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EFFECTS OF NANOSILICA ON COMPRESSIVE STRENGTH AND WATER SORPTIVITY OF CONCRETE AT DIFFERENT WATER-CEMENT RATIOS

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ABSTRACT

Compressive strength and water sorptivity index (WSI) are among the decisive parameters defining the strength and durability of concrete in corrosive environments. Previous research on concrete technology has largely been attentive to methods to obtain highly resistant concrete. Importantly, marked capillary porosity inside the concrete enhances the ingression of detrimental ions into the concrete. To avoid this, WSI needs to be maximally diminished. Currently, there are some strategies such as the partial substitution of cement with nanosilica (a highly active artificial pozzolan) in the concrete mixing plan to enhance concrete properties. This research explored the effects of adding nanosilica on the compressive strength and WSI of concrete. A total of 336 cube concrete specimens were examined for 7 and 28 days in the Concrete Research Laboratory of Qazvin Azad University. Experiments covered 28 mixing plans involving 1, 2, 3, 4, 5, and 6% cement substitution with nanosilica at water-cement ratios of 0.35, 0.40, 0.45, and 0.50. It was found that adding nanosilica to the concrete mixing plan enhances compressive strength and reduces WSI.

Keywords: Concrete durability, Compressive strength, Water sorptivity, Nanosilica

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INTRODUCTION

Nanotechnology is a rapidly expanding area in civil engineering. Nanoparticle (NP) is defined as a particle of matter with a diameter of less than 100 nm. Overall, a decline in the surface area of a particle enhances the surface-area-to-volume ratio of that particle, and, in concrete technology, this significantly increases the reactivity of materials in nano dimensions. Such a greater reactivity gives NPs superiority over other larger particles (1). NPs can be used to effectively fill ultrafine pores of hydrated cement and enhance concrete's strength and durability. Additionally, they can activate some reactions to alter the chemical compositions of the concrete (2). Nanosilica is an NP that outperforms other natural and synthetic pozzolans due to its high surface area, enhanced reactivity, and improved chemical activity. The engineering properties of concrete (e.g., compressive strength and water sorptivity) are directly influenced by the number, type, size, and distribution of pores in the cement paste, compositions of aggregates, and the interfacial transition zone (ITZ) (3). Within the following reaction, nanosilica easily reacts with free calcium hydroxide ($Ca(OH)_2$) in the capillary pores of the concrete and produces insoluble crystals of calcium silicate (Ca_2SiO_4), ultimately enhancing the compacted structure of cement paste.

Eq. (1) $Ca(OH)_2 + SiO_2 = Ca_2SiO_4$

In most of concrete structures, durability and strength parameters of concrete (e.g., water sorptivity index – WSI) are largely overlooked, and concrete designs are merely based on compressive strength. Accordingly, a rise in concrete permeability and ingression of deteriorative ions culminates in premature failure of concrete structures. Thus, there is a need for strategies to cover both compressive strength and WSI of the concrete. One strategy is to add nano admixtures, which have been a subject of interest in many studies. For example, Collepardi et al. reported that using nanosilica in concrete enhances microstructures, reduces capillary pores and WSI, and improves the compressive strength of concrete (4). Elsewhere, Ramzanianpour et al. reported that nanosilica improves the compressive strength of concrete, with the maximum strength that is attained within 7 days (5).

This research explores the effects of adding nanosilica at different water-cement ratios on compressive strength and WSI of concrete and specifies the optimal volume of nanosilica required to attain maximum compressive strength and minimum WSI.

METHODS

Materials

The concrete was made according to the ASTM C94-83 standard using the drinking water of Qazvin city (6≤pH≤8) (6, 7). Portland cement type 2 was purchased from Abyek Cement Factory. Broken coarse-grained sands were purchased from the Shotorak mine of Qazvin, and fine-grained gravels were prepared from the Ghassam mine of Qazvin. Concrete specimens were made in 10×10×10 cm molds. Thus, the size of coarse aggregates (sands) was maximally 19 mm to pass through a sieve grade #3.4 (8). Tables 1 and 2 summarize specifications and grading of aggregates according to the ASTM C 136-84 standard (9).

Table 1. Characteristics of the aggregates

Aggregate	Type	Specific weight (γ)	Water sorptivity (%)	Diameter of the largest aggregate (mm)
Sand	Broken	2.6	1.8	19
Gravel	Natural	2.55	2.3	4.75

Table 2. Grading of stone materials			
Sieve No.	**Maximum nominal size of aggregate**	**Fine grains (sand) passing (%)**	**Coarse grains (gravel) passing (%)**
#3.4	19 mm	-	89
#1.2	12.5 mm	-	46
#3.8	9.5 mm	-	20
#4	4.75 mm	94	0.002
#8	2.36 mm	78	0.0018
#16	1.18 mm	47	-
#30	600 µm	22	-
#50	300 µm	12	-
#100	150 µm	3	-
#200	75 µm	1.5	-

In this research, cement was partially substituted with colloidal nanosilica. Upon adding, however, some nanosilica particles may remain as colloids and unreacted in the concrete. Thus, nanosilica was used as water-soluble NP with a purity of 15%. Tables 3 and 4 present the chemical structure and physical characteristics of nanosilica particles used in the concrete mixing plans.

Table 3. Chemical composition of cement and nanosilica (w%)

	SO3	P2O5	K20	Na2O	MgO	CaO	Al2O3	Fe2O3	SiO2	C	SiC	H2O
Cement	1.8	-	0.58	0.58	1.8	65	5.2	4	21.5	-	-	-
Nanosilica liquid	0.1	0.16	1	0.31	0.97	0.49	1.3	0.87	14.5	3	5	80

Table 4. Physical properties of nanosilica NPs

Mean diameter	Color	Physical status	Density	pH	SiO_2 (%)
<30 nm	Transparent milky	Liquid	$1.3\ {}^{gr}/_{cm^3}$	9.5~104	13~14.6

The significant water sorptivity of nanosilica after adding it to concrete requires a strong plasticizer to be used in the mixing plan. In this research, a superplasticizer made by Abadgaran Company based on polycarboxylate under the trade name of ABAPLASTWR-4610 type “F” was used in the concrete. This plasticizer well complies with ASTM-C1017, ASTM-C494-TYPE-F, and ISIRI-2930 standards (10, 11).

Concrete mixing plan

As given in Table 5, cement type and type and quantity of aggregates were constant in the concrete mixing plan, whereas the water-cement ratio ($\frac{w}{c}$), the volume (w%) of nanosilica NPs, and the age of concrete curing were supposed to be variable. The mixing plan adopted in this research was based on the ASTM C305 standard, with a minor modification due to using plasticizer and nanosilica (12, 13).

Table 5. Constants and variables			
No.	**Item**	**Variable**	**Constant**
1	Type and material of aggregates	-	✓
2	Quantity of aggregates	-	✓
3	Type of cement	-	✓
4	Water-cement ratio	✓	-
5	Substitution by nanosilica (%)	✓	-
6	Age of curing at the time of experimenting	✓	-

For the mixing plan, the dry aggregates (sand and gravel) were first mixed in a concrete mixer for 2 min. Next, nearly 5% of the water was poured into the mixer, and the aggregates were immersed for 2 min, followed by gently adding cement to the wet aggregates. Then, liquid nanosilica was gradually (within one min) added to the materials rotating inside the concrete mixer. Ultimately, the plasticizer was added to the mixing plan. After pouring all the materials and additives, the concrete mixer was allowed to rotate at an angle of 45 degrees for about 4 min until all the ingredients were well blended and yielded a homogeneous mixture. Table 6 summarizes the specifications of the mixing plan.

Table 6. Mixing plan statistics								
Plan No.	**Plan**	$\frac{W}{C}$	**Cement** $(\frac{kg}{m^3})$	**Sand** $(\frac{kg}{m^3})$	**Gravel** $(\frac{kg}{m^3})$	**Substitution with nanosilica (%)**	**Superplasticizer**	**Slump (cm)**
1	0.35-N-0	0.35	400	1000	800	0	0	1.5
2	0.35-N-1	0.35	396	1000	800	1	1.9	5
3	0.35-N-2	0.35	392	1000	800	2	3	3.5
4	0.35-N-3	0.35	388	1000	800	3	4	4
5	0.35-N-4	0.35	384	1000	800	4	5.8	4.5
6	0.35-N-5	0.35	380	1000	800	5	8	4
7	0.35-N-6	0.35	376	1000	800	6	9.6	3
8	0.40-N-0	0.40	400	1000	800	0	0	3.5
9	0.40-N-1	0.40	396	1000	800	1	1.65	5
10	0.40-N-2	0.40	392	1000	800	2	2.35	4
11	0.40-N-3	0.40	388	1000	800	3	2.8	5
12	0.40-N-4	0.40	384	1000	800	4	3.85	5
13	0.40-N-5	0.40	380	1000	800	5	6	4.5
14	0.40-N-6	0.40	376	1000	800	6	8.9	4
15	0.45-N-0	0.45	400	1000	800	0	0	4.5
16	0.45-N-1	0.45	396	1000	800	1	1	5
17	0.45-N-2	0.45	392	1000	800	2	1.53	4.5

18	0.45-N-3	0.45	388	1000	800	3	2.3	5
19	0.45-N-4	0.45	384	1000	800	4	3.54	5
20	0.45-N-5	0.45	380	1000	800	5	4.9	6
21	0.45-N-6	0.45	376	1000	800	6	8.3	4
22	0.50-N-0	0.50	400	1000	800	0	0	10.5
23	0.50-N-1	0.50	396	1000	800	1	1	8
24	0.50-N-2	0.50	392	1000	800	2	1.08	8
25	0.50-N-3	0.50	388	1000	800	3	1.85	7
26	0.50-N-4	0.50	384	1000	800	4	2.93	8
27	0.50-N-5	0.50	380	1000	800	5	3.6	6.5
28	0.50-N-6	0.50	376	1000	800	6	5.50	9

Preparation of concrete specimens

To improve the quality of concrete specimens, the entrapped air was expelled from the freshly placed concrete by using a concrete vibrator or blowing a plastic hammer. After 24 hours, the specimens were removed from the molds and kept and cured in a water pool until 7 and 28 days.

Experiments

Compressive strength

The compressive strength testing was based on BSl1881 – Part 116 (14). After the intended curing age, the specimens were removed from water pools and tested for compressive strength using a hydraulic pressure jack. For more accuracy and less error, both the upper and lower jaws of the jack are recommended to be kept co-level before testing. Likewise, the center of the cubic specimen is suggested to be placed at a central point between the upper and lower jaws to ensure a vertical load is applied on the specimen, otherwise, the unconfined compression will be accompanied by lateral shear stress. In this test, the compressive strength increases from 0.2 MPa/s to 0.4 MPa/s loading speed (15). The results of this test can be a basis for controlling concrete quality, ratios in the mixing plan, conformity with specifications, and evaluating the effects of admixtures on the concrete.

Water sorptivity

The specimens were immersed in the water pool for 30 min (for short term; according to the BS1881 standard) and 24 hours (for long term; according to the ASTM C642 standard) (16, 17). After removing from the water pool, the specimens were dried in an incubator at 60 °C for 7 days, and the water sorptivity of them was obtained from the equation below:

$$\text{Water sorptivity (v\%)} = \frac{(\text{M1} - \text{M0}) \times 100}{\text{M0}}$$

Where “M0” is the weight specimen dried in the incubator and “M1” is the weight of the wet specimen.

RESULTS

Compressive strength

Figures "1.1" to "1.6" show the results of compressive strength testing of three cubic concrete specimens.

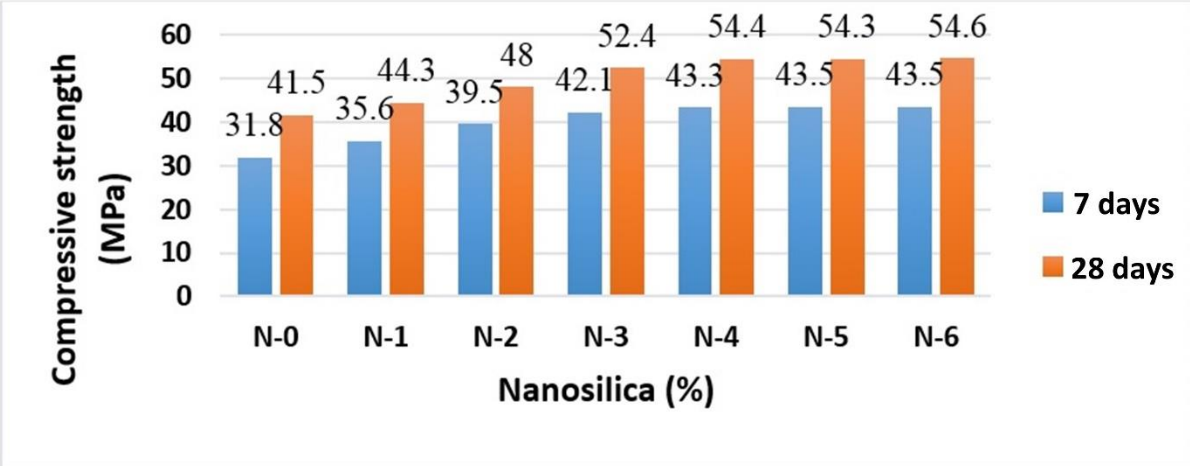

Figure 1.1. Compressive strength for the mixing plan (W-C ratio: 0.35)

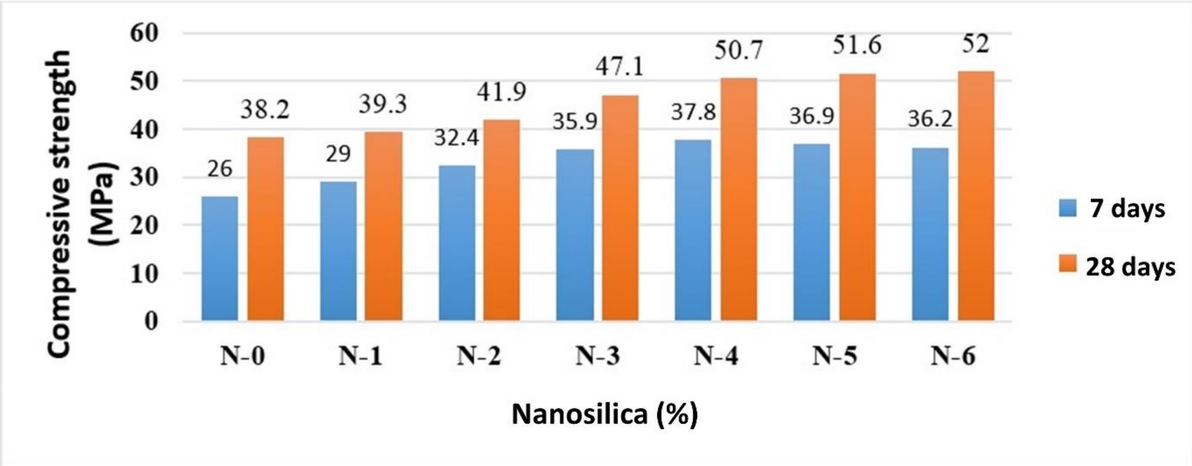

Figure 1.2. Compressive strength for the mixing plan (W-C ratio: 0.40)

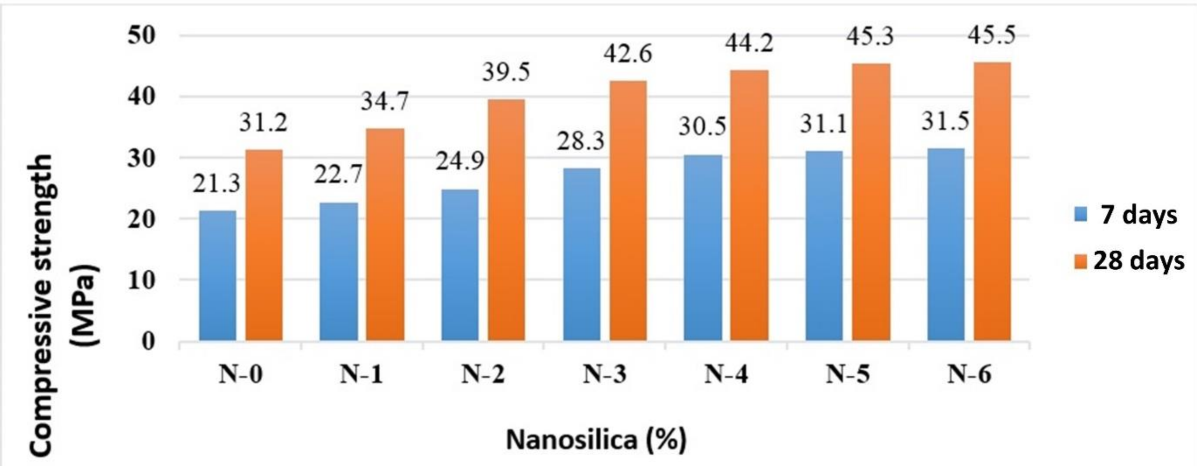

Figure 1.3. Compressive strength for the mixing plan (W-C ratio: 0.45)

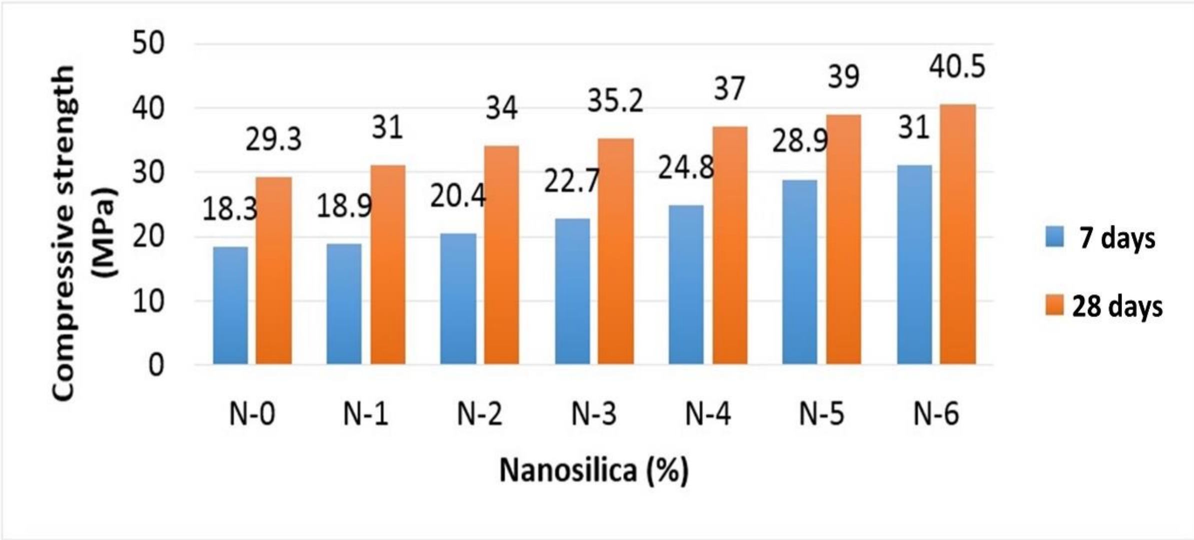

Figure 1.4. Compressive strength for the mixing plan (W-C ratio: 0.50)

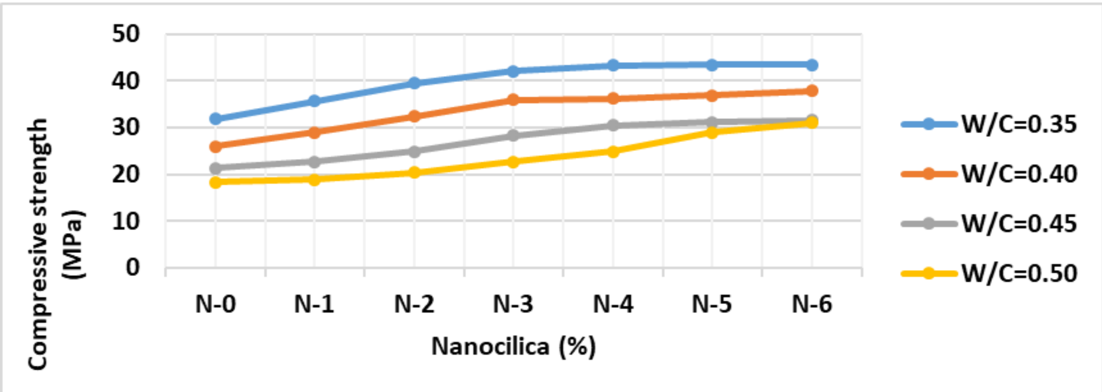

Figure 1.5. Variations in the 7-day compressive strength for different water-cement ratios

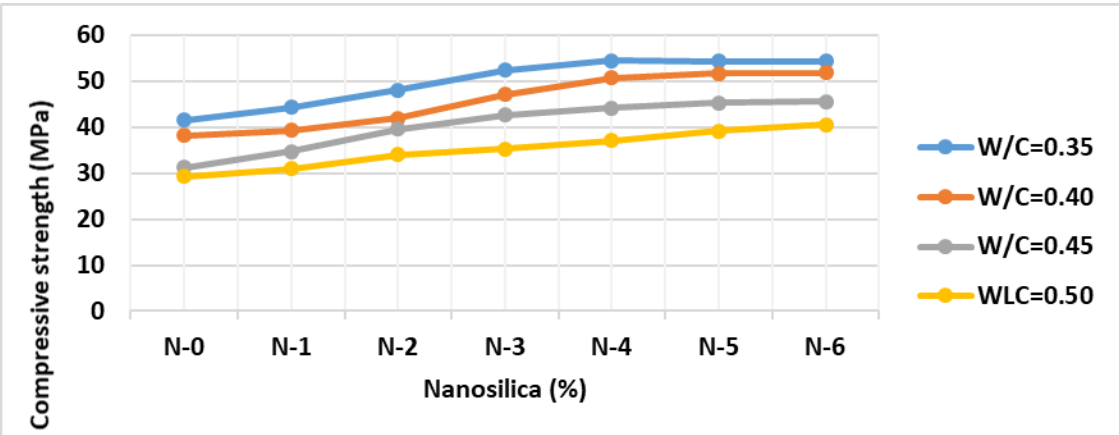

Figure 1.6. Variations in the 28-day compressive strength for different water-cement ratios

2.5.2. Water sorptivity

Figures 2.1 and 2.2 show the results for water sorptivity at short-term and long-term conditions.

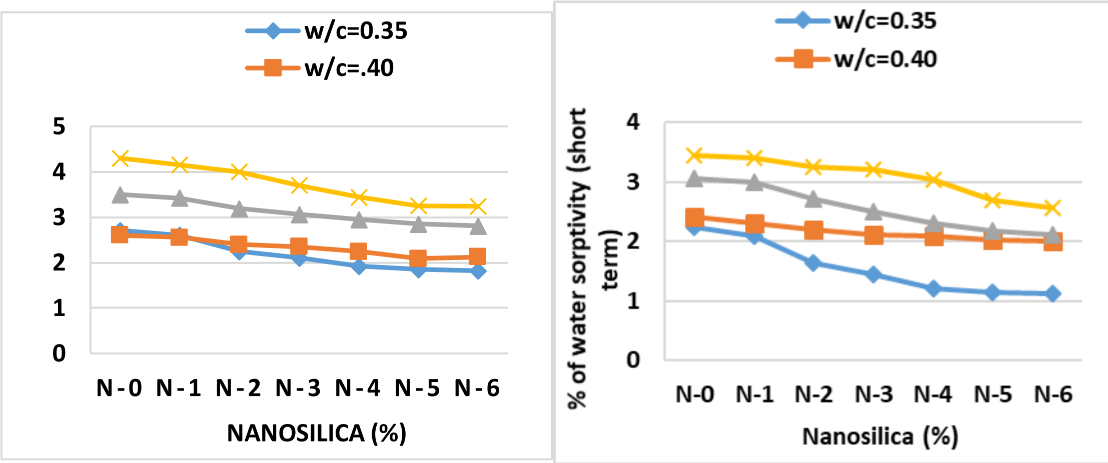

Figure 2.1. Short-term variations in water sorptivity for different water-cement ratios at curing ages of 7 to 28 days

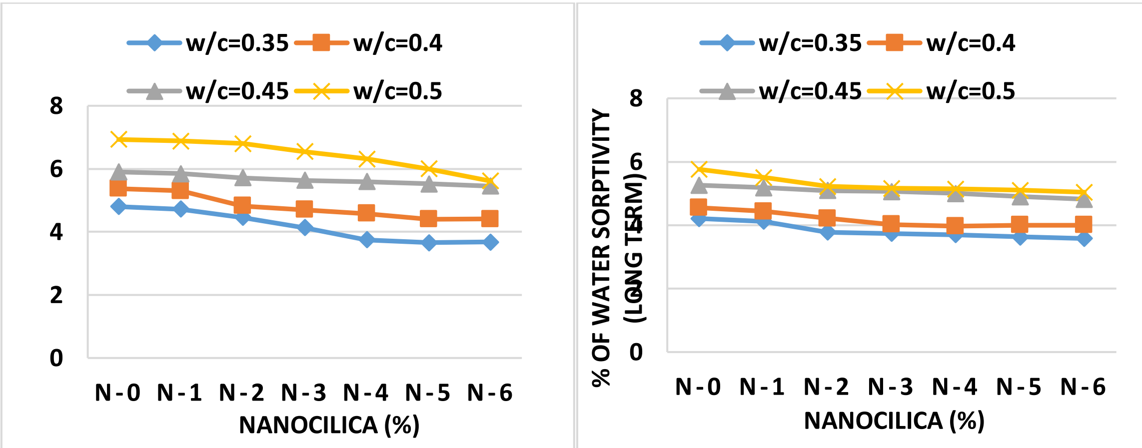

Figure2.2. Long-term variations in water sorptivity for different water-cement ratios at curing ages of 7 to 28 days

CONCLUSION

According to the obtained results from investigating a given type of nanosilica and other materials in this study, the following can be outlined. Note that for other materials, there is a need for tailored experiments in the future.

- Nanosilica (a substitute for cement in concrete) enhances the mechanical properties of concrete. Indeed, NPs markedly influence concrete technology and those such as nanosilica make the chemical reactions in concrete stronger due to their high energy level.
- For water-cement ratios of 0.35, 0.40, and 0.45 at curing ages of 7 and 28 days, the optimal volume of nanosilica to be used in the mixing plan is estimated at 4%. At volumes beyond 4%, no further enhancement in the compressive strength of concrete will be observed.
- For the water-cement ratio of 0.5, enhancement in compressive strength occurs by adding nanosilica up to 6%.
- The greatest compressive strength enhancement (by 70%, compared to control) is observed in the mixing plan “0.50-N-6” (i.e., 6% nanosilica and W/C: 0.5).
- The least compressive strength enhancement is observed in the mixing plan “0.35-N-6” (i.e., 6% nanosilica and W/C: 0.5).
- As the W/C ratio increases, more capillary pores are formed in concrete. This highlights the effect of nanosilica in filling these capillary pores. The greatest compressive strength enhancement (than control) occurs in specimens with a W/C of 0.5.
- No significant compressive strength enhancement occurs in specimens with 1% nanosilica,

particularly at W/C ratios of 0.5 and 0.45. This can be due to inadequate cement substitution by nanosilica and, thereby, trivial filling of capillary pores in concrete.

- Overall, adding nanosilica and superplasticizer diminishes the WSI of concrete, particularly as the curing age increases. This implies sounder hydration reactions and a marked decline in capillary pores. Notably, the hydration reaction reaches a maximum at the curing age of 28 days.
- Adding 1% of nanosilica to the mixing plan culminates in a trivial WSI decline, compared to the control. On the other hand, a decline in WSI will not be noticeable as going beyond 5% of nanosilica in the mixing plan. Thus, cement substitution with 5% nanosilica can be suggested as the optimal threshold for achieving maximum reduction in WSI.
- After adding nanosilica, the decline in WSI within 72 hours is more noticeable than within 3, 6, and 24 hours.

REFERENCES

1. Kumar Mehta P., “Concrete: Microstructure, Properties, and Materials”. Translated by Ramazanianpour, Ali Akbar. 2004. First Edition. Amirkabir University of Technology Press.
2. Ramazanianpour Ali Akbar, Jahormi Masoud, Mahdi Khani Mahdi. (October 2009). Comparing the effects of nanosilica over silica fume on concrete properties, microstructure, and durability. Iran's National Concrete Conference, first session.
3. Rastgar Mahdi. (2008). Effect of bubblers on water sorptivity and chloride ions of concrete and corrosion of rebars", MSC thesis, University of Tehran.
4. Collepardi, M., Ogoumah Olagot, J., Troli, R., Simonelli, F. and Collepardi, S., Combination of Silica Fume, Fly Ash, and Amorphous Nano-Silica in Superplasticized.
5. Ramazanianpour Ali Akbar, Firouzmakan Shabnam, Abedi Taghi, Bahrami Hamed. (May 2011). Effect of nanosilica on mechanical properties and durability of concrete. 6th National Civil Engineering Congress of Iran, Semnan University.
6. Ramzanianpour Ali Akbar, Shah Nazari Mohammad Reza. (2003). Concrete Technology. Sanat Gostar Publications.
7. McCOY, J, W, (1978). "Mixing and curing water for concrete, ASTM Sp Tech Publicn No 169B pp 765-73".
8. Topic 9 of Iran's National Construction Cods. (2013). Nashr-e Tosea Publication.
9. "ASTM C136-84a", Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, aggregate, course aggregate, fine aggregate, gradation, grading.
10. “ASTM C-494, 1996 (Standard Specification for chemical Admixtures of Concrete – Type F.
11. "ASTM C1017," "Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete1"
12. National Standard of Iran No. 2930, (2013). "Concrete and Mortar Additives, Section II: Concrete Additives, National Standard Organization of Iran".
13. "ASTM C305" Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency.
14. "BS 1881-part 116". 1983. ("Standard Method for determination of compressive strength of concrete cubes".
15. Shah Nazari Mohammad Reza. (2010). "Concrete Testing Instructions", Science and Industry Publications.
16. BS 1881 Part 22 (1983). (Testing concrete. Method for determination of water absorption, British Standard).
17. ASTM C642-97., (1997) "Standard test method for density, absorption, and voids in hardened concrete"