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STUDY OF CORROSION RESISTANCE OF NANOMODIFIED CONCRETE IN BIOLOGICALLY AGGRESSIVE ENVIRONMENTS

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ABSTRACT

The impact carried out at the atomic-molecular level in the development of nanocomposites is a relevant area of modern research in construction materials science. One of the key methods for creating nanocomposites is their modification using various additives and specialized technological processes. This article presents the results of testing concrete modified with nanoparticles in the context of studying their biological corrosion, which is one of the factors affecting the durability of concrete and reinforced concrete structures. As part of the experimental study, microbiological diagnostics was carried out, as a result of which the composition of biofilms was determined. The results of strength tests demonstrated a significant effect of biocorrosion on the strength characteristics of nanomodified cement concrete. Graphs displaying changes in the concentrations of Ca2+ cations in the liquid phase showed their increased values compared to conventional uninfected concrete, which is associated with the products of microorganisms. Measurements of the pH level of concrete samples showed that the influence of a biologically aggressive environment leads to an increase in the pH level.

Keywords: cement concrete, corrosion, nanomodification, strength, biostability.

INTRODUCTION

Nowadays, one of the most dynamically developing fields of knowledge is nanoscience, which is a body of knowledge about the properties of materials at the nanometer level. It can be noted that the terms "nanoparticles" and "nanotechnology" are becoming increasingly popular, encountered not only in the scientific community, but also in everyday life. For a construction specialist with basic knowledge of chemical technology, mastering the methods of creating materials using nanotechnology does not present significant difficulties (Fedosov et al., 2019a, 2019b, 2019c; Gusev, 2009; Kashnikov et al., 2014; Loginova, 2020a; Roumyantseva et al., 2019). There are several approaches to obtaining nanostructured materials. One of them is the targeted implementation of a certain technological process, involving components with predetermined characteristics to form a system both at the nanoscale and in the required ratio by volume and mass. Achievements in the fields of physical chemistry, colloid chemistry, as well as insight into the features of highly dispersed systems and membranes, surfactant effects, mechanochemical activation of solid particles and water open up opportunities to create material properties that previously seemed difficult to achieve.

The production processes of various building materials, such as concrete, ceramics and asbestos concrete, are closely related to the phenomena of coagulation-crystallization structure formation. The formation of micro- and macrostructures, as well as the methods of their regulation in systems where the dispersed phase is represented by a liquid medium, are quite complex. This is explained by the presence of phase transitions, which has a significant effect on both the dispersion and the shape of the dispersed phase. In the modern production of concrete, solutions and pastes based on mineral binders, many use additives, including surface-active substances (Fedosov et al., 2019a, 2019b). These additives significantly affect predetermined and sometimes unexpected properties. Their action is carried out through chemical reactions on the surfaces of solid, liquid and gaseous phases. Adsorption layers of modifiers on solid particles perform various functions, including suppression of crystal growth, change in their shape and habit, regulation of surface tension and the degree of wettability of dispersed particles. All these processes occur on the nanoscale.

In recent years, there has been growing interest in protecting building materials from biological degradation (Roumyantseva et al., 2019). Most often, biological corrosion of cement stone is associated with a chemical reaction occurring under the influence of microorganisms, which ultimately leads to its decomposition and damage (Fedosov et al., 2019a; Kabylbekova et al., 2024; Roumyantseva et al., 2019). However, a more in-depth study of this process is important for assessing the strength of cement stone, as this will allow us to assess its durability under the active influence of microorganisms (Fedosov et al., 2019a, 2019b, 2019c; Roumyantseva et al., 2019).

The process of biological degradation of concrete includes chemical reactions caused by the metabolic products of microorganisms (bacteria and fungi) with one of the key components present in hardened concrete - free calcium hydroxide (Kashnikov et al., 2014; Yerbayev et al., 2023). These reactions contribute to increased diffusion of the target component from the pores of concrete, which ultimately leads to its neutralization (Gusev, 2009; Kashnikov et al., 2014). Thus, biological corrosion of cement concrete can be explained through heat and mass transfer mechanisms (Fedosov et al., 2019b, 2019c; Gusev, 2009; Kashnikov et al., 2014; Loginova, 2020a, 2020b; Roumyantseva et al., 2019).

The aim of the research is to identify patterns of influence of microbiota on changes in the strength characteristics of nanomodified cement concrete, concentration of the target component and changes in its pH. The aim of the research is to explain the obtained results on the reliability and durability of cement concrete based on the analysis of theoretical and experimental data, as well as to substantiate the degree of influence of biocorrosion on the technical condition of building structures during inspection of buildings and structures.

MATERIAL AND METHODS

Methods

The following equipment was used in the production of concrete samples and weighing of additive components: electric manual vibrator Zitrek Z-35-1.5, electronic scales Mucheng 0.1-500 (weighing accuracy 0.1÷500g).

An electron microscope was used to study the microstructure of the surface of cement samples Meiji Techno (Japan). When studying the concentration of calcium hydroxide in pore solutions of samples, the method of complexometric titration was used. For sample solutions also using a portable certified pH meter Testo 206 PH1 the values of pH were measured to determine their corrosion resistance.

For testing control samples in the experimental part the following devices and equipment were used: a test press Matest C055N, a digital SLR camera with the ability to quickly shoot the Canon 1200D brand.

As a destructive control, the method of testing the strength of concrete according to control samples was used, in accordance with GOST 10180-2012 "Concrete. Methods for determining strength from control samples". The essence of the method is the destruction of a concrete sample on a test press, which will provide data on the actual breaking load for concrete, which determines the concrete's compressive strength class (Fedosov et al., 2018, 2020a, 2020b; Meza et al., 2017; Serebryakov et al., 2019).

For destructive testing, samples-cubes of 3×3×3 cm in size were made from cement dough of normal density (V/C=0.3) prepared by mixing portland cement M500D0 with distilled water. The concrete mix was compacted during mixing using a manual electric vibrator. After initial hardening, the samples were placed in a wet hardening chamber at atmospheric pressure (humidity 99÷100%). After a certain period of hardening, the compressive strength of the samples was determined by breaking on a certified press.

For corrosion tests samples-cubes of 3×3×3 cm in size made of portland cement of the M500D0 with a water-cement ratio V/C = 0.3. The system under study was made up of tightly fitted 1x3x3 cm plates (Figure 1).

The method of testing the corrosion resistance of concrete in aggressive environments corresponds to GOST 27677-88 "Corrosion protection in construction. Concretes. General requirements for testing" (Supplement 1).

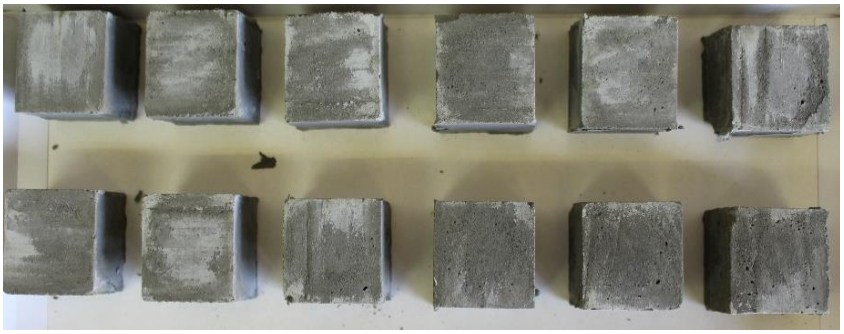

Figure 1. General view of test samples made of nanomodified concrete.

All obtained results of strength characteristics and pH values of solutions were averaged and entered in tables.

RESULTS

Data on determining the compressive strength of concrete by destructive testing are included in Table 1.

Table 1. Results of strength tests by destructive testing of samples after exposure to various aggressive environment.

No. of sample	Sample type	Test method	Average compressive strength of cement stone during the hardening period of 28 days, MPa	Average compressive strength during 90 days in an aggressive environment, MPa
1	Samples not exposed (K-1)	Destructive testing according to GOST 10180-2012.	42,02	36,17
2	Samples after exposure to water (K-2)	Destructive testing according to GOST 10180-2012.	42,5	33,74
3	Samples subject to biocorrosion (K-3)	Destructive testing according to GOST 10180-2012.	41,94	21,96

Based on the results of data analysis in Table 1, a general graph of changes in the strength characteristics of concrete samples with a hardening period of 28 days as a result of their being in an aggressive environment for a period of 90 days is constructed.

Data on the dynamics of changes pH various of concrete samples are shown in Table 2.

Table 2. Change in the pH of the solution test samples.

pH	τ, days							
	0	14	28	42	56	70	84	98
	samples is not exposed to microorganisms							
K-1, K-2	6,60	7,40	7,63	7,70	7,75	7,80	7,95	7,98
	samples exposed bio							
K-3	6,59	7,55	7,68	7,78	7,98	8,68	8,76	8,81

A comprehensive examination of nanomodified cement stone specimens using electron microscopy, after a 90-day exposure to biological influences in an aquatic setting, demonstrated a 2 to 2.5-fold increase in pore diameter compared to the control samples. Furthermore, new formations indicative of biological corrosion processes, likely resulting from the enzymatic activities of microbiota, were observed on the surface of the biologically treated samples. Notably, by the 28th day of immersion, a light-colored microbial film began to develop on the samples.

The findings from strength testing revealed a significant link between biological corrosion and alterations in the physical and mechanical properties of the cement materials. Specifically, the average compressive strength of cement stone samples undergoing biocorrosion was roughly 30% lower than that of samples submerged solely in water.

This decline in mechanical strength closely correlates with the enzymatic action of bio-destructors, which facilitates chemical interactions leading to the neutralization of the cement's structural components. Hence, evaluating physical and mechanical properties serves as a crucial metric for assessing the fungus resistance of the cement stone. Additionally, observations of pH shifts in cement stone solutions indicated a consistent increase in medium alkalinity over time, significantly impacting microbial growth and enzymatic activity. Longitudinal measurements of calcium hydroxide concentrations through complexometric titration revealed that equilibrium for calcium cations was reached after 70 days of exposure to the aggressive environment. Moreover, the bioexposed samples exhibited elevated Ca2+ levels relative to those in water-only conditions, influenced by microbial secretions reliant on nutrient medium components. Enhanced bacterial fermentation activities were noted in the presence of Ca2+ ions, with active transport occurring during bacterial sporulation. The variations in calcium hydroxide concentrations over time provide valuable insights into mass transfer kinetics and contribute to the foundation for future mathematical modeling of corrosion processes (Bazhenov et al., 2012; Chernyshov, 2009; Erofeev et al., 2016a, 2016b; Ponomarev, 2007; Roumyantseva et al., 2020; Uaissova and Zharlykassov, 2024).

CONCLUSIONS

Analyzing the results of the experiments, we can draw the following logical conclusions:

- A strategy is proposed for creating a new generation of biocorrosion inhibitors that exhibit unrivaled efficiency at the nanolevel;
- the relevance of increasing the biostability of materials using special nanomodifiers is shown;
- The biological corrosion process results in an enlargement of the diameter and width of the pores in cement stone, increasing approximately 2 to 2.5 times compared to its original state;
- In aquatic environments, biological corrosion leads to a rise in the concentration of calcium cations (Ca^{2+}) in the solution, attributed to the neutralization of byproducts produced by microorganisms, particularly organic acids;
- The mass transfer that occurs during the biological corrosion of cement stone results in a reduction of its strength by 30% relative to the effects of the aqueous environment when compared to the initial strength of samples that have cured for 28 days;
- Assessing the strength properties of cement stone can also indicate its resistance to fungal attack, a claim supported by experimental findings;
- Variations in the pH of the solution significantly influence microbial growth, altering their activity levels and enzyme production;
- Biocorrosion leads to an increase in the pH of the cement stone's pore solution, promoting alkalinization of the environment, which facilitates the neutralization of the produced organic acids;
- It was shown that nanomodification contributed to the increase in biostability of composites based on organic and inorganic binders, due to effective interaction with the additive components at the nanolevel.

REFERENCES

1. Bazhenov YuM, Falikman VR, Bulgakov BI, (2012). Nanomaterials and nanotechnologies in the present-day concrete technology, Vestnik MGSU 12, 125-133;
2. Chernyshov EM, (2009). The nano-technology studies of construction composites: General considerations, main directions and results, Scientific Online Journal "Nanotechnologies in Construction" 1(1), 45-59;
3. Erofeev VT, Kalashnikov V, Emelyanov D, Balathanova E, Erofeeva I, Smirnova O, Tretiakov I, Matvievskiy A, (2016a). Biological resistance of cement composites filled with limestone powders, Solid State Phenomena 871, 22-27. https://doi.org/10.4028/www.scientific.net/MSF.871.22;
4. Erofeev VT, Rodin A, Rodina N, Kalashnikov V, Erofeeva I, (2016b). Biocidal binders for the concretes of unerground constructions, Procedia Engineering 165, 448-1454. https://doi.org/10.1016/j.proeng.2016.11.878;
5. Fedosov SV, Roumyantseva VE, Konovalova VS, Goglev IN, (2020a). The influence of structure formation conditions of the composite on the mass transfer processes, IOP Conference Series: Materials Science and Engineering 753, 042047. https://doi.org/10.1088/1757-899X/753/4/042047;
6. Fedosov SV Roumyantseva VE, Konovalova VS, Goglev IN, (2020b). Mass transfer phenomena in the system "Cement mortar-fiberglass reinforcement" at the stage of composite structure formation. Part 1. Physical representations and mathematical formulation of the problem, Academia. Architecture and Construction 1, 118-123;
7. Fedosov SV, Roumyantseva VE, Konovalova VS, Goglev IN, Narmaniya BE, (2019a). Control of corrosion destruction processes of building materials on the basis of mass transfer laws, Bulletin of Civil Engineers 3(74), 106-111. https://doi.org/10.23968/1999-5571-2019-16-3-106-111;
8. Fedosov SV, Roumyantseva VE, Konovalova VS, Loginova SA, (2018). Mathematical modelling of diffusion processes of mass transfer of "free calcium hydroxide" during corrosion of cement concretes, International Journal for Computational Civil and Structural Engineering 14(3), 161-168. https://doi.org/10.22337/2587-9618-2018-14-3-161-168;
9. Fedosov SV, Roumyantseva VE, Krasilnikov IV, Konovalova VS, (2019b). Physical and mathematical modelling of the mass transfer process in heterogeneous systems under corrosion destruction of reinforced concrete structures, IOP Conference Series: Materials Science and Engineering 456, 012039. https://doi.org/10.1088/1757-899X/456/1/012039;
10. Fedosov SV, Roumyantseva VE, Loginova SA, Narmaniya BE, (2019c). Osobennosti matematicheskogo modelirovaniya pri bakterial'noy korrozii tsementnogo kamnya [Features of mathematical modeling for bacterial corrosion of cement stone]. In: Aktual'nyye Voprosy Arkhitektury i Stroitel'stva [Current Issues of Architecture and Construction]: Proceedings of the Eighteenth International Scientific and Technical Conference: in 2 Parts (Ed. by A.D. Bogatov, V.D. Cherkasov, V.P. Selyaev, V.D. Antoshkin, A.S. Boriskin, A.V. Razumov and A.M. Astashov), pp. 348-353. National Research Mordovian State University named after N.P. Ogarev, Saransk;
11. Gusev BV, (2009). The problems of nanomaterials creation and nanotechnologies development in construction industry, Scientific Online Journal "Nanotechnologies in Construction" 1(2), 5-9;
12. Kabylbekova B, Vysotskaya N, Anarbayev A, Spabekova R, Kurbanbekov K, Khussanov Z, Kaldybekova G, (2024). Role of heat carrier components in the formation of corrosion and scale deposits in the pipes of heat supply systems, Mathematical Modelling of Engineering Problems 11(10), 2731-2739. https://doi.org/10.18280/mmep.111015;
13. Kashnikov VI, Erofeev VT, Moroz MN, Troyanov IYu, Volodin VM, Suzdaltsev OV, (2014). Nanohydrosilicate technologies in concrete production, Construction Materials 5, 88-91 ;
14. Loginova SA, (2020a). Influence of microorganisms on the phase composition of cement stone. In: Inzhenernyye i Sotsial'nyye Sistemy [Engineering and Social Systems]: Collection of Scientific Papers of the Institute of Architecture, Construction and Transport of IVSPU (Ed. by M.V. Tanichev), pp. 8-11. Ivanovo State Polytechnical University, Ivanovo;
15. Loginova SA, (2020b). Test of a cement stone for the ability to serve a power supply for bio-destructors. In: Inzhenernyye i Sotsial'nyye Sistemy [Engineering and Social Systems]: Collection of Scientific Papers of the Institute of Architecture, Construction and Transport of IVSPU (Ed. by M.V. Tanichev), pp. 3-7. Ivanovo State Polytechnical University, Ivanovo;

16. Meza A, Ortiz J, Peralta L, Sánchez C, (2017). Comparison between destructive and nondestructive tests in the evaluation of abrasion resistance of concrete, Journal of Testing and Evaluation 46(3), 906-912. https://doi.org/10.1520/JTE20160159;
17. Ponomarev AN, (2007). Nanobeton: Kontseptsiya i problemy [Nanoconcrete – Concept and problems], Construction Materials 6, 69-71;
18. Roumyantseva VE, Goglev IN, Loginova SA, (2019). The use of field and laboratory methods for the determination of carbonization, chloride and sulphate corrosion at inspection constructions of buildings and structures, Construction and Industrial Safety 15(67), 51-58;
19. Roumyantseva VE, Goglev IN, Loginova SA, Truntov PS, Burkov AA, (2020). Development and research of properties cement concrete hardening accelerator additive based on a mixture of inorganic fluorine-containing salts, IOP Conference Series: Materials Science and Engineering 753, 052026. https://doi.org/10.1088/1757-899X/753/5/052026;
20. Serebryakov A, Chirkin M, Mishin V, Klimakov V, Davydov G, Gorlin O, Ulitenko A, (2019). Electronic system of non-destructive buildings and structures condition control. In: Proceedings of the 8th Mediterranean Conference on Embedded Computing, MECO 2019, Budva, Montenegro, pp. 1-4. https://doi.org/10.1109/MECO.2019.8760113;
21. Uaissova M, Zharlykassov B, (2024). Application of AI techniques for asphalt concrete mix production optimization, Journal Européen des Systèmes Automatisés 57(2), 353-361. https://doi.org/10.18280/jesa.570205;
22. Yerbayev YT, Zhumagaliyeva GB, Abdygalieva AK, Ryskaliyev MZ, Shulanbayeva LT, Shegenbayeva RK, Abiyeva GS, Yerimbetov KA, (2023). Application of electrothermal phosphoric slag as a binder for foam concrete production, ARPN Journal of Engineering and Applied Sciences 18(7), 836-843;