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EFFECT OF NANO-SILICA, SILICA FUME, CEMENT CONTENT AND CURING CONDITIONS ON THE CONCRETE COMPRESSIVE STRENGTH AT 7 AND 28 DAYS

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ABSTRACT

Recently there is a strong trend in engineering researches in the field of engineering materials for the production of high and ultra- high strength concrete. Using different additives which are added to the concrete mix reduced the water cement ratio and caused an increase in the concrete strength. As well as the use of ultra-fine materials such as Nano-silica increase the strength of concrete dramatically. In spite of the success of this research to get to compressive strength up to 150 MPa or more, however, many problems have found in the mechanical behavior of these concretes, which turned into a decrease in the fracture toughness significantly**.** An experimental program was designed to investigate the effect of cement content, silica fume and Nano silica percent, and curing on the compressive strength of concrete at different curing ages. The results of the present work clearly showed an increase in the value of 28-day concrete compressive strength with existence of silica and Nano silica. Steam curing, also, led to an improvement in compressive strength as compared to water curing.

Keywords: Nano-silica, High strength concrete, steam curing, cement contents

INTRODUCTION

The compressive strength of concrete depends on the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate**.** An experiment was conducted to determine the effect of different sizes of different aggregates for concrete production on the compressive strength of concrete. The results showed that the smallest coarse aggregate size gave the highest compressive strength and lowest slump at constant water/cement ratio [1, 2, 3].

The addition of supplementary cementitious materials such as silica fume reduces both pore sizes and porosity, and increase strength. Silica fume is very reactive therefore it increases both the early and later age strength by affecting cement hydration immediately. The compressive, split-tensile and flexural strengths of concrete are increased. The interfacial transition zone can be improved by the addition of pozzolanic materials like silica fumes, fly ash, GGBS etc. which reacts with Ca(OH)2 crystals forming CSH. Silica fume particles consume Ca(OH)2 available in transition zone and makes it dense and uniform [4,5,6].

The influence of curing regimes on compressive strength of ultra-high strength concrete was studied in several works. It is suggested that 48 hrs thermal curing followed by water curing strength gains the more than 200 MPa. The choice of ingredients and curing regimes plays

dominant role in high strength concrete and in high performance concrete. Samples were casted by Praphat et al, achieved compressive strength of 170 MPa under a combination of normal water curing, hot water curing and hot air curing. Thermal curing regime enhances the micro structural changes of hydrated structure. Increasing temperature and duration causing formation of different C-S-H gel crystal such as Tobermorite, xonotlite and scwatite. It is observed that thermal curing regime increase the compressive strength up to 40% nearly when sample compared with that of normal water curing. At normal water curing, pozzalanic reaction of silica fume and quartz powder is not activated, only they act as filler material [7].
Steam curing at ambient pressure is the most common technique among the accelerated curing methods of concrete. In applications, such as pre-cast concretes and pre-stressed reinforced concretes, which require high mechanical performances at very early ages, the steam curing enables concretes which normally have slower strength gain, such as fly ash concretes, to achieve faster strength gain at the required levels. The steam-cured concretes showed 4 to 15% higher 1-day compressive strength than their air-cured counterparts due to the acceleration of the CSH gel formation. The 28 and 90-day compressive strengths of the steam-cured concretes were similar to those of air-cured concretes when using the same type of aggregate [8, 9].

Over the past decade, the definition of nanoparticles has been controversial. Nanoparticles are commonly defined as objects with a diameter less than 30 x 10^{-9} m, but no clear size cut-off exists, and this usual boundary does not appear to have a solid scientific basis. Nano-silica is being incorporated into the cement to give enhanced mechanical property, lower porosity and permeability, which are crucial factors for increased durability. Several studies show that the application of Nano silica in cementitious system improves the compressive strength at early age of hydration. The addition of nanomaterials not only shortened the dormant period but also lead to an early appearance of the second peak. The nano-SiO2 mainly contributed to the early strength development of UHSC before 7 d. The CH content in UHSC series dropped significantly with the increase of nano-SiO2 content. Nano-SiO2 demonstrated nucleation and filling effects and resulted in less porous and more homogeneous structure [10,11].

It is a common practice to use high cement content for achieving higher strength concrete. Strength is considered to be a function of w/c and independent of cement content for a given w/c, therefore increasing cement content does not affect strength. Furthermore, according to Abrams rule, paste content does not affect strength although it is affected by the paste quality [12].

In the way to produce high or ultra-high strength concrete, it is important to investigate the effect of cement content, silica fume and Nano silica percent, and curing on the compressive strength of concrete at different curing ages. Therefore, an experimental program was designed to study these effects.

EXPERIMENTAL PLAN

The details descriptions of the materials used through this investigation, particularly cement, aggregate, silica fume, water and chemical admixtures are given in this section. The used materials in the current research were chosen from the available materials in Egypt. The experimental plan includes preparation of materials, test specimens, mixing, casting, curing, and testing of hardened concrete.

Materials

Ordinary Portland Cement (OPC) (CEM I 52.5 N) produced by Bani Sweif cement factory was used in this study. The different laboratory tests were conducted on cement conforms to Egyptian Standards (ES 4756-1/2009) [13]. The chemical analysis and calculated chemical composition of the used cement are given in tables (1) and (2). The chemical analysis was conducted in Housing & Building National Research Center (HBRC). The physical and mechanical properties of cement are shown in table (3).

Table (1) Chemical composition of the cement

Oxide composition	Percent by Weight (%)
Silicon Oxide (SiO_2)	21.58
Aluminum Oxide (Al_2O_3)	4.94
Ferric Oxide (Fe_2O_3)	3.56
Calcium Oxide (CaO)	61.09
Magnesium Oxide (MgO)	1.65
Sulpher Trioxide (SO_3)	3.22
Loss on Ignition (L.O.I)	2.60
Sodium Oxide (Na_2O)	0.50
Potassium Oxide (K_2O)	0.18
Total	99.91
Insoluble Residue(IR)	1.71

Table (2) Calculated compounds of cement

Name of compounds	Content %
Tricalcium Silicate C_3S	37.1637
Dicalcium Silicate C_2S	33.913
Tricalcium Aluminate C_3A	7.0746
Tetracalcium Aluminoferrite C_4AF	10.8224

Table (3) Physical and mechanical properties of the cement

Test		Test result	(ES 4756-1/2009) limits
specific gravity		3.15	-----
Specific surface area (cm^2/gm)		3600	≥2750
Setting time (Vicat apparatus) (min)	Initial	75	≥45 min
	Final	190	≤10 hours
Compressive strength 2 days (MPa)		23.5	≥20 MPa
Compressive strength 28days (MPa)		54.4	≥52.5 MPa
Consistency of standard cement paste		W/C= 28 %	26% - 33%

All aggregates used in this research are locally available; it consisted of basalt and quartz. Coarse aggregate was washed 7 days before being used and left dry to avoid the effect of fine materials in aggregate. The coarse aggregates used in the experimental work is Basalt 1 from Beni sweif with a maximum nominal size 10 mm. Testing of the used coarse aggregate was complied with the Egyptian Standards ES 1109-2008 [14]. Table (4) shows the grading of the used coarse aggregate. The physical properties of the used coarse aggregate are given in table (5)

Table (4) grading of the coarse aggregate

Sieve size (mm)	37.5	20	10	5	2.36	1.18
Passing (%),Basalt 1	100	99.3	96.2	11.7	1.5	0.22

Table (5): The physical properties of the used coarse aggregate

Property	Basalt 1	Limits*
Specific weight	2.7	-
Bulk density (t/m3)	1.47	-
Coefficient of abrasion (Loss Angloss) %	18	Less than 30
Coefficient of impact %	15	Less than 30
Crushing value %	26	Less than 30
Absorption %	1.6	Less than 2.5
Clay and fine dust content %	0.8	Less than 3.0

*The limits according to Egyptian Specification No (1109/2008).

Crushed Quartz is used as fine aggregate. Testing of the used fine aggregate was complied with the Egyptian Standards ES 1109-2008 [14]. The physical properties of used fine aggregate are given in table (6).

Table (6): The physical properties of the fine aggregate

Property	Crushed Quartz	Limits*
Specific weight	2.5	-
Bulk density (t/m3)	1.52	-
Fineness modulus	3	-
Material finer than No 200 sieve %	2.62	Less than 3%

*The limits according to Egyptian Specification No (1109/2008).

The silica fume used in this research as a mineral admixture was brought from Sika Company in Egypt. Table (7) show the physical composition of the used silica fume as obtained from the manufacture data sheet.

Table (7): The physical properties of the used silica fume

Property	Result*
Surface area (cm^2/gm)	170000
Particle size , µm	8.00
Specific gravity	2.20

*By the manufacture data sheet.

Table (8): Properties of the Nano silica

Property	Result
Particle size ($x10^{-9}$ m)	5 : 20
Surface area (cm^2/gm)	2400000
Density (Kg/m^3)	505
Purity %	99.8
Color	white

The used Nano silica (SiO_2, 99.8 %) was brought from National Research Center. Table (8) shows the properties of Nano Silica used in this work. A high performance superplasticizer concrete admixture Sika Viscocrete - 3425 was used in this work, it is a third generation superplasicizer for homogenous concrete, it meets the requirements for superplasticizers according to ASTM-C-494 types G and F and BS EN 934 part 2:2001. Using this type of superplasticizers we can obtain extremely powerful water reduction and resulting in high density and strengths. It, also, improves shrinkage, creep behavior and water impermeability. The used dosage of superplasticizers was constant in all mixes equal 4.5 % of the weight of cement, Table (9) show the properties of superplasticizers used in this work.

Table (9): Properties of the superplasticizers

Property	Result*
Appearance / color	Clear liquid
Density (Kg/lit)	1.08
PH value	4.0
Solid content (% by weight)	40

*By the manufacture data sheet.

Clean tap drinking water was used in mixing. The water to cement ratio W/C was 0.20 in all beams to get ultra-high strength concrete.

Mix Design, casting and curing

The preliminary mix Proportions were determined and the weight of each component to produce one cubic meter of concrete can be calculated based on absolute volume method. The mixes configuration and experimental program are given in table (10).

Table (10): Mixes configuration for the present experimental program

Mix	C.C	water	SF	N	Aggregate Type		Aggregates (100%)		Curing
	Kg/m^3	Lit/m^3	%C	%C	Coarse	Fine	Coarse (%)	Fine(%)	
M1	500	100	10%	4.00%	Basalt 1	Quartz	50%	50%	Steam
M2	500	100	10%	4.00%	Basalt 1	Quartz	50%	50%	Water
M3	500	100	10%	0.00%	Basalt 1	Quartz	50%	50%	Steam
M4	800	160	10%	4.00%	Basalt 1	Quartz	50%	50%	Steam
M5	800	160	10%	0.00%	Basalt 1	Quartz	50%	50%	Steam
M7	800	160	10%	0.00%	Basalt 1	Quartz	50%	50%	Water
M8	800	160	20%	0.00%	Basalt 1	Quartz	50%	50%	Steam

Mixing of concrete components was done by using a horizontal mixer. The aggregates (coarse and fine), cement, silica fume, were added into the mixer in dry state and mixed for 2 minutes. The mixing water and superplasticizer were added gradually and mixed for another 3 minutes to get uniform and homogeneous mixes. The properties of fresh concrete were measured just after mixing; concrete was removed out from the mixer, slump flow and T50cm time test were carried out.

The fresh concrete taken from the mixer was placed in the molds. As result of using high percentage of superplasticizer in this work, the consistency is similar to self-compacting concrete. Therefore, the concrete was placed in the molds under its own weight without any vibration effort. The specimens were kept in the molds for 24 hours in air. The specimens were removed from the molds and stored under fresh water until the test. For steam curing the specimens were removed from the molds and cured at atmospheric pressure using a steam resulting from boiling water at temperature of 100°C for 3 days. After that the specimens were left to cool for 2hrs and then cured using tap fresh water until performing compressive test.

Test specimens

Twelve cubes (10×10×10 cm) were cast for each concrete mix. All the specimens were removed from the curing tank before testing age and left about 2 hours to dry in laboratory. The compressive strength after 7, 28 and 56 days were measured. Three specimens from each mixture were tested at each testing age. The compressive test was performed in accordance with BS EN 12390-3:2002 [15], by using hydraulic testing machine with a capacity of 200 tons and accuracy of 0.5 ton in concrete laboratory, faculty of engineering, Mansoura University.

RESULTS AND DISCUSSION

Effect of Nano -Silica content

Figures 1a and 1b show the effect of incorporating 4% Nano silica on concrete compressive strength at 7 and 28 days, with cement content 500 Kg/m3, respectively. The mixes M3 and M1 have the same aggregate, w/c ratio, and curing conditions. The data in figures clearly show an improvement in the compressive strength due to addition of Nano silica by 4%. Where, the strength at 7 days increased from 530 to 557 Kg/cm2 by about 5.1%. While the strength at 28 days increased from 587 to 656 Kg/cm2 by about 11.75%. These result were attributed to the well-known physical role of Nano silica at 7 days and may be to the physical and pozolanic role at 28 days.

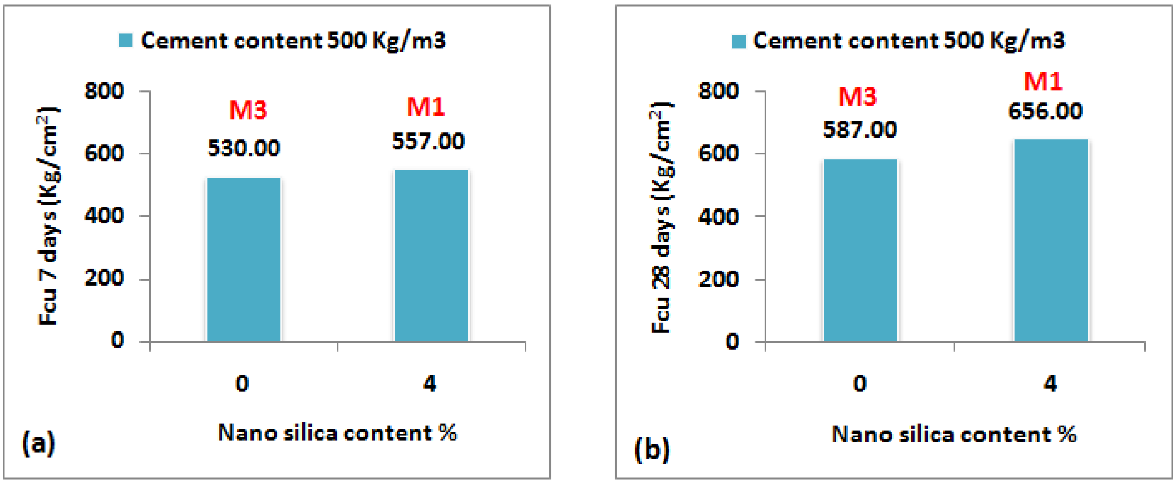

Fig (1) Effect of Nano silica on concrete compressive strength, (a) at 7 days and (b) at 28 days with cement content 500 Kg/m^3

A similar result was noticed in figure 2a and 2b for cement content 800 Kg/m^3. The mixes M4 and M5 have the same aggregate, w/c ratio, and curing conditions. The data in figures clearly show an improvement in the compressive strength due to addition of Nano silica by 4%. Where, the strength at 7 days increased from 565 to 577 Kg/cm^2 by about 2.1%. While the strength at 28 days increased from 624 to 695 Kg/cm^2 by about 11.4%. These result were attributed to the well-known physical role of Nano silica at 7 days and may be to the physical and pozolanic role at 28 days.

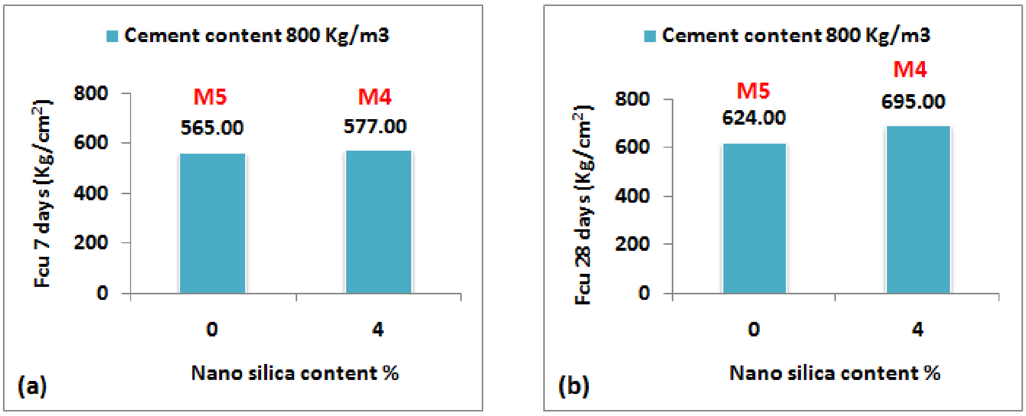

Fig (2) Effect of Nano silica on concrete compressive strength, (a) at 7 days and (b) at 28 days with cement content 800 Kg/m^3

Several studies show that the application of Nano silica in cementitious system improves the compressive strength at early age of hydration. Nano-silica is being incorporated into the concrete mix to give enhanced mechanical property, lower porosity and permeability, which are crucial factors for increased strength at 7 days. Z. Wu et al. [10] concluded that nano-SiO2 decreased the follow ability and accelerated the heat of hydration. The addition of nanomaterials not only shortened the dormant period but also lead to an early appearance of the second peak. As mention by [10], the CH content in the concrete containing nano-SiO2 dropped significantly with the increase of nano-SiO2 content. Nano-SiO2 demonstrated nucleation and filling effects and resulted in less porous and more homogeneous structure. This finding may be explaining the present results in our work. Nano silica addition significantly alters the proportion of low and high stiffness C–S–H. A similar result was reported by Singh et al., [11].

Effect of silica fume content

The very small particles of silica fume can enter the space between the particles of cement and thus improve packing. The compared concrete mixes M5 and M8 have the same aggregate grading, the same water to cement ratio 0.20, the same Nano-silica content 0% and the same super plasticizer content 4.5%. At age of 7 days there is insignificant increase in compressive strength, about 1.59%, but at age of 28 days the compressive strength showed small increase, about 3.84%, as shown in fig 3a and 3b.

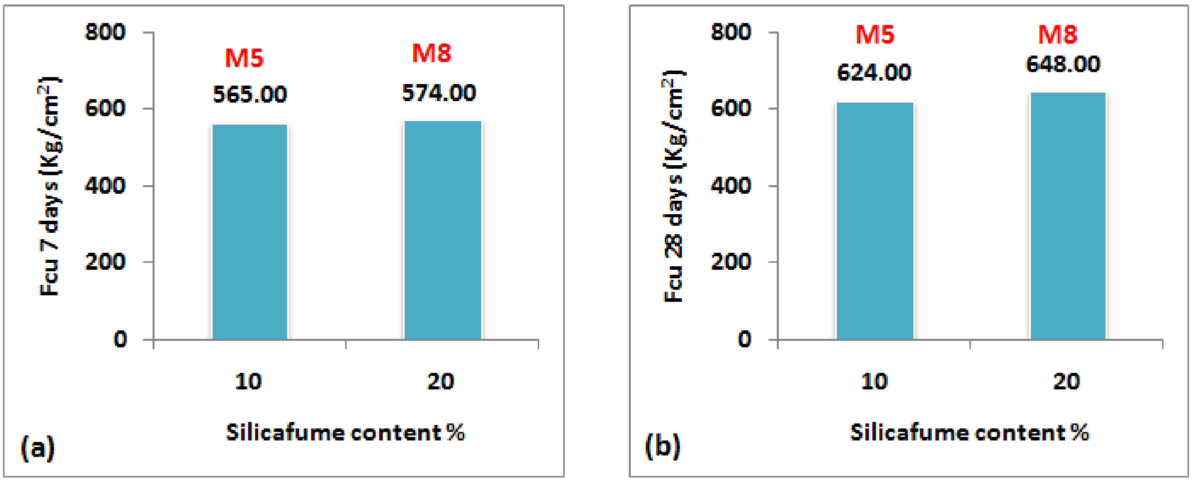

Fig (3) Effect of silica fume content on concrete compressive strength, (a) at 7 days and (b) at 28 days with cement content 800 Kg/m^3

The data in figure (3) clearly show that there is a little enhancement in early compressive strength of concrete, at 7 days, as the silica fume content increases from 10% to 20%. The same results were noted in [4 and 5]. Lakshmi, et al. [5] in their study concluded that, with the addition of mineral admixtures, the compressive, split-tensile and flexural strengths of concrete are increased**.** Increase the percent of silica fume cause an increase in compressive strength. K.Anusha, S.Kesavan [4] reported that one of the most beneficial uses for silica fume in concrete is because of the chemical and physical properties and it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable.

Effect of cement content

In general, the increase in cement content causes an increasing in the compressive strength of concrete. Figures 4a, 4b, 4c, and 4d show the effect of cement content on the compressive strength with and without using Nano-silica additions. For mixes with Nano-silica, (M1 and M4), the increase of cement content from 500 Kg/m^3 to 800 Kg/m^3 caused an increase in compressive strength by about 3.5% at 7 days and by 5.9% at 28 days. For mixes without Nano silica, the increase in cement content from 500 Kg/m^3 to 800 Kg/m^3 caused an increase in compressive strength by about 6.6% at 7 days and by 6.3% at 28 days. It clear from the result in figure (4) that the percentage increases in compressive strength at 7 and 28 days due to increase in cement content is more pronounced in the mixes without Nano silica. This behavior may be attributed to the absence of pozolanic effect especially at early ages.

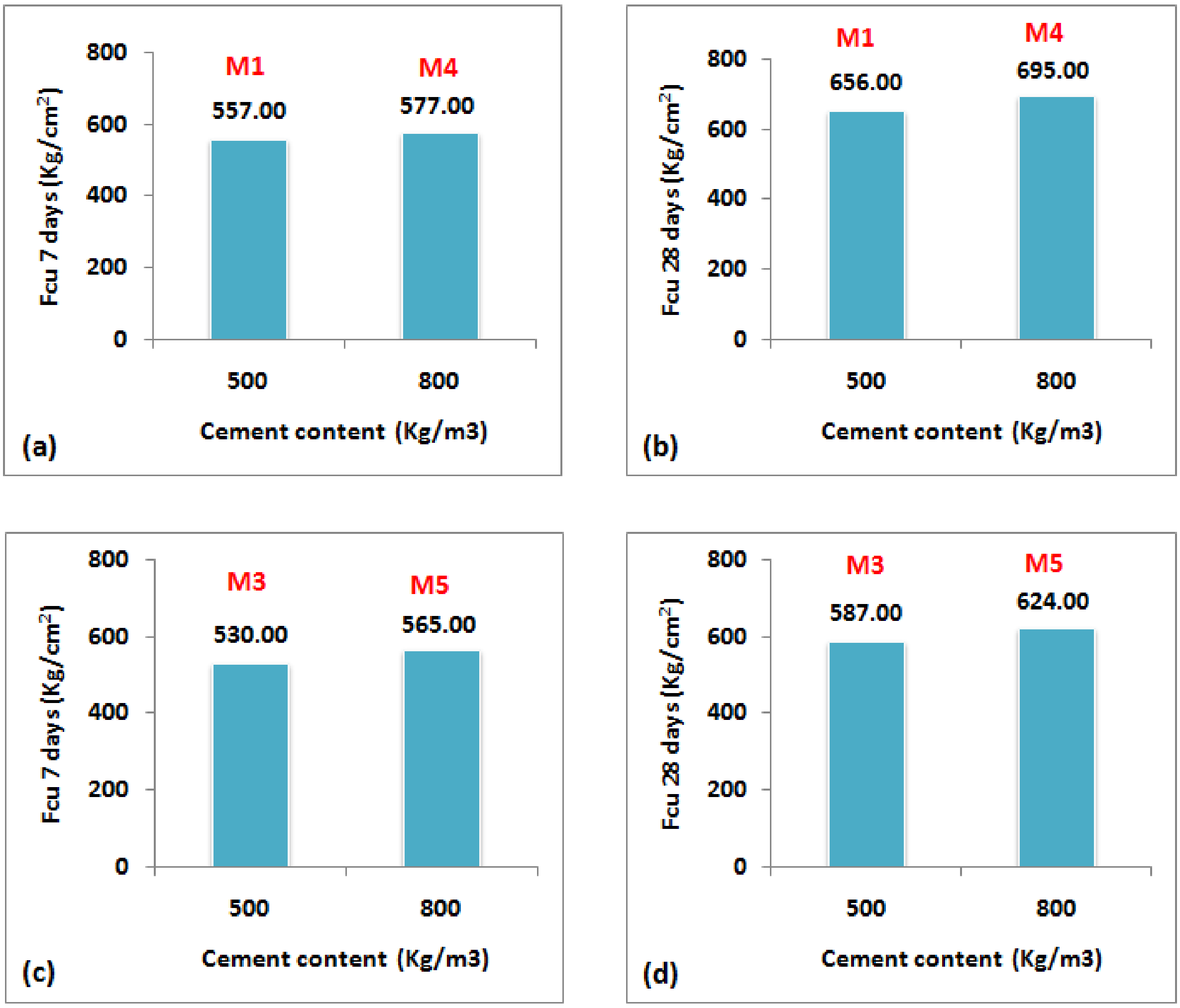

Fig (4) Effect of cement content on concrete compressive strength with and without Nano silica

Effect of curing type

Figures 5a and 5b show comparison between the compressive strength for mixes M1 and M2 at ages 7 and 28 days respectively. The cement content in two mixes was 500 Kg/m^3 and the Nano-silica content was 4%. The specimens of M1 were cured firstly by steam for 3 days and followed by water curing until test. On the other hand, the specimen of M2 was cured in water only until test. The data in figures clearly show a remarkable increase in compressive strength at two ages of test due to steam curing. The 7-days compressive strength increased by about 39.25 % whiles the 28-day compressive strength increased by about 50.1%.

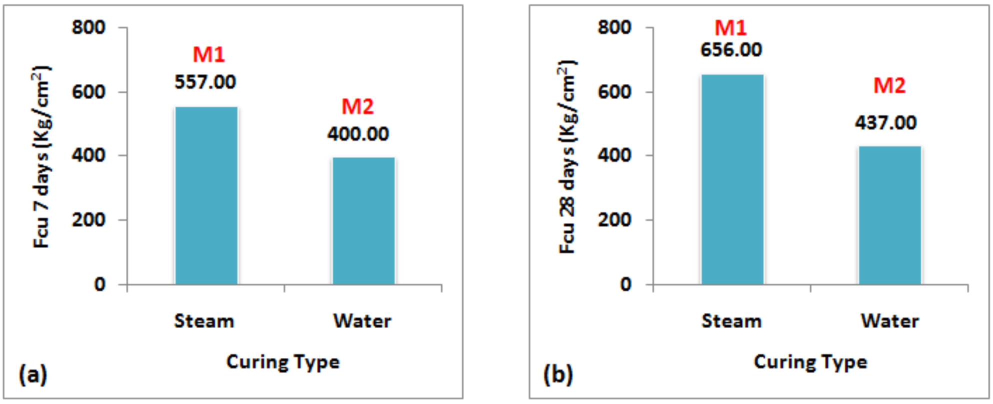

Fig (5) Effect of curing Type on compressive strength, (a) at 7 days and (b) at 28 days with cement content 500 Kg/m3

Figures 6a and 6b show comparison between the compressive strength for mixes M5 and M7 at ages 7 and 28 days respectively. The cement content in two mixes was 800 Kg/m^3 and the Nano silica content was 0%. The specimens of M5 were cured firstly by steam for 3 days and followed by water curing until test. On the other hand, the specimens of M7 were cured by water only until test. The data in figures clearly show a remarkable increase in compressive strength at two test ages due to steam curing. The 7-days compressive strength increased by about 20.7 % whiles the 28-day compressive strength increased by about 30%.

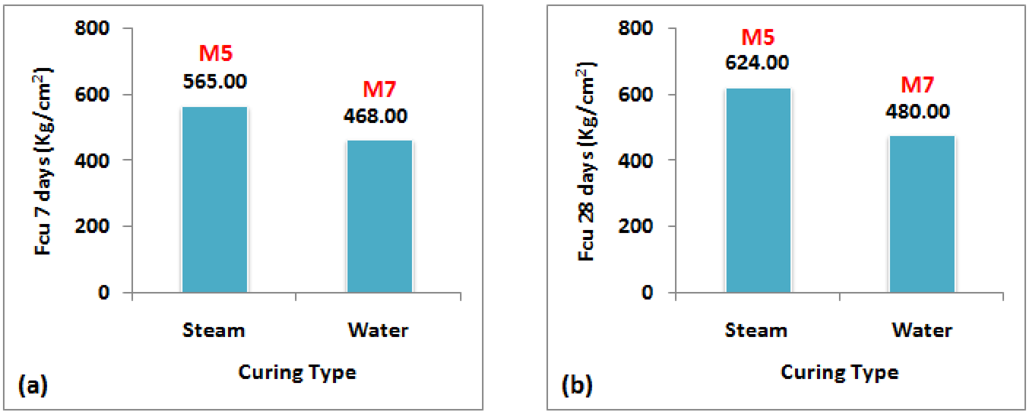

Fig (6) Effect of curing type on compressive strength, (a) at 7 days and (b) at 28 days with cement content 800 Kg/m3

It is clear from the results in Figures 5 and 6 that the steam curing is more effective with existence of Nano silica in mixes M1 and M2. Steam curing at normal pressure is the most common technique among the accelerated curing methods of concrete. In applications, such as pre-cast concretes and pre-stressed reinforced concretes, which require high mechanical performances at very early ages, the steam curing enables concretes to achieve faster strength gain at the required levels. Thermal curing regime enhances the micro structural changes of hydrated cement. Increasing temperature and duration causing formation of different C-S-H gel crystal such as Tobermorite, xonotlite and scwatite. It is observed that thermal curing regime increase the compressive strength up to 40% nearly when sample compared with normal water curing. At normal water curing, pozzalanic reaction of silica fume and quartz powder is not activated, only they act as filler material [7, 8, 9].

CONCLUSIONS

The results in the present investigation reveal several conclusions:

1- The results in this work show an improvement in the compressive strength due to addition of Nano silica by 4%. Where, the strength at 7 days increased by about 2.1% whiles the strength at 28 days increased by about 11.4% for water curing condition.

2- Addition 10% silica fume led to insignificant increase in compressive strength at 7 days but at age of 28 days the compressive strength showed small increase
3- For mixes with Nano-silica the increase of cement content from 500 Kg/m^3 to 800 Kg/m^3 caused an increase in compressive strength by about 3.5% at 7 days and by 5.9% at 28 days. On the other hand, mixes without Nano silica showed an increase in compressive strength by about 6.6% at 7 days and by 6.3% at 28 days.
4- The results in this investigation show a remarkable increase in compressive strength at 7 and 28 days due to steam curing. The 7-days compressive strength increased by about 39.25 % whiles the 28-day compressive strength increased by about 50.1% for mixes containing Nano silica.

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