SILICA NANOPARTICLES HYDROSOL FOR CONCRETE STRENGTH INCREASE BY ADDING TO MIXING WATER

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ABSTRACT

The article presents the results of tests of cement mortars prepared on activated (by an acoustic field frequency 22 kHz, power 4.0 W·cm^{-2} and electrochemical treatment voltage 15 V, current density 4.5 mA·cm^{-2}, steel electrodes) mixing water modified with silicon dioxide nanoparticles in the form of 3 %, 6 % and 10 % hydrosol. The construction of modern nuclear power facilities, solar energy panels base and other seismically resistant structures were required using of modified building materials that have high strength and protection levels. Currently, in the global construction industry, the main focus is on nano-additives that contribute to a significant increase in these indicators. Using the described technology allowed us to increase the strength of concrete by one grade.

Keywords: silica nanoparticles, mixing water, hydrosol, concrete, strength.

INTRODUCTION

The new composition of protective and structural concretes is necessary to take a new approach. Both traditional physical and chemical, also mechanical parameters the concretes used as the substructure of solar and wind energy objects also nuclear power plants (NPP) construction, industrial construction as a structural building material, and a number of specific parameters inherent in materials of protective structures of NPP [1]. Moreover important role is related to the main stages of the life cycle of nuclear power facilities. During the construction phase, they largely determine the value of the object. For example, there are about 500 000 tons of concrete required for the construction of NPP unit with an electrical capacity of 1000 MW. During the operational phase, concrete protective structures ensure the safety of personnel, the public and the environment [2]. More important is the role of building concrete protective structures in the decommissioning of NPP.

The design and construction of new generation NPP requires, in particular, taking into account the decommissioning stage already at the design process [3 - 5]. High safety requirements power facilities, including nuclear power facilities, required new types of high-quality building materials, for example, nano concrete. Specifically modified and nano-additives concretes are characterized by high strength, lightness, water resistance and fire resistance (up to 750◦C).

It is most effective to increase the concrete performance characteristics associated with strength and seismic resistance, activation of mixing water with the help of acoustic, electrical or electromagnetic fields that contribute to the stabilization of the structural and technological characteristics of the product. Ultrasonic and electromagnetic waves used for activation significantly increase the uniformity of the resulting product, contributing to its seismic, environmental and climatic sustainability, which are relevant in the construction of supports for solar cell mounts. Such methods of physical processing of mixing water are being intensively developed along with the chemical modification of Portland cement systems by introducing organic and mineral additives into them, taking into account the fact that the water present in the concrete mixture is its active component.

Silicon dioxide hydrosols used in a wide field of industry purposes: production of catalysts, heat-resistant binders for foundry technologies, refractories, electrical insulation coatings of transformer steels, anti-corrosion coatings, polishing suspensions, buildings [6, 7]. The special attention in the Republic of Uzbekistan is paid to research and creating seismic resistant materials, especially relevant in the seismic regions as the Central Asia.

The special attention in the Republic of Uzbekistan was paid to the addition of nanoparticles to the raw material studies of nanocement and nanoconcrete were carried out in small quantities now. The main goal of our research is the activation of concrete slurries by adding nanoparticles into the mixed water as a suspension during their preparation for creating foundation material with high strength and seismic stability. In this work, we report modified technological method by using dispersible compositions with low carbon footprint.

EXPERIMENTAL

Natural water was used for prepare silica nanoparticles hydrosol in the form of 3 %, 6 % and 10 % suspensions. In addition to that, mixing water was activated by complex treatment both an acoustic field and electrochemical method according to description in [8]. Aerosil 100 nm nanoparticles were used in suspension. The total concentration of SiO_2 nanoparticles in the continuous was 10^8 particles per mL. The size distribution of nanoparticles in an aqueous medium was determined using the Malvern Nanosight LM10 nanoparticle analyzer [9] according to the NTA (nanoparticles tracking analysis) technique based on the free diffusion behavior of particles in solution [10], the laser wavelength used is 642 nm (Fig. 1).

Concrete samples modified by silica nanoparticles were tested in the certification laboratory of the research center “Strom” at the Academy of Sciences of the Republic of Uzbekistan. The sample of Portland cement standard composition PC-D0 was prepared as comparison sample. Pure natural water was used for pouring of standard concrete sample beams (40×40×160 mm) from the control Portland cement grade 500 (PC-

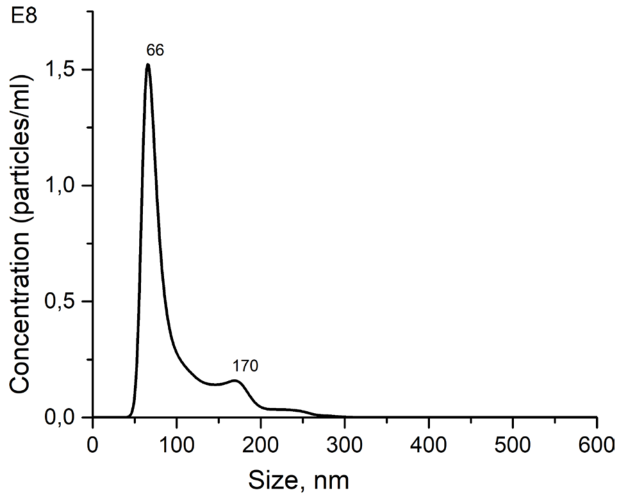

Fig. 1. The size distribution of SiO_2 nanoparticles in aqueous solution.

D0). Activated and modified by silica nanoparticles in the form of 3 %, 6 %, and 10 % water hydrosol was used for samples (PC-1, PC-2, PC-3) as mixing water. The samples were storage in humid conditions 1 day and in water up to 28 days. The ultimate strength of samples was determinate after 2, 7 and 28 days of hardening in water. Samples-beams were made from a cement-sand mortar of the composition 1:3, having previously determined its consistency for each pouring, with the determination of the consistency of each type of cement mortar along the cone spread.

To prepare the cement slurry, 500 g of cement, 1500 g of monofractional standard sand and 200 g (mL) of natural water are mixed. We used the corresponding hydrosol (SP-1, SP-2, SP-3) to form samples with the addition of silica nanoparticles.

Hydrosols with the addition of 3 %, 6 %, 10 % nanoparticles of silicon dioxide as mixing water, cement-sand mortars reach an identical consistency, determined by cone spread, when the values of the water-cement ratio change from 0.40 (for PC - D0) up to 0.42; 0.44; 0.46, respectively, for cement mortars PC - 1, PC - 2, PC - 3 are shown in Table 1. The sequence of preparation of cement slurries (without and with additive) and the determination of their cone spreading on a shaking table was carried out in accordance with the test method [11].

The actual content of silicon dioxide nanoparticles in cement-sand mortars PC-DSP-1, PC- DSP-2, PC-DSP-3, prepared for molding beams, amounted to 1.24, 2.57 and 4.40 %, respectively.

Table 1. The cement-sand mortars parameters.

Conventional designation of cement mortars	PC-D0	PC- 1	PC- 2	PC- 3
Portland cement, g	500	500	500	500
Standard sand, g	1500	1500	1500	1500
W/C mortar 1:3	0.40	0.42	0.44	0.46
Mixing water	Nature water	3% hydrosol	6% hydrosol	10% hydrosol

Table 2. Compressive strength of concrete samples with the nanoparticles of silicon dioxide addition.

Conventional designation of cement mortars		PC-D0	PC -1	PC -2	PC -3
Added,% of mass		-	1.24	2.57	4.40
Mixing water		Nature water	3% hydrosol	6% hydrosol	10% hydrosol
Compressive strength, MPa	2d	26.46	30.38	24.50	24.50
	7d	43.71	49.88_	49.88	49.88
	28d	52.53	59.48	59.48	59.09
Brandby ND		500	600	600	600

RESULTS AND DISCUSSION

There is a slightly delayed hardening of Portland cements PC-DSP-2 and PC-DSP-3 with a content of 2.57 % and 4.40 % of silicon dioxide nanoparticles in the initial period of hardening (up to 2 days). At the age of 7 and 28 days of hardening, all Portland cements with the addition of nanoparticles of silicon dioxide have the same strength and exceed the values of the compressive strength of samples from the control Portland cement PC-D0 Brandby ND grade 500. All samples from Portland cements containing the addition of silicon dioxide nanoparticles in amounts of 1.24 %, 2.57 % and 4.49 % at the age of 28 days are characterized by the values ultimate strength in compression up 59.09 to 59.48 (~600 kgf·cm^{-2}), refers them to the guaranteed grade 600. Concrete samples compressive strengths were shown in Table 2.

For the preparation of the concrete mixture Portland cement grade M500 D0 according to GOST 31108-2003 is used. The value 500 means that a cement stone made from such a powder is able to withstand a maximum brand load of up to 500 kg·cm^{-3}. In addition to the standard constituents, nanosized (40 nm) silicon dioxide was used as a modifying additive. In this case, the dispersion of the filler plays a decisive role, the increase of which allows to reduce the optimal consumption of the additive. Additionally for the PC-1 sample natural water activated by an acoustic field (frequency 22 kHz, power 4.0 W·cm^{-2}) and electrochemical treatment (voltage 15 V, current density 4.5 mA·cm^{-2}, steel electrodes) were used as mixing water. The comparison sample was made similarly, but without modification and activation of mixing water. The tests were carried out on samples made of concrete mix measuring 40×40×160 mm^3 on day 28 after they were poured using standard methods: “Concretes. Methods for determining the strength of the control samples (GOST 10180-90)”; “Concrete. Methods for determining the density (GOST 12730.1-78.)”; “Transient Hot Bridge method for determining thermal conductivity, thermal diffusivity and heat capacity.” The results are shown in Table 3.

The results show that the developed concrete composition in terms of parameters 2 - 4 is close to the class of high-strength lightweight concrete [12] while the compressive strength is more than 20 % higher than the strength of the comparison sample. Moreover, samples from the developed composition are characterized by values of compressive strength of 621 kgf·cm^{-2}, which, according to the requirements of GOST 10178-85,

Table 3. Physical parameters of the developed concrete composition by adding 3 % SiO_2 nanoparticles hydrosol with activated nature water.

№	Concrete parameters	Prepare composition	Comparison sample
1	Density, kg/m^3	1514	1391
2	Specific heat (at 25 °C), kj/(kg·K)	1.302	1.174
3	Thermal conductivity, W/(m·K)	0.605	0.788
4	Compressive strength, MPa	62.37	52.53

classifies them as guaranteed grade 600, while the reference sample has grade 500, which indicates the possibility of increasing the grade of concrete using activated of mixing water by a developed method and by adding silica nanoparticles hydrosol. The nanoparticles stability conditions in solution can be described in terms of nanothermodynamics [13 - 15]. The chemical potential of a modifying nanoparticle, which can be considered in nanothermodynamics framework [15] as a supramolecule consisting of {n} structural units (n_1 structural units of the first grade, n_2 structural units of the second grade, etc.), using the result of statistical mechanics for ordinary molecules (as given in [15]) has the form:

$$\mu_{\{n\}} = G^0_{\{n\}} + kT\ ln\left(c_{\{n\}}\Lambda^3_{\{n\}}f_{\{n\}}\right) \qquad (1)$$

where $\mu_{\{n\}}$ is chemical potential of the supramolecule, $G^0_{\{n\}}$ is Gibbs energy of a supermolecule {n}in a given medium under the condition of a resting center of mass and without of other supramolecules; k is Boltzmann's constant, T is temperature; $c_{\{n\}}$is concentration of supramolecules; $\Lambda_{\{n\}}$ is mean de Broglie wavelength and $f_{\{n\}}$is supramolecules activity coefficient, reflecting their interaction. $G^0_{\{n\}}$ contain the supramolecule interaction with the medium; if included in $G^0_{\{n\}}$ activity factor $f_{\{n\}}$ as part of $kT\ lnf_{\{n\}}$ the expression for the chemical potential takes the form:

$$\mu_{\{n\}} = G^0_{\{n\}} + kT\ ln\left(c_{\{n\}}\Lambda^3_{\{n\}}\right) \qquad (2)$$

where $G^0_{\{n\}}$ already takes into account the interaction of the supramolecule not only with the medium, but also with other supramolecules. Nanothermodynamics provides a condition for the most probable form of emerging supramolecular formations:

$$w^{\alpha}n + w^{\alpha\sigma}bn^{2/3} - (kT/2)ln(I_1I_2I_3) + kTlnf_{\{n\}} = \\ = \min \qquad (3)$$

where $w^{\alpha\beta}$ is the structural unit transferring work from supramolecule to the solution; $w^{\alpha\sigma}$ is the structural unit transferring work to the supramolecule surface; b is a numerical coefficient depending on the chemical structure and the supramolecule geometric shape, I_1,I_2,I_3 are the main moments of inertia. If w^{α} is the transferring work of structural units to the formed structure does not depend on its shape, this condition takes the form:

$$w^{\alpha\sigma}bn^{2/3} - (kT/2)ln(I_1I_2I_3) + kTlnf_{\{n\}} = \min \qquad (4)$$

CONCLUSIONS

A compressive strength study of Portland cement-concrete solutions containing modified 40 nm silicon dioxide nanoparticles and mixing water by using the electrochemical activation method was presented. Here is shown that the dispersion of the nanosilica hydrosol filler plays a key role to increase the strength of the solution and it leads to be more than 18.5 % higher than the strength of the comparison sample by a developed electrochemical activation method. The compressive strengths of concrete samples show the enhancement of the grade of concrete by activated of mixing water with the acoustic field.

In the process of testing concrete mixtures, the combined method of activating mixing water, combining ultrasonic and electrochemical methods of exposure, proved to be most effective. Due to the synergistic processes in the solvent, the efficiency of the operational characteristics, expressed in the ability to stabilize, hydrate, strengthen properties, is significantly increased. The combination of these parameters makes it possible to create modified cement-concrete solutions of increased strength and seismic resistance. This indicates the prospects of the developed technology for use in the manufacture of concrete structures with a wide profile including the special physical properties. We have developed new technological approaches based on the use of water dispersible compositions, which currently successfully displace products based on organic solvents, being environmentally safer both in production and in operation with low-carbon footprint. Further research is planned to creation of radiation-resistant concrete by modifying the mixing water or cement mixture with metallurgical slags, which opens up broad prospects for its use in NPP foundation building.

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