APPLICATION OF NANOTECHNOLOGY IN SELF-COMPACTING CONCRETE DESIGN

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Abstract In this study, first, different mix design of four types of Self-Compacting Concrete (SCC), 1. SCC consisted of only nanosilica, 2. SCC included only microsilica, 3. SCC consisted of both microsilica and nanosilica and 4. SCC without microsilica and nanosilica called as control mix, were casted and tested to find out the values of the Slump Flow, L-Box and 7 and 28 days compressive strength. Then, based on the results obtained and as yet there is no universally accepted standard for characterizing of SCC, the most suitable four concrete mixes were selected for further investigation of fresh and hardened concrete. For selected mixes, the fresh concrete properties such as values of the Slump Flow, L-Box, V-Funnel, J-Ring and hardened engineering properties such as compressive and flexural strength, shrinkage and swelling values were investigated for three curing conditions at short and long term. The results showed that the engineering properties of SCC mixes could not be improved by adding only nanosilica. However, a satisfactory behavior can be achieved using microsilica in the SCC mixes. However, by adding both microsilica and nanosilica to the SCC mixtures, the best effect on the engineering properties was reported while comparing to the control mixes.

Keywords Self-Compacting Concrete, Microsilica, Nanosilica, Engineering Properties

چکیده در تحقیق حاضر، ابتدا طرح مخلوط‌های مختلفی برای چهار نوع بتن خودمتراکم (SCC)، ساخته و آزمایش‌شد: ۱. بتن خودمتراکم حاوی فقط نانوسیلیکا، ۲. بتن خود متراکم حاوی فقط میکروسیلیکا، ۳. بتن خود متراکم حاوی میکروسیلیکا و نانوسیلیکا، ۴. بتن خودمتراکم شاهد، فاقد نانو و میکروسیلیکا. بدین ترتیب مقادیر جریان اسلامپ، جعبهٔ L و مقاومت فشاری ۷ و ۲۸ روزهٔ نمونه‌ها تعیین شد. سپس بر اساس نتایج و ازآنجاکه تاکنون آیین‌نامهٔ مدونی جهت خصوصیات بتن خودمتراکم تهیه نشده است، مناسب‌ترین مخلوط برای چهار طرح اختلاط بتن جهت تحقیقات بیشتر در فاز خمیری و سخت‌شده انتخاب شد. برای طرح‌های منتخب، خواص خمیری بتن تعیین شد؛ ازجمله؛ مقادیر جریان اسلامپ، جعبهٔ L، قیف V و حلقهٔ J. همچنین خواص مکانیکی سخت‌شدهٔ آنها ازجمله؛ مقاومت فشاری و مقاومت خمشی، مقادیر انقباض و انبساط برای سه شرط عمل‌آوری در سنین کوتاه و طولانی نتایج نشان می‌دهد که افزودن تنها نانوسیلیکا به مخلوط بتن خودمتراکم باعث بهبود خواص مهندسی بتن نشده است. هرچند، امکان عملکرد رضایت‌بخش با کاربرد میکروسیلیکا در طرح اختلاط‌های این نوع بتن وجود دارد. همچنین باافزودن همزمان میکرو و نانوسیلیکا به مخلوط‌های بتن خود متراکم، بهترین تأثیر در خواص مهندسی درمقایسه با بتن خودمتراکم شاهد ایجاد شده است.

1. INTRODUCTION

Self-Compacting Concrete (SCC) is a new type of concrete, which has generated tremendous interest, since its initial development in Japan by Okamura in the late 1980s in order to reach durable concrete structures [1]. Since that time, Japanese contractors have used SCC in different applications. In contrast with the Japan, research in Europe, America and Iran started only recently [2,3].

The advantages of SCC offers many benefits to the construction practice: the elimination of the compaction work results in reduced costs of placement, equipment needed on construction, shortening of the construction time and improved quality control [4,5].

There is widespread agreement that nanotechnology has the potential to revolutionize the world of concrete materials science. The fundamental processes that govern the most pertinent issues to the study of concrete technology (strength, ductility, early age rheology, creep and shrinkage, fracture behavior, durability, etc.) all are affected, if not dominated, by the performance of the material at nanoscale. Yet, there is a lack of agreement about how to pursue concrete materials science research at the nanoscale, to improve the value of the material, and how to develop these nanoscale ideas and bring them to the industry. It would greatly benefit the research community to have well-defined goals in the pursuit of nanotechnology in concrete materials science.

In many ways, the aspects that make concrete such an appealing building material, make it a difficult material to modify at the nanoscale. Concrete is an engineered product, but not in the same sense that a nano-electromechanical (NEMS) device is an engineered product. Whereas a NEMS device can be rigorously engineered from the atomic scale upwards, for concrete the Portland cement and aggregate must, on some level, be considered a “given” in the process. When constructing a multistory concrete structure, attention to the nanoscale variations in the cement and the aggregates is not a possibility [6].

The addition of nanoscaled materials to the Portland cement system can also have an effect on the material. Nanosilica (nano-SiO_2) is a synthetic product with spherical particles in the range of 1-50 nanometers. Nanosilica has been successfully incorporated into Portland cement concrete materials in the laboratory [7]. Much like silica fume on the microscale, nanosilica reduces the porosity of the hydrated cement paste by filling the voids left in the spaces between larger particles (fly ash and cement grains) at the nanoscale. In addition, nanosilica provides pozzolanic activation to fly ash materials, resulting in a quicker gain in strength, and the potential to alleviate the problems of slow strength gain in highly pozzolanic materials. Nanosilica could also reduce the amount of cement required for concrete; thus reducing the heat generation and shrinkage problems associated with high cement contents [6].

Microsilica has been widely used in the construction industries by incorporating it into concretes of a new generation. The environmental pressures and the necessity of reducing the energy consumption in the structural materials industry by the partial replacement of cement with the industrial wastes caused the first interest in the application of the microsilica to concretes. The first experience of the microsilica use for concrete was registered at the Fisco steel works, Norway, in 1971. With the presence of the Microsilica, increase in water demand for mortars and concretes as well as some increase in the compressive strength were observed [8].

In recently limited published research dealing with the influence of nano-sized mineral additions on performance of normal (vibrating) concrete, no report was observed by the authors, for such influence on the self-consolidating concrete (i.e., no need of vibrating). Therefore, the objective of this research work was to study the effect of nano particles on the mechanical properties of SCC.

2. MATERIALS USED

The concrete mixtures investigated in this study were prepared with Portland cement type II, microsilica powder and nanosilica solution (both this materials are prepared by an inner company supplier (in Iran) and the chemical analysis of nanosilica solution was performed in chemistry Department of Kerman University). The specific gravity of microsilica and nanosilica is 2.17 and 1.03, and they are silica particles with a maximum size of 0.2 μm and 50 nm, respectively. In addition, nanosilica is a water emulsion with 50 % of dry solid and PH of 10. The typical analysis of cement and microsilica is shown in Table 1. The control mix which was exclude of microsilica and nanosilica.

Continuously graded aggregate with nominal particle size of 20 mm and well-graded sand with a fineness modulus of 2.92 were employed. The particle size distributions of both coarse and fine aggregates were within ASTM C-33 limits, as shown in Table 2. The relative density values of the coarse and fine aggregates were 2.7 and 2.49 and their absorption rates were 1.2 and 1.92 %, respectively. The superplasticizer used in all mixtures, was Poly-Carboxylic Ether (PCE) and had a specific gravity of 1.03 and PH of 7. In addition, Limestone Powder (LSP) with maximum

TABLE 1. Typical Analysis of Portland Cement and Microsilica.

	Cement	Microsilica
SiO_2	21.74	93.86
Al_2O_3	5.0	1.32
Fe_2O_3	4.0	0.87
CaO	63.04	0.49
MgO	2.0	0.97
SO_3	2.3	0.10
Cl	0.035	0.04
$Na_2O+0.658K_2O$	1.0	0.974
C_3S	45.5	--
C_2S	28.0	--
C_3A	6.5	--
C_4AF	12.2	--
Loss on Ignition	1.3	--
Insoluble Residue	0.6	--
Free CaO	1.4	--
Na_2O	--	0.31
K_2O	--	1.01
SiC	--	0.53
C	--	0.34
P_2O_3	--	0.16
Fineness (cm^2/gr)	2900	200000
Residue on 90 μm Sieve (%)	4.0	--

TABLE 2. Particle Size Distribution of Coarse and Fine Aggregates (by Mass).

Screen Size (mm)	Coarse Aggregate (% Passing)	Fine Aggregate (% Passing)
19	100	--
12.5	72	--
9.5	35	100
4.75	1	98
2.36	--	84
1.18	--	60
0.6	--	41.5
0.3	--	22
0.15	--	2.5

size of 0.3 mm and relative density of 2.65 was employed.

3. WORKABILITY OF SCC

There is yet no universally accepted standard for characterizing of SCC. Nevertheless, a few testing methods seem to reappear several times in literature and tend to become internationally recognized as suitable methods to characterize the self compatibility of a concrete [2]. The same testing methods were prepared in this research.

3.1. Slump Flow Test The Slump Flow test specified by the Japan Society of Civil Engineers evaluates the capacity of a concrete to deform under its own weight without any restraint, except from the friction of the surface and the test is based on the slump cone test, used for traditional concrete. To measure the slump flow, an ordinary slump test cone is filled with SCC without compaction and leveled. The cone is lifted and the average diameter of the resulting concrete spread is measured. A slump flow value ranging from 500 to 700 mm for a concrete to be self compacted [9]. Here, the ranging values obtained were 620 to 650 mm (Table 3) and a typical measurement is also shown in Figure 1.

3.2. J-Ring Test The J-Ring test is used to determine the blocking characteristics of self-compacting concrete. The equipment consists of a ring placed on several rebar with adaptable gap widths, combined to the Abram's cone or the Orimet test. Both blocking and segregation can be detected visually [10].

The J-Ring tests combined to the cone were prepared. A typical test measurement is shown in Figure 2 and the ranging values obtained were given in Table 3.

3.3. L-Box Test With the L-Box apparatus, it is possible to measure different properties such as flow ability, blocking and segregation of the concrete [11-13]. The height of concrete remaining in the vertical section (h_1) and the height of concrete at the end of the horizontal part (h_2) are determined, and then the (h_2/h_1) value is calculated. The ratio between these two heights (h_2/h_1), which

TABLE 3. Properties of Selected Mixes.

Mix Labels / Material	S	SN	SM	SMN
Cement (Kg)	400	400	360	360
Microsilica (Kg)	--	--	40	40
Nanosilica (Liter)	--	2	--	2.4
Water (Kg)	168	168	168	168
LSP (Kg)	100	100	100	100
Coarse Aggregate (Kg)	750	750	750	750
Fine Aggregate (Kg)	870	870	870	870
PCE (Liter)	2.4	2.4	2.8	2.8
W/CM*	0.42	0.42	0.42	0.42
Fresh Properties				
Slump Flow (mm)	640	650	620	630
L-Box (h_2/h_1)	0.78	0.8	0.79	0.82
Slump Flow + J-Ring (mm)	610	620	590	610
V-Funnel, 1 minute (s)	5.65	5.4	4.5	4
V-Funnel, 5 minute (s)	--	--	7.2	7

*CM: Cement + MS

Figure 1. Slump flow test.

is usually 0.7-0.9 for SCC [14], was used to evaluate the ability of the SCC mixtures to flow around obstructions. This limit, however, has been proposed to be within 0.8 and 1.0 by EFNARC guidelines [15].

For this study, a gap of 55 mm between 12 mm-diameter bars was selected where the top aggregate size was 20 mm [12,16]. Here, the ranging values obtained were 0.78 to 0.82 (Table 3) and a typical test is also shown in Figure 3.

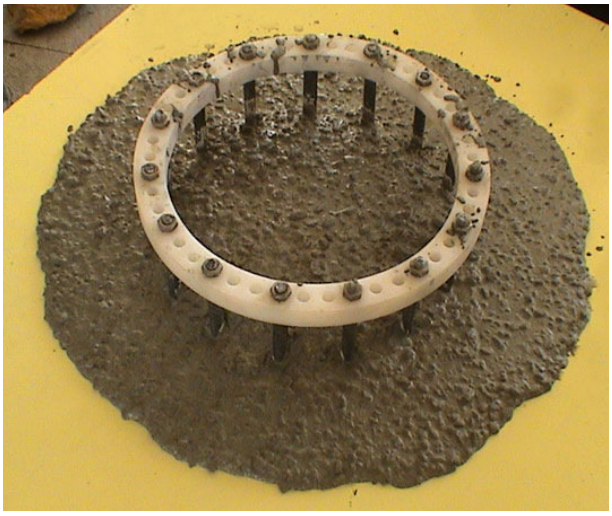

Figure 2. J-Ring test combined to the cone.

Figure 3. L-box test.

3.4. V-Funnel Flow Time Test The test was developed in Japan and used by Ozawa, et al [17]. This test covers evaluation of narrow-opening possibility, which involves viscosity of freshly mixed self-compacting concrete from observation of flow speed of the sample through the specially designed funnel under self-weight. This test also covers evaluation of segregation resistance of freshly mixed self-compacting concrete by the observation of the variation on the flow speed due to the difference of the sample's remaining period in the funnel [18,19]. In this test, the funnel is filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow out (Figure 4). The flow of the concrete is noted as the lapse of time between the removal of the outlet and the seizure [20]. Acceptable value range is between 4 and 10 s [21]. In this study, the ranging values obtained were between 4 to 6 S (Table 3) and a typical test is also shown in Figure 4.

Figure 4. V-Funnel test.

4. MIX DESIGN

To produce the SCC, First, different mix design of SCC were casted and tested to find out the fresh concrete properties such as values of the Slump Flow, L-Box tests and hardened concrete properties such as 7 and 28 days compressive strength. The brief summary results of the some trial mixes are shown in Table 4.

Based on these results, the following four mixes, (1) SCC "S", as the control mix, (2) SCC with nanosilica "SN", (3) SCC with microsilica "SM" and (4) SCC with microsilica and nanosilica "SMN" (Table 3) were selected for further investigation of the properties of fresh and hardened concrete.

TABLE 4. Trial Mixtures Characteristics.

Mix No.	Cement (Kg)	Micro Silica (Kg)	Nano Silica (L)	W/CM[1]	Gravel (Kg)	Sand (Kg)	LSP (Kg)	PCE (L)	Slump Flow (mm)	Compressive Strength (MPa)	
										7 Days	28 Days
1	400	-	2.8	0.45	450[2]	1250	-	3.2	670	17.3	25.9
2	400	-	-	0.45	750[2]	870	150	3.2	800	23.5	29.5
3	400	-	-	0.45	750[2]	870	150	2.8	705	21.2	27.0
4	400	-	-	0.42	750[2]	870	150	5.6	-	27.1	30.0
5	400	-	-	0.42	750[2]	870	150	2.8	630	20.7	29.3
6	400	-	2.8	0.42	750	870	-	2.1	640	24.1	35.9
7	400	-	-	0.42	650	1050	100	2.6	510	12.9	21.7
8	400	-	-	0.42	650	1050	100	2.8	660	19.3	22.0
9	400	-	-	0.42	750	870	100	2.8	730	18.5	31.0
10	400	-	-	0.42	750	870	100	2.6	705	23.5	31.1
11	400	-	-	0.42	750	870	100	2.4	700	18.9	22.4
12	400	-	-	0.42	750	870	100	2.2	585	20.2	26.0
13	400	-	2.0	0.42	650	1050	100	2.8	560	19.1	26.3
14	400	-	1.8	0.42	650	1050	100	2.8	580	19.7	23.0
15	400	-	1.6	0.42	650	1050	100	2.8	640	18.9	24.1
16	400	-	2.0	0.42	750	870	100	2.4	490	22.6	26.9
17	400	-	2.0	0.42	750	870	100	2.4	630	23.4	27.8
18	400	-	-	0.38	750	870	100	2.6	-	23	41
19	360	40	-	0.42	750	870	100	2.8	620	30	50
20	360	40	2.4	0.42	750	870	100	2.8	630	29	53
21	360	40	-	0.38	750	870	100	3.2	660	27	52
22	360	40	3	0.38	750	870	100	3.2	680	25	56
23	360	40	-	0.37	750	870	100	3.6	660	28	56
24	360	40	3	0.37	750	870	100	3.6	690	25	47

[1] CM: Cement + MS

[2] Maximum Gravel Size of 10 mm

For ‘SM’ and ‘SMN’ mixes, first, the dry materials were mixed in the mixture for one minute. Then, two third (2/3) of water was added during one minute and continued mixing for another one minute. After that, one third of remaining water mixed with PCE and added to the mix continuously for one minute and finally, they were mixed for one more minute. However, for ‘SN’ and ‘SMN’ mixes, the nanosilica was added to initial two third of water.

5. EXPERIMENTAL TESTS AND RESULTS OF HARDENED CONCRETE

In this study, three different curing conditions were assumed. All of concrete specimens were made and covered with a plastic sheet and burlap for the first 24 hours to prevent moisture loss. After 24 hours, the specimens were demolded and immediately placed in the water, which was saturated with the lime. After 7 days, some of the specimens were transferred to a room with the temperature of 28 ± 4˚C and a relative humidity of 30 ± 5 %, called as dry (D) condition. The another group of specimens were placed in 5 % sodium sulfate (Na_2SO_4) solution, (S) condition, and the remaining were kept in water up to 28 days age, called as (W) condition and then they were cured in the same condition of (D).

5.1. Compressive Strength tests and Results

For four cases of studied at three storage conditions, concrete cube specimens of 10 × 10 × 10 cm were casted and tested at 3, 7, 14, 28 and 90 days age. The results are shown in Figures 5-7. Also the comparison for different mixes was prepared and the results were given in Table 5. The results at different ages show that for any storage condition, either short or long term, the compressive strength of SMN specimens was higher than the other mixes. As an example, this rise in strength of SMN while comparing with the S specimens for sodium sulfate curing condition was 33 % and 20 % for 28 and 90 days age, respectively.

It seems by adding both of microsilica and nanosilica to mixes, the rate of increase in compressive strength was higher while comparing to the other mixes for every curing conditions and ages.

Furthermore, by comparison of the strength results of four mixes, it can be concluded that, at 28 days age, the mixes had a better behavior for (D) storage condition (Figure 8), whereas, the results show higher compressive strength for (W) storage condition at 90 days age (Figure 9).

In addition, it seems that there is no any increase in compressive strength by adding only nanosilica in SCC mixes.

5.2. Flexural Strength Tests and Results

For all cases of studied at two curing conditions (W and D), concrete prism specimens of 10 × 10 × 45 cm were casted and tested at 28 and 90 days age, and test results have been shown in Figures 10 and 11.

The results show that a similar trend was observed for flexural strength, i.e., a better behavior obtained when SCC consisted of both microsilica (SM and SMN). Meanwhile, by use of both microsilica and nanosilica (SMN), the increase in flexural strength was higher while compare with the other mixes.

In addition, it seems that by adding of only nanosilica in the mixes, no rise in strength can be achieved.

5.3. Shrinkage Tests and Results

When the concrete specimens are exposed to a dry environment after an initial moist curing condition, the shrinkage of concrete may be divided into two components: drying shrinkage and autogeneous shrinkage. According to ACI 116 R, the drying shrinkage is defined as “shrinkage resulting from loss of moisture”, whereas the autogenous shrinkage is defined as “change in volume produced by the continued hydration of cement, exclusive of the effects of applied load and change in either thermal condition or moisture content”. The autogeneous shrinkage is a consequence of the withdrawal of water from the capillary pores by the hydration of cement-a process known as self-desiccation [22].

Typical values of autogenous shrinkage of ordinary concrete arc approximately 40×10^{-6} at the age of 1 month and 100×10^{-6} after 5 years [23], which are relatively low compared with those of drying shrinkage. And hence, usually the autogenous shrinkage is ignored for practical purposes in ordinary concrete. However, for concrete with a low w/c ratio, particularly when it contains silica fume, autogenous shrinkage may be important. At a very

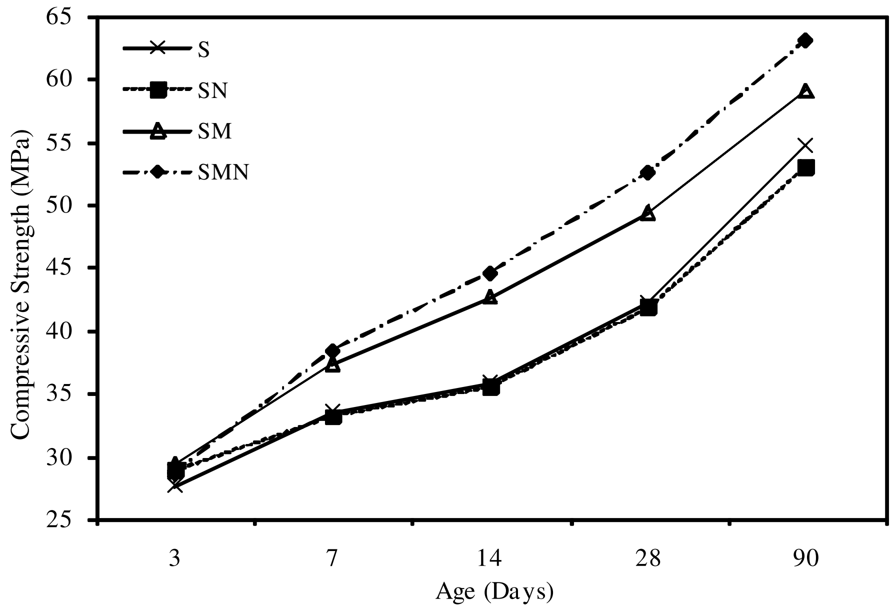

Figure 5. The compressive strength of mixes for (W) curing condition in different ages.

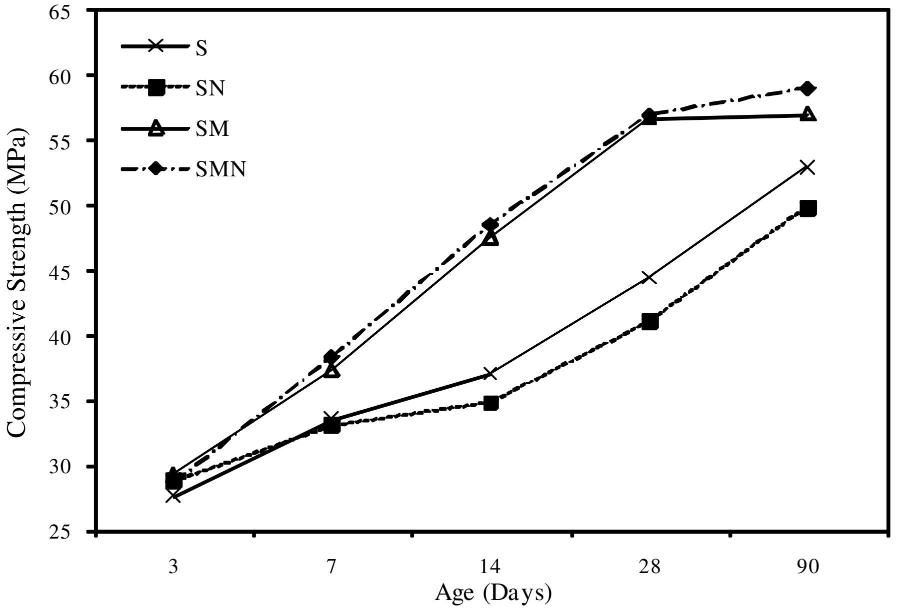

Figure 6. The compressive strength of mixes for (D) curing condition in different ages.

low w/c ratio of 0.17, an autogenous shrinkage of 700 × 10^{-6} for concrete was reported [24]. Hence, the shrinkage of concrete exposed to a dry environment is a combination of drying and autogenous shrinkage.

In this investigation, the prism specimens of 10 × 10 × 45 cm was casted and at the age of one day, the specimens were demolded and the Demec points were glued on two opposite surfaces of the specimens with a fast-setting epoxy [25,26]. Then

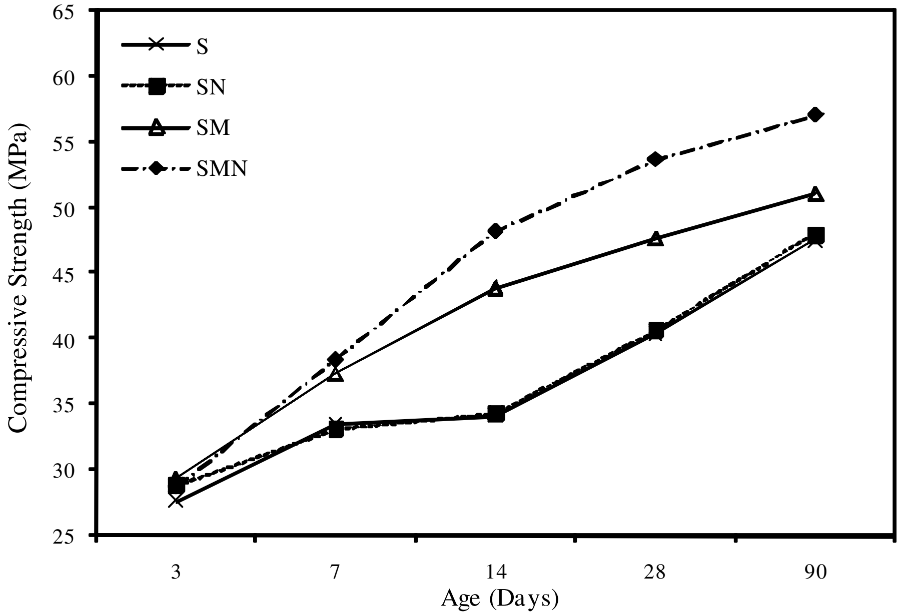

Figure 7. The compressive strength of mixes for (S) curing condition in different ages.

TABLE 5. Increase/Decrease of Compressive Strength in Different Curing Conditions (%).

Age (Days)	Curing Conditions	Y X	SMN	SM	SN	S
28	(W)	SMN	0	7	26	25
		SM	--	0	18	17
		SN	--	--	0	-1
	(D)	SMN	0	1	39	29
		SM	--	0	38	28
		SN	--	--	0	-1
	(S)	SMN	0	13	32	33
		SM	--	0	17	18
		SN	--	--	0	1
90	(W)	SMN	0	7	19	15
		SM	--	0	11	8
		SN	--	--	0	-3
	(D)	SMN	0	4	19	12
		SM	--	0	15	8
		SN	--	--	0	-6
	(S)	SMN	0	12	19	20
		SM	--	0	7	8
		SN	--	--	0	1

Example: Increase of compressive strength of SMN relative to S in (W) curing condition at the 28 days age: $\frac{X}{Y} = 25\%$.

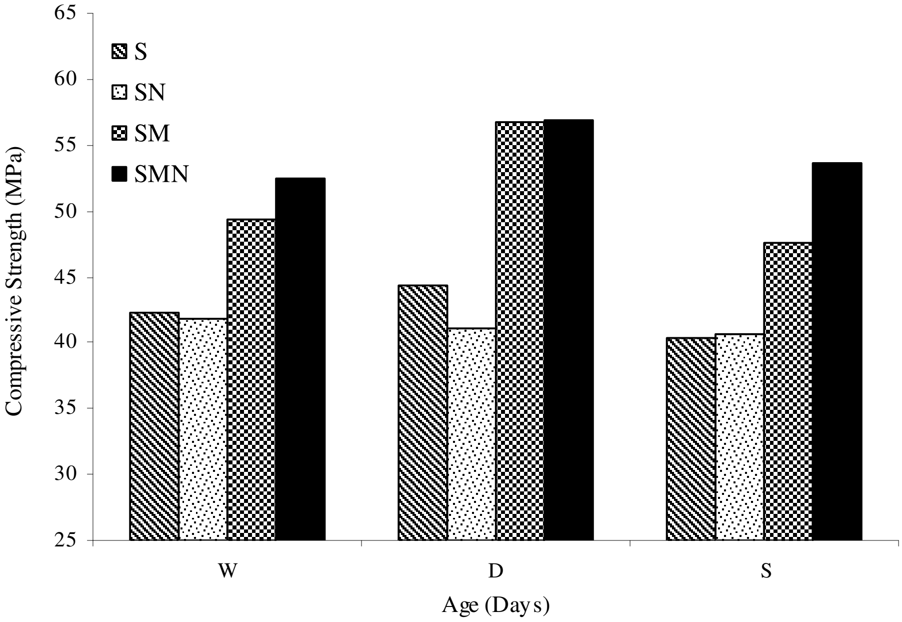

Figure 8. The compressive strength for different curing conditions at 28 days age.

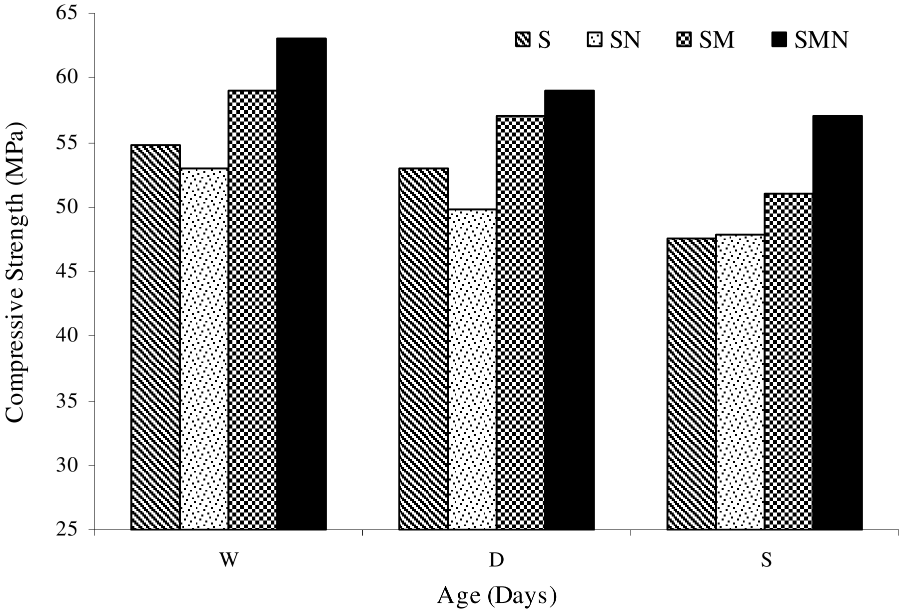

Figure 9. The compressive strength for different curing conditions at 90 days age.

they were kept either at (D) or (W) storage conditions. At different ages, the amount of shrinkage was measured by the mechanical strain gauge and the average values for two opposite surface of specimens were plotted in Figures 12 and 13.

Again, the comparison of results for different mixes was preformed (see Table 5). By literature search and also from the results of Figures 12 and 13, the amount of shrinkage was high for SCC mixes. The obtained values were 1290 × 10^{-6} for S

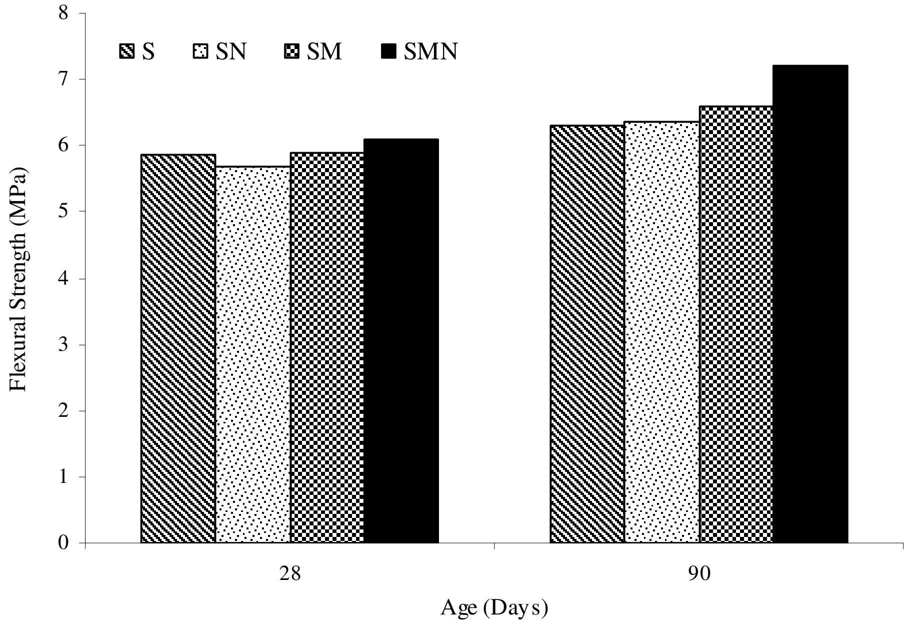

Figure 10. The flexural strength of mixes for (W) curing condition.

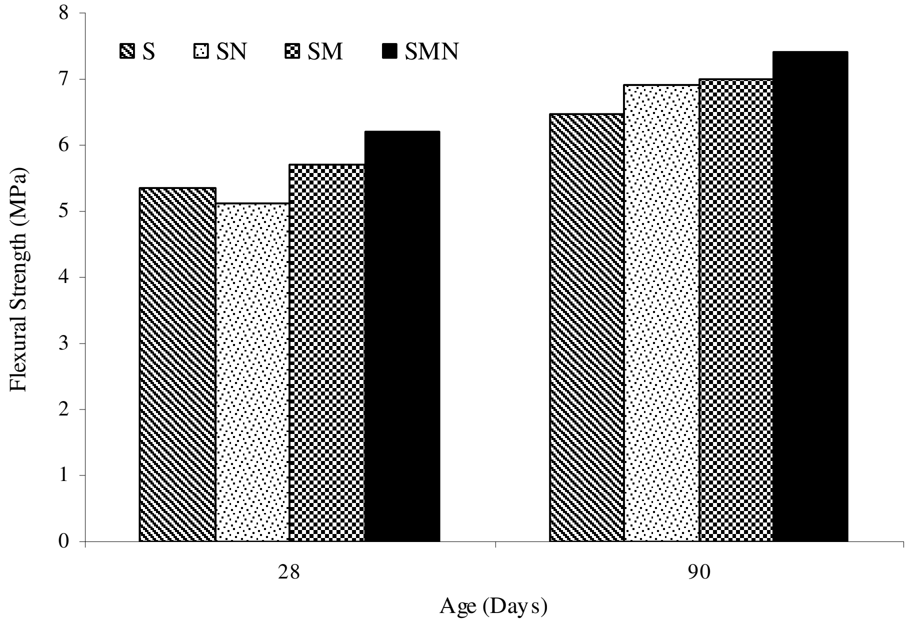

Figure 11. The flexural strength of mixes for (D) curing condition.

and SN mixes for (D) curing condition (see Figures 12 and 13).

As shown, the amount of shrinkage for the samples kept at (D) condition was more than values for (W) condition in the mixes S and SN.

For two curing conditions, the shrinkage amount of mixes consists of microsilica was lower and it was also found that the mixes consists of both microsilica and nanosilica had the lowest shrinkage values of 350 × 10^{-6} for (D) curing conditions, i.e.

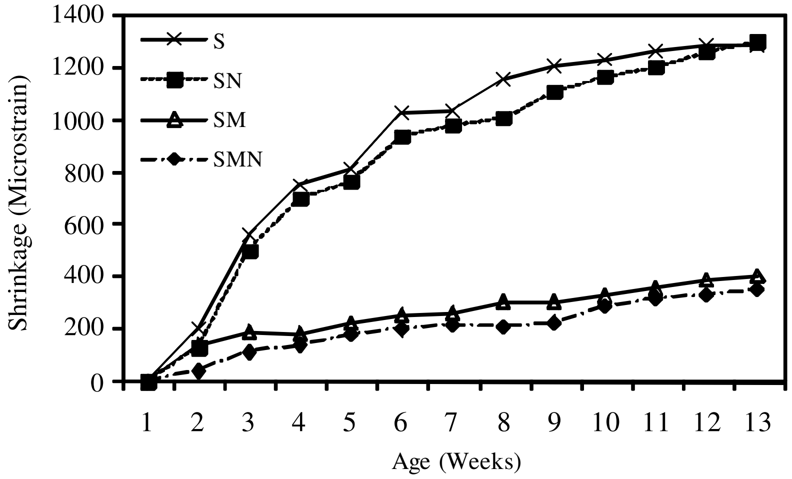

Figure 12. Shrinkage values for (D) condition at different ages.

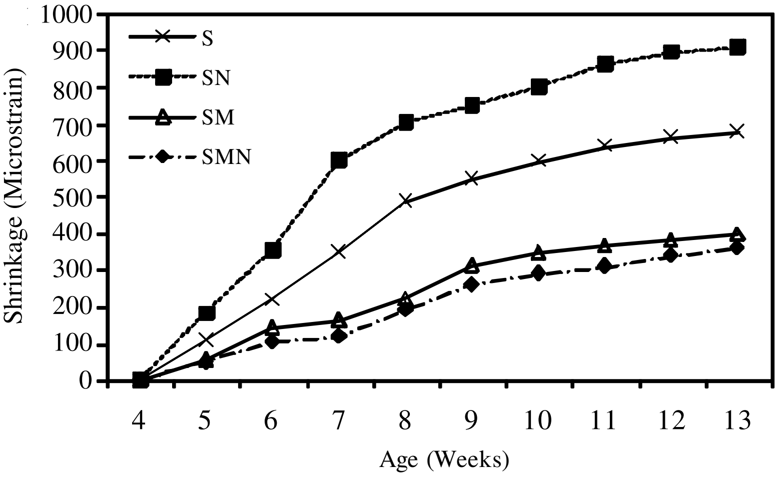

Figure 13. Shrinkage values for (W) condition at different ages.

the values reduced by 73 % (Table 6).

In other words, the disadvantage of high shrinkage values for SCC mixes can be improved by adding both microsilica and nanosilica to SCC mixtures.

5.4. Swelling Tests and Results In this study, for four mixes, the prism specimens were prepared and the Demec points were glued on surfaces of the specimens similar to shrinkage test. Then specimens were kept in water for all ages and at different ages, the amount of swelling was measured by the mechanical strain gauge and its results were drawn in Figure 14. However, the comparison of the results was given in Table 7.

From the results, it is clear that the amount of swelling for SMN was less than the mixes S and SN.

Considering the specimen SMN in comparison to the control concrete specimen, S, the reduced swelling amount is 52 %. Again it can be concluded that the disadvantage of high swelling value for SCC mixes can be improved by adding both microsilica and nanosilica to the SCC mixtures.

TABLE 6. Increase/Decrease of Shrinkage Amounts in Different Curing Conditions (%).

Curing Conditions	Age (Days)	X \ Y	SMN	SM	SN	S
(D)	28	SMN	0	-24	-80	-82
		SM	--	0	-73	-76
		SN	--	--	0	-7
	90	SMN	0	-14	-73	-73
		SM	--	0	-69	-69
		SN	--	--	0	0
(W)	90	SMN	0	-10	-60	-47
		SM	--	0	-56	-41
		SN	--	--	0	34

Example: Decrease of shrinkage of SMN relative to S in (W) curing condition at the 90 days age: $\frac{X}{Y} = 47\%$.

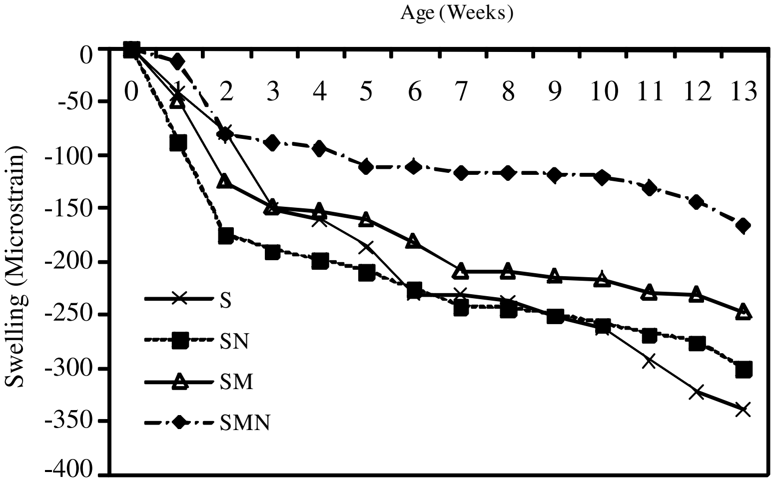

Figure 14. Swelling values at different ages.

TABLE 7. Increase/Decrease of Swelling Amounts (%).

Age (Days)	Y X	SMN	SM	SN	S
28	SMN	0	-40	-55	-45
	SM	--	0	-25	-6
	SN	--	--	0	25
90	SMN	0	-34	-45	-52
	SM	--	0	-18	-28
	SN	--	--	0	-12

Example: Decrease of swelling of SMN relative to S at the 90 days age: $\frac{X}{Y} = 52\%$.

6. CONCLUSIONS

Based on experimental research for four self compacting concrete mixes, the following conclusions can be drawn for short (up to 28 days) and long (up to 90 days) term:

6.1. Short Term, up to 28 Days:

6.1.1. The compressive and flexural strength of SCC mixes can be increased while the SCC design is consisted of both microsilica as well as nanosilica. The amount of increase in compressive strength was about 25, 29 and 33 %, respectively under curing conditions of wet, dry and sodium sulfate solution.

6.1.2. The shrinkage amount of SCC mixes can be decreased while designing the SCC with both microsilica as well as nanosilica. The amount of decrease in shrinkage was almost as much as 80 % under (D) curing condition. It seems such achievement is important for SCC mixture which is usually containing a high shrinkage values.

6.1.3. The swelling amount of SCC mixes can be decreased while designing the SCC with both microsilica as well as nanosilica. The amount of decrease in swelling values was about 45 %. It seems such achievement is important for SCC mixture which is usually containing a high shrinkage values.

6.2. Long Term, up to 90 Days:

6.2.1. By the passage of time, a further increase in compressive strength of SCC mix design can be achieved while designing the SCC with both microsilica and nanosilica. The rise in strength at the age of 90 days was as much as 15, 12 and 20%, respectively for wet, dry and sodium sulfate solution conditions.

6.2.2. One of the disadvantages of SCC is its high amount of shrinkage with respect to the normal concrete. Therefore, it was possible to overcome such a disadvantage, by designing the SCC with both microsilica and nanosilica in mixtures. It was possible to reduce amount of shrinkage about 47% and 73 %, respectively under curing condition of wet and dry, by adding the microsilica and nanosilica to SCC mixture.

6.2.3. The swelling amount of SCC mixes can also be decreased, while designing the SCC with both microsilica as well as nanosilica. The amount of decrease in swelling values was about 52%.

6.3. The engineering properties of SCC mix could be improved in sodium sulfate solution condition, while designing such a mix with both microsilica and nanosilica.

6.4. For all ages and curing conditions studied, a reasonably better serviceability condition (i.e. low amount of shrinkage and swelling and high values of compressive and flexural strength) of the reinforced concrete structures while using self compacting concrete can be reached (in short and long term) by designing the SCC with microsilica and nanosilica.

As a general conclusion, the comparison of results of SMN and SN specimens indicated that, a more suitable continuating in aggregate grading is achieved, due to the presence of gravel, sand, LSP, cement, micro and nanosilica, in SMN mixes, and therefore, a more dense concrete was developed; this is affected on improving mechanical properties of the SCC.

Also the results indicated that, for the SMN mixes, the available quantity of silica in concrete based on both micro and nano scale, could play a suitable pozolanic active role in congestion with the cement paste. However, the available quantity of nanosilica alone in concrete for SN mixes, could not prepared the mentioned situations either from the point of view of aggregate grading nor the pozzolanic activaties compared to the SMN mixes.

Also, although a better mechanical property was obtained for SM mixes while compare to the SN one, never the less, the SM mixes treated weaker than the SMN mixes. In other words, the applications of nano materials have suitable effect on SCC technology.

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