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Strength Portland Cement with Suspension of Silicon Dioxide Nanoparticles Additives

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Abstract— *The construction of modern nuclear power facilities requires the use 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. The article presents the results of tests of cement mortars prepared on activated mixing water modified with silicon dioxide nanoparticles in the form of a 3, 6 and 10 percent suspension.*

Keywords— *Activated water, mixing water, cement mortar, nuclear power plant, silicon dioxide nanoparticles, suspension.*

I. Introduction

The important role, which solved at a new stage in the development of nuclear energy, materials and structures for radiation and biological protection of nuclear power plants, mainly structural and protective modified by nanoparticles concretes. Moreover, this 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. So for the construction of a nuclear power plants (NPP) unit with an electrical capacity of 1000 MW, about 500,000 tons of concrete are required. During the operational phase, concrete protective structures ensure the safety of personnel, the public and the environment.

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 [1-7]. Using traditional and development of new compositions of protective and structural concretes, it is necessary to take a new approach. Both traditional physical and mechanical parameters the concretes used in the construction of NPP, industrial construction as a structural building material, and a number of specific parameters inherent in materials of protective structures of NPP.

High safety requirements power facilities, including nuclear power facilities, required new types of high-quality building materials, for example, nanoconcrete. Modified and nano-additives concretes are characterized by high strength, lightness, water resistance and fire resistance (up to 750°C).

In Uzbekistan special attention was paid to the addition of nanoparticles to the raw material studies of nanocement and nanoconcrete and were carried out in small quantities now. The main goal of our research is the activation of cement slurries by adding nanoparticles into the mixed water as a suspension during their preparation.

II. Materials and Sample Preparation

Portland cements with various additives of silicon dioxide nanoparticles were tested at the research and development center "Strom" certification laboratory of the Academy of Sciences of the Republic of Uzbekistan.

For testing, 3 samples with silicon dioxide nanoparticles prepared in the form of 3, 6 and 10 percent suspensions in an amount of 2 liters each others and were delivered to the accredited testing laboratory of the Strom Research and Development Center.

To prepare suspensions, nature water was used, which was preliminarily subjected to the process of complex activation 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) with nanoparticles of silicon dioxide simultaneous modification.

As a result of complex activation, suspensions of the following compositions (at a flow rate of 1 liter) and conventional designations were obtained:
- SP 1 (3% concentration) - 970 ml of water + 30 g of nanoparticles of silicon dioxide;
- SP 2 (6% concentration) - 940 ml of water + 60 g of nanoparticles of silicon dioxide;
- SP 3 (10% concentration) - 900 ml of water + 100 g of nanoparticles of silicon dioxide.

The following volumes of work and types of tests were carried out:
- selection of a sample of Portland cement composition PC-D0 for testing;
- preparation of Portland cement for testing in accordance with the requirements [8];
- pouring of standard concrete sample beams (40×40×160 mm) from the control Portland cement (PC-D0) and samples (PC-D3, PC-D6, PC-10), during the molding of which, instead of mixing water, the addition of silicon dioxide nanoparticles was used in the form of 3, 6, and 10 percent suspensions;
- storage of samples in humid conditions (1 day) and in water (up to 28 days);
- determination of the ultimate strength of samples after 2, 7 and 28 days of hardening in water;
- assessment of quality indicators of cements with the addition of nanoparticles of silicon dioxide for compliance with the requirements [9].

U.A. Yokubov, K.B. Egamberdiev, M.V. Gofurova, S.K. Telyaev, and O.V. Trunilina, “Strength portland cement with suspension of silicon dioxide nanoparticles additives,” *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 3, Issue 5, pp. 30-33, 2020.

The following materials were prepared for testing:
- Portland cement grade 500 (PC 500-D0), meeting the requirements in all quality indicators [9];
- 3, 6 and 10 percent suspensions with modified silica nanoparticles.

III. Results and Discussion

A. Physical and mechanical properties of Portland cements with the addition of silicon dioxide nanoparticles

In accordance with the requirements of [9], the main indicators of the quality of Portland cements are the values of ultimate strength in bending and compression.

To determine the strength characteristics of cements, beams (40×40×160 mm) were pouring from Portland cement PC 500-D0 (for comparative tests) according to the method [10] and samples using instead of mixing water modified suspensions prepared by the customer with additives of silicon dioxide nanoparticles SP-1, SP-2, SP-3.

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 determine the consistency of the cement slurry, 500 g of cement, 1500 g of monofractional standard sand according to [11] and 200 g (ml) of nature water are weighed. To form samples with the addition of silicon dioxide nanoparticles, instead of water, we used the corresponding suspensions (SP-1, SP-2, SP-3).

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 [10].

According to the method [10] (clause 2.1), the spread of the cone with W/C = 0.40 (with a ratio of 200 g of water to 500 g of cement) should be within 106-115 mm. If the cone spread is less than 106 mm, the amount of water is increased to obtain a cone spread of 106-108 mm. When a cone spread of more than 115 mm is obtained, the amount of water is reduced.

TABLE I. Results of determining the consistency of cement-sand mortars.

Conventional designation of cement mortars		PC-D0	PC-DSP-1	PC-DSP-2	PC-DSP-3
Material composition of cement-sand mortar	Portland cement, g	500	500	500	500
	Standard sand, g	1500	1500	1500	1500
	Mixing water, g	200	210	220	230
W/C mortar 1:3		0.40	0.42	0.44	0.46
Cone spread, mm		113	110	110	106
Mixing water		Nature water	3% suspension	6% suspension	10% suspension

The results of the preparation of cement-sand mortars are shown in Table I. Table I is shown suspensions 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-DSP-1, PC-DSP-2, PC-DSP-3. However, using the simple calculations, it is possible to correct the material composition of cement-sand mortars, taking into account the content of silicon dioxide nanoparticles in each concentration of a suspension:
- 100 g of a 3% suspension (SP-1) contains 3 g of silicon dioxide nanoparticles, and 210 g - 6.3 g;
- 100 g of 6% suspension (SP-2) contains 6 g of silicon dioxide nanoparticles, and 220 g - 13.2 g;
- 100 g of a 10% suspension (SP-3) contains 10 g of silicon dioxide nanoparticles, and 230 g - 23.0 g.

The calculated material composition of the studied cement-sand mortars with the addition of silicon dioxide nanoparticles is shown in Table II.

TABLE II. Estimated material composition of cement-sand mortars.

Conventional designation of cement mortars		PC-D0	PC-DSP-1	PC-DSP-2	PC-DSP-3
The substance composition of the cement-sand mortar, g	C	500	500	500	500
	D	0	6,3 **1,24 %**	13, 2 **2,57 %**	23,0 **4,40 %**
	∑	500.0	506.3	513.2	523.0
	Sand	1500	1500	150	1500
	SP	-	210	220	230
	W	200	203.7	206.8	207.0
W/C mortar 1:3		0.400	0.402	0.403	0.396
CS, mm		113	111	110	106

Note. In Table II, the following abbreviations and symbols are adopted: C - cement; D - additive of nanoparticles of silicon dioxide; SP - suspension; W - water; W/C - water-cement ratio; CS - cone spread.

The data given in Table II shows that the introduction of nanoparticles of silicon dioxide in the form of an activated suspension into cement-sand mortars does not significantly affect their water demand. 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, 4.40%, respectively.

To determine the strength characteristics from cement-sand mortars prepared with the appropriate consistency (Table II), beams were made according to [10] (Section 2.2). Storage of samples in water and determination of ultimate strength in bending and compression for each specified period of their tests was carried out according to [10].

The bending strengths of Portland cement specimens with the addition of silicon dioxide nanoparticles are shown in Table III.

The data in Table III shows that the values of the ultimate strength in bending of Portland cements with additives PC-

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DSP-1, PC-DSP-2, PC-DSP-3 practically do not differ from the values of the bending strength of the control cement PC-D0 at all times of hardening (2, 7, 28 days).

TABLE III. Estimated material composition of cement-sand mortars.

№	Conventional designation of cements	Actual content of nanoparticles of SiO_2,% by weight of cement	Ultimate strength in bending, (kgf / cm²) aged		
			2d	**7d**	**28d**
1	PC-D0	-	6,58 (67,20)	7,89 (80,50)	8,58 (87,58)
2	PC-DSP-1	1,24	6,20 (63,17)	7,43 (75,82)	8,58 (87,58)
3	PC-DSP-2	2,57	6,20 (63,17)	7,43 (75,82)	8,58 (87,58)
4	PC-DSP-3	4,40	6,38 (65,18)	7,66 (78,16)	8,58 (87,58)

The compressive strengths of samples made of Portland cements with the addition of silicon oxide nanoparticles are shown in Table IV.

TABLE IV. Compressive strength of Portland cements with the nanoparticles of silicon dioxide addition.

Conventional designation of cement mortars		PC-D0	PC-DSP-1	PC-DSP-2	PC-DSP-3
Added,% of mass		-	1.24	2.57	4.40
Compressive strength, MPa (kgf/cm²), %	**2d**	26,46 (270) 100	30,38 (310) 114	24,50 (250) 92	24,50 (250) 92
	7d	43,71(446) 100	49,88 (509) 114	49,88 (509) 114	49,88 (509) 114
	28d	52,53 (536) 100	59,48(607) 113	59,48 (607) 113	59,09 (603) 112
Brandby ND		500	600	600	600

The ultimate compressive strength of Portland cement with silicon dioxide nanoparticles of 1.24% (PC-DSP-1) are (13-14)% higher than the values of the compressive strength of the control PC-D0 cement as in the initial hardening period (2,7 days) and at the age of 28 days.

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 grade 500. Ultimate strength from Portland cement samples PC-DSP-1, PC-DSP-2, PC-DSP-3 at the age of 7 days of hardening was 509 kgf/cm². 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 607 kgf/cm², which according to the requirements of [9] refers them to the guaranteed grade 600.

IV. Conclusion

Thus, on the basis of tests carried out it was established:

1. The positive effect on the strength characteristics of Portland cement with silicon dioxide nanoparticles as an 3, 6, 10 percent suspensions additives and the most stable properties are possessed by Portland cement PC-DSP-1, the samples of which were made using a 3% suspension.
2. The positive effect of silicon dioxide nanoparticles on the cement-sand mortar strength properties is explained by the physical structure of nanoparticles of silicon dioxide, as well as some of their chemical activity. Silica nanoparticles, are distributed between the cement grains and thereby provide a denser and stronger cement stone. In addition, finely dispersed particles of silicon dioxide can be the centers of crystallization of the products of hydration of cement minerals, which also leads to the acceleration of hydration and the formation of a strong structure of the cement stone.
3. Ultimate strength in compression at the age of 28 days of hardening, cement-sand mortars prepared using of silicon dioxide nanoparticles 3, 6, 10 percent suspensions per grade exceed the strength indicators of the control cement PC-D0, which comparative evaluation for compliance with the requirements [9]. It should also be noted that an increase in the content of silicon dioxide nanoparticles in cement slurries from 1.24 to 4.40% does not affect their strength characteristics. At the age of 7 and 28 days of hardening, all samples from these solutions have the same strength characteristics. The hardening of mortar mixtures based on Portland cement PC-DSP-2 and PC-DSP-3 with a silicon dioxide nanoparticles of 2.57% and 4.40% content is observed somewhat delayed in the initial period (up to 2 days). The most stable properties at all times of hardening are possessed by samples made using a 3% suspension of silicon dioxide nanoparticles.
4. Based on the above, we consider it expedient to carry out additional tests of the studied additive in concretes, using for their preparation 3, 6, 10% suspensions of silicon dioxide nanoparticles.

The efficiency of building materials production, reduce their cost and play an important role in obtaining materials with high strength, due to the effect of ultrasonic waves on the properties of the mixing water of cement slurries, the physicomechanical and operational characteristics of the resulting structure.

At the same time, in the planning and construction of nuclear power plants of a new generation in our country, use of a 3% suspension of nanoparticles of silicon dioxide based on activated water makes it possible to draw a conclusion about the effectiveness of the production of safe and durable structures.

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