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Effect of Nanofibers on the Behavior of Cement Mortar and Concrete

Mostafa Osman, Ata El-kareim Shoeib

Abstract**—**The main objective of this paper is study the influence of carbon nano-tubes fibers and nano silica fibers on the characteristic compressive strength and flexural strength on concrete and cement mortar. Twelve tested specimens were tested with square section its dimensions (40×40 ×160) mm, divided into four groups. The first and second group studied the effect of carbon nano-tubes (CNTs) fibers with different percentage equal to 0.0, 0.11%, 0.22%, and 0.33% by weight of cement and effect of nano-silica (nS) fibers with different percentages equal to 0.0, 1.0%, 2.0%, and 3.0% by weight of cement on the cement mortar. The third and fourth groups studied the effect of CNTs fiber with different percentage equal to 0.0%, 0.11%, and 0.22% by weight of cement, and effect of nS fibers with different percentages were equal to 0.0%, 1.0%, and 2.0% by weight of cement on the concrete. The compressive strength and flexural strength at 7, 28, and 90 days is determined. From analysis of tested results concluded that the nano-fibers is more effective when used with cement mortar more than used with concrete because of increasing the surface area, decreasing the pore and the collection of nano-fibers. And also by adding nano-fibers the improvement of flexural strength of concrete and cement mortar is more than improvement of compressive strength.

Keywords**—**Carbon nano-tubes fibers, nano-silica (nS) fibers, compressive strength, flexural.

I. Introduction

Concrete is the most common used material for construction and their design consumes almost the total cement production in the world [1]. As defined by [2], concrete can be nano-engineered by the incorporation of nano-sized (less than 100 nm) building blocks or objects (e.g., nanoparticles and nano-tubes) to control material behavior and add novel properties, or by the grafting of molecules onto cement particles, cement phases, aggregates, and additives (including nano-sized additives) to the addition of small amounts of calcium silicate hydrate (C-S-H) to Portland cement and tricalcium silicate (C_3S) pastes was investigated by [3]

It was demonstrated that nano-C-S-H particles cause a significant acceleration of the early hydration. It was proposed that C-S-H provides nucleation sites for the precipitation of hydration products out of the pore solution [4]. Better understanding the structure at nano-level helps to influence the important processes related to production and use of construction materials as strength development, fracture, corrosion and developing new functionalities [4]. Façade and interior applications require new finishing materials with self-cleaning properties, discoloration resistance, anti-graffiti, and high-scratch resistance. Self-cleaning tiles, window glass, and paints were developed using the TiO_2 photocatalyst technology which is based on the decomposition of organic pollutants under ultraviolet (UV) light [5]. The particle size and specific surface area scale related to concrete materials reflect the general trend to use finer materials as shown in Fig. 1.

Advanced technological aspects demand for higher performing cement-based materials with improved tensile strength and toughness for use in civil engineering projects. Cementitious materials are typically characterized as quasibrittle materials, with low tensile strength and low strain capacity, and hence affect long-term durability of structures. These days, discrete short fibers are widely used to control cracking in fiber reinforced concrete (FRC) [6].

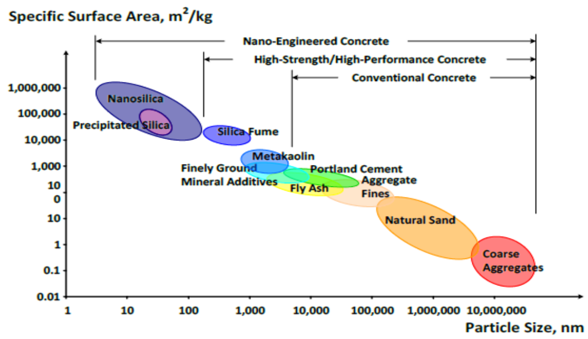

Fig. 1 Particle size and specific surface area related to concrete materials [1]

By using carbon nano-tubes, a new material which exhibits enhanced tensile strength, young's modulus and improved early a strain capacity can be created [7]. Experimental works carried out by [6] showed that by adding 0.25 wt% of cement MWCNTs to the plain cement beams, one may get a remarkable enhancement in both flexural strength and toughness.

In comparison with plain cement beams, the CNTs reinforced beams showed 47% increase in the load carrying capacity and an average of 25% increase in the toughness. CNT/cement composites under flexure with 0.08wt% of cement MWCNTs with proper dispersion was tested, and it was found that fracture properties of cement matrices can be substantially increased by adding a very low amount of CNTs (e.g., 0.025 wt% to 0.10 wt% of cement). Scanning Electron Microscopy results showed that the addition of a small amount

Associated Prof. Mostafa Osman and Ata El-kareim Shoeib are with the Civil Engineering Department, Faculty of Engineering (Mataria), Helwan University, Cairo, Egypt (Corresponding author: Ata El-kareim Shoeib Soliman; Tel: +201004310530; e-mail: ataelkareim_2008@yahoo.com).

of CNTs enables the control of matrix cracks at the nano-scale level. [8].

In this work, the effect of nano fibers on the compressive and tensile strength of cement mortar and concrete was determined. And the rate of increasing of strength comparing control tested specimens was analysis.

II. Experimental Work

Natural sand is used as fine aggregate. It is composed of siliceous materials. The used sand is clean and free. The specific gravity of sand is 2.68 and the volume weight is 1640 kg/m3. Table I shows the percentage of passing of sand and gravel that is used in this work according to limits of Egyptians Standard Specification (E.S.S). Ordinary Portland cement (Tura cement) was used as binding material in this work. Drinking water has been used for mixing and curing all concrete specimens in this work. The powder carbon nano-tubes (CNTs) fiber and nano-silica (nS) were used as ratio of cement weight. The properties of CNTs, and nS fibers were illustrated in Table II. Three molds were especially made for prism 40mm×40mm×160mm. Dry sand and cement were mixed mechanically for one minute to ensure uniformity of the mix, then water was added and mixed thoroughly. Mixing operation continued after adding water until a uniformly color is obtained. The mix proportions of materials were given in Table III. After the molds were compacted, the specimens are covered with wet burlap for 24 hours. After 24 hours the sides of the form were stripped away and the prisms were totally submerged in water up to test. Testing Apparatus consists of a Load Frame 50kN (Tons) capacity.

Fig. 2 Tested set up for tested specimens

A compression tested machine as shown in Fig. 2 was used. Testing Apparatus consists of a Load Frame 50kN (5 Tons) capacity. The compression tested machine was used to apply vertical static load with rating 1.25mm/min for all tested specimens in compression and flexural tested specimens. Twelve tested specimens with four groups were tested after 7, 28 and 90 days for determined the compressive strength and flexural strength of tested specimens with different materials. In the first and second, the CNTs fibers and nS fibers were added to cement mortar with different ratio equal to 0.0, 0.11%, 0.22% and 0.33% for CNTs fibers, and 0.0, 1.0%, 2.0%, and 3.0% for nS fibers respectively. In the third and fourth group, the CNTs fibers and nS fibers were added to concrete with ratios equal to 0.0, 0.11%, and 0.22% for CNTs fibers, and the ratios equal to 0.0, 1.0%, and 2.0% for nS fibers for checking of efficiency of using these materials after adding the coarse aggregate.

TABLE I
Gird Analysis of Used Sand and Gravel

Sieves no.	Total Retained on Sieves	
	Gravel	Sand
2	33%	0.0
1.60	33%	7.0%
1.0	100%	33.0%
0.50	--------	67.0%
0.16	---------	87.0%
0.08	---------	100.0%

TABLE II
Properties of CNT_s Fibers and nS Fibers Used

Carbon Nanotube Fibers Properties	Diameter	(15-40) nm
	Length	$(1-2)*10^{-3}$ mm
	Purity	>95%
	Surface area	350 m^2/g
	Bulk density	0.05-0.17g/cm^3
Nano-Silica	Diameter	(25-55) nm
	Purity	>98%
	Surface area	180-200 m^2/g
	Bulk density	2.0-2.17 g/cm^3

TABLE III
Weight of Materials Used for Tested Specimens

Type of material	G:S	W:C	Fiber Weight (kg)
Cement mortar	-----	1:2	V_f x (C)
Concrete	1.5:1	1:2	V_f x (C)

Notes: G = Gravel, S= Sand, C= Cement, W= Water; V_f= % fibers as weigh of cement

III. Test Result and Analysis

In this part, the tested results of compressive strength and flexural strength at 7, 28, 90 days is presented in Tables IV and V. the discussion the tested results is done as the following

A. Effect of Nano-Fiber on the Compressive Strength of Cement Mortar

In the part the effect adding nano-fibers to cement mortar and concrete on the compressive strength is discussion as shown in Table IV for groups G1, and G2) and Figs. 3-6. The effect of increasing compressive strength at 7, 28, and 90 by adding nano-fiber is analyses.

As shown in Fig. 3, by adding CNTs fibers with ratios equal to 0.0, 0.11%, 0.22%, and 0.33%, the compressive strength at (7, 28, and 90) days were equal to (17.3MPa, 19MPa, and 22.1MPa), (21.2MPa, 20.6MPa, and 25.2MPa), (23.6MPa, 24.8MPa, and 28.9MPa) and (22.2MPa, 23.3MPa, and 23.9 MPa) respectively. From this found that by used the CNTs fibers with ratio equal to 0.33%, the increasing compressive strength was less than that at the ratio 0.22%.

As shown in Fig. 4, by adding nS fibers with ratio equal to, 0.0%, 1.0%, 2.0%, and 3.0% the compressive strength at (7, 28, and 90) days were (17.3MPa, 19MPa, and 22.1MPa), (20.6MPa, 22.51MPa, and 33.3MPa), (24.6MPa, 34.75MPa, and 38.7MPa) and (19.8MPa, 22.97MPa, and 27.8MPa) respectively. Moreover, by used nS fibers the compressive strength with ratio equal to 3.00% was less than the compressive strength with ratio equal to 2.0%. From this concluded that the optimum ratio for tested specimens of CNTs fibers and nS fibers can be approximately equal to 0.22% and 2.0% respectively.

Fig. 5 shows that by using CNTs fibers the rate of increasing compressive strength at early stages (7day) is more than that after that (28day, and 90day). Moreover the rate of increasing compressive is the 28 the more than that of 90days. From this concluded that the CNTs fibers increased the early compressive strength of cement mortar. Fig. 6 shows that by using nS fibers with ratio 2.00% the rate of increasing compressive strength increased by the times.

B. Effect of Nano-fiber on the Compressive Strength of Concrete

In this part, the effect adding nano-fibers to concrete on the compressive strength is discussion as shown in Table IV for groups three and four, and Figs. 7-9. The effect of increasing compressive strength at 7, 28, and 90 by adding nano-fibers is as the following:

As shown in Fig. 7, by adding CNTs fibers with ratios equal to 0.0, 0.11%, and 0.22%, the compressive strength at (7, 28, and 90) days were equal to (23.30MPa, 26.50MPa, and 30.00MPa), (31.70MPa, 43.30MPa, and 37.80MPa), and (29.46MPa, 37.57MPa, and 38.5MPa) respectively. And also, by using nS fibers with ratio equal to 0.0, 1.10% and 2.20%, the compressive strength at (7, 28, and 90) days were equal to (23.30MPa, 26.50MPa, and 30.0MPa), (31.70MPa, 43.30MPa, and 37.80MPa) and (29.46MPa, 37.57MPa, and 38.50MPa). As shown in Fig. 8, the rate of increasing compressive strength due to adding CNTs fibers for tested specimens was the maximum for 28days. As shown in Fig. 9, the rate of increasing compressive strength due to adding nS fibers is increased by the time and can be linear. From this concluded that adding nS fibers increasing the gained compressed strength after 28days. And also, the optimum ratios of nano-fibers used in concrete is not as this the optimum ratios in the cement mortar.

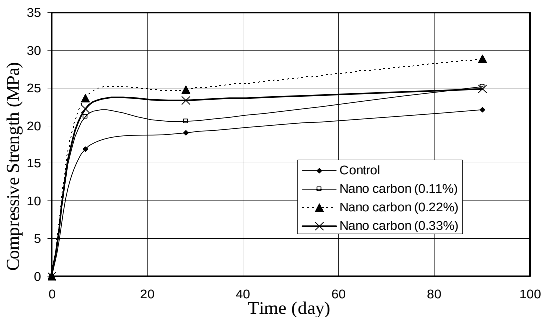

Fig. 3 The effect of CNTs fibers on the cement mortar compressive strength

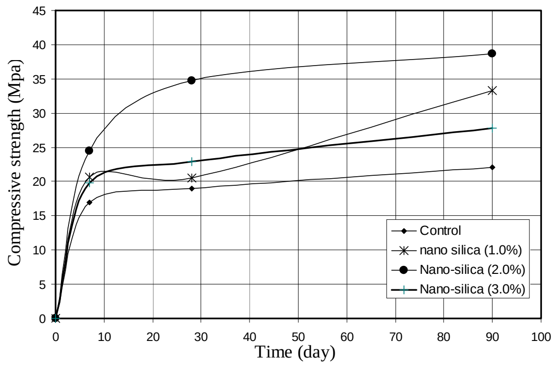

Fig. 4 Effect of nS fibers on the cement mortar compressive strength

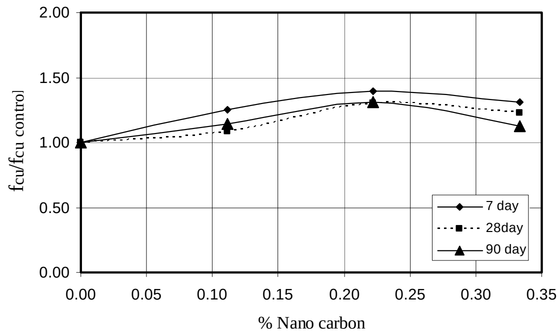

Fig. 5 Effect of CNTs fibers on the cement mortar compressive strength by changing the time

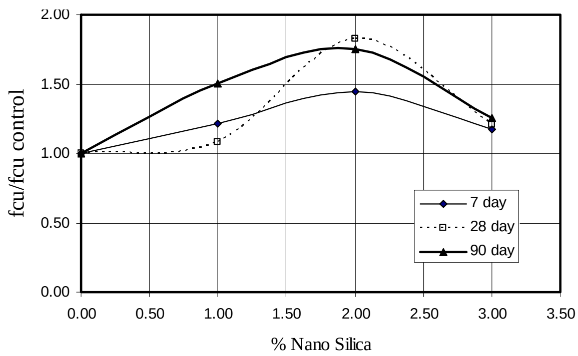

Fig. 6 Effect of nS fibers on the compressive strength for cement mortar by changing the time

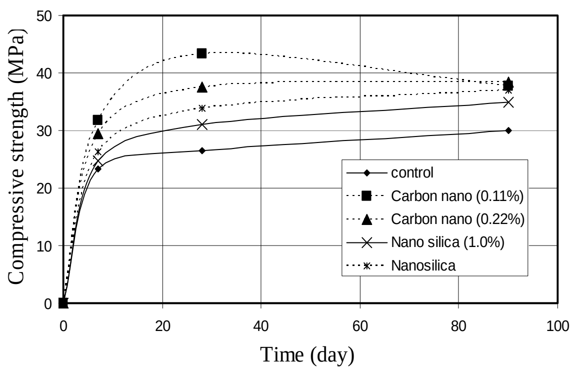

Fig. 7 Effect of CNTs and nS fibers on the concrete compressive strength

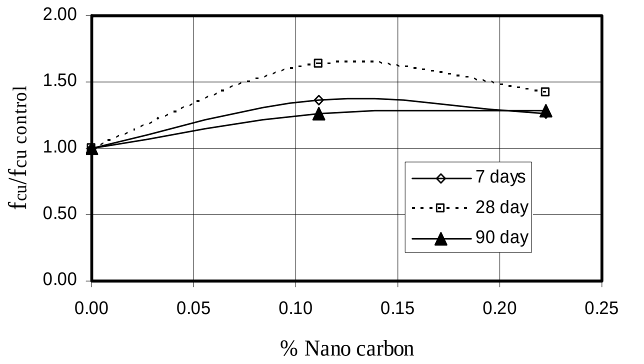

Fig. 8 Effect of CNTs fibers on the concrete compressive strength by changing the time

C. Effect of Nano-fiber on the Flexural Strength of Cement Mortar

In this part, the effect adding nano-fibers to cement mortar for group one and two on the flexural strength are discussion as shown in Table V and Figs. 10-13. The effect of increasing compressive strength at 7, 28, and 90 by adding nano-fibers is analyses.

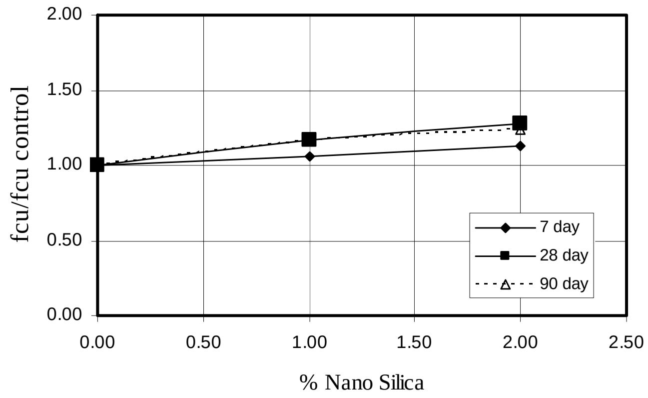

Fig. 9 Effect of nS fibers on the compressive strength for concrete by changing the time

As shown in Fig. 10, by using CNTs fibers with ratios equal to 0.0, 0.11%, 0.22%, and 0.33%, the flexural strengths at (7, 28, 90) days were equal to (4.60MPa, 4.90MPa and 6.40MPa), (5.06MPa, 5.36MPa, and 7.30MPa), (5.62MPa, 5.70MPa, and 9.60MPa) and (6.70MPa, 5.80MPa, and 10.12MPa) respectively. As shown in Fig. 11, by using the nS fibers with ratios equal to 0.0%, 1.0%, 2.0%, and 3.0% the flexural strengths at (7, 28, and 90) days were equal to (4.60MPa, 4.90MPa and 6.40MPa), (4.52MPa, 6.42MPa, and 6.48MPa), (4.40MPa, 5.86MPa, and 7.25MPa) and (4.77MPa, 5.72MPa, and 9.38MPa) respectively. From this concluded that by increasing the ratio of CNTs fibers, and nS fibers, the flexural strength increased, and the maximum recommended ratio is more than 0.22% and 3% for CNTs fibers and nS fibers respectively. From Figs. 12 and 13 find that, by using nano-fiber with cement mortar increasing, the rate of flexural strength increased by the times regardless the ratio 0.22% and 3% for CNTs fibers and nS fibers respectively.

D. Effect of Nano-fiber on the Flexural Strength of Concrete

In the part, the effect adding nano-fiber to concrete for group three and four on flexural strength of is discussion as shown in Table V and from Figs. 14-16 as the following:

As shown in Fig. 14, by adding CNTs fibers with ratios equal to 0.0, 0.11%, and 0.22%, the flexural strength at (7, 28, 90) days were (5.85MPa, 5.90MPa and 6.70MPa), (5.49MPa, 6.32MPa, and 7.20MPa), and (5.95MPa, 6.57MPa, 6.60MPa) respectively. And also, by using nS fibers with ratio equal to 0.0, 1.1% and 2.2%, the flexural strength (7, 28, 90) days were equal to (5.85MPa, 5.90MPa and 6.70MPa), (5.85MPa, 5.90MPa, and 6.70MPa) and (6.66MPa, 7.59MPa, and 8.90MPa) respectively. As shown in Fig. 15, the rate of increasing flexural strength due to adding CNTs fibers may be not affecting by the time. As shown in Fig. 16, the rate of increasing flexural strength due to adding nano-silica (nS) fibers is constant after 28 days.

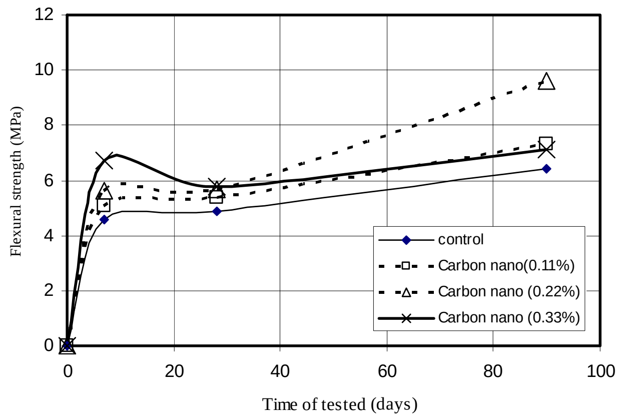

Fig. 10 Effect of CNTs fibers on the cement mortar flexural strength

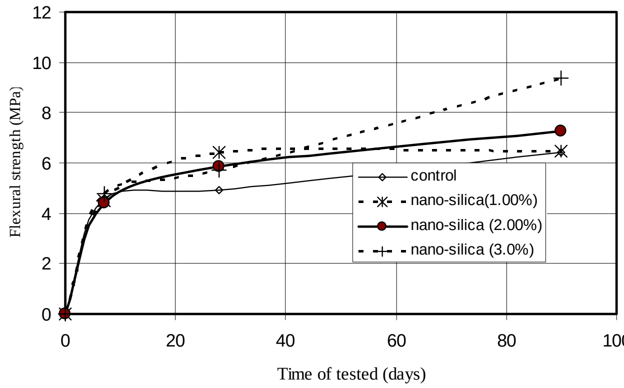

Fig. 11 Effect of nS fibers on the cement mortar flexural strength.

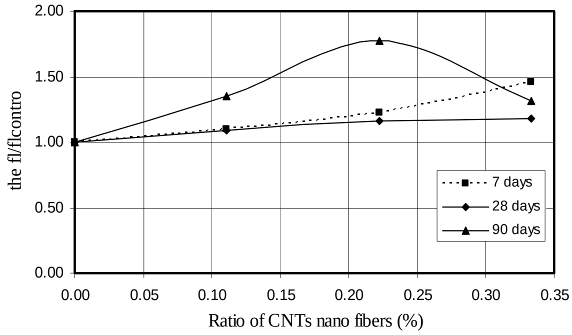

Fig. 12 Effect of CNTs fibers on the rate of increasing flexural strength by the time for cement mortar

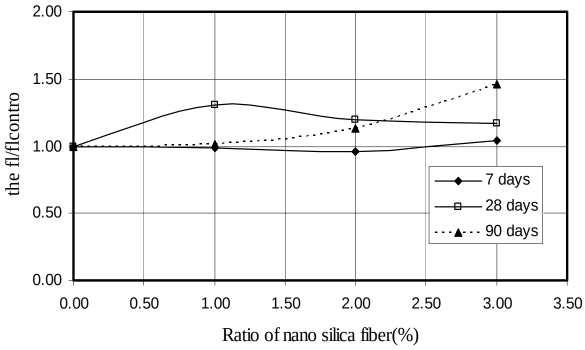

Fig. 13 Effect of nS fibers on the rate of increasing flexural strength for cement mortar

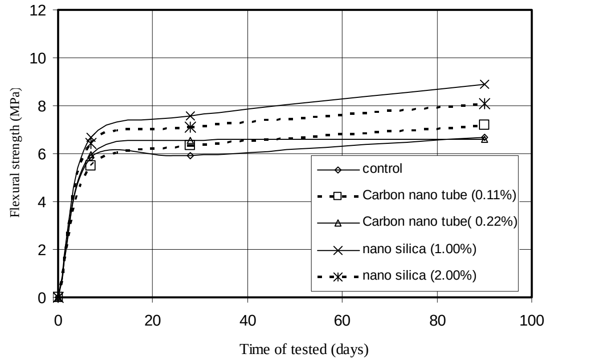

Fig. 14 Effect of CNTs fibers and nS fibers on the concrete flexural strength

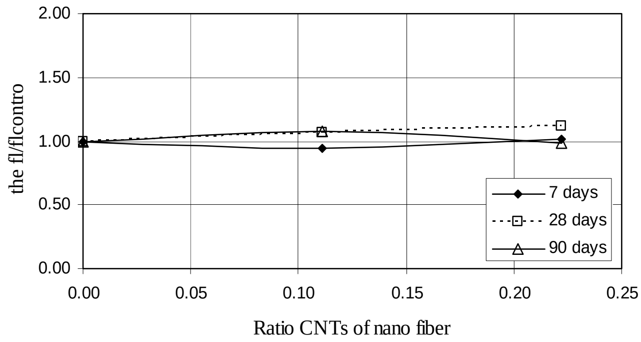

Fig. 15 Effect of CNTs fibers on the rate of increasing flexural strength by the time for concrete

TABLE IV
CHARACTERISTIC COMPRESSIVE STRENGTH OF TESTED SPECIMENS

Group	Beam Code	Type of Fiber	% of fibers	Compressive Strength (f_{cu})			$f_{cu,nano}$ / $f_{cu,control}$		
				7	28	90	7	28	90
G1	B1	Control	0.00	17.3	19.0	22.1	1.00	1.00	1.00
(mortar)	B5	Carbon nano-tube (CNTs)	0.11	21.2	20.6	25.2	1.23	1.08	1.14
	B6	Carbon nano-tube (CNTs)	0.22	23.6	24.8	28.9	1.36	1.31	1.31
	B7	Carbon nano-tube (CNTs)	0.33	22.2	23.3	23.9	1.28	1.23	1.08
G2	B1	Control	0.00	17.3	19	22.1	1.00	1.00	1.00
(mortar)	B2	Nano-silica (nS)	1.00	20.6	22.51	33.3	1.19	1.18	1.51
	B3	Nano-silica (nS)	2.00	24.5	34.75	38.7	1.42	1.83	1.75
	B4	Nano-silica (nS)	3.00	19.8	22.97	27.8	1.14	1.21	1.26
G3	B10	Control	0.00	23.3	26.48	30.0	1.00	1.00	1.00
(Concrete)	B8	Carbon nano-tube (CNTs)	0.11	31.7	43.3	37.8	1.36	1.64	1.26
	B9	Carbon nano-tube (CNTs)	0.22	29.46	37.57	38.5	1.26	1.42	1.28
G4	B10	Control	0.00	23.3	26.48	30.0	1.00	1.00	1.00
(concrete)	B11	Nano-silica (nS)	1.00	24.7	31.05	35.0	1.06	1.17	1.17
	B12	Nano-silica (nS)	2.00	26.3	33.84	37.07	1.13	1.28	1.24

TABLE V
FLEXURAL STRENGTH OF TESTED SPECIMENS

Group	Beam Code	Type of Fiber	%of fibers	Flexural Strength (f_l)			$f_{l,nano}$ / $f_{l,control}$		
				7	28	90	7.0	28	90
G1	B1	Control	0.00	4.6	4.9	6.4	1.00	1.00	1.00
(mortar)	B5	Carbon nano-tube (CNTs)	0.11	5.06	5.36	7.3	1.10	1.09	1.35
	B6	Carbon nano-tube (CNTs)	0.22	5.62	5.7	9.6	1.22	1.16	1.78
	B7	Carbon nano-tube (CNTs)	0.33	6.7	5.8	10.12	1.46	1.18	1.32
G2	B1	Control	0.00	4.6	4.9	6.42	1.00	1.00	1.00
(mortar)	B2	Nano-silica (nS)	1.00	4.52	6.42	6.48	0.98	1.31	1.01
	B3	Nano-silica (nS)	2.00	4.4	5.86	7.25	0.96	1.20	1.13
	B4	Nano-silica (nS)	3.00	4.77	5.72	9.38	1.04	1.17	1.46
G3	B10	Control	0.00	5.85	5.9	6.7	1.00	1.00	1.00
(Concrete)	B8	Carbon nano-tube (CNTs)	0.11	5.49	6.32	7.2	0.94	1.07	1.07
	B9	Carbon nano-tube (CNTs)	0.22	5.95	6.57	6.6	1.02	1.11	0.99
G4	B10	Control	0.00	5.85	5.9	6.7	1.00	1.00	1.00
(concrete)	B11	Nano-silica (nS)	1.00	6.66	7.59	8.9	1.14	1.29	1.33
	B12	Nano-silica (nS)	2.00	6.41	7.09	8.1	1.10	1.20	1.21

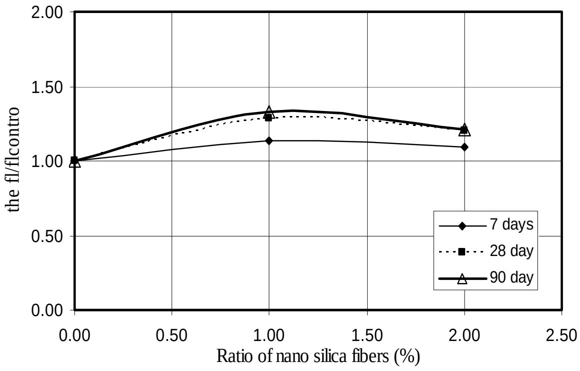

Fig. 16 Effect of nS fibers on the rate of increasing flexural strength by the time for concrete

IV. Conclusion

From analysis of tested results for using CNTs fibers and nS fibers with concrete and cement mortar, the conclusion can be drawn as the following

1) The CNTs increased the early compressive strength of cement mortar (after 7 days) and the nS fibers affect after 28 days.
2) The used of nano-fibers is more effective when used with cement mortar than that of used with concrete because of increasing the contact surface area due to fine particles, and decreasing the pores and the collection of nano-fibers
3) The adding nano-fibers (CNTs, and nS) for tested specimens is more effective of using on concrete than using on the cement mortar for increasing flexural strength.
4) More studied required with different sand, gravel, and cement contents for understanding the real effect of nano-fibers on the compressive and flexural strength.

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