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Performance of the lightweight concrete with available nano-silica in case fully replacement of coarse aggregate

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Abstract—A lot of research has been done on the nano-silica show its effect on enhancing both strength and durability of concrete. Nevertheless, there are few types of research in the field of using nano-silica with lightweight concrete. The objective of this research is to investigate the performance of lightweight concrete with nano-silica. Different concrete mixes with 350 kg/m3 cement content and 0.4 as a constant water-cement ratio were produced with different dosage of nano-silica Different mixes were produced using LECA with different dosage of nano- silica (0.75%, 1.5%, and 2%). Strength and durability of all mixtures were studied, also the microstructure of concrete mixes was observed. The test results demonstrated that using nano-silica improved the compressive and tensile strength. At the compressive strength, it is considered that the percent 0.75% of nano- silica is the ideal percentage at ages 7, 28 and 90 days. Adding nano-silica produced more homogeneity and fewer voids in the concrete microstructure. Comparing the results of this research by the results of previous research, this research has proved a clear improvement in strengths using LECA with nano-silica at densities (1400-1600) kg/m3.

Index Terms— Nano-silica, lightweight aggregate concrete, Light expanded clay aggregate (LECA), Hardened properties, Durability, Microstructure visualization, lightweight concrete beam, flexure test.

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1 INTRODUCTION

There are a lot of studies around the world about nano-silica and lightweight concrete. [13] Mentioned that Lightweight concrete (L.W.C.) has been used since the days of the Roman Empire when many different materials have been used for fine arts and temporary structure works. At 20th century, the limited resources and technology available have been superseded by the improved technology and organized research possible only through the shared knowledge and shared financial support offered by a formal industry association, the expanded shale clay and slate institute that founded in 1952.[22] classified the concrete based on unit weight into three categories what the Low-strength concrete: less than 20 MPa (1800 kg/m3), Moderate-strength concrete: 20 to 40 MPa (1800 to 3500 kg/m3) and High-strength concrete: more than 40 MPa (3500 psi).so Moderate-strength concrete also referred to as ordinary or normal concrete, is used for most structural work. High-strength concrete is used for special applications. [1,23,24] agreed on two sources of lightweight aggregate: 1) natural materials sources such as shales, clays, pumice, diatomite, volcanic cinders, and slates or artificial materials source (by-products) such as iron blast furnace slag, clay, sintered fly ash, and shale.

Also, lightweight aggregates of lightweight aggregate concrete were classified into three categories depending on the air dry unit weight of the lightweight aggregate concrete at figure(1):

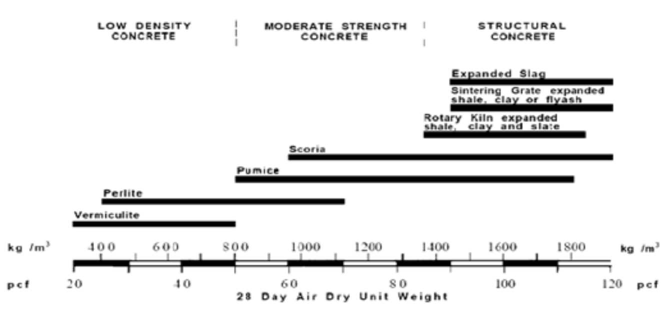

Fig (1): the lightweight aggregates classification chart [1]

[1,13,18] have proved that The expanded clay aggregate can use to produce the structural lightweight concrete beginning 1500kg/m3 weight. The polystyrene and perlite get unstructured at the low-density concrete by laboratory experiments. Also, the last one confirmed that the foamed concrete is not suitable to be a structural concrete. Lightweight Expanded Clay Aggregate (LECA) is a special type of clay that has been pelletized at high temperature. As it is fired, the organic compounds in the clay burn off forcing the pellets to expand and become honeycombed while the outside surface of each granule melts and is sintered. The resulting ceramic pellets are lightweight, porous, chemically inert, have a neutral ph. value and non-biodegradable. They are also non-combustible, have excellent sound and thermal insulation properties, contain no harmful substances, are resistant to frost and chemicals and will not break down in water. These previous findings had been shown by [25]. The lightweight concrete is classified into three type's lightweight aggregate concrete, aerated concrete and no-fines concrete so the lightweight concrete is different normal concrete in certain materials. Advantages of lightweight concrete are a higher strength to weight ratio as compared with normal concrete, enhanced in thermal, sound insulation and fire resistance properties [18, 19].

Although the cubic meter of lightweight concrete may be sometimes more expensive than the cubic meter of normal concrete. Using the lightweight concrete in construction especially in tall buildings will reduce the total cost of construction because of reduction dead load result of reduce structural el-

ements and minimize the steel reinforcement [9, 15, 17, 18, 32].
The density of concrete is found to decrease with the increase in percentage replacement of normal aggregate by Light Expanded Clay Aggregate. Compressive Strength and split tensile strength of concrete are found to decrease from 34.60 to 21.77 MPa and 3.20 to 1.5 MPa respectively with increasing in LECA content from 0% to 100% [30].
[16] Showed LECA mixtures with 400 kg/m3 cement content and 0.5 water-cement ratios. Mixtures were mixed with and without linen fibers by densities 1340 and 1440 kg/m3 that have compressive strength at 7 and 28 days 10.2 and 11.8 MPa for the first one and 9.3 and 10.4 MPa for the second mixture respectively.

Recently, Nanotechnology is one of the most worldwide important researchers which have wide applications in almost all the fields. Generally, nanotechnology has a good effect in improving the engineering materials especially nano silica that has a big role to improve concrete.
[28] Studied a liquid form of nano-silica particle (40.6 % SiO2 of slurry weight) in five different dosages (0, 0.2, 0.4, 0.6 and 0.8 % by weight) added to the Portland cement paste. The compressive strength increased with the amount of nano-silica until it reached an optimal amount of 0.6 % and then dropped to some lower value at 0.8 % addition. [29] Showed that the addition of small amounts of NS (i.e., 0.25%) caused 10% increase in compressive strength at 28 days. [21] Demonstrated the effect of NS addition on the permeability of eco-concrete. It was shown with a mercury porosity test that the relative permeability and pores sizes decreased with the addition of 1 and 2% NS by weight of cement. Addition of 0.6 % obtained the highest compressive strength at all ages.
[26] Used different dosages of nano- silica (1, 2, 3, 4, and 5% of cement weight) added to high-performance concrete. The compressive strength of concrete had shown an increasing trend with the increase in the quantity of nano-silica but the increment was stopped when the Nano-silica was beyond 2%.The strength of concrete has drastically decreased by 50% when the Nano-silica is at 4%. Based on the above and because of few national resources, broken clay brick, crushed red brick, broken a light building brick and polystyrene surrounded with cement will be used as lightweight aggregate for an attempt in addition to light expanded clay aggregate to get structural lightweight concrete at the medium densities. Also in this study the effect of adding nano silica by the different dosages to the suitable lightweight concrete mixture of the target density range (1400:1500) kg/m3 and the constant water to cement ratio (w/c= 0.4). According to [20] the nano-silica was effective in improving the strength, with increasing amount cement replaced. The Scanning Electron Microscope (SEM) observations also revealed that the nano-silica was not only acting as a filler but also as an activator to promote hydration. If the nanoparticles were uniformly dispersed it could improve the microstructure of the cement paste as well. Also, it is effective to add nano-SiO2 particles to cement mixtures for introducing high-performance to concrete because nano-silica behaves not only as filler to improve mortar cement microstructure but also as a promoter of pozzolanic reaction. [11]
The use of lightweight concrete in the construction of the floor slabs in tall buildings will reduce the geometric nonlinearity effect presented by PΔ-effect. The steel reinforced lightweight concrete beams showed the same behavior like normal concrete beams. In addition to the lightweight concrete beams could be one option to reduce damage and post-repair works for beam-column joints after earthquake excitations [15].
Furthermore, the investigation of the ultimate moment and deflection of the beams revealed that for making a flexural element by using LECA lightweight concrete, it is preferred to use a lighter concrete that may have lower compressive strength [27].

2 TEST PROGRAM:

2.1 phase (1):

The objective of this phase is choosing the suitable lightweight aggregate that gets higher compressive strength at the required density range (1400:1500) kg/m^3 and w/c ratio =0.4. The following table show used materials as lightweight aggregate and their concrete ID.

Table (1): Concrete ID for each lightweight aggregate type:

Concrete ID	A	B	C	D	E	F	G
Lightweight Aggregate	Broken burnt bricks	crushed clay bricks	polystyrene	adibor 55	Kiment Block	Delta Block	LECA

2.2 Phase (2):

After choosing the suitable lightweight aggregate, the effect of adding nano silica by the different dosages (0%, 0.75%, 1.5%, and 2%) will be studied on the suitable lightweight concrete mixture by testing the hardened and durability properties and observed by the microstructure test.

2.2.1 Test of hardened properties:

- **Compressive strength test:**

Compressive strengths were tested by three specimens for each age on 7, 28 and 90 days on Ø100 x 200 mm cylindrical according to [3].

- **Splitting tensile strength test:**

Splitting tensile strength was tested by three specimens for one age at 28 days of curing on Ø100 x 200 mm cylindrical according to [4].

2.2.2 Durability tests:

- **Density, Absorption, and Voids in Hardened Concrete:**

In this test to determine density, absorption and voids volume, the test specimens that no less than 350 cm^3 as a volume, pass several stages according to [5].

- **Water sorptivity:**

According to [6], In this study The rate of absorption of water by concrete is determined by measuring the increase in mass of a specimen due to absorption of water as a function of time when only one surface is exposed to water (no more than

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3 mm immersed in water) on the Ø100 x 50 mm specimens. The initial absorption (mm) from 1 min to the first 6 h and the secondary absorption (mm) from 1 day to 8 days were determined by measuring the mass of the concrete specimens regularly. The absorption (I) is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. The initial rate of water absorption value (mm/sec½) is calculated as the slope of the line that is the best fit to "I" plotted against the square root of time (sec½).

- **Abrasion resistance:**

The preparation for this test samples is put in the oven at a temperature 110 °C for 24 hours. The test specimen is a cube with dimensions 70mm*70mm* 70mm that cut after molding in the cube (100*100*100) mm, then using [12] which made 16 cycles including 22 rotations of each face for each specimen to determine the thickness loss percentage cause of abrasion resistance.

2.3 Phase (3):

Improve the selected mixture at these possible materials and density range to get high compressive strength making the high strength structural element like a reinforced beam. Then, the beam has to be tested, recorded all results to compare adding nano silica effect to the structural elements.

2.4 Materials:

Lightweight concrete differs from normal concrete in terms of the composition of the type of aggregates, additives. In this study, according to the cement is produced according to [14] and [32] was used rank (CIM I/52.5N) to get the most strength resistance. The chemical and physical properties of it will be shown in the table (2) and (3) respectively. Also, the gradation of used sand will be shown at the table (4). The main factor was added to cement in this study is nano silica which the chemical properties will be shown in the table (5). Finally, the superplasticizer (SP) was added to all concrete mixes according to [7] to facilitate the workability as a constant percentage of cement weight that equals 2% and a density equals 1080 kg/m³.

Table (2): Chemical composition of cement:

Chemical Composition	SiO_2	$Al\ O_3$	Fe_2O_3	CaO	MgO	K2O	Na_2O	SO_3	CL^-	In. Residue	L.O.I
Chemical analysis (%)	24.6	3.68	3.11	62.1	1.66	0.52	0.31	0.08	0.12	2.1	1.63

Table (3): Physical and mechanical properties of cement:

Physical property	Specific gravity	Soundness (mm)	Initial setting time (min.)	Compressive strength (Mpa) (2days)	Compressive strength (Mpa) (28days)
Cement	3.15	5	88	25.63	57.79

Table (4): Particle size distribution and physical properties of fine particles (sand):

Particle size(mm)	10	4.75	2.36	1.18	0.6	0.3	0.15	filler	Bulk density (kg/m3)
sieve no		4	8	16	3	5	1	–	1650
passing %	100	97.6	93.4	83.1	48.2	15.5	3	0	

Table (5): Properties of Nano-Silica particles:

Diameter (nm)	Purity (%)	Surface area(m^2/g)	Density(g/cm^3)	Molecular	Molecular weight
42965	98	240	0.5	SiO_2	60.08

About materials, there are a lot of types of lightweight aggregate which some of them were used in this study as lightweight expanded clay aggregate (LECA) material that has density 950 kg/m³, crashed clay of bricks, broken burnt bricks that both have density 1700 kg/m3 and polystyrene has density 21kg/m³. Adibor 55 is trade name of polystyrene surrounded with cement at CMB Company in Egypt which has density 150 kg/m³. It's containing a bonded material like cement and other materials. In this study, it was separated before using at a group of trials. Kiment blocks which consist of a mortar, polystyrene, and additives pouring at traditional bricks molds producing also by CMB Company in Egypt, have density is 700 kg\m³. Delta Block consists of white sandal bricks as fig (1) which is produced by Belena Egypt Company with density 650 kg/m³ and its properties were presented at the table (6). Delta block, kiment block, and red burnt bricks were broken to size 4.75 and 10 mm to use as L.W.A.

Table (6): Properties of lightweight sandal bricks (Delta block):

properties	lightweight sandal bricks density 650 kg/m3
average dry density	650 kg/m3
thermal conductivity	0.136 watt/m c°
shrinkage	0.01%
porosity	22%
avg. compression strength	50 kg/cm2
lower compression strength	40kg/cm2
Technical properties	according to German slandered code DIN 4165 Egyptian slandered code 2005/1401

Fig (2): Delta Block

Fig (3): Kiment Block

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Fig (4): broken burnt bricks

Fig (5): Crashed burnt clay

Fig (6): Polystyrene

Fig (7): Adibor 55

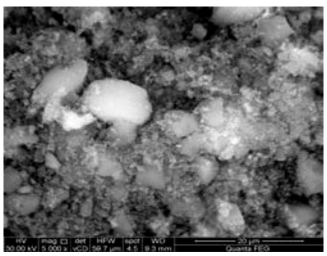

Fig (8): Nano silica (zoom 3000%)

Fig (9): lightweight expanded clay aggregate

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3 Mixing producer and Preparation and Curing of the specimens:

Initially, the cement, fine aggregate (sand) and nano silica powder were mixed in dry form for 2 minutes. The water was mixed with the superplasticizer in the external pot. Then, the mixture powder is mixed with water and superplasticizer for 5 minutes to get great homogeneity. Finally, the lightweight aggregate (LECA) was added to this mixture and was mixed for 10 minutes to get completely mixing. Samples of concrete were poured by layers to present the concrete all over the mixer then were compacted for (1~2) minutes by the automated vibrator kept in steel molds for 24 hours. After that, they were removed from the molds and cured in water at 23 ± 2˚C until the age for each test according to [2].

4 Test Results and Discussion:

4.1 Phase (1):

The choice stage of the ideal lightweight concrete (LWC) depends on the compressive strength and density. The following table presents some trials of each material.

About mixture (A), Limestone was used in this mixture as a fine aggregate instating of sand. This method gets a good compressive strength. One of the disadvantages of broken burnt bricks is its voracity of water because of its content materials type. It has a high density so it can't be used as L.W.A. Also red clay material at mixture (B) that enters in burnt bricks manufacturing has a high density that can't make a low-density mix (out of target density range).The mixture (C) using polystyrene, It's a good strength result of polystyrene because use a gravel by replacement percentage of sand and polystyrene. All trials of polystyrene that have only sand and polystyrene as an aggregate, have a very small strength (1.5~3) MPa relative to this mixture. After many trials, the mixture (D) using Adibor 55 is a good strength sample but it is out of density range target and the lower range of density has a very small compressive strength value. Mixtures (E) and (E1) Kiment block proved that it's very weak to break and use as aggregate. The mixture (F) of Delta block mixture presented a good strength at density 1750 kg/m³. Also, trials proved that delta block concrete mixtures have very low strength at the density between 1430 to 1700 kg/m³ that reaches to 4 to 7.7 MPa as shown at density 1670 kg/m³ of the mixture (F1). Also, trials using the cement content 400 kg/m³ instead of 350 kg/m³ needs a big amount of water plus these bricks are voracious water so in this mix the water to cement ratio doesn't be 0.4 as the target. The mixture (G) using LECA is a good suitable material. It has a good strength at the required density. The mixture (G1) is out of target density range but it is very good comparing other mixtures.

Conc. ID	Cement	Water	Sand	Gravel	lime stone	L.W.A	S.P.	Density	slump	w/c	Fc 7d	Fc 28d
	kg/m³								cm	-	Mpa	
A	350	262.5	-	-	375	615	7	2010	-	0.75	16.4	19.1
B	350	281.25	250	-	-	750	7	2065	-	0.8	10.8	12.24
C	350	140	518	478	-	8	7	1580	0.5	0.4	4.08	5.52
D	350	140	503	250	-	250	7	1670	1	0.4	10.32	12
E	350	140	200	153	-	650	7	1770	2.5	0.4	7.2	8.4
E1	350	140	153	100	-	750	7	1470	3	0.4	1.68	2.4
F	350	255	330	-	333	340	7	1750	1	0.73	13.8	15.48
F1	350	140	602	-	-	330	7	1670	1.5	0.4	6	9
G	350	140	433	-	-	570	7	1420	0.3	0.4	10.8	12
G1	350	147	503	-	-	500	7	1560	0.8	0.42	17.8	22.9

Table (7): Concrete mix design of lightweight aggregate:

4.2 Phase (2):

After many trials, Mixture (G) that is shown in the table (7), is the ideal mix design with the suitable lightweight aggregate (LECA). In this stage, nano silica will be added by the different dosages 0%, 0.75%, 1.5%, and 2% as a replacement percentage of cement weight. Every test result will be discussed with comparing by the suitable mix design of LECA with and without nano-silica to study the effect of nano-silica.

4.2.1 Hardened properties:

Results show that the 0.75%NS samples improve compressive strength about 30% than 0% NS samples. After that results dropped observed at 1.5%NS sample. At 2%NS samples stress has increased to near as those of 0.75 NS % sample at 90 days

Table (8): Compressive and tensile strength properties of

L.W.C mixtures:

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Concrete ID	N.S.%	Compressive strength (MPa)			Splitting tensile strength (MPa)
		7 days	28 days	90 days	28 days
G-0%	0%	10.8	12.24	12.7	1.926
G-0.75%	0.75%	12.48	16.08	17.98	2.372
G-1.5%	1.50%	11.7	15	16.8	2.245
G-2%	2%	12.12	15.48	18.5	2.786

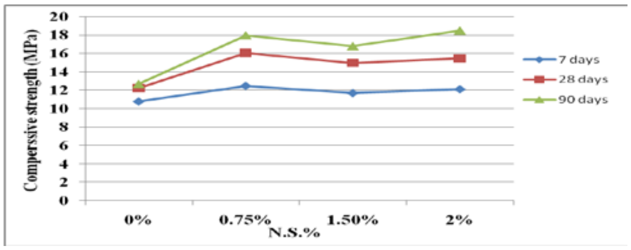


Fig. (10): Compressive strength (MPa)

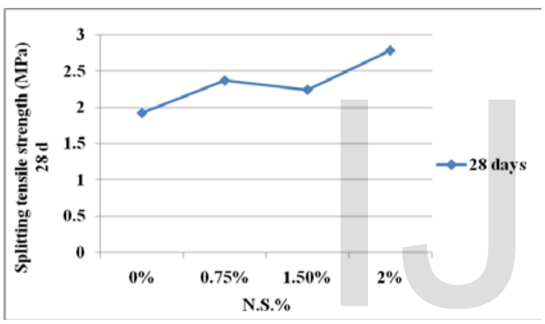


Fig.(11): Splitting tensile strength (MPa)

4.2.2 MICRO-STRUCTURAL ANALYSIS:

Scanning Electron Microscope (SEM) was used for the analysis of concrete samples produced in this research and that are consistent with the concrete mix and vary in nano-silica replacement ratio for each mixture and two ratios 0%, 0.75%, 1.5%, 2%, and this test is detected as follows: First to reveal a small voids within the concrete that filled nano-silica because of their small particles size.

Second, disclosure of the extent of the integration of material concrete mix with them and that help nano-silica in their integration through the pozzolanic reaction property that produces more C-S-H gel that would fill a large voids in the concrete, which helps to increase the resistance of concrete, which is produced when mixing nano-silica particles with calcium oxide (Ca (OH) 2) caused by mixing cement with mixing water. The following images show under a microscope for the concrete samples at rates of 0% and 0.75% and 1.5% and 2% to illustrate the effect of the use of nano-silica concrete with those of different ratios.

For 0% nano-silica replacement percentage:

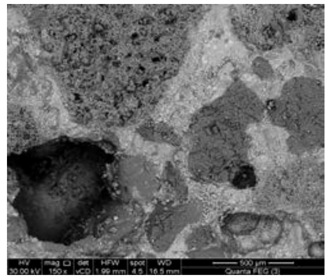


Fig. (12): Zoom 150, **0%**

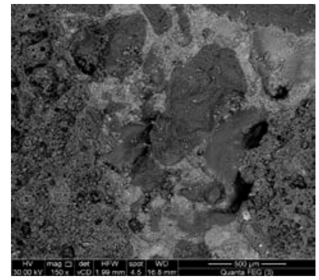


Fig. (13): Zoom 150, **0%**

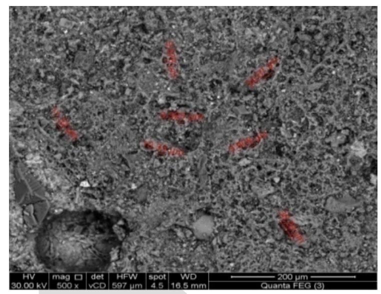


Fig. (14): Zoom 500, 0%

For 0.75% nano-silica replacement percentage:

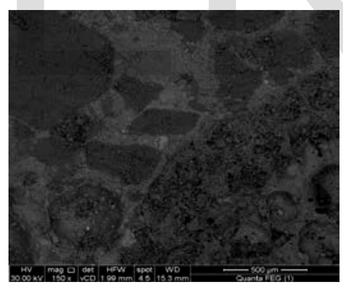


Fig. (15): Zoom 150, 0.75%

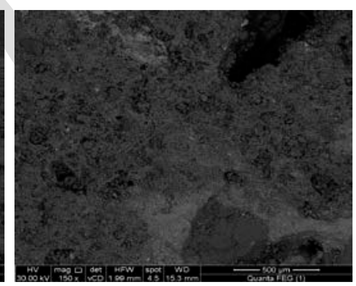


Fig. (16): Zoom 150, 0.75%

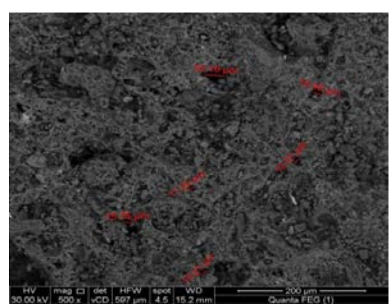
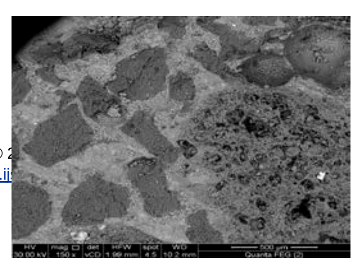


Fig. (17): Zoom 500, 0.75%

For 1.5% nano-silica replacement percentage



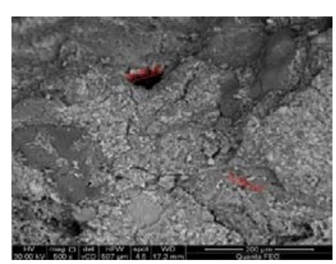


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Fig. (18): Zoom 150, 1.5%   Fig. (19): Zoom 500, 1.5%

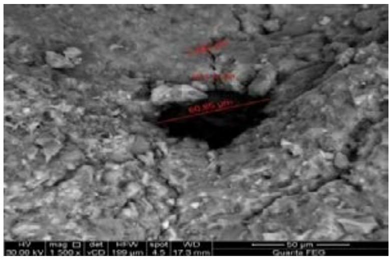


Fig. (20): Zoom 1500, 1.5%

For 2% nano-silica replacement percentage

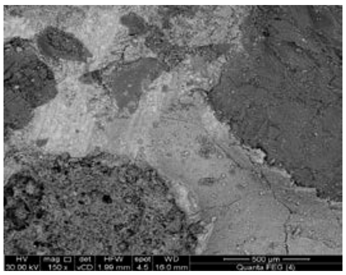


Fig. (21): Zoom 150, 2%

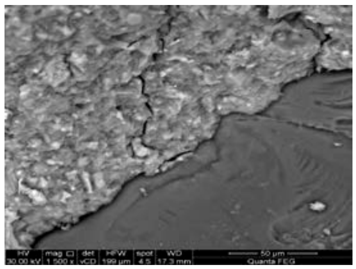


Fig. (22): Zoom 1500, 2%

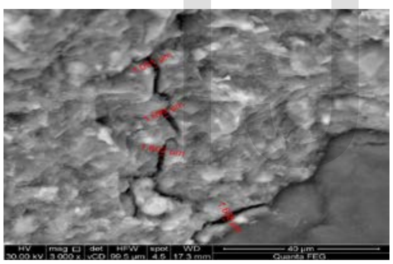


Fig. (23): Zoom 3000, 2%

As shown, there are many and big pores in 0% NS sample lightweight concrete. The 0.75% NS sample has small and little pores and don't have any cracks as 1.5% and 2% NS samples. These capillary porosities are founded result from the pozzolanic reaction property that produces the more C-S-H gel that would fill large voids in the concrete, which helps to increase the resistance of concrete but after a long time this C-S-H gel is drought and left mini cracks depending on the nano-silica amount. So the 1.5% NS sample has a little pore with cracks and 2% NS sample has a little almost no pores with cracks. It nears to [10] that showed the role of silica fume in reducing the diffusivity of cement. The results are consistent with an inherent reduction in the diffusivity of pozzolanic C-S-H relative to that of the convertible C-S-H. the microstructural models suggest that in systems containing silica fume, at high (< 20%) capillary porosities, the diffusivity is regulated by percolated capillary pores network, while at low(>20%) capillary porosities. It is controlled by the volume fraction and percolation characteristics of the two types of C-S-H. Considering the reduced capillary porosity presents an equal degree of cement hydration in the system containing silica fume. After equal hydration times, a 10% addition of silica fume could result in chloride ion diffusivity more than 15 times less than that of comparable concrete made without SF. All above notes are of the silica fume. The nano-silica which is used in this study is so fine more than silica fume.

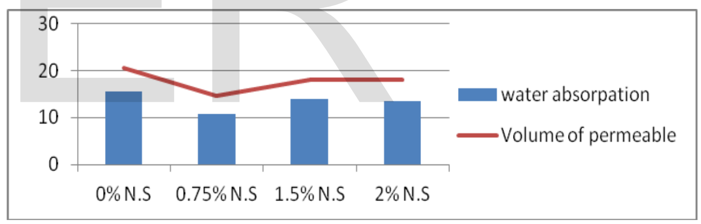
4.2.3 Durability tests:

Density, Absorption, and Voids in Hardened Concrete:
Results of this test showed that 0%NS samples have a lot of voids and this made it having high absorption percentage of other samples. Also, it shows that nano-silica is a good additive to the concrete to a limit then it doesn't improve the concrete properties efficiently. For this test 0.75%NS is the optimum percentage that will show at the following table and graph.

Table (9): Density, Absorption, and Voids determination test:

Conc. ID	N.S.% OF Wc	Absorption after immersion and boiling, %	Bulk density dry (g1)	Bulk density after immersion	Bulk density after immersion and boiling	Apparent density (g2)	Volume of permeable pore space (voids) %
1	0%	15.667	1.314	1.489	1.520	1.655	20.62
2	0.75%	10.877	1.338	1.477	1.483	1.566	14.54
3	1.5%	13.921	1.294	1.453	1.475	1.579	18.07
4	2%	13.547	1.327	1.479	1.507	1.618	17.97

Fig. (24): water absorption and volume of permeable of each nano-silica dosage:



Water sorption:

According to [6], at unsaturated concrete, the rate of ingress of water or other liquids is largely controlled by absorption due to capillary rise. In this test, Results showed the big positive effect of nano-silica which improves the absorption as shown at 0.75%NS samples. Also, results showed that voids type were founded in 1.5%NS and 2%NS, is a connected lattice crack. So 0.75%NS samples is a perfect percentage for this test as shown in the following table and graph where slop line equation for the initial and second stage is.

Table (10): initial stage of water absorption test:

Conc. ID	N.S.% of Wc	Water absorption (%)										
		Time (sec)										
		60	300	600	1200	1800	3600	7200	10800	14400	18000	21600
1	0%	1.91	2.76	3.22	3.83	4.13	4.46	4.88	5.25	5.41	5.54	5.71
2	0.75%	0.71	1.2	1.32	1.6	1.78	2.06	2.43	2.69	2.88	3	3.12
3	1.50%	1.03	1.72	2.17	2.65	2.86	3.1	3.58	3.99	4.14	4.31	4.45
4	2%	1.15	1.97	2.25	2.66	2.92	3.26	3.64	3.98	4.11	4.31	4.43

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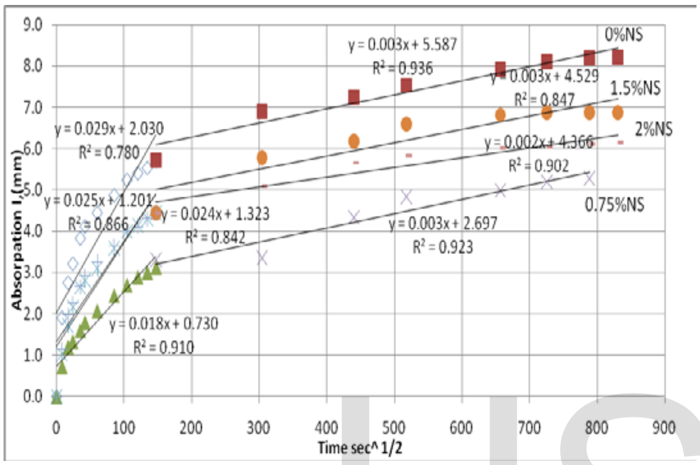
Table (11): second stage of water absorption test:

Concrete ID	N.S.% of Wc	Water absorption (%)						
		Time (sec)						
		92220	193200	268500	432000	527580	622200	691200
1	0%	6.89	7.23	7.53	7.91	8.1	8.19	8.22
2	0.75%	3.3	3.35	4.34	4.84	5	5.19	5.29
3	1.50%	5.78	6.17	6.6	6.82	6.88	6.95	7
4	2%	5.08	5.66	5.83	6.01	6.04	6.11	6.15

Fig. (25): Rate of Absorption of Water:



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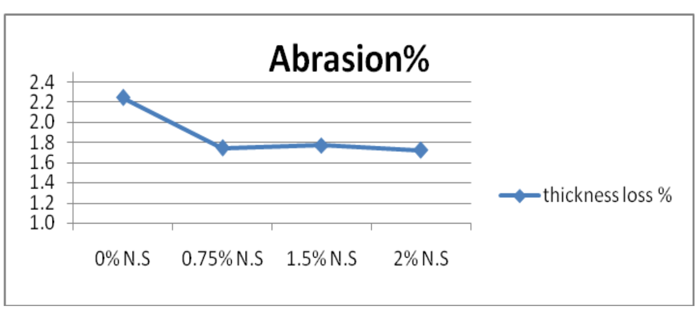
✚ Abrasion resistance:

In this test, results of all nano silica samples near each other and the 2%NS sample is higher than others by the small difference as shown at the following table (12) and figure (26). So 0.75%NS is the ideal percentage economically. This test isn't affected by the porosity percentage because nano-silica improves the concrete surface according to [20].

Table (12): Abrasion resistance:

Conc. ID	N.S.% of Wc	weight before test (gm)	thickness before test (mm)	weight after test (gm)	thickness after test (mm)	weight loss %	thickness loss %
1	0%	396.5	70	383.8	67.5	3.20	2.242
2	0.75%	422	70	411.5	68	2.49	1.742
3	1.5%	402.8	70	392.6	69	2.53	1.773
4	2%	390	70	380.4	69	2.46	1.723

Fig. (26): thickness loss percent result - corrosion test



4.2 Phase (3):

The chosen mix was an ideal mix at all above available materials in terms of strength and another test. So in this stage of research, the chosen mixture will be improved to study the effect of adding nano-silica in terms at strength when it uses for making the structural element as the beam.

4.2.1 Mix design:

Concrete ID	Beam ID	Cement	Nano-silica	Sand	Water	Leca	S.P.
normal concrete (1)	B1	400	0	700	180	500	8
nano-silica concrete (2)	B2	397	3	700	180	500	8

Table (13): Mix design of beams concrete:

4.2.2. Improved elements:

1) Using the cement content 400 kg/m³ instead of 350 kg/m³.
2) Using anther addition from BASF Egypt Company (**MasterGlenium RMC 315**).
3) About nano-silica mixture, using nano-silica as a solution before adding to mixture.

Fig (27): Nano-silica solution making by ultra-sonication device

4.2.3. Strength Results of mixture cubes:

Concrete type	Avg. Density	Avg. Compressive Strength at 7 days	Avg. Compressive Strength at 28 days	Avg. Compressive Strength at 90 days
unit	Kg/m3	MPa		
Normal concrete	1626.6	14.7	22.05	22.3
nano-silica concrete	1697	13.84	21.7	22.75

Table (14): Strength cubes results of beams mixtures:

4.2.4. Beams:

Beams have been designed to be tested for flexure only without shear so stirrups had been increased to 7ϕ8 /m' with dimensions (12*16*150) cm³. Also, strain gage had been compacted at beams to measure the strain of steel. The following table shows the reinforcement steel at beams according to [8].

Table (15): the reinforcement steel of beams:

Concrete type	Concrete ID	Main top reinforced steel	Main bottom reinforced steel	stirrups
normal concrete	B1	2 φ12	2 φ12	7 φ 8
nano-silica concrete	B2	2 φ12	2 φ13	7φ 8

The following table shows some of results of beams testing.

Table (16): Main results of flexure test for beams:

Concrete type	Concrete ID	first cracking level		Ultimate level	
		Load (KN)	Deflection (mm)	Load (KN)	Max. Deflection (mm)
normal concrete	B1	0.98	0.131	66.052	9.562
nano-silica concrete	B2	2.1854	0.223	65.464	7.646

The test result shows at the first cracking level that cracks appeared at the nano-silica beam (B2) at load level higher than the first cracking load of the normal beam (B1). Also, the first crack load of B2 happened by deflection equals 0.223 mm while the first crack load of B1 happened by deflection equals 0.131 mm which Leeds to the flexibility and well strength of the nano-silica concrete.

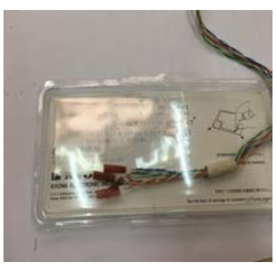


Fig (28): strain gages Fig (29): Beams during pouring

At the ultimate level, the ultimate load of B1 is similar to B2 but the ultimate deflection of normal concrete of B1 is deeper than the nano-silica concrete deflection of B2.The following charts show the relationship between deflection values and load values from zero to the yielding stage.

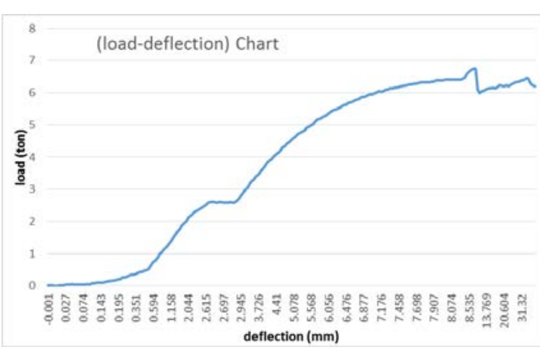


Fig (30): load-deflection curve of B1

Fig (31) :load-deflection curve of B2

On the other side, when the beams reach the yielding stage the maximum crack width at normal concrete beam (B1) equals 2.72 mm while it is at the nano-silica concrete beam (B2) equals 5.594 mm before destroying concrete stage. The steel strain was be accounted by more than one of strain gages that showed that maximum steel strain at B1 "normal concrete beam" was 30038 mm and at B2 "nano-silica concrete beam" was 21711 mm. from the above, it's concluded that the nano-silica concrete has more flexibility than the normal concrete showing at the nano-silica concrete can hold out tensile so the steel strain of B2 more ideal than tensile of steel strain of B1.

5 Conclusions:

1. Light expanded clay aggregate (LECA) is the ideal aggregate of the lightweight aggregate because of its density and its high strength.
2. Using nanotechnology represented in nano-silica with lightweight concrete improve the compressive strength between 25%~40% of the original value depending on the nano-silica percentage and age of concrete. Also, nano-silica gets a good increment in the splitting tensile strength and durability.
3. In this study, Hardened and durability tests proved that at a long time the 0.75%NS sample is an ideal percentage because the 0.75%NS sample nears to the 2% NS sample but the drop at results of stresses has happened at the 1.5%NS sample because of vermicelli connected cracks plus a few pores. So the 0.75%NS is the ideal percentage in terms of efficiency and financial economics.
4. The percentage of added nano-silica to the concrete mix depends on mix design especially the cement content and water-cement ratio.
5. The compressive strength is improved at later ages for lightweight concrete samples having a percentage of N.S of its mixture so it means that nano-silica is affecting at the concrete on a long time positively as showing at compressive strength test and flexure test for beams.
6. nano-silica that was added to the beam concrete mixture, delays the first crack appearing of the beam. the first crack for the beam is appearing at bigger load and deeper deflection relative to the beam results without nano-silica which indicating the flexibility of concrete because of because of increasing the bonding between concrete particles due to adding nano-silica.

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