13th Scientific/Research Symposium with International Participation
„METALLIC AND NONMETALLIC MATERIALS“ B&H, 27th May 2021

EFFECT OF NANOSILICA ADDITION ON CONCRETE POROSITY AND SORPTIVITY

Adnan Mujkanović[1], Anesa Ključanin[1], Marina Jovanović[1],Amel Zahirović[1], Amna Karić[1]
[1]University of Zenica
Zenica

Nevzet Merdić[2]
[2]Cement Plant Kakanj
Kakanj

Key words: nanosilica, concrete, sorptivity, water absorption, porosity

ABSTRACT

This paper presents an experimental investigation into the effect of nanosilica addition to porosity and capillary absorption of concrete. Three concrete mixtures 0%, 2%, and 4% nanosilicaby weight of cementweretested.The procedure described in ASTM C642-06 was used to determine the total volume of permeable voids.Water absorption and the rate of water absorption (sorptivity) was tested in accordance with ASTM C1585-13. The initial and secondary rate of absorption was calculated for each mix. Also, concrete compressive strength at 28 days was determined. Testresults indicated that the incorporation of nanosilicainconcrete resulted inadecreased volume of permeable voids, total water absorption and rate of water absorption, and increased compressive strength at 28 days.

1. INTRODUCTION

Concreteisthemostwidelyusedconstructionmaterialin the world and is applied indifferent environmental conditions.However, after its exposure to some harsh environments, concrete can deteriorate and thesubsequent corrosion of reinforcing steel may occur.The process of water penetration into concrete is veryimportant for its durability [1]. Water acts as the medium by which aggressive agents ingress into the material.Twoprincipal mechanisms control the permeation of water within concrete – permeability and absorption [2]. Permeability is an indicator that represents steady flow in response to an imposed water pressure gradient. However, in reality, concrete is rarely fully saturated, since concrete structures are being exposed to wind and sun. The capillary absorption of water isthedominant factor in the ingress of aggressive substances into unsaturated concrete [3]. For that reason, sorptivity, which is a parameter that characterizes the tendency ofconcrete to absorb and transmit water by capillarymechanism, is more appropriate than permeability to evaluate concrete durability potential. The rate of water absorptionbyconcrete capillary suction can provide useful information related to the pore structureand durability of concrete.

Sorptivity test is relatively simple and quick test to measure the material property that characterizes the tendency to absorb and transmit water by capillaritywhen no pressure of water exists. It is measured as the rate of uptake of water [5].

Minimizing sorptivity is important to reduce the ingress of potentially harmful agents into concrete. It is known thattheaddition of 5-10 % microsilica (by weight of Portland cement), decreases sorptivityofPortlandcementcomposites [6-9].Recently, particular attention has been given to nanosilica, which hasnoticeably higher reactivity than microsilica. Nanosilica is typically prepared by the neutralization of sodium silicate solutions with acidwheresilica monomers are allowed to condense to colloidal particles and aggregates. Nanosilica is commercially available in both powder and colloidal forms. Compared with microsilica, nanosilica affects the properties of concrete owing to its superior reactivity and very small particle size.The addition of nanosilica can influence the properties of cement-based materials in three ways: the nucleation effect which accelerates the hydration of cement; the filling effect, which strengthens the microstructure of the material; and the pozzolanic activity, which produces additional C–S–H gel, improving the mechanical properties and durability of concrete [10]. Literature survey showed that onlyfewstudies have been conducted to evaluate the influence of colloidalnanosilica on concrete sorptivity,a very important indicator of durability of concrete structures.Therefore, this study was undertaken to investigate the effect of 2 and 4 % nanosilica addition on the concrete porosity, sorptivity, and compressive strength at 28 days.

2. MATERIALS AND METHODS

2.1. Materials

Ordinary Portland cement type CEM I 52.5 N was used in this study. A commercial slurry of colloidal nanosilica (Levasil CB22 by Nouryion Chemicals) containing 30% solids and has a density of 1.3 g/cm^{3}was used.The surface area of nanosilica is 220 m^2/g and the average particle size is 12 nm [12].Crushed limestone with a maximum particle size of 16 mm and complying with the requirements of EN 12620-1 [13] was used as aggregate in the concrete mixes. A polycarboxylate-based high-range water-reducing admixture(HRWRA) and air-entraining concrete admixture formulated from modified naturally occurring and synthetic surfactants, both conforming to EN 934-2 [14]were used.

2.2. Mix proportions

Proportions of the reference mix and the mixes containing2% and 4% nanosilica (nS) by weight of cement are listed in Table 3. As nanosilica was introduced into mixes in the form of a slurry, the same water-binder ratio in each mix is obtainedbyreducing the added water by amount contained in the nanosilica slurry.

Table 3. Mix proportions of the concrete

Material		0% nS	2% nS	4% nS
Cement (kg/m^3)		400	392	384
Nanosilica (kg/m^3)		-	8	16
Agreggate (kg/m^3)	0-4 mm	885	885	885
	4-8 mm	355	355	355

	8-16 mm	530	530	530
Water (kg/m^3)		176	176	176
HRWRA (kg/m^3)		3,2	3,2	3,2
Air entraining agent (kg/m^3)		0,4	0,4	0,4

2.3. Mixing procedure

First, the fine and coarseaggregateswere added to the mixer, followed by dry-mixing with cement for 120 s. Then, nanosilica slurry and around 75% of the total amount of water are slowly added and mixed for another 120 s. Finally, the remaining mixing water and additives (HRWRA and Air entraining agent) were added into the mixer, during the consecutive mixing for 180 s. The whole mixing time was 7 min for all the batches.

2.4. Test methods

After mixing, slump test wascarriedouton each mix in accordance withEN 12350-2 [15]. For testing hardened concrete properties cubic samples 100×100×100 mm were prepared. All specimens had been demoulded after 24 hours and then stored in water at a temperature of 20 °C until tests were conducted. At the curing age of 28 days, water sorptivity was measured (ASTM C1585-13), as well as density, permeable voids and water absorption (ASTM C642-06)and compressive strength (EN 12390-3) [16, 17, 18].

ASTM C642-06was used to determine the total amount of water absorption and volume of permeable voids. The samples at age 28 days were placed in an oven at a temperature of 105° C for 48 hours and the mass of each dried sample wasmeasured.After that, the saturated mass of samples was determined by immersing them in the water at 20°C for 72 hours.Finally,the saturated mass by using immersion in boiling water was determined. Samples were covered by tap water and boiled for 5 hours.Thewater absorption and volume of voids were calculated using massof dried samples, immersed apparent massofsamples, and immersed and boiled saturated mass valuesof samples.

The rate of absorption (sorptivity)of water was obtained by using procedure described in ASTM C1585-13. The schematic procedure of the test is shown in Fig. 1. The test was conducted on the specimens of 100×100×50 mm size after 28 days of curing. This test method consistsofpreconditioningsamples, followed byexposing the bottom surface of the sample to liquid water andmeasuring the increase in mass resulting from water absorption. The samples were preconditioned using an oven able to maintain a temperature of 50±2°C and a desiccator. The relative humidity is controlled in the desiccator at 80±0.5 % by a saturated solution of potassium bromide.All surfaces of the specimen except top and bottom were sealed to prevent moisture ingress. Only the bottom surface of thesample was left exposed for water penetration. The samples were placed over the water and the level of the water was maintained at 2 ± 1 mm. The change in weight after the certain intervals was recorded and the normalized absorbed fluid volume (i) was calculatedas:

$$i = \frac{m_t}{(a \cdot \rho)}$$

where m_t is the change in specimen mass at time t, a is the area of the specimen exposed to the fluid, and q is the density of the absorbed fluid water.Then, the calculated absorption value at each time is plotted against the square root of time ($t^{1/2}$) to investigate the slope of its linear trend, sorptivity. This index is determined in two stages; initial and secondary absorption due to the absorption time.

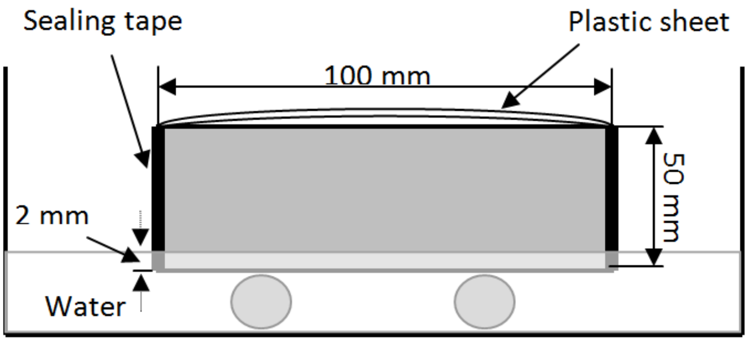

Figure 1. Schematic of the procedure in accordance to ASTM C 1585-13

3. RESULTS AND DISCUSSION

The slump of fresh concrete mixes versus the amount of nanosilica is presented in Fig. 2. The data illustrates the direct relation between the nanosilica amount and the workability of fresh concrete: with the addition of nanosilica, the slump of fresh decreases linearly. The slump reduction is explained by the fact thatthe specific surface area of silica particles is larger than that of cement, and it absorbs more water.

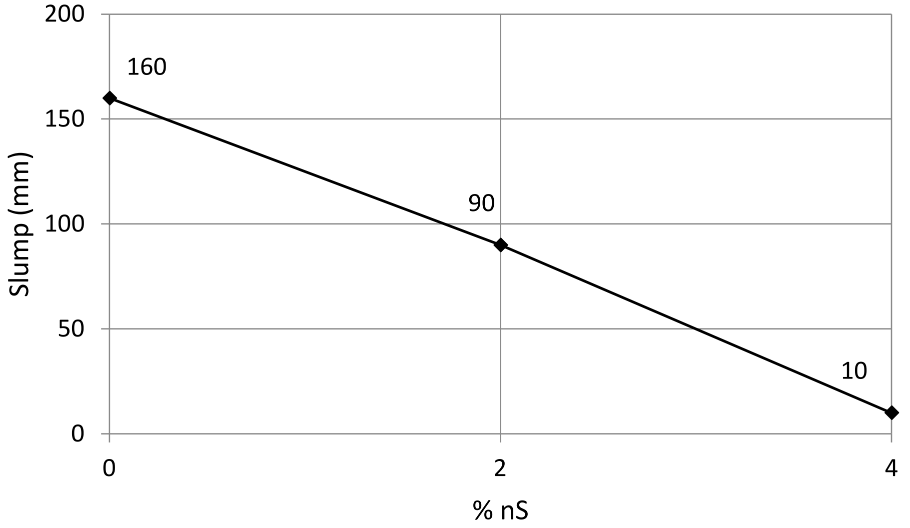

Figure 2.Slump of concrete mixes at different nS additions

Porosity (volume of permeable voids)and water absorption of hardened concreteare presented in Fig. 3 and Fig. 4, respectively. It can be seen that with the addition of nanosilica, both volume of permeable pores and water absorption of concrete decreases.

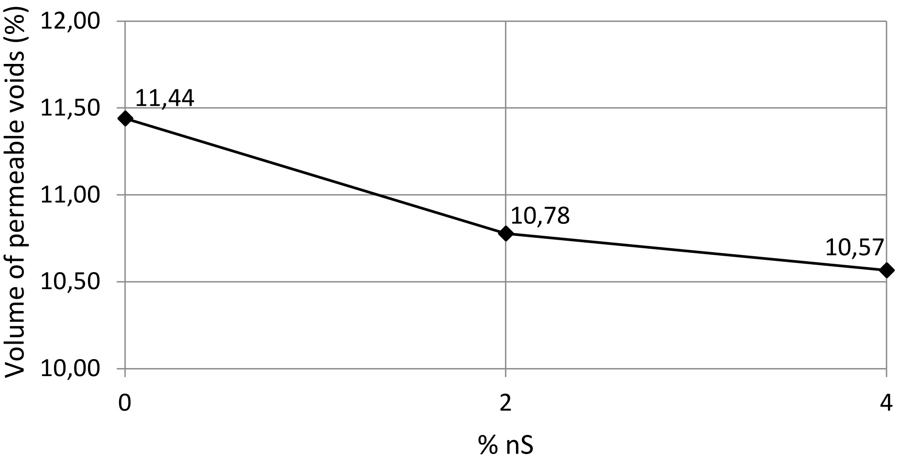

Figure 3. Volume of permeable pores of concrete at different nS additions

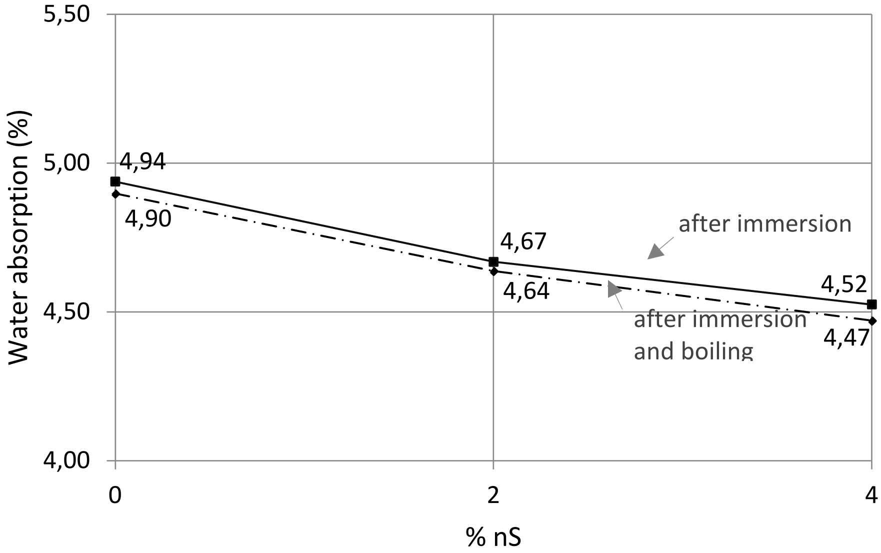

Figure 4. Water absorption of concrete at different nS additions

After samples were conditioned for 18 days (3 days in a desiccator and 15 days in a sealed container), testing was performed in accordance with ASTM C1585-13, with results provided in Figure 5. In addition, Figure 6 shows the calculated initial sorptivityand secondary sorptivity from these tests.

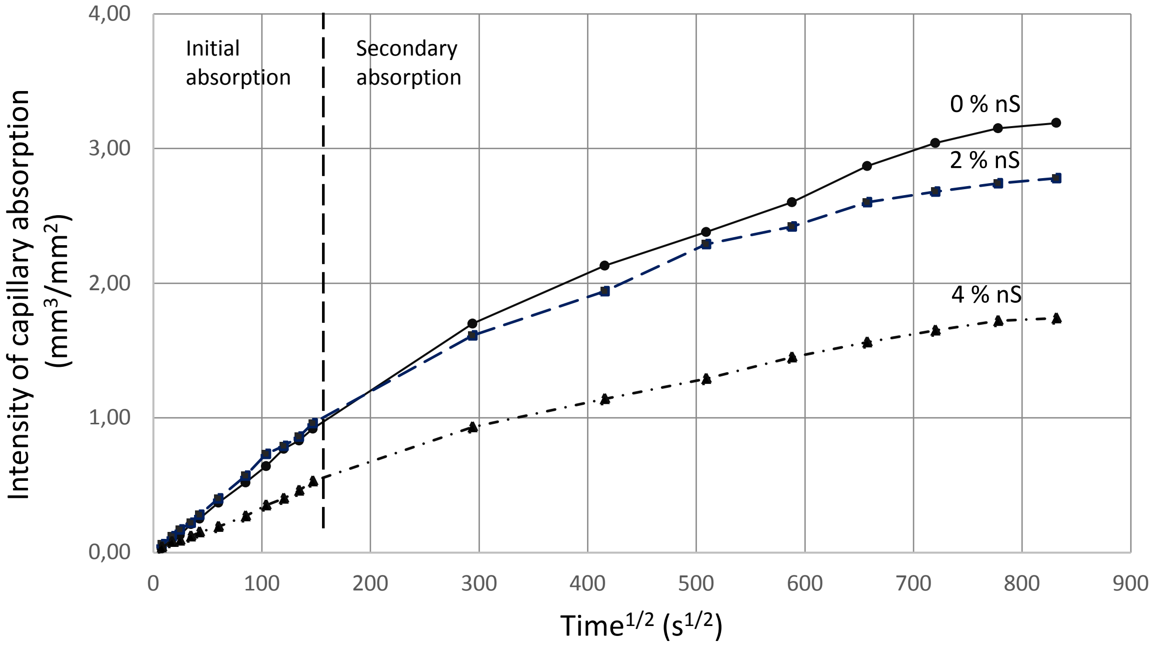

Figure 5. Cumulative water absorption of concrete at different nS additions

It can be seen from Fig. 5 and Fig.6 that sorptivity values decreased with the inclusion of nanosilica as cement replacement.

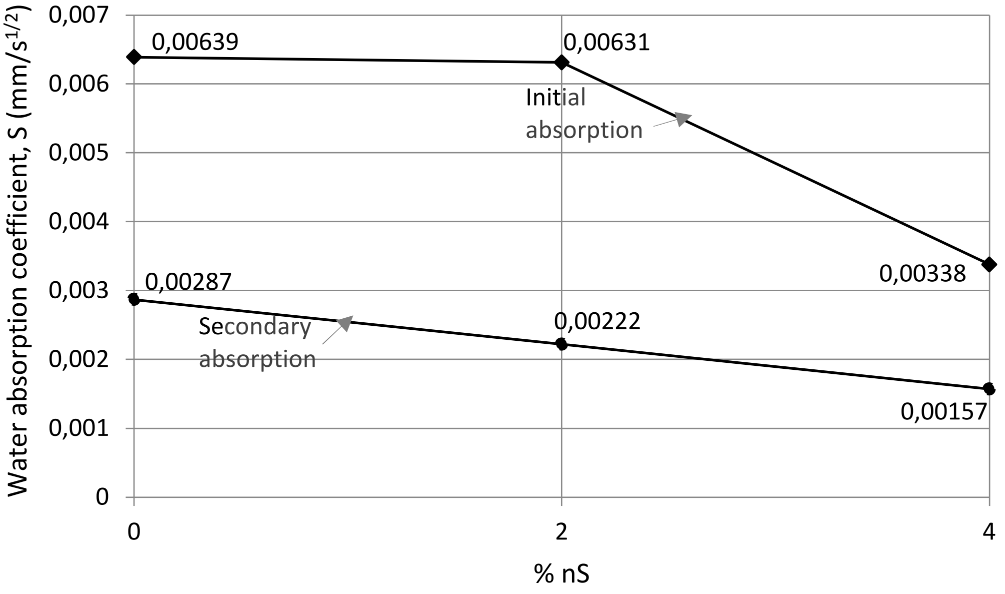

Figure 6. Water absorption coefficient of concrete at different nS additions

The average compressive strength of the tested mixturesat 28days are given in Fig. 7.The results show that the addition of nanosilica is beneficial to the compressive strength of concrete. Compressive strength at 28 days of nanosilicamodified concrete increases for 9,6% at 2% nanosilica, and for 13,7% at 4% nanosilica.

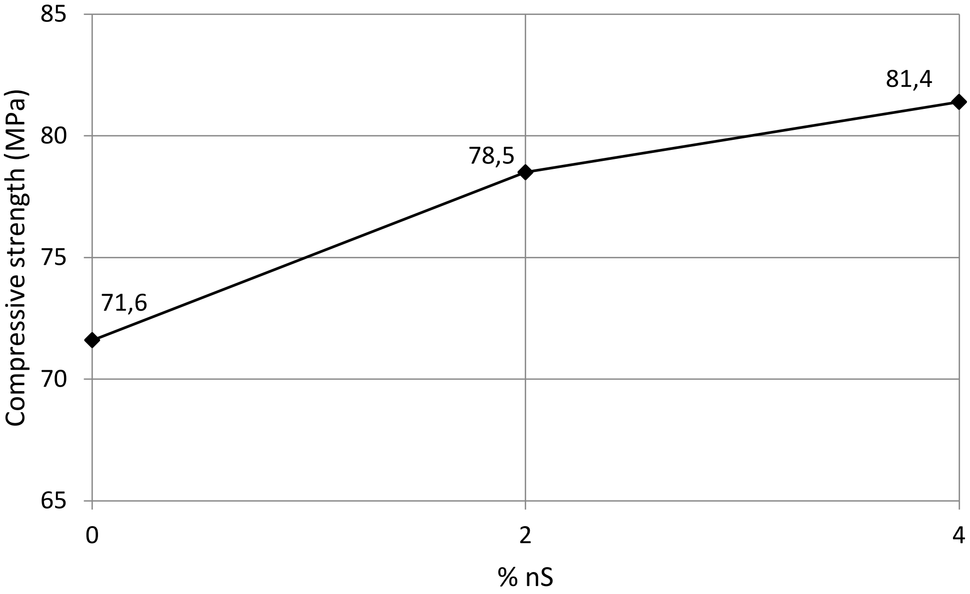

Figure 7. Compressive strength at 28 days of concrete at different nS additions

Theprobable explanation of porosity and sorptivity decreasing and compressive strength increasing is the positive effect of nanosilica on cement hydration. It is well known, due to the nucleation effect of nanosilica, the formation of C–S–H phase is no longer limited on the grain surface alone.For that reason, the hydration degree of cement is higher and more pores (the week points in the structure of concrete) can be filled by the newly generated C–S–H phase [19].

4. CONCLUSION

The following conclusionsare drawn from the study:

- The addition of nanosilica to cementitious mixes produces a remarkable reduction of the mix workability.
- Volume of permeable pores and water absorption of concrete decreases with nanosilica addition, as well as initial and secondary sorptivity.
- At 2% nanosilica addition, volume of permeable pores is reduced for 5,8%, water absorption for 5,5%, initial sorptivity for 0,1%, and secondary sorptivity for 39,3%.
- At 4% nanosilica addition, volume of permeable pores is reduced for 7,6%, water absorption for 8,5%, initial sorptivity for 22,6 %, and secondary sorptivityfor 45,3%.
- Compressive strength at 28 days of nanosilicamodified concrete increases for 9,6% at 2% nanosilica, and for 13,7% at 4% nanosilica.

Acknowledgement

This research was funded and supported by Federal Ministryof Education andScience (FB&H). The authors gratefully acknowledge the contribution and continuous support from Federal Ministryof Education andScience to our research work.

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