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EFFECT OF NANO-SILICA AND SUPER ABSORBENT POLYMERS ON THE SHRINKAGE AND STRENGTH OF CONCRETE AT EARLY AGES

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ABSTRACT

As plastic shrinkage cracking of concrete still causes considerable repair costs annually, an understanding of the phenomenon is essential to prevent its damage effects in the concrete structures. In this paper, the chemical admixture Super Absorbent Polymers (SAP) and the mineral admixture Nano-silica (NS) have been used as a new methodology to avoid the plastic shrinkage. This paper studies the effect of the chemical and mineral admixture on the behavior of concrete at early ages. The main parameters addressed in the research are the type of admixture (Nano-silica with 0.5, 1.0, 2.0 and 2.5% and super absorbent polymers with 0.2 and 0.3% as a percent of cement weight), method of curing (water, air of the laboratory and open atmosphere). The compressive strength for the mixes has been measured at ages (1, 3, 7 and 28 days). The plastic and dry shrinkage for the different mixes have also been measured. Results from these tests show that the optimum ratio of Nano-silica is 2.5% of cement weight at water curing improve the behavior of concrete due to shrinkage and the compressive strength at early ages. Also 0.3% SAP of cement weight is the best value to enhance the behavior of shrinkage of concrete.

Keywords: Nano-silica, Super absorbent polymers, Plastic shrinkage, Drying shrinkage, Elevated temperature.

1. INTRODUCTION

Cracking due to plastic shrinkage occurs in concrete, where concrete is a mixture of cement, water, fine aggregate (sand) and coarse aggregate (gravel or crushed rock) in which the cement and water have hardened by a chemical reaction called hydration [1]. Plastic state concrete is formed where it is capable of being shaped [2], and more or less behaves like a fluid or liquid. A plastic concrete is, therefore, still in the liquid or fluid phase which occurs only for a few hours after water has been added to the concrete. The plastic phase ends when the concrete becomes unworkable, which means that concrete placement, compaction and finishing becomes difficult. This point in time is called the initial set of concrete [3]. Shrinkage refers to a volume reduction. This volume reduction of the concrete during the plastic phase is mainly due to the loss of water because of evaporation. Cracking tells us that the concrete cracked due to this shrinkage or

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volume reduction [4]. From an aesthetical point of view, plastic shrinkage results in unsightly surface cracks which give a non-uniform appearance of the concrete surface [5]. It is widely acknowledged that the origin of plastic shrinkage is capillary pressure. This was confirmed by Wittman as far back as 1976 [6]. The most significant mechanisms that influence the occurrence of plastic shrinkage cracking are the evaporation of water from fresh concrete, the bleeding of concrete, the material constituents, and the paste mobility [7]. A similar concept that fibers may provide bleeding channels for evaporable water replenishment was experimentally examined in reference [8]. The effect of low water-to-cement ratio (w/c) systems at a very early age on the volume contraction and internal micro-cracking were studied in reference [9]. The effect of volumes of coarse monofilament polypropylene fibers on the workability was also studied in reference [10]. Drying shrinkage occurs when the specimen is exposed to the environment and allowed to have volumetric changes. Normally, the entire shrinkage strain is assumed to be from drying shrinkage, and any contribution from autogenously shrinkage is neglected [11]. The ultimate drying shrinkage of mortar increases with the increased of silica fume (SF) content at 28 days, but the long-term drying shrinkage after 365 days was not significantly affected by the addition of silica fume [12]. A. Idiart conducted a finite element to analyze the mechanical problems, yields to dry shrinkage and external sulfate attack in concrete specimens [13]. Mounir M. Kamal et al [14] have been evaluated the plastic and dry shrinkage for fiber Self-Compacting Concrete (SCC) mixes. Also the plastic shrinkage of concrete was studied by F. Sayahi [15]. X. Wang [16] has been studied the effect of cementitious materials on the behavior of drying shrinkage of the mortar. N. F. Hossein et. al. [17] have been studied the effect of Nano-silica on the drying shrinkage. They studied the microstructure of the cement mortar. They concluded that using Nano-silica improve the microstructures for the cement mortar so the drying shrinkage for the mixes increased. M. Sonebi et. al. [18] investigated the properties of fresh and hardened mortar using Nano-silica and fly ash. Density, plastic shrinkage, and drying shrinkage up to 20 days were recorded. They formulated equations to optimize proportions of the mortar for fresh and hardened state. S. Abd El Aleem et. al. [19] studied the effect of fillers on filling the pore. They concluded that as the particle size of Nano-silica decreases, the pore diameter decreased and so the microstructures improved. J. Dang et. al. [20] have been evaluated the effect of super absorbent polymers (SAP) on the workability and the strength of the concrete under different curing conditions. From the experiment results, as the SAP increases the slump of the mixture increases. Also as the age increases, the compressive strength increases epically in 28 days at the natural curing. The shrinkage of concrete reduced with using SAP. X. M. Kong et. al. [21] have been studied the effect of the super absorbent polymer (SAP) on the strength of the concrete as an internal curing agent. They showed that the compressive strength, autogenously shrinkage as well as the early-age shrinkage reduced. P. Zhang et. al. [22] have been used Nano-silica to modify light weight concrete properties. They carried out the mechanical properties to evaluate the effect of Nano-silica on the hardened properties of light weight concrete. M. A. Sanjuán et. al. [23] have been used Nano-Fe_2O_3 and Nano-SiO_2 to study their effect on the mechanical properties of the cement mortar. The porosity and electrical resistivity of cement mortars were also studied. They resulted that the compressive strength decreased compared to control mix at 7 and 28 days. The microstructures for the cement mortar confirm the results of the compressive strength.

2. RESEARCH SIGNIFICANCE

In this paper, the effect of Nano-silica and super absorbent polymers on the plastic and drying shrinkage of concrete is presented and the concrete behavior at early ages is examined. The effect of using different percentages of Nano-silica and super absorbent polymers (SAP) is investigated. The effect of curing conditions on the concrete behavior is also evaluated.

3. EXPERIMENTAL PROGRAM

To achieve the aim of the research, seven mixes have been prepared. Each mixture has a different composition of Nano-Silica (NS) and super absorbent polymers (SAP). Mixes features are reported in Table (1). The mixtures are used to construct various types of concrete specimens. A total of 324 concrete cubes have been constructed. The length of each cube side is 100 mm. The cubes are exposed to different weather conditions to examine its behavior under various curing conditions. 156 cubes have been tested to determine the compressive strength of the mixes especially at early-ages. Furthermore, a total of 63 prisms, having 70×70×250 mm dimensions, have been cast and tested to determine the drying shrinkage strain of hardened concrete at different curing conditions (water, air of the laboratory: 25 °C and 50% relative humidity) and open atmosphere (ranged from 10 to 45 °C and the relative humidity ranged from 40% to 80%). Besides, a total of 21 cylinders of 100 mm diameter and 200 mm height have been constructed and tested to determine the plastic shrinkage after a short period of time (normally up to 24 hours) subsequent to casting.

Table (1) Mix proportions by weights (kg/m³)

Code	Cement	Dolomite	Sand	SF	NS	SAP	HRWR	Water
CM	400	1104.7	736.5	40	-	-	8	140
N.S 0.5%		1103.3	735.5		2			
N.S 1.0%		1101.9	734.6		4			
N.S 2.0%		1099.1	732.7		8			
N.S 2.5%		1097.7	731.8		10			
SAP 0.2%		1131.9	754.6		-	0.06		
SAP 0.3%		1131.4	754.3			0.09		

SF.: silica fume NS: Nano-silica SAP: Super Absorbent Polymers
HRWR: High range water reducer CM: control specimens

Materials

Portland cement (CEM I 42.5 N) conformed to the requirements of the ES 4756-1/2012 [24] with a specific gravity of 3.15 and Blaine fineness of 3990 cm^2/g has been used. Silica fume (SF) has been delivered in 25 kg sacks. According to the manufacture's data sheet SF has an average particle size of 0.1 micrometer, specific surface area of 170000 cm^2/g and specific gravity of 2.2 g/cm^3. Crushed dolomite with maximum nominal size 10 mm has been used. The specific gravity of dolomite is 2.66 g/cm^3 and its absorption is 2%. Well graded siliceous sand has been used with a specific gravity of 2.60, absorption of 0.81%, and a fineness modulus of 2.55. Nano-silica with specific gravity 2.2 g/cm^3 and particle size less than 1 µm has been used. Super absorbent polymers have spherical shape. SAP is white powder with specific weight 1.08 g/cm^3 and with an average particle size of approximately 200 µm have been used. SAP used as internal curing materials. After SAP are mixed with water it converted to gel state. Conditions of preparation was 25 ºC and 45% relative humidity. The cement content has been maintained constant at 400 kg/m³ in all mixes and a water to cement ratio (w/c) of 0.35 has been employed. Tap water has been used for mixing the concrete. High range water reducer (HRWR) with a density of 1.18 kg/liter at room temperature has been used as superplasticizer in compliance with the requirements of ASTM C494 [25]. The amount of HRWR was 2% of the cement weight.

Casting and testing procedure

Cement and both coarse and fine aggregate were mixed for one minute. The slurry (water, Nano-silica or super absorbed polymers, and HRWR) was added and the mixing process was continued for four more minutes to ensure complete mixing. Plastic shrinkage was started. After that, the early-age deformation of fresh concrete was measured by means of an optical apparatus, which is shown schematically in Figures (1 and 2).The details of the apparatus calibration method and procedure for the test were in accordance to ASTM C827/C827M-10 [26]. During tests, measurements were recorded at uniform intervals of time; the final reading was taken 2 hours after the test started. After 24 hours, the test samples were hardened and a final measurement was recorded. The deformations were converted to shrinkage strain using the following equation:

$$\varepsilon = \frac{X}{M\,L} \tag{1}$$

Where ε is the plastic shrinkage strain, X is the deformation (mm), M is the magnification factor, and L is the height of the specimen (mm) [26].

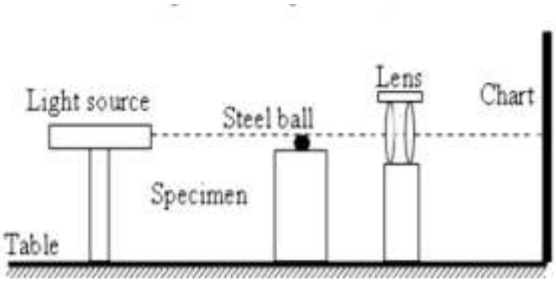


Figure (1) layout of plastic shrinkage apparatus.

Figure (2) apparatus for measuring plastic shrinkage.

Testing of drying shrinkage was carried out according to the ASTM C157 [27]. Three specimens having dimensions of 70×70×250 mm were prepared for each mixture. As the length of the specimen was much larger than the cross-sectional dimensions, shrinkage was assumed to take place only in the longitudinal direction. The measurement of shrinkage rate can then provide a measure of the one dimensional shrinkage for the tested material. A mechanical gauge was used to measure the change in the length of the test specimens at proper time intervals. Figure (3) shows a photograph of the apparatus of drying shrinkage measurement. The drying shrinkage strain at time (t) is calculated as $\Delta L/L_o$; where: ΔL is the measured change in the length and L_o is the original length measured at the start of measurements. After 24 hours of casting, the specimens were removed from the molds and subjected to three curing scenarios prior to evaluating the compressive strength. 21 specimens were submerged in water at 20 ºC. 21 specimens were stored in the laboratory and exposed to the indoor air (25 ºC and 50% relative humidity). 21 specimens were stored in an open area and exposed to the prevailing atmosphere. 2000 kN capacity compressive strength testing machine was used to determine the compressive strength of concrete.

Figure (3) Apparatus for measuring drying shrinkage.

4. RESULTS AND DISCUSSIONS

The behavior of different mixture under the various curing process has been examined and the effect of composition, curing method, and temperature have been also studied. The following sections presents the results obtained from the investigation. To facilitate the discussion, each effect is presented separately.

4.1 Effect of Nano-silica on plastic shrinkage

Figure (4) shows the variation of the plastic shrinkage with elapsed time for different mixes containing different values of Nano-silica. It can be seen from the figure that as the percentage composition of Nano-silica increases, the plastic shrinkage decreases. The plastic shrinkage increases rapidly in the first two hours then the rate of increase flattens during the remaining 24 hours. At 2 hours the plastic shrinkage was 0.000118, 0.000104, 0.000070 and 0.000062 for the mixes with 0.5, 1.0, 2.0 and 2.5% Nano-silica as an addition of cement content, respectively. This indicates an improvement in the behavior of plastic shrinkage by 58, 62, 75 and 78% respectively compared with the control mix. Also at 24 hours a reduction in the plastic shrinkage by 51, 62, 74 and 77% compared with the control mix. 24%, 13%, 10% and 7% were the ratio of the plastic shrinkage strain at 24 hours compared with the plastic shrinkage at 2 hours at 0.5, 1.0, 2.0 and 2.5% of Nano-silica as an addition of cement content, respectively. This illustrates that the magnitudes of reduction in the plastic shrinkage strain becomes smaller with time as the percent of Nan-silica increased. Consequently the volumetric change decreases as increases the percent of Nano-silica**.**

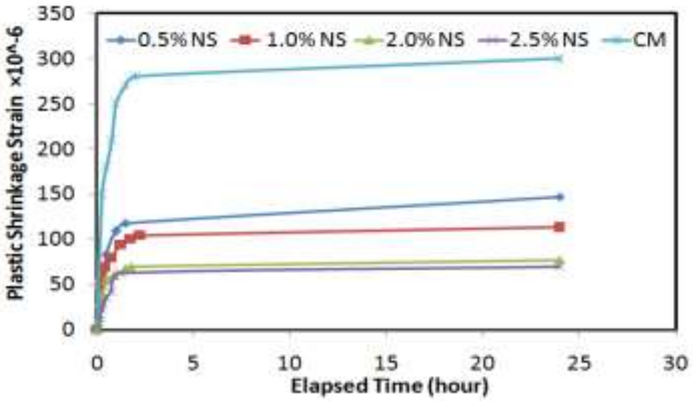


Figure (4) relation between plastic shrinkage strain and elapsed time for mixes with different percent of Nano-silica as an addition of cement content.

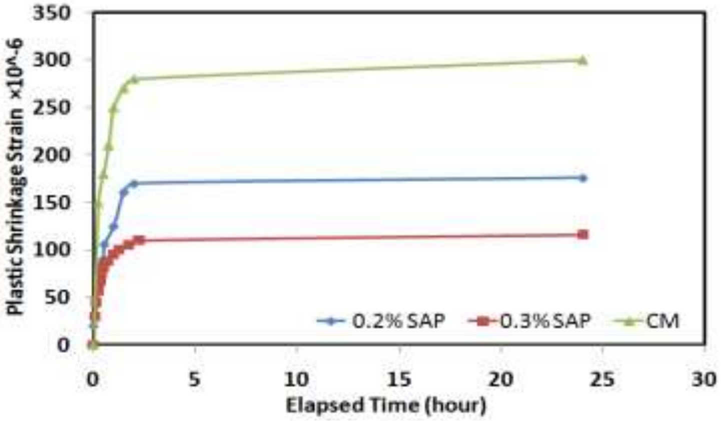


Figure (5) relation between plastic shrinkage strain and elapsed time (hours) for mixes with different percent of super absorbent polymers.

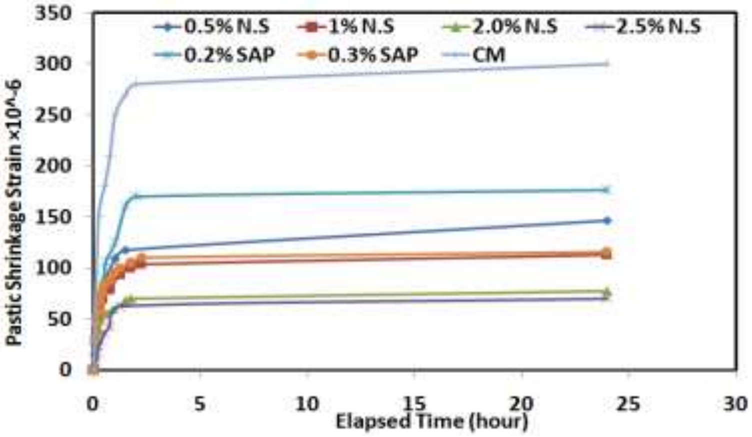


Figure (6) relation between plastic shrinkage strain and elaspsed time for mixes with different Nano-silica and super absorbent polymer.

4.2 Effect of super absorbent polymers on plastic shrinkage

Figure (5) shows the variation of the plastic shrinkage strain with elapsed time for different mixes containing different values of super absorbent polymer (SAP) as a percent of cement content. A reduction in the plastic shrinkage strain was recorded as the percent of super absorbent polymer increases. After 2 hours, the plastic shrinkage was 0.000170 and 0.000110 for the mixes with 0.2 and 0.3% of super absorbent polymers, respectively. This indicate an improvement in the behavior of plastic shrinkage strain by 43 and 63% compared with the control mix. After 24 hours; 41 and 61% reduction were recorded in the plastic shrinkage strain for 0.2 and 0.3% of super absorbent polymers, respectively compared with the control mix. The ratio of the plastic shrinkage strain after 24 hours and the plastic shrinkage starin after 2 hours was 4.0% and 6.0% for the mixes with 0.2 and 0.3 % super absorbent polymers, respectively. A comparison between the Nano-silica and super absorbent polymers illustrate their effect on the plastic shrinkage strain was conducted and the results are shown in figure (6). It is found that, the plastic shrinkage for the mixes with Nano-silica was less than that for the mixes with super absorbent polymer. For example, the shrinkage strain at 2 hours was 0.000170 and 0.000110 for 0.2% and 0.3% SAP, respectively. Also the shrinkage strain was 0.000104, 0.00007 and 0.000062 for 1.0, 2.0 and 2.5% Nano-silica, respectively. The same trend was noticed at 24 hours where 3.0, 34.0 and 40.0% reduction in the plastic shrinkage strain at 1.0, 2.0 and 2.5% Nano-silica compared with 0.3% super absorbent polymers.

4.3 Effect of admixture type on drying shrinkage

Figure (7) shows the relationship between the drying shrinkage strain and elapsed time for mixes with different percent of Nano-silica and super absorbent polymer. These mixes were cured in water. It can be seen that as the percent of NS and SAP increased the drying shrinkage decreased. The drying shrinkage increases exponentially during the first 200 days then it changes linearly up to 670 days for all the mixes with Nano-silica and super absorbent polymers. At 200 days the dry shrinkage was 0.00570, 0.00590, for the mixes with 0.2%, 0.3% SAP, respectively. In addition to 0.00555, 0.00530, 0.00480 and 0.00460 for the mixes with 0.5%, 1.0%, 2.0% and 2.5% Nano-silica, respectively. This indicates an improvement in the behavior of dry shrinkage by 16 and 14% for the mixes with 0.2 and 0.3% SAP, respectively compared to the control mix. The percentage reductions are 18, 22, 29 and 32% for the mixes with 0.5%, 1.0%, 2.0% and 2.5% Nano-silica, respectively compared by the control mix. In case of 0.2% and 0.3% SAP after 670 days, a reduction by 17.7 and 15%, respectively in the drying shrinkage strain is obtained in comparison with the control mix.

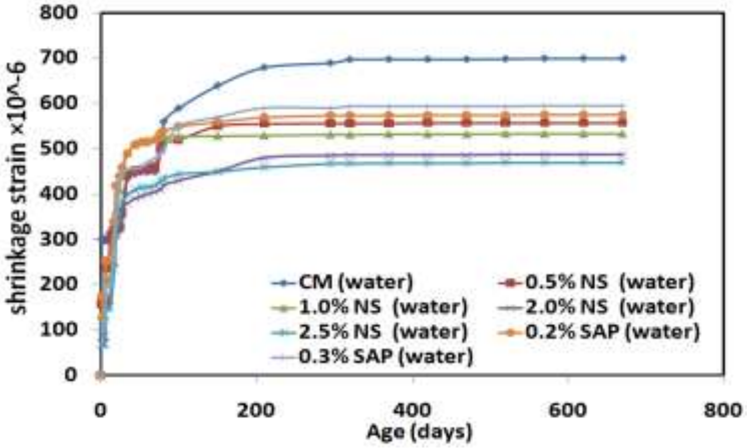
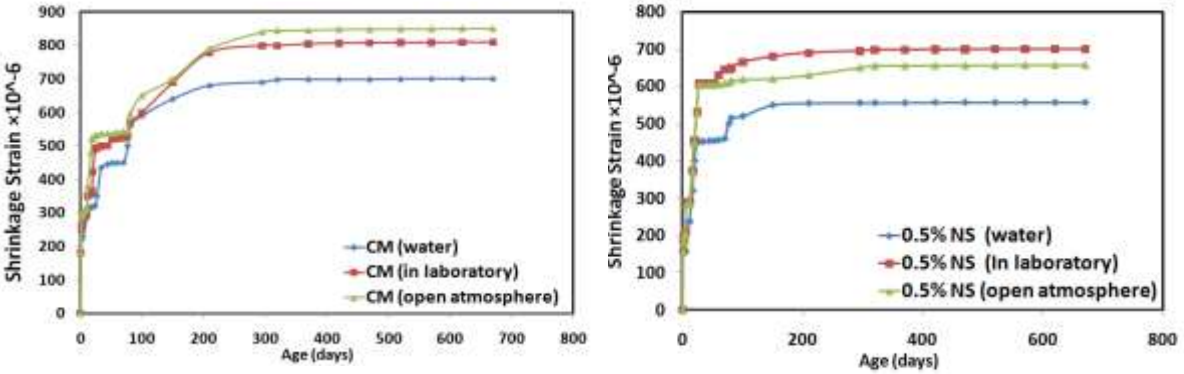
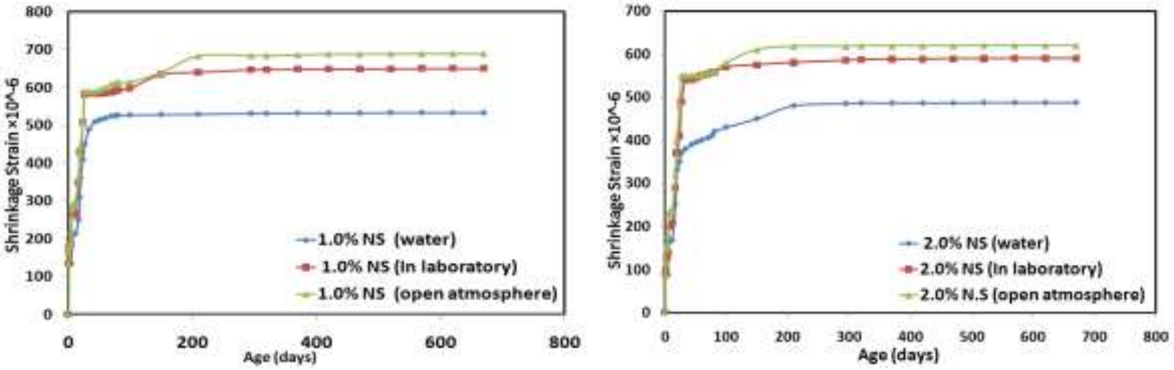


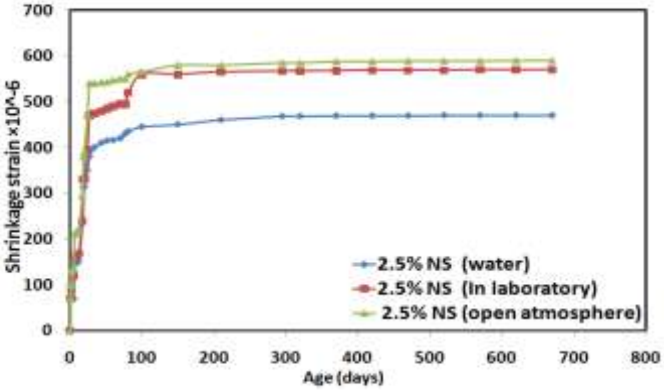
Figure (7) relation between drying shrinkage strain and age for mixes with different percent of Nano-silica and super absorbent polymers.



(a) Control mix. (b) 0.5% NS.



(c) 1.0% NS. (d) 2.0% NS.



(e) 2.5% NS.

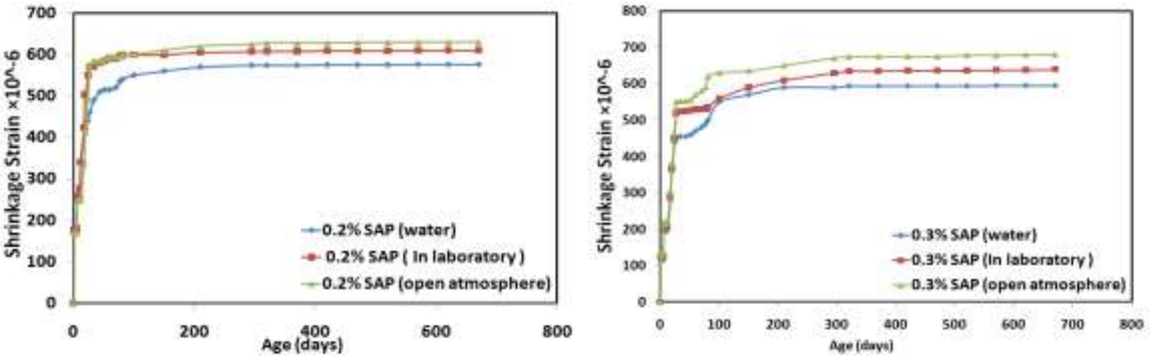
Figure (8) relation between drying shrinkage strain and age (days) for mix with Nano-silica as an addition of cement content at different curing conditions.

Also, 20.5, 23.7, 30.4 and 32.8% reduction in the drying shrinkage strain at 0.5, 1.0, 2.0 and 2.5% Nano-silica, respectively compared with the control mix were recorded. Comparing the drying shrinkage strain at the end of test (670 days) by the drying shrinkage at 200 days, it is observed that former has increased by an average 1.0% more than the later for all the mixes compared with the control mix. The figure also illustrates that the drying shrinkage strain for the mix with Nano-silica is less than that with super absorbent polymer. For example, at 200 days the shrinkage strain was (0.00570 and 0.00590) for 0.2% and 0.3% SAP, respectively. Also the shrinkage strain was (0.00555, 0.00530, 0.00480 and 0.00460) for 0.5, 1.0, 2.0 and 2.5% NS, respectively. The same trend was noticed at the end of test at 670 days where (3.2, 7.3, 15.5 and 18.5%) reduction at (0.5, 1.0, 2.0 and 2.5% N.S) in the shrinkage strain compared with the mix 0.2% SAP. Also 6.4, 10.0, 18.2 and 21% reduction at 0.5, 1.0, 2.0 and 2.5% NS in the shrinkage strain compared with the mix 0.3% SAP.

4.4 Effect of curing conditions on drying shrinkage

Figure (8) presents the effect of Nano-silica as a percentage of cement content on the dry shrinkage strain at different curing conditions. It is noticed that the drying shrinkage strain for all the mixes which are cured in water is less than that cured in air (laboratory and open atmosphere). For control mix, the drying shrinkage for the mixes curing with water has a reduction about 13.6% and 17.6% compared with the mix curing in the laboratory and in the open atmosphere. For the mixes with 0.5% Nano-silica, the drying shrinkage for the mixes cured with water has a reduction of about 15.2% and 20.4% compared with the mix cured in the laboratory and in the open atmosphere. For the mixes with 1.0% Nano-silica, the drying shrinkage for the mixes cured with water has a reduction about 17.8% and 22.6% compared with the mix cured in the laboratory and in the open atmosphere. For the mixes with 2.0% Nano-silica, the drying shrinkage for the mixes cured with water has a reduction about 17.4% and 21.4% compared with the mix cured in the laboratory and in the open atmosphere. For the mixes with 2.5% Nano-silica, the drying shrinkage for the mixes cured with water has a reduction about 17.5% and 20.3% compared with the mix cured in the laboratory and in the open atmosphere.

Figure (9) presents the effect of super absorbent polymers as a percentage of cement content on the dry shrinkage strain at different curing condition. Similar behavior was noticed where the drying shrinkage strain for all the mixes which was cured in water is less than that cured in air (laboratory and open atmosphere). For the mixes with 0.2% super absorbent polymers, the drying shrinkage for the mixes cured with water has a reduction about 5.6% and 8.6% compared with the mix cured in the laboratory and in the open atmosphere. For the mixes with 0.3% super absorbent polymer, the drying shrinkage for the mixes cured with water is reduced by about 7.0% and 12.5% from with the mix cured in the laboratory and in the open atmosphere.



(a) 0.2% SAP. (b) 0.3% SAP.

Figure (9) relation between drying shrinkage strain and age (days) for mix with super absorbent polymers as percent of cement content at different curing conditions.

4.5 Effect of admixture type on the compressive strength

Figure (10) shows the relation between compressive strength and age in days for different mixes containing different percentages of Nano-silica and super absorbent polymers. It can be seen that as the percent of Nano-silica increases the compressive strength increased, while the vice versa was recorded for the super absorbent polymers. The early ages are considered to be the period of 1, 3 and 7 days. Results obtained during this period are compared with those recoded at 28 days while adapting water curing. It is noticed that at early ages the compressive strength has 70, 50 and 25.7% as a ratio of the compressive strength at 28 days for mix containing 0.5% of Nano-silica cured with water. Also, the compressive strength has 65.8, 44.7 and 19.74 as a ratio of the compressive strength for mix contains 1.0% of Nano-silica cured with water. And the compressive strength has 54.8, 40.5 and 14.3% as a ratio of the compressive strength for mix contains 2.0% of Nano-silica cured with water. The compressive strength has 50, 30 and 10.7% as a ratio of the compressive strength for mix contains 2.5% of Nano-silica cured with water. The compressive strength has 63.2, 44.2 and 24.3% as a ratio of the compressive strength for mix contain 0.2% of super absorbent polymers as percent of cement content and were cured with water. The compressive strength has 67.3, 47.8 and 27.3% as a ratio of the compressive strength for mix contain 0.3% of super absorbent polymers as percent of cement content and were cured with water.

The maximum increase in the compressive strength was noticed for 2.5% of NS compared with control mix. An increase of 152.7, 109.6, 80.3 and 46.4% in the compressive strength is noticed at 1, 3, 7, 28 days, respectively. The maximum increase in the compressive strength was noticed at 0.2% of super absorbent polymers cured in water compared with control mix. An increase of 33.3, 19.8, 9.4 and 5.0% is recorded for the compressive strength at 1, 3, 7, 28 days, respectively.

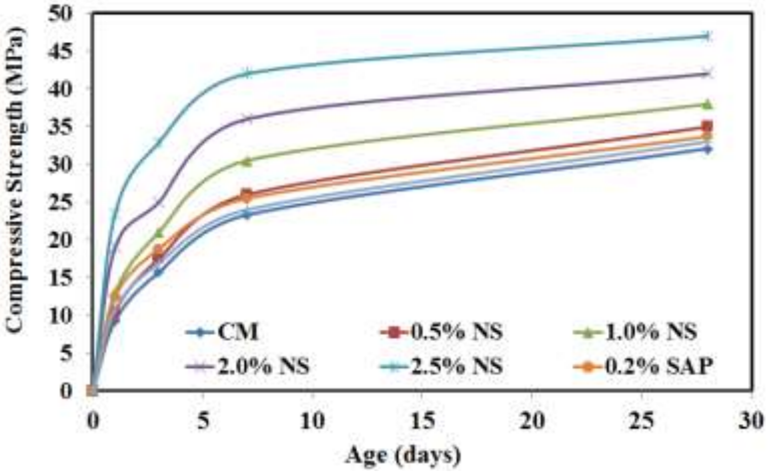


Figure (10) the relation between compressive strength and age (days) for different mixes.

4.6 Effect of curing on compressive strength

Figure (11) shows the relation between the compressive strength and the age for the mixes with Nano-silica for different curing conditions. It is clear that the compressive strength for the mixes cured in water is higher than those cured in the laboratory air. For the mix with 0.5% NS, the compressive strength increased by 23.5, 25.0, 30.0 and 25.0% at 1, 3, 7 and 28 days respectively compared with that cured in open air. For the 1.0% Nano-silica mix, the compressive strength increases by 30.0, 16.7, 27.0 and 31.0% after 1, 3, 7 and 28 days, respectively compared with that cured in air. For the 2% Nano-silica mix the compressive strength increased by 40.7, 31.6, 44.0 and 40.0% at 1, 3, 7 and 28 days, respectively, compared with that cured in air. For mix 2.5% Nano-silica the compressive strength increased by 56.7, 49.5, 40.0 and 34.3% at 1, 3, 7 and 28 days, respectively compared with that cured in air.

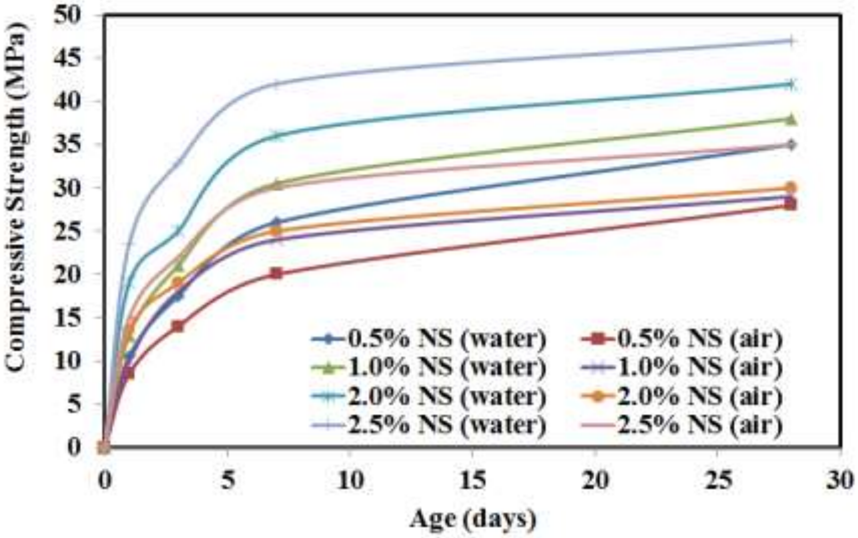


Figure (11) the relation between compressive strength and age (days) for mix containing different percent of Nano-silica with different curing.

Figure (11) shows that the compressive strength for the mix with 0.2% SAP and cured in the laboratory air is lower than that for mixes cured in pure water. The compressive strength decreased by 53.3, 31.3, 19.2 and 8.0% at 1, 3, 7 and 28 days, respectively. The same trend was noticed for the mix with 0.3% SAP, where the compressive strength decreased by 61, 32.5, 19.2 and 12.4% at 1, 3, 7 and 28 days, respectively.

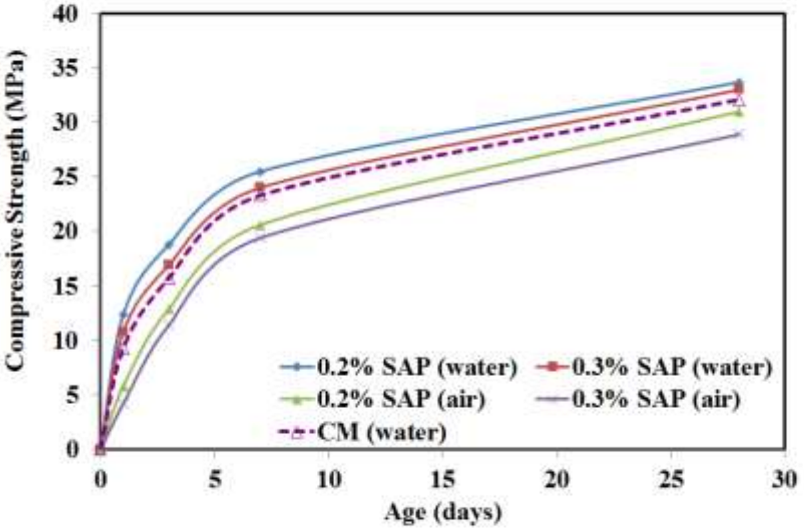


Figure (12) the relation between compressive strength and age (days) for mix containing different percent of SAP with different curing.

CONCLUSIONS

The following conclusions could be drawn from the results:

1- For the mixes with Nano-silica, the plastic shrinkage strain decreases as the percent of Nano-silica percent increase. The percentage improvement in the maximum plastic shrinkage strain is about 58, 62, 75 and 78% at 0.5, 1.0, 2.0 and 2.5% of Nano-silica, respectively compared with the control mix.
2- For the mixes with super absorbent polymer as a percent, the plastic shrinkage strain decreases as the percentage of SAP increases. The percentage improvement in the maximum of plastic shrinkage strain is about 43 and 63% at 0.2 and 0.3% of super absorbent polymers, respectively compared with the control mix.
3- Using Nano-silica improved the plastic shrinkage for the mixes more than for the mixes with super absorbent polymers.
4- The average drying shrinkage strain for the mixes with Nano-silica is reduced by about 26.85, 23.8 and 22%, respectively of the control mix when cured in water, in indoor laboratory air, and in the open atmosphere. While corresponding reductions are reduction about 16.35, 22.85 and 22.4%, respectively of the control mix for the mixes with super absorbent polymers using the different curing scenarios.
5- Water curing reduces the average drying shrinkage strain by about 17% and 21% from those cured using indoor and outdoor air, respectively in case of mixes with Nano-silica. Corresponding reductions are 6.3% and 10.6% in case of super absorbent polymers.
6- For water cured specimens, after 1 day of casting, the average compressive strength reaches 49% of the value it would attain after 28 days in case of mixes with Nano-silica while it reaches 65% for the mixes with super absorbent polymer.
7- For water curing, the maximum increasing in the compressive strength was noticed at 2.5% of Nano-silica and at 0.2% of super absorbent polymers compared with control mix.
8- The compressive strength increases by 152.7, 109.6, 80.3 and 46.4% at 1, 3, 7, 28 days, respectively for 2.5% of Nano-silica and by 33.3, 19.8, 9.4 and 5.0% respectively for 0.2% super absorbent polymers compared with control mixes and were cured with water.
9- In general by eliminate the shrinkage; tensile stress will limit so that the cracking, the internal warping and the external deflection will be prevented. The durability of the structures will increase and so saving the money due to the maintance needed for reinforced concrete structures.

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