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Cement-Based Materials Modified with Nanoscale Additives

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Abstract. The most common and reliable material without which modern construction is indispensable is concrete. The development of construction production is pushing for new solutions to improve the quality of concrete mix and concrete. The most demanded and significant indicators of a concrete mixture are the compressive strength and mobility of the concrete mixture. Every year, the volume of research on nanomaterials as modifying components of concrete is significantly increasing, and the results indicate the prospects for their use. Nanoparticles with a large specific surface are distinguished by chemical activity, can accelerate hydration and increase strength characteristics due to nucleation and subsequent formation of C–S–H and compaction of the material microstructure. Sol of nanosilica, which can be used instead of microsilica from industrial enterprises, and carbon nanomaterial have a wide reproduction base. This paper presents studies of these types of nanomaterials and the results of their application in cement concrete. Studies have shown that the effect is also observed with the introduction of an additive containing only one type of nanoparticles. The dependence of the obtained characteristics of cement concretes on the content of these nanomaterials has been established. It has been found that the best results were obtained with an additive in which the above-mentioned nanomaterials were used together. Compressive strength of heavy concrete samples, improved by the complex nanodispersed system, was 78.7 MPa, which exceeds the strength of the sample containing the CNT additive in a pair with a super-plasticizer by 37 %. The paper proposes the mechanism for action of the presented complex additive.

Keywords: water sol of nanosilica, carbon nanotubes, super-plasticizer, heavy concrete, strength

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Материалы на основе цемента, модифицированные наноразмерными добавками

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Реферат. Самым распространенным и надежным материалом, без которого не обходится современное строительство, является бетон. Развитие строительного производства подталкивает к новым решениям в улучшении качества бетонной смеси и бетона. Наиболее востребованные и значимые показатели бетонной смеси – прочность при сжатии и подвижность бетонной смеси. С каждым годом исследований наноматериалов в качестве модифицирующих компонентов бетона становится больше, а результаты указывают на перспективность их применения. Наночастицы, обладающие большой удельной поверхностью, отличаются химической активностью, могут ускорять гидратацию и повышать прочностные показатели за счет зародышеобразования и последующего формирования C–S–H, уплотнения микроструктуры материала. Широкую базу воспроизводства имеют золь нанокремнезема, который может быть использован взамен микрокремнезема с индустриальных предприятий, и углеродный наноматериал. В статье представлены исследования данных видов наноматериалов и результаты их применения в цементных бетонах. Исследования показали, что эффект наблюдается также при введении добавки, содержащей только один вид наночастиц. Установлена зависимость получаемых характеристик цементных бетонов от количества данных наноматериалов. Выявлено, что наилучшие результаты были получены с добавкой, в которой совместно использовались вышеперечисленные наноматериалы. Прочность на сжатие образцов тяжелого бетона, улучшенная комплексной

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нанодисперсной системой, составила 78,7 МПа, что превышает прочность образца, содержащего добавку углеродных нанотрубок в паре с суперпластификатором, на 37 %. Изучен механизм действия представленной комплексной добавки.

Ключевые слова: водный золь нанокремнезема, углеродные нанотрубки, суперпластификатор, тяжелый бетон, прочность

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Introduction

Currently, nanoscale materials have found their application in industry, as modifying components. Having very large values of the specific surface, nanosized particles are capable of affecting the physicomechanical characteristics of the new material. Depending on the type of raw material and the production method, the characteristics of the obtained nanomaterials vary widely [1–8]. All this affects the results obtained when using the same concrete mix formulations.

An analysis of the literature shows nanomaterials, such as carbon nanotubes and silica fume, were initially used only as a means to increase the strength characteristics of modified concrete. A little later it became known that the use of these nanomaterials together with plasticizing additives provide an effective reduction in water and an increase in the durability (frost resistance) of the created concrete [9–25]. However, questions regarding the compaction of the structure and the filling of voids between cement particles and even larger sand particles remain open at the moment. The working hypothesis of the study is that a complex nanodispersed system consisting of nanosilica, multilayer carbon nanotubes (MCNT) and a superplasticizer (SP) will allow to obtain a synergistic effect, i. e. summation of the positive properties and qualities of each of the components.

Materials and methods of experimental studies

The following materials were used in the work as nanomaterials: water sol of nanosilica SiO_2, obtained from hydrothermal fluids, with characteristics of a pH = 9.2, density $\rho = 1075$ g/dm^3, solids content of nanosilica SiO_2 = 120 g/dm^3, total salinity equal to 1720 mg/dm^3 [26–28] and carbon nanotubes obtained in a plasma of a high-voltage atmospheric pressure discharge with the optimal composition of the CH_4 gas mixture: air = = 1:(2.4–2.5), followed by chemical treatment with a mass fraction of solids of not less than 37 %, pH = 7.0, $\rho = 1.1$ g/cm^3 [29–36]. Superplasticizer from a series of polycarboxylates highly effective in water-reducing ability in the form of an aqueous solution.

Portland cement CEM I 42.5N was used as a binder as a fine aggregate, quarry sand with a fineness modulus $M_f = 3.8$ with a true density ρ = = 2572 kg/m^3 and bulk density ρ = 1540 kg/m^3 was used. As a coarse aggregate, the fraction is 5–20 mm thick, bulk density ρ = 1460 kg/m^3.

The particle size distribution of water sols of nanosilica was determined using the Analysette 22 laser diffraction device, which is built on the principle of "Inverse Fourier Optics" or a converging laser beam (Fig. 1). Reverse Fourier Optics also allow extremely high resolution measurements. By automatically moving the measuring cell supported by the computer in a converging beam in the NanoTec model, it is possible to create a supermatrix with a max 520 measuring channels for calculating. In this case, the measurement range is from 0.01 to 1000 μm.

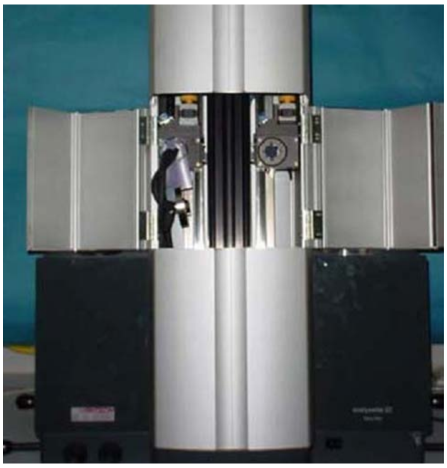

Fig. 1. Laser analyzer Analysette 22 NanoTec

The results of determining the particle size of nanosilica were given the following results: the size of the solid particles of nanosilica contained in aqueous ash is less than 10 nm, which is explained by the resolution of the device (from 10 nm to 1000 μm).

The concentration and solids content of nanosilica SiO_2 in the sol was determined by evaporation of the initial water sol with a mass of $m_{initial}$ = = 100 cm^3 in an oven at a temperature of $t = 150$ °C.

Weight reduction according to studies:

1 day – m_1 = 233 ml/g;

2 days – m_2 = 166 ml/g;

3 days – m_3 = 146 ml/g;
4 days – m_4 = 145 ml/g;
8 days – m_8 = 145 ml/g.

This indicates that the SiO_2 = 120 g/dm^3 approximating value for the indicated solid particle content is solid; the mass from the 4th day remained unchanged due to the room humidity. Upon evaporation, the sol particles stuck together.

The results of measuring the particle size distribution of the dispersed composition of carbon nanomaterial are presented in Fig. 2.

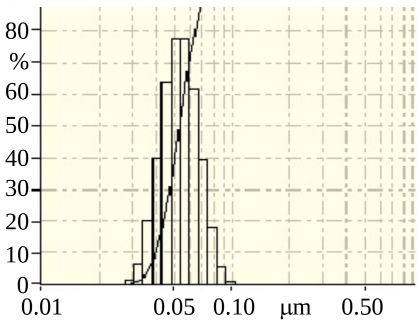

Fig. 2. The size distribution of nanostructured carbon particles

In order to study the effect of nanomaterials on the basic properties of cement concrete, an additive was made and a series of laboratory studies was carried out. The amount of added additive in all studied compositions was 0.8 % by weight of cement.

To determine the effect of an aqueous sol of SiO_2 (NS) silica on the strength characteristics of concrete, it was preliminarily mixed with mixing water, uniformly distributed throughout the volume, after which water was introduced into the concrete mixture. The mixture filled the cube-shaped nests (100×100 mm), which was mounted on a vibrating table and compacted. After manufacture, the samples were unformed and stored in bathtubs with water until they reached a certain age. Testing the samples for compressive strength was carried out on the 1st, 7th, 14th and 28th days.

The data obtained showed that when the sol content of nanosilica SiO_2 in the amount of 0.1 wt. % in cement (NS 0.47) the increment in compressive strength compared to the control (Control) was +30 % on the first day, +20 % on the 28th (Fig. 3).

It was found that an increase in the concentration of this nanosupplement NS 4.7 leads to a decrease in strength by 1.2 times, which indicates the advisability of using SP in this system.

A method of preparing a plasticizing additive used hereinafter consists in dispersing a superplasticizer and nanomaterial (nanosilica or nanocarbon) in a mixer for several minutes. After that, concrete samples were manufactured and tested according to the above methodology.

Tests of a plasticizing additive, including a nanosilica sol paired with a superplasticizer, were carried out at W/C values from 0.2 to 0.3 (Fig. 4).

An additive containing a nanosilica sol with a concentration of solid SiO_2 equal to 0.47 g/kg, introduced into the superplasticizer in amounts of 8, 4, and 1 g/t when determining the compressive strength, showed the best result of 73.7 MPa when solid SiO_2 4 g was added per 1 t of superplasticizer.

At the same time, the introduction of NS increased the strength of concrete to 30 % compared to concrete containing only SP and to 40 % compared to the control sample.

The effect of a complex additive containing MCNT (MLCNT), NS and SP on the strength characteristics of concrete are presented in Fig. 5.

The compressive strength of samples of heavy concrete, improved by an integrated nanodisperse system, was 78.7 MPa, which exceeds the strength of a sample containing an MLCNT additive paired with superplasticizer by 27 %.

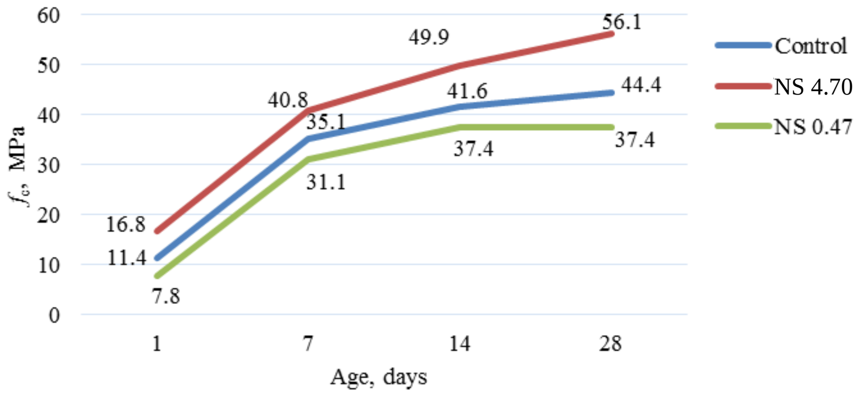

Fig. 3. The effect of nanosilica sol on the strength characteristics of heavy concrete

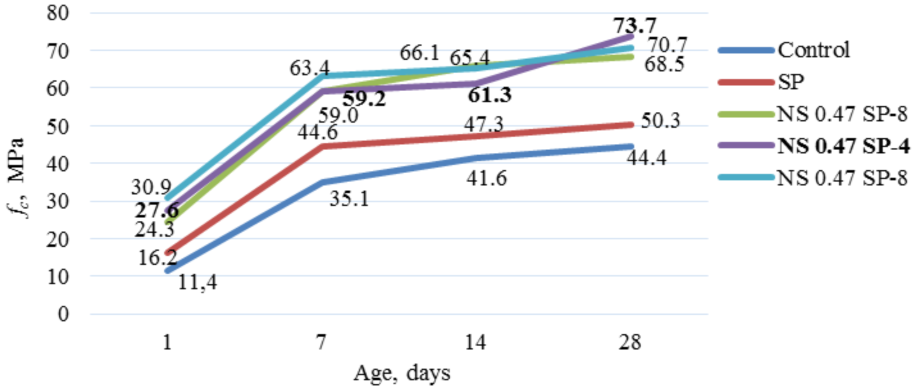

Fig. 4. The effect of nanosilica sol in combination with superplasticizer on the strength characteristics of heavy concrete

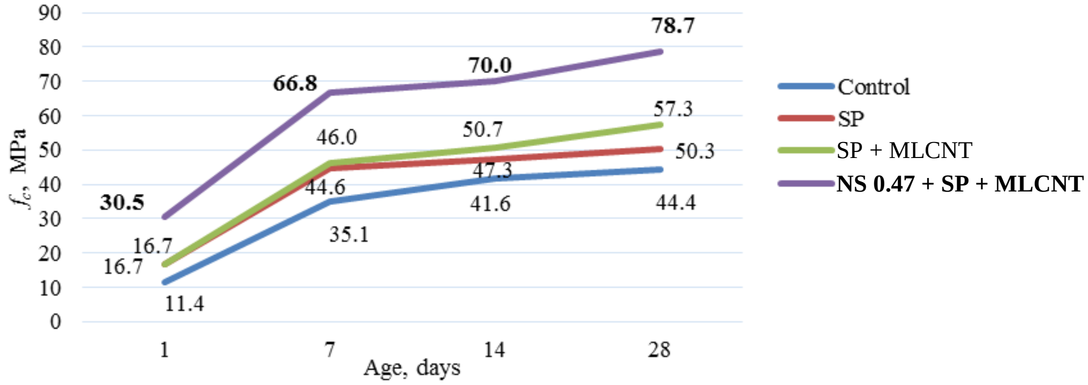

Fig. 5. The effect of complex additives on the strength characteristics of heavy concrete

It can be assumed that the mechanism of action of the presented complex additive is as follows: the introduction of a nanocarbon material into the cement system leads to the packing density of the particles of the system, and when an even smaller nanosilica is introduced, additional crystallization centers of hydrated neoplasms are created. Therefore, nanosilica acts as a nanofiller of this system, which more actively affects the concentration of Ca^{2+} and OH^{-} and reduces the number of pores.

CONCLUSION

Based on the analysis of the test results, it can be concluded that a complex nanodispersed system, including multilayer carbon nanotubes, nanosilica and superplasticizer, helps to bring together particles, densify the structure and form intergrowth contacts, which effectively affects the structure of heavy concrete. Thus, this effect is achieved by directed structural modification of the main components of the cement stone – calcium hydrosilicates relative to the composition and morphology of neoplasms.

List of accepted symbols and abbreviations

f_c – compressive strength of concrete, MPa;
$m_{1...8}$ – weight reduction, ml/g;
pH – pH value;
M_f – size module;
ρ – density, kg/m^3;
indexes:
c – compression;
f – large-ness.

REFERENCES

1. Shabanova N. A., Sarkisov P. D. (2012) *Sol-Gel Technologies. Nanodispersed Silica*. Moscow, BINOM Publ. 328 (in Russian).
2. Kondratenko V. S., Kobysh A. N., Petrulyanis N. E., Sorokin A. V., Filimonova E. V. (2006) The Adsorption Properties of SiO_2 Micropowders Obtained by the Sol-Gel Method. *Mezhdunarodnaya Nauchno-Tekhnicheskaya Kon-*

ferentsiya "Informatsionnye Tekhnologii v Nauke, Tekhnike i Obrazovanii" [International Scientific and Technical Conference "Information Technologies in Science, Technology and Education"]. Egypt, 46–48 (in Russian).

3. Shena Y., Zhaoa P., Shao Q. (2014) Porous Silica and Carbon Derived Materials from Rice Husk Pyrolysis Char. *Microporous and Mesoporous Materials,* 188, 46–76. https://doi.org/10.1016/j.micromeso.2014.01.005.
4. Kuskov N. I., Boguslavskii L. Z., Smal'ko A. A., Zubenko A. A. (2007) Obtaining Nanocarbon by the Method of Electric Discharge Treatment of Organic Liquids. *Elektronnaya Obrabotka Materialov = Electronic Processing of Materials,* (4), 46–52 (in Russian).
5. Sergienko I. G., Znosko K. F., Tarkovsky V. V. (2017) Obtaining Nanosized Particles by the Method of Electric-Discharge Destruction of Materials in Liquid and Study of their Properties. *Vesnik Hrodzenskaha Dziarzhaunaha Universiteta imia Ianki Kupaly. Seryia 6. Tekhnika = Vesnik of Yanka Kupala State University of Grodno. Series 6. Engineering Science*, 7 (1), 56–65 (in Russian).
6. Kolosov A. D., Nemarov A. A., Nebogin S. A. (2017) Technology of Obtaining and Using Nanosilica in the Production of New Materials for Mechanical Engineering. *Sovremennye Tekhnologii. Sistemnyi Analiz. Modelirovanie = Modern Technologies. System Analysis. Modeling,* (3), 59–66 (in Russian).
7. Bazhenov Yu. M., Falikman V. R., Bulgakov B. I. (2012) Nanomaterials and Nanotechnologies in Modern Concrete Technology. *Vestnik MGSU = Monthly Journal on Construction and Architecture,* (12), 125–133 (in Russian).
8. Khroustalev B. M., Leonovich S. N., Yakimovich B. A., Yakovlev G. I., Pervushin G. N., Polyanskikh I. S., Pudov I. A., Khazeev D. R., Shaybadullina A. V., Gordina A. F., Ali El Sayed Mohamed, Keriene Ja. (2014) Dispersion of Multi-Walled Carbon Nanotubes in Building Science of Materials. *Nauka i Tekhnika = Science & Technique*, (1), 44–52 (in Russian).
9. Singh L. P., Zhu W., Howind T., Sharma U. (2017) Quantification and Characterization of C–S–H in Silica Nanoparticles Incorporated Cementitious System. *Cement & Concrete Composites,* 79, 106–116. https://doi.org/10.1016/j.cemconcomp.2017.02.004.
10. Constantinides G., Ulm F. J. (2007) The Nanogranular Nature of C–S–H. *Journal of the Mechanics and Physics of Solids,* 55 (1), 64–90. https://doi.org/10.1016/j.jmps.2006.06.003.
11. Gorkaya D. O., Chulkova I. L. (2018) Modification of the Properties of Cement Stone with an Aqueous Suspension of Technical Carbon. *Fundamental'nye i Prikladnye Issledovaniya Molodykh Uchenykh: Sbornik Nauchnykh Trudov II Mezhdunarodnoi Nauchno-Prakticheskoi Konferentsii Studentov, Aspirantov i Molodykh Uchenykh* [Fundamental and Applied Research of Young Scientists. Collection of Scientific Papers of the II International Scientific and Practical Conference of Students, Postgraduates and Young Scientists]. Omsk, Siberian State Automobile and Highway University, 423–426 (in Russian).
12. Rassokhin A. S., Ponomarev A. N., Figovsky O. L. (2018) Silica Fumes of Different Types for High-Performance Fine-Grained Concrete. *Magazine of Civil Engineering,* (2), 151–160.
13. Derevyanko V. M., Grishko G. M., Frost V. Yu. (2018) The Influence of Nanoadditives on the Hydration of Gypsum Binders. *Zbirnik Naukovikh Prats' Ukraïns'kogo Derzhavnogo Universitetu Zaliznichnogo Transportu = Collected Scientific Works of Ukrainian State University of Railway Transport,* (178), 88–97 (in Russian).
14. Nizina T. A., Ponomarev A. N., Balykov A. S., Pankin N. A. (2017) Fine-Grained Fiber Concretes Modified by Complexed Nanoadditives. *International Journal of Nanotechnology,* 14 (7–8), 665–679. https://doi.org/10.1504/ijnt.2017.083441.
15. Burmistrov I. N., Il'inykh I. A., Mazov I. N., Kuznetsov D. V., Yudintseva T. I., Kuskov K. V. (2013) Physical and Mechanical Properties of Composite Concrete Modified with Carbon Nanotubes. *Sovremennye Problemy Nauki i Obrazovaniya = Modern Problems of Science and Education,* (5), 80–87 (in Russian).
16. Sheida O. Yu., Batyanovsky E. I. (2015) Production Testing of a New Chemical Additive Containing Carbon Nanomaterial. *Sovremennye Problemy Vnedreniya Evropeiskikh Standartov v Oblasti Stroitel'stva: Sbornik Mezhdunarodnykh Nauchno-Tekhnicheskikh Statei (Materialy Nauchno-Metodicheskoi Konferentsii), 27–28 Maya 2014 g. Ch. 2* [Modern Problems of the Implementation of European Standards in the Field of Construction: Materials Scientist. Conf., May 27–28, 2014. Part 2]. Minsk, BNTU, 7–19 (in Russian).
17. Pukharenko Yu. V., Aubakirova I. U., Nikitin V. A., Letenko D. G., Staroverov V. D. (2010) Mixed Nanocarbon Material in Cement Composites. *Stroitel'nye Materialy, Oborudovanie, Tekhnologii XXI Veka* [Building Materials, Equipment, Technologies of the XXI Century], (10), 16–17 (in Russian).
18. Khroustalev B. M., Leonovich S. N., Yakovlev G. I., Polianskich I. S., Lahayne O., Eberhardsteiner J., Skripkiunas G., Pudov I. A., Karpova E. A. (2017) Structural Modification of New Formations in Cement Matrix Using Carbon Nanotube Dispersions and Nanosilica. *Nauka i Tekhnika = Science and Technique,* 16 (2), 93–103. https://doi.org/10.21122/2227-1031-2017-16-2-93-103 (in Russian).
19. Yakovlev G. I., Pervushin G. N., Pudov I. A., Eberkhardshtainer Dzh., Lakhain O., Al'rfai A., Leonovich S. N. (2014) Influence of Multilayer Carbon Nanotubes on the Elastic Modulus and Microhardness of the Cement Matrix. *Sovremennye Problemy Stroitel'stva i Zhizneobespecheniya: Bezopasnost', Kachestvo, Energo- i Resursosberezhenie: Sbornik Materialov III Vserossiiskoi Nauchno-Prakticheskoi Konferentsii, Yakutsk, 3–4 Marta 2014 g.* [Modern Problems of Construction and Life Support: Safety, Quality, Energy and Resource Conservation. Proceedings of the III All-Russian Scientific-Practical. Conf., 3–4 March, 2014], Yakutsk, 387–393 (in Russian).
20. Fakhratov, M. A. Girshtel M. A., Evdokimov V. O., Borodin A. S. (2018) Prospects for the Use of Nanostructured Concrete in Construction. *Don's Engineering Gazette,* 3 (50), 124–132. Available at: https://cyberleninka.ru/article/n/perspektivy-primeneniya-nanostrukturirovannogo-betona-v-stroitelstve (Accessed 12.02.2020).
21. Lkhasaranov S. A., Urkhanova L. A., Buyantuev S. L., Kondratenko A. S., Danzanov A. B., Pshenichniko-

va L. I. (2012) Increased Strength Concretes Based on Composite Binders. *Stroitel'nyi Kompleks Rossii. Nauka. Obrazovanie. Praktika: Mat. Mezhdunar. Nauch.-Prakt. Konf.* [Building Complex of Russia. The Science. Education. Practice: Mat. International Scientific-Practical. Conf.]. Ulan-Ude, East Siberian State University of Technology and Management, 225–228 (in Russian).

22. Urkhanova L. A., Hardaev P. K., Lhasaranov S. A. (2015) Modification of Cement Concretes with Nanodispersed Additives. *Stroitel'stvo i Rekonstruktsiya = Building and Reconstruction,* (3), 167–175 (in Russian).
23. Khroustalev B. M., Yaglov V. V., Kovalev Ya. N., Romaniuk V. N., Burak G. A., Mezhentsev A. A., Gurinenko N. S. (2015) Nanomodified Concrete. *Nauka i Tekhnika = Science & Technique,* (6), 3–8 (in Russian).
24. Urkhanova L. A., Khardaev P. K., Lhasaranov S. A. (2015) Modification of Cement Concretes with Nanodispersed Additives. *Stroitel'stvo i Rekonstruktsiya = Building and Reconstruction,* (3), 167–175 (in Russian).
25. Sanchez F., Sobolev K. (2013) Nanotechnology in Concrete Production. Overview. *Vestnik Tomskogo Gosudarstvennogo Arkhitekturno-Stroitel'nogo Universiteta = Journal of Construction and Architecture,* (3), 262–289 (in Russian).
26. Gorev D. S., Potapov V. V., Goreva T. S. (2014) Obtaining a Sol of Silicon Dioxide by Membrane Concentration of Aqueous Solutions. *Fundamental'nye Issledovaniya = Fundamental Research,* (11), 1233–1239 (in Russian).
27. Potapov V. V., Efmenko Y. V., Gorev D. S. (2019) Determination of the Amount of $Ca(OH)_2$ Bound by Additive Nano-SiO_2 in Cement Matrices. *Nanotehnologii v Stroitel'stve = Nanotechnologies in Construction,* 11 (4), 308–325 (in Russian).
28. Potapov V. V., Gorev D. S. (2018) Physico-Chemical Characteristics of Nanosilica (Sol, Nanopowder-Shock) and Microsilica. *Fundamental'nye Issledovaniya = Fundamental Research,* (6), 23–29 (in Russian).
29. Zhdanok S. A., Krauklis A. V., Samtsov P. P., Volzhankin V. M. (2006) *Installation for the Production of Carbon Nanomaterials.* Patent RB No 2839 (in Russian).
30. Zhdanok S. A., Khrustalev B. M., Batyanovsky E. I., Leonovich S. N. (2009) Nanotechnology in Building Materials Science: Reality and Perspectives. *Vestnik BNTU* [*Bulletin of the Belarusian National Technical University*], (3), 5–22 (in Russian).
31. Eberhardsteiner J., Zhdanok S., Khrustalev B., Batyanovskii E. I., Leonovich S., Samtsov P. (2012) Investigation of the Effect of Nanosized Additives on the Mechanical Behavior of Cement Blocks. *Nauka i Tekhnika = Science & Technique,* (1), 52–55 (in Russian).
32. Zhdanok S. A., Solntsev A. P., Krauklis A. V. (2005) *A Method for Producing Carbon Nanomaterials.* Patent RB No 10010 (in Russian).
33. Eberhardsteiner J., Zhdanok S., Khroustalev B., Batsianouski E., Leonovich S., Samtsou P. (2011) Characterization of the Influence of Carbon Nanomaterials on the Mechanical Behavior of Cement Stone. *Journal of Engineering Physics and Thermophysics,* 84 (4), 697–704. https://doi.org/10.1007/s10891-011-0531-7.
34. Zhdanok S. A., Potapov V. V., Polonina E. N., Leonovich S. N. (2020) Modification of Cement Concrete with Additives Containing Nano-Sized Materials. *Journal of Engineering Physics and Thermophysics*, 93 (3), 669–673. https://doi.org/10.1007/s10891-020-02163-y.
35. Zhdanok S. A., Polonina E. N., Leonovich S. N., Khroustalev B. M., Koleda E. A. (2019) Physicomechanical Characteristics of Concrete Modified by a Anostructured-Carbon-Based Plasticizing Admixture. *Journal of Engineering Physics and Thermophysics,* 92 (1), 12–18. https://doi.org/10.1007/s10891-019-01902-0.
36. Zhdanok S. A., Polonina E. N., Leonovich S. N., Khroustalev B. M., Koleda E. A. (2019) Influence of the Nanostructured-Carbon-Based Plasticizing Admixture in a Self-compacting Concrete Mix on its Technological Properties. *Journal of Engineering Physics and Thermophysics,* 92 (2), 376–382. https://doi.org/10.1007/s10891-019-01941-7.

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