concrete mixtures decreases with the increasing of fly ash content in concrete mixtures according to this study. The compressive strength of concrete samples with 5% of fly ash slightly higher than the control samples, while the compressive strength of 10% and 15% fly ash concrete samples was less than that for control samples.
4. The compressive strength of concrete mixtures containing silica fume higher than control mixtures.
5. The compressive strength of concrete mixes with silica fume increases with the increasing of silica fume content in concrete mixtures up to about 10% content It show a decrease in the compressive strength as using 15% silica fume content. The best results achieved by using silica fume as 10% of cement content.
6. All concrete mixtures containing Nano-silica achieved a higher compressive strength than the control mixtures. Using dosages more than 5 % of Nano-silica leads to reverse results that the test results showed a decrease in the compressive strength of concrete mixtures as increasing the Nano-silica content.
7. Tensile strength improved as using fine materials, especially as using silica fume and Nano-silica. As used silica fume as 10% of cement content, the best tensile strength obtained. As using Nano-silica, the best tensile strength value obtained by using a ratio of 5%. The tensile strength increases as using pozzolanic admixtures up to optimum value, then decrease as increasing their content.
8. All concrete mixtures containing fly ash, silica fume and Nano-silica have a higher flexure strength than the control mixture. The best flexure strength results of tested mixes obtained as using 5% Nano-silica or as using 10% silica fume concrete mixture or as using 10% fly ash as additive in concrete mixtures. The flexure strength increases by adding fly ash, silica fume or Nano-silica in concrete mixes up to optimum value, then it decreases as increasing their dosage.
9. The bond strength increases up to optimum value, then it decreases as increasing the content of fly ash, silica fume or Nano-silica in concrete mixes as pozzolanic additives. In silica fume concrete mixes the best bond strength values achieved by using 10% of silica fume or as using 5% Nano-silica concrete mixtures.
10. When considering the permeability of obtained concrete, the fly ash concrete mixtures show a high rate of water penetration depth, the Nano-silica concrete mixture is impermeable concrete and show no penetration depth, in silica fume concrete mixtures the penetration depth increases with increasing silica fume content. The best results of the permeability test represented by 5% and 10% Nano-silica concrete mixtures and 5% silica fume concrete mixture that show no penetration depth which considered impermeable concrete.
11. Using pozzolanic admixtures is effective to improve the strength and permeability of high strength concrete. The strength increases by adding fly ash, silica fume or Nano-silica in concrete mixes up to optimum dosage, then it decreases as increasing their content.

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