12th Scientific/Research Symposium with International Participation
„METALLIC AND NONMETALLIC MATERIALS“ B&H, 19th-20th April 2018

THE EFFECTS OF NANOSILICA ON THE PHYSICAL-MECHANICAL PROPERTIES OF CONCRETE

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Keywords: nanosilica, concrete, compressive strength, flexural strength, dynamic modulus of elasticity

ABSTRACT
The physical-mechanical properties of concrete with nanosilica were experimentally studied. Nanosilica in powder form was used as a partial replacement of cement at dosage of 3 and 6 wt.%. The experimental results show that the compressive strengths of concretes with nanosilica particles were all higher than those of reference concretes at ages 1, 7, 28 and 90 days. Also, at age of 28 days flexural strength, dynamic modulus of elasticity and apparent density have been increased, while water absorption has been decreased.

1. INTRODUCTION
A possibility of improvement cement-based composites properties by using nanoparticles has attracted considerable attention among researchers during last decade. Numerous types of nanoparticles are used in concrete, such as NS (SiO_2), calcium carbonate ($CaCO_3$), aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), zinc peroxide (ZnO_2) and zirconium dioxide (ZrO_2). Among these materials, nanosilica (NS) takes special attention of researchers, since it is very similar to silica fume (microsilica), an addition highly praised by concrete manufacturers. Applying silica fume for modification cement-based materials, has achieved great successes in recent decades. The best examples are high performance concrete, reactive powder concrete and so on. Due to its exceptional fineness, amorphous structure and high silica content, silica fume is a very effective pozzolanic material [1, 2].
In recent years, NS has been introduced into cement and concrete research. NS, is also a highly reactive pozzolan but it has much smaller particles than silica fume. Since the rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction, the pozzolanic activity of NS is much greater than that of silica fume. Another mechanism, by which NS can influence cement composite properties, is seeding effect. NS could provide extra sites for the precipitation of hydration products, leading to the acceleration of early stage hydration [3]. NS consumes calcium hydroxide (portlandite) crystals, decreases the orientation of portlandite crystals, reduces the size of portlandite crystals at the interface and

improves the interface structure more effectively than silica fume [4, 5]. This paper reports on the effects of nano-sized amorphous silica on the physical-mechanical properties of concrete.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1. Materials

The cement used in this study is Ordinary Portland Cement (OPC) CEM I 52.5 N. A polycarboxylic ether-based water-reducing admixture is used to adjust the workability of concrete mixtures. NS Ultrasil 7005 (Evonic Industres AG) with a Blaine fineness of 190 m^2/g was used in powder form as a partial cement replacement. SEM micrograph of Ultrasil 7005 is shown in Fig. 1. Finally, crushed limestone aggregate with maximum grain size 16 mm and tap water were used for making concrete mixtures.

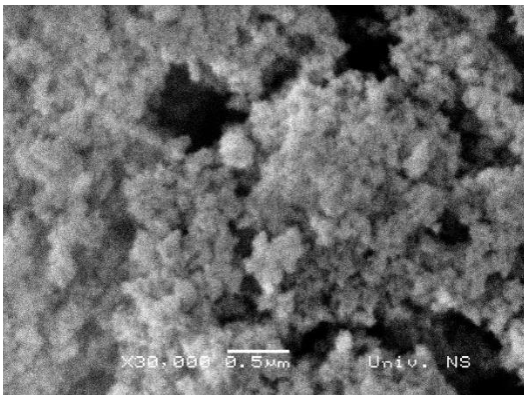

Figure 1. Ultrasil 7005 SEM micrograph [6]

2.2. Experimental procedure

Three concrete mixtures were made for experimental investigation. Reference mixture incorporated only cement as a binder, and in the second and third mixtures, respectively 3 and 6 wt.% cement were replaced with NS. Since cement replacement with NS increased the mixture water demand, the amount of superplasticizer in the mixtures with NS was increased till it reached assumed consistency. The composition of the concrete mixtures is shown in Table 1.

Table 1. Concrete mixes composition

Concrete component	**Reference concrete**	**Concrete with 3 wt.% NS**	**Concrete with 6 wt.% NS**
Cement (kg/m^3)	390	378.3	366.6
NS (kg/m^3)	-	11.7	23.4
Water (l/m^3)	170.0	170.0	170.0
Aggregate 0-4 mm (kg/m^3)	1000	1000	1000
Aggregate 4-8 mm (kg/m^3)	200	200	200
Aggregate 8-16 mm (kg/m^3)	800	800	800
Superplasticizer (kg/m^3)	2.0	2.2	2.5
Σ (kg/m^3)	2411.0	2411.0	2411.0

Concrete consistency was tested on the fresh concrete mixes according to BAS EN 12350-2. Concrete cube specimens of 150 mm were prepared according to standard BAS EN 12390-2. Compressive strength of concrete cubes was tested after 1 day, 7 days, 28 days and 90 days, according standard BAS EN12390-3.

The following tests were conducted to determine the mechanical properties of the concretes containing NS, with respect to control mix:

- concrete consistency on the fresh concrete mixes according to BAS EN 12350-2,
- compressive strength of concrete cubes at 1 day, 7 days, 28 days and 90 days, according BAS EN 12390-3,
- flexural strength of concrete at 28 days according to 12390-5,
- density and water absorption according to ASTM C 642,
- dynamic modulus of elasticity by ultrasonic pulse velocity method according to BS EN 12504-4.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The results of the consistency test of concrete mixtures are shown in Table 2. The same consistency class (S2) of the three concrete mixes was obtained by adding a larger amount of superplasticizer to the mixtures of concrete with NS (see Table 1).

Table 2. Slump of concrete mixes

Concrete mix	**Slump (mm)**
Reference concrete	140
Concrete with 3 wt.% NS	140
Concrete with 6 wt.% NS	135

The average compressive strengths of the specimens at different curing ages are shown in Table 3 and in Figure 2. Three replicates were used for each test.

Table 3. Compressive strength test results

Compressive strength (MPa)				
Age	**1 day**	**7 days**	**28 days**	**90 days**
Reference concrete	25.4	46.6	56.3	60.4
Concrete with 3 wt.% NS	27.4	52.3	68.2	73.5
Concrete with 6 wt.% NS	27.8	55.2	78.3	80.6

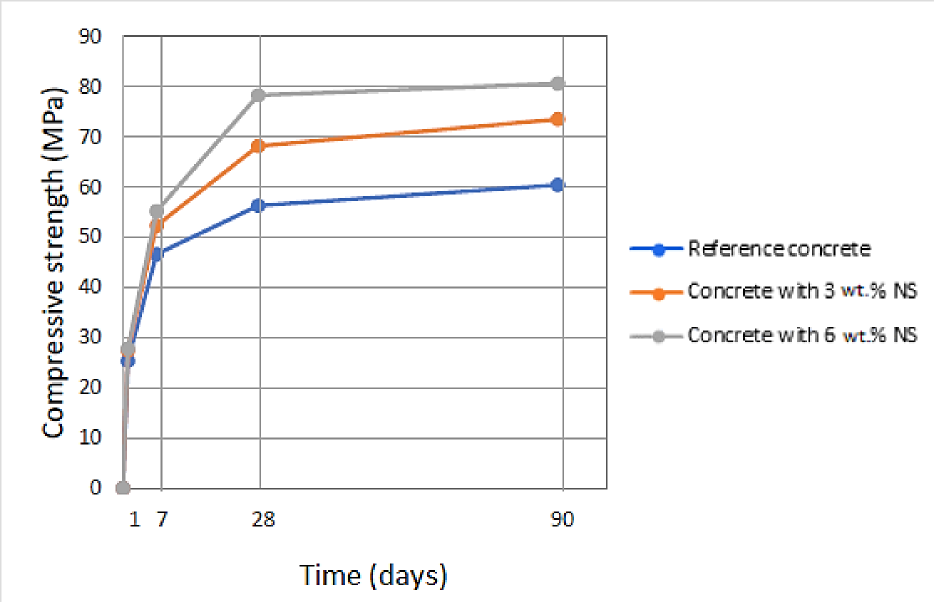

Figure 2. Concrete compressive strength development

The percentage of increase in compressive strength compared to the reference concrete is shown in Table 4.

Table 4. The increase in compressive strength compared to the reference concrete

The increase in compressive strength (%)				
Age	**1 day**	**7 days**	**28 days**	**90 days**
Concrete with 3 wt.% NS	7.87	12.23	21.14	21.69
Concrete with 6 wt.% NS	9.45	18.45	39.08	33.44

The results of flexural strength tests are shown in Table 5.

Table 5. Flexural strength test results

Concrete mix	**Flexural strength (MPa)**
Reference concrete	6.97
Concrete with 3 wt.% NS	7.33
Concrete with 6 wt.% NS	7.96

The results of water absorption and apparent density tests are shown in Table 6.

Table 6. Water absorption and apparent density test results

Concrete mix	**Water absorption (%)**	**Apparent density (kg/m^3)**
Reference concrete	2.82	2416.35
Concrete with 3 wt.% NS	2.13	2455.60
Concrete with 6 wt.% NS	1.83	2482.10

The results of dynamic modulus of elasticity tests are shown in Table 7.

Table 7. Dynamic modulus of elasticity test results

Concrete mix	**Dynamic modulus [GPa]**
Reference concrete	49.7
Concrete with 3 wt.% NS	52.4
Concrete with 6 wt.% NS	56.2

Table 3 and Fig. 2 show that replacement of cement with NS lead to increase in compressive strength in all testing ages. Concrete samples with 6 wt.% NS had better properties than samples with 3 wt.% NS. At 28 days concrete with 3 wt.% of NS have compressive strength for 21.14 %, flexural strength 5.16 % and dynamic modulus 5.43 % higher than reference concrete. At the same age concrete with 6 wt.% of NS have compressive strength for 39.08 %, flexural strength 14.26 % and dynamic modulus 13.08 % higher than reference concrete. Test results also show that concretes with NS has increased density and reduced water absorption relative to reference concrete.

In this investigation NS were added to mixtures in dry form. However, the strong tendency of NS to produce agglomerates was observed and it may decrease the dispersion of the particles in the matrix. So, it is probably possible to achieve greater improvement in mechanical properties of concrete by using some special techniques of mixing, such as adding of NS in a colloidal form of an aqueous suspension.

4. CONCLUSION

Based on the test results of reference concrete and concretes in which cement was replaced by NS, it can be concluded that:

- All tested properties of hardened concrete were improved by introducing the NS into the composition of concrete mixtures.
- Compressive strength, dynamic modulus of elasticity and density increase, while water absorption of concrete decrease with increase in NS content from 3 to 6 %.
- The consistency of the mixtures with NS worsened with respect to the consistency of the reference concrete. To maintain the assumed consistency, it is necessary to add an increased amount of superplasticizer.
- Increasing strength and density and reducing water absorption and Portland's content provide grounds for assuming that NS addition to concrete increases its durability. However, additional tests are required to confirm this assumption.

5. REFERENCES

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