

Original article

CC BY 4.0

<https://doi.org/10.15828/2075-8545-2025-17-6-750-759>

## Influence of nanoadditives on the physical and mechanical performance of cement concrete

Svetlana A. Loginova<sup>1\*</sup> , Maxim V. Tanichev<sup>1,2</sup> , Ilya N. Goglev<sup>2</sup> 

<sup>1</sup> Yaroslavl State Technical University, Yaroslavl, Russia

<sup>2</sup> Ivanovo State Polytechnical University, Ivanovo, Russia

\* Corresponding author: e-mail: loginovasa@ystu.ru

### ABSTRACT

**Introduction.** The influence of nanoadditives on the physical and me-chanical performance of cement concrete remains a relevant issue driven by the need for finding the most promising and cost-effective solutions to enhance performance during in situ concreting. This issue has been thoroughly examined by the authors in earlier publications. **Methods and Materials.** Two experimental formulations of a composite concrete nanoadditives were developed, based on ammonium hexafluorosilicate ( $(\text{NH}_4)_2\text{SiF}_6$ ) and silicon carbide (SiC). **Results.** In the first part of the study, concrete samples were tested after 28 days of hardening to assess mechanical strength properties. The kinetics of hardening and the influence of each of the specified additives on the concrete were studied. Discussion. The conducted studies allowed for the establishment of the optimal combination of nanoparticles included in the special additive, as well as a detailed investigation of the mechanism of strength gain in cement stone. It was found that the use of the best additive formulation (combination No. 2) significantly improved the strength characteristics of the concrete mix, providing an average strength increase of 38%, as confirmed through both destructive and non-destructive testing. **Conclusion.** The optimal dosage of nanocomponents for the production of the recommended additive per cubic meter of concrete is approximately 0.0141 of the mass of the main raw material, which confirms the economic feasibility of its application. In addition, low concentration of nanoparticles in the additive ensures environmental compatibility of the finished product, minimizing the impact on the environment. The optimal dosage of nanocomponents ensures the uniform distribution of particles in the concrete structure, contributing to an increase in its durability and resistance to environmental influences.

**KEYWORDS:** cement concrete, curing accelerators, complex nanoadditives, silicon carbide, ammonium hexafluorosilicate, compressive strength enhance-ment

### FOR CITATION:

Loginova S.A., Tanichev M.V., Goglev I.N. Influence of Nanoadditives on the Physical and Mechanical Performance of Cement Concrete. *Nanotechnologies in Construction*. 2025;17(6):750–759. <https://doi.org/10.15828/2075-8545-2025-17-6-750-759>. – EDN: QSIZUY.

## Исследование воздействия нанодобавок на физические и механические свойства цементных бетонов

Светлана Андреевна Логинова<sup>1\*</sup> , Максим Владимирович Таничев<sup>1,2</sup> , Илья Николаевич Гоглев<sup>2</sup> 

<sup>1</sup> Ярославский государственный технический университет, Ярославль, Россия

<sup>2</sup> Ивановский государственный политехнический университет, Иваново, Россия

\* Автор, ответственный за переписку: e-mail: loginovasa@ystu.ru

### АННОТАЦИЯ

**Введение.** Исследование влияния различных нанодобавок на физико-механические свойства цементных бетонов является актуальной задачей, поскольку ведется поиск наиболее перспективных и экономичных решений по улучшению его свойств при выполнении монолитных работ. Данный вопрос подробно рассматривался авторами статьи в более ранних работах.

© Loginova S.A., Tanichev M.V., Goglev I.N., 2025

**Методы и материалы.** Авторами были предложены две экспериментальные рецептуры комплексной нанодобавки в бетон на основе флюата аммония ( $(\text{NH}_4)_2\text{SiF}_6$ ) и карбида кремния ( $\text{SiC}$ ). **Результаты.** В первой части исследования проведены испытания прочностных свойств цементных бетонов после 28 суток твердения. Изучена кинетика твердения и влияние каждой из указанных добавок на бетон. **Обсуждение.** Проведенные исследования позволили установить оптимальное сочетание наночастиц, входящих в состав специальной добавки, а также детально исследовать механизм набора прочности цементного камня. Было установлено, что использование оптимальной рецептуры добавки (комбинация № 2) способствует значительному улучшению прочностных характеристик бетонной смеси, обеспечивая увеличение ее прочности в среднем на 38%, что подтверждено результатами испытаний методами как неразрушающего, так и разрушающего контроля. **Вывод.** Дозировка наноконпонентов для изготовления рекомендованной добавки на один кубический метр бетона составляет приблизительно 0,0141 от массы основного сырья, что подтверждает экономическую целесообразность ее применения. Кроме того, незначительное содержание наночастиц в составе добавки позволяет сохранить экологичность готового продукта, минимизируя воздействие на окружающую среду. Оптимальная дозировка наноконпонентов обеспечивает равномерное распределение частиц в структуре бетона, способствуя повышению его долговечности и устойчивости к внешним воздействиям.

**КЛЮЧЕВЫЕ СЛОВА:** бетон, ускорители твердения, комплексная нанодобавка, карбид кремния, флюат аммония, набор прочности

#### ДЛЯ ЦИТИРОВАНИЯ:

Логинова С.А., Таничев М.В., Гоглев И.Н. Исследование воздействия нанодобавок на физические и механические свойства цементных бетонов. *Нанотехнологии в строительстве*. 2025;17(6):750–759. <https://doi.org/10.15828/2075-8545-2025-17-6-750-759>. – EDN: QSIUZU.

## INTRODUCTION

Cement concretes made with a cement binder are widely used in the construction of cast-in-place concrete structures due to their performance characteristics [1, 2]. Cast-in-place reinforced concrete is in demand in the construction of various facilities across diverse climatic zones, ranging from the temperate climate of Central Europe to the harsh conditions of cold regions in Norway, Finland, Alaska, and the northern territories of Russia [3, 4].

A characteristic feature of cast-in-place concrete structures in regions with low ambient temperatures is the necessity to maintain favorable conditions for concrete hardening, as the rate of achieving design strength characteristics influences the schedule of subsequent construction operations. One of the most critical requirements is the timely attainment of a minimum strength of 70%, which ensures the feasibility of promptly proceeding to subsequent construction phases.

To date, there is a large number of various concrete additives, and their number continues to increase every year [2–5]. Most of the commercially available additives have both positive and negative effects on concrete. Special chemical additives are used to accelerate cement hydration processes and enhance the stability of the structure in adverse conditions [5–7]. Among them are curing accelerators that reduce the setting period and increase strength at the early stages of concrete hardening. Anti-freeze additives prevent the destruction of the crystal-line structures of cement stone at low ambient temperatures, maintaining the strength gain processes at sub-zero temperatures [8–10]. Anti-corrosion additives help protect steel reinforcement from the effects of aggressive environ-

ments and moisture [11–13]. Anti-corrosion additives play a key role in ensuring the durability of reinforced concrete structures by protecting steel reinforcement from negative environmental influences, including exposure to moisture and aggressive substances. Such additives create a protective barrier on the metal surface, preventing corrosion processes that occur due to the penetration of water, oxygen, and chemically active compounds inside the structure. This is especially important in conditions of high humidity, marine or industrial environment, or when operating structures in harsh climatic conditions. The effectiveness of anti-corrosion additives is manifested in the increased lifespan of construction structures, reduced costs for repair and maintenance of buildings and facilities, as well as enhanced reliability of the entire structures [14, 15]. The use of modern technologies for reinforcement protection significantly improves construction quality and reduces the risks of load-bearing structure destruction due to internal reinforcement corrosion.

Modern construction practices are gradually shifting towards a comprehensive approach to the selection of additives that involves combining several beneficial properties at once [16]. Such combined additives integrate the effects of hardening acceleration, frost resistance, and anti-corrosion protection, increasing the efficiency of the construction process and reducing material costs. However, only a small portion of these additives have minor negative effects on the hardening concrete or reinforcement (for example, they cause the formation and crystallization of side reaction byproducts in the pores of the concrete [17, 18]. Increased crystallization in the pores of concrete (Fig. 1) may indicate that the grinding of the initial reagents in the additive is not fine enough,



**Fig. 1.** Crystallization of side reaction byproducts in the pores of concrete. Cracks inside the sample

and therefore, it is recommended to use substances and/or their mixtures for which grinding can be performed at the micro or nano level.

Nanodispersed components increase the contact area between phases, improve compositional homogeneity and enhance intermolecular interactions, thus favorably influencing the mechanical properties of concrete and its resistance to external factors [19]. Consequently, it becomes evident that the development of a promising complex additive based on micro- or nano-ground powders is currently a relevant study objective, as it enables a comprehensive understanding of the impact of additive particle size on the nature of hardening and the degree of strength development in concrete.

Furthermore, the incorporation of nanoadditives affects the emergence of a distinctive microcrystalline structure in concrete, contributing to the production of composition materials with enhanced performance properties. Fine particles are uniformly distributed throughout the cement paste volume, ensuring increased structural stability and reducing internal stresses that develop during the hardening process. These factors collectively result in an increase in mechanical strength, resistance to cracking, and an improvement in the durability of the final product. The use of nanotechnology provides new opportunities for improving the characteristics of conventional construction materials, enabling the creation of high-performance compositions with distinctive physical and chemical properties.

The process of strength development and frost resistance enhancement in cement stone is attributable to the reactions of individual components within complex additives with one of the key constituents of hardening concrete: free calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) that was identified by S.V. Fedosov, academician of the Russian Academy of Architecture and Construction Sciences, as the primary factor [20] influencing material strength.

Free calcium hydroxide forms as a product of cement hydration and exists within the concrete structure as

calcite crystals. Complex additives contain components capable of chemically interacting with  $\text{Ca}(\text{OH})_2$ , forming new compounds with increased strength and resistance to environmental influences [21, 22].

In addition to chemical bonding, some additives promote accelerated diffusion of free calcium hydroxide from the pore space, ensuring uniform distribution of hydration products and reducing concentration gradients, which also positively affects the structure and properties of hardened concrete [23]. Beyond accelerating the hydration process and stabilizing the concrete structure, specific chemical compounds are capable of forming supplementary protective layers around steel reinforcement, thereby extending the service life of reinforced concrete in aggressive environments [24–26]. Examples of such additives include complexes based on organic acids and phosphate compounds, which form a protective film on the metal surface, restricting the ingress of moisture and oxygen. Another significant aspect is the capability of certain additives to regulate the evaporation rate of free water from concrete, maintaining optimal moisture levels throughout the hardening period [27]. This prevents the occurrence of cracks and deformations caused by rapid drying and creates conditions for the formation of a high-strength and stable matrix. Optimal humidity, in turn, contributes to effective cement hydration and achieving maximum density of the concrete structure.

Frost resistance of complex additives can be ensured by the ability of a component to form crystalline hydrates with water, thereby lowering its crystallization temperature during the mixing and hardening of concrete. For example, this is the mechanism of action of a common antifreeze additive based on calcium formate ( $\text{Ca}(\text{HCOO})_2$ ) [28].

Thus, the comprehensive impact of reagents allows for a significant acceleration of the hardening process and improves the quality of the final product, making it possible to use concrete under increased loads and extreme climatic conditions.

The study presented in the article was aimed at achieving specific goals and solving the set tasks based on the available literature data [29–31].

The aim of this study was to evaluate a composite modifier incorporating silicon carbide and ammonium hexafluorosilicate reagents ground to nanoscale dimensions, whose preliminary testing demonstrated a substantial increase in cement stone strength (up to 20%). It was necessary to assess the impact of the additive on strength indicators and identify potential advantages and disadvantages of its use.

The main task was to scientifically substantiate the effectiveness of the developed compositions by analyzing the characteristics of modified concrete, calculating the optimal amount of additive per cubic meter of the

mixture, as well as comparing the advantages and disadvantages of its introduction into the concrete mixture.

## METHODS AND MATERIALS

During the experiments, including the preparation of control samples, weighing of materials, and preparation of experimental mixtures, the following devices were used:

- ONIKS-2.5 impact-echo tester for non-destructive testing, manufactured by Interpribor (state registration certificate of the Russian Federation No. 30252-10, serial number 887, verification certificate dated January 29, 2025, Fig. 2a);
- PSU-50 testing press (Fig. 2b);
- Testo 606-1 dielectric moisture meter, designed for measuring the moisture content of materials (Fig. 2c);
- Canon 1200D digital SLR camera, providing fast photography;
- Zitrek Z-35-1.5 handheld electric vibrator used for compacting the mixture;
- Mucheng 0.1-500 electronic scales, intended for precise dosing of components (measurement accuracy ranges from 0.1 to 500 grams).

The research procedure was divided into theoretical and practical parts.

As a result of theoretical studies, tables of combinations of various additive components were compiled (Tables 1–2).

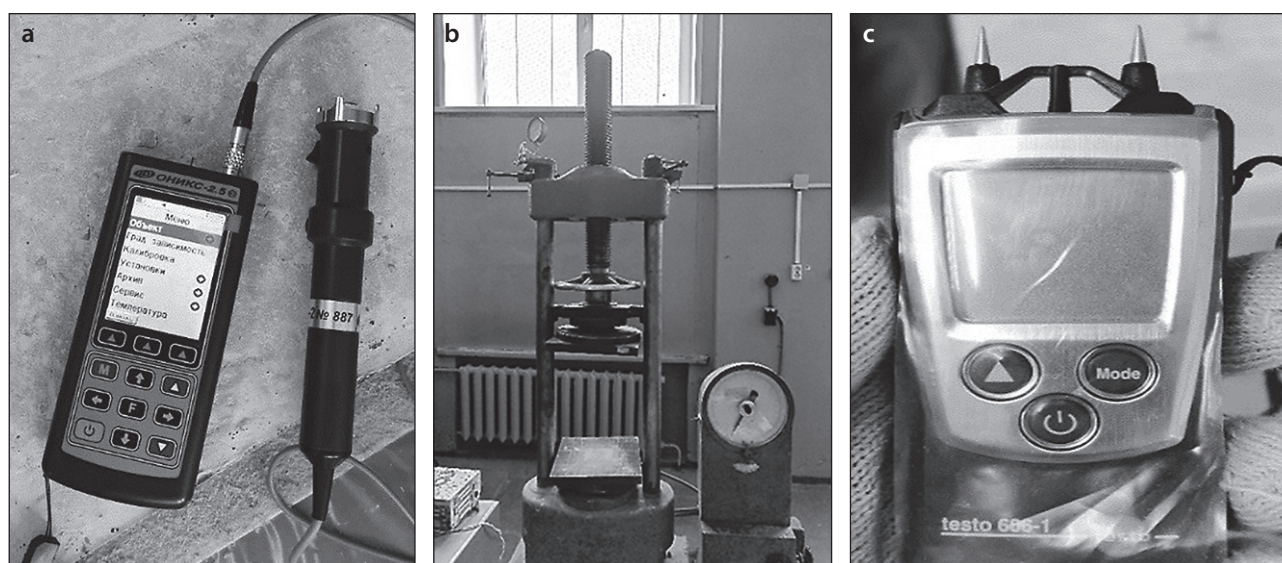
To assess the strength of concrete, the shock-pulse method was used according to the national standard GOST 22690-2015 “Concretes. Determination of strength by mechanical methods of non-destructive testing.” This method is based on the relationship between the strength

**Table 1.** Combinations No. 1 of individual additive components

Reagent and/or component	Quantity, %
Distilled water (GOST 6709-72), component X1	1) 24.4
	2) 24.1
	3) 23.2
	4) 21.7
Silicon carbide (SiC) nanopowder, component X2	1) 2.2
	2) 3.6
	3) 7
	4) 13
Portland cement grade M500D0	1) 73.4
	2) 72.3
	3) 69.8
	4) 65.3

characteristics of concrete and the impact energy (including its changes) that occur during the contact of a special tool with a sensor on the concrete surface. The strength of the concrete was also determined by testing cubic samples for compressive strength using a PSU-50 press.

The concrete mixture was compacted during mixing using a handheld electric vibrator. For conducting non-destructive testing, samples measuring 30×30×30 mm (Fig. 3) were made from cement mortar of optimal consistency (approximate water-to-cement ratio = 0.3). The cement mortar was prepared by mixing Portland cement grade M500D0 (Fig. 4a) with an additive solution (or



**Fig. 2.** a) ONIKS-2.5 Impact-echo non-destructive testing device; b) PSU-50 testing press; c) Testo 606-1 dielectric moisture meter

**Table 2.** Combinations No. 2 of individual additive components

Reagent and/or component	Quantity, %
Distilled water (GOST 6709-72), component X1	1) 28.5
	2) 28.47
	3) 28.4
	4) 28.2
	5) 28.0
	6) 27.8
	7) 27.6
	8) 27.4
Ammoniumhexafluorosilicate (fluorosilicate) ((NH <sub>4</sub> ) <sub>2</sub> [SiF <sub>6</sub> ]) nanopowder, component X4	1) 0.18
	2) 0.36
	3) 0.71
	4) 1.41
	5) 2.1
	6) 2.78
	7) 3.45
	8) 4.11
Portland cement grade M500D0	1) 71.32
	2) 71.17
	3) 70.89
	4) 70.39
	5) 69.9
	6) 69.42
	7) 68.95
	8) 68.49

individual components, Fig. 4b), with the samples subsequently stored in a moisture curing room at normal atmospheric pressure and relative humidity of 99–100%.

A total of 150 control samples (without additives) and samples with different combinations of additive compo-

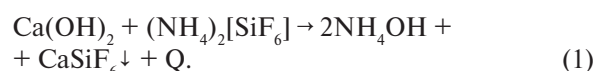
sitions were made (50 pieces of each type: X1, X1+X2, X1+X4). After the specified curing periods, testing for compressive strength was conducted using the impact-echo method and by testing the samples on a press.

Additionally, the moisture content of the samples was measured using a portable moisture meter. The average moisture content of the concrete samples during the testing period was 1.6%. After mixing, it was found that combination No. 2 caused the concrete mixture to heat from 23 to 42 °C, which theoretically allows the use of this component for winter concreting. The mixture gradually cooled over the period from 45 minutes to 1 hour.

The obtained data were averaged and entered into results tables, on the basis of which graphs of the kinetics of cement stone hardening were constructed.

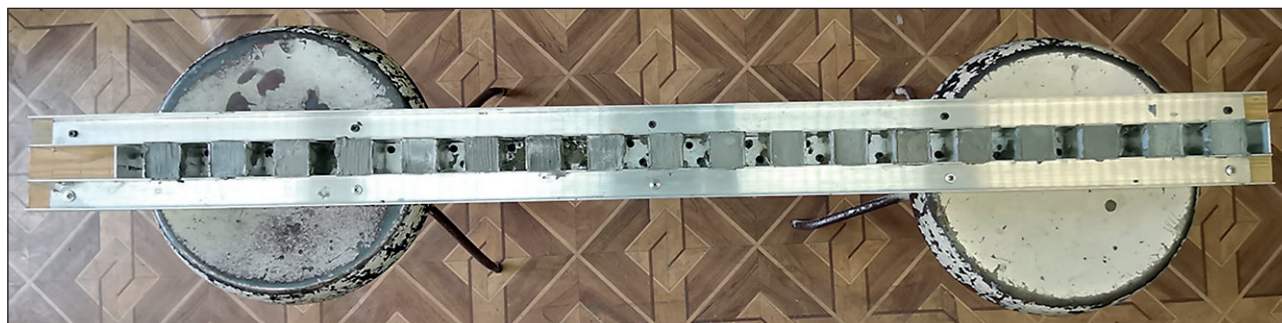
## RESULTS

The principle of action of the individual components of the proposed additive is based on the ability to bind free calcium hydroxide present in concrete (Ca(OH)<sub>2</sub>) [32, 33] with hexafluorosilicate ions to form slightly soluble calcium hexafluorosilicate (CaSiF<sub>6</sub>) through direct reaction (1):



It should be noted that since hexafluorosilicates are essentially complex compounds in which 2 molecules of hydrofluoric acid (HF) are attached via hydrogen bonding to a molecule of silicon tetrafluoride (SiF<sub>4</sub>), the reaction is exothermic, as calcium oxide and hydroxide always react with hydrofluoric acid solution with heat release.

It is known that individual components of the additive increase the solubility of cement particles in the water-salt solution, increasing the content of hydration products in it. Calcium hexafluorosilicate, formed as a result of this process, is in a nanodispersed state [22, 32]. This ensures rapid bonding of cement grains with each other, which

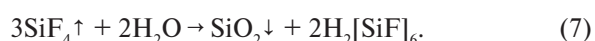
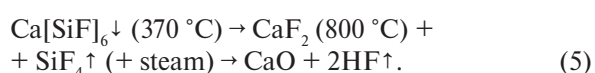
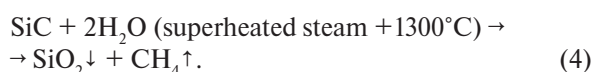


**Fig. 3.** General view of the test samples for non-destructive testing



**Fig. 4.** a) Weighing Portland cement on electronic scales; b) Example of one of the additive components (silicon carbide (SiC) nanopowder)

accelerates the hardening of the material and increases the rate of strength gain.



The ammonia ( $\text{NH}_3$ ) generated within the system evaporates upon the addition and mixing of water with Portland cement. Consequently, when this nanoadditive is introduced into concrete, a strong smell of ammonia is noticeable in the first minutes of mixing with water.

Unlike ammonium hexafluorosilicate, silicon carbide does not participate directly in the reaction (2) with the hydration products of Portland cement (which would require elevated temperature, strong alkaline conditions, and the presence of oxygen in the system); rather, it functions as micro- and nano-dispersed particles capable of occupying the pores within the hardening cement stone. Theoretically, the incorporation of silicon carbide may enhance the hardness of cement stone, however, this issue

has not yet been fully studied in the industry. Additionally, potential effects of introducing micro- or nanoparticles of silicon carbide into concrete may include enhanced fire resistance (silicon carbide undergoes decomposition by superheated steam at temperatures exceeding  $+1300^\circ\text{C}$ ), as well as acting as a “trap” for inorganic fluorides (i.e., other possible additive components in the system) during concrete exposure to high-temperature environments, thereby binding fluoride components within the system (see reactions 4–8). An extensive review of Russian and international literature was conducted on the subject of this study [5–21].

Data processing following non-destructive testing was performed using the Microsoft Excel software package. Measurement precision was ensured through systematic averaging of actual compressive strength values for each sample series.

Based on the obtained average results and strength values determined by the impact-echo method, comparative hardening kinetics graphs were constructed for concrete samples containing the proposed additive components (combinations No. 1 and No. 2) and unmodified concrete (control) samples over the period from 3 to 28 days (Figures 5–6).

Based on the results of the conducted studies, it was established that the average rate of strength gain of samples using additive combination No. 1 is comparable to the indicators of control samples. The experimental data obtained convincingly demonstrate that combination No. 2 among the proposed complex additives most effectively accelerates the process of strength gain of cement stone both at

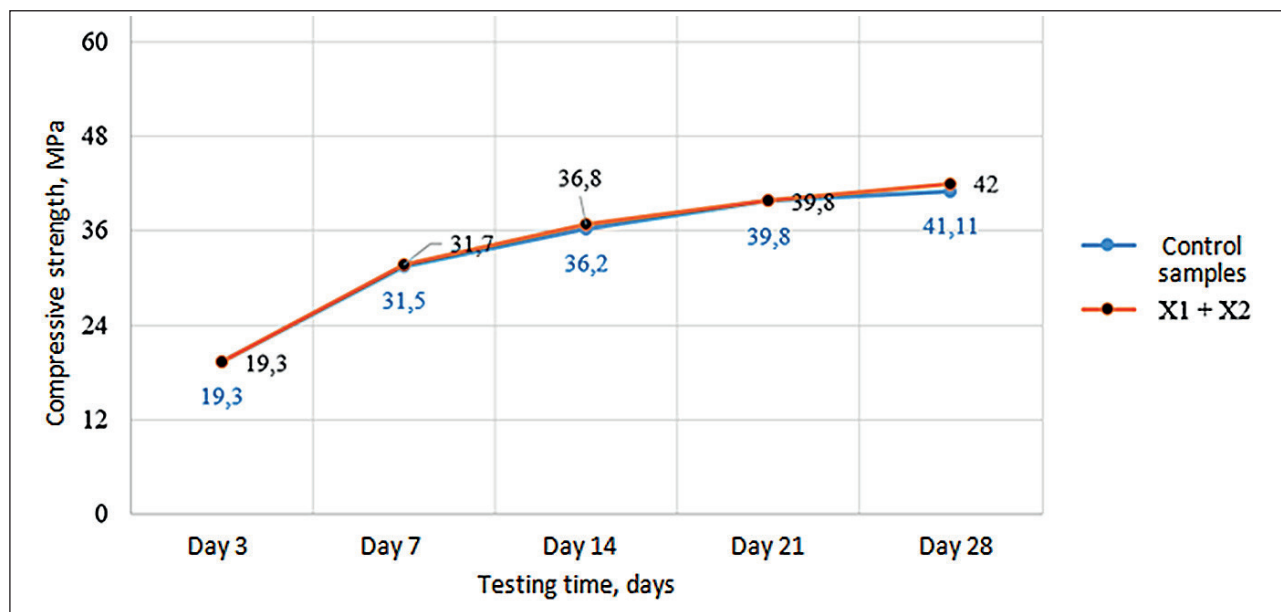


Fig. 5. Diagram of the maximum indicators of the kinetics of cement stone hardening according to non-destructive impact-echo control data for combination No. 1 (X1+X2)

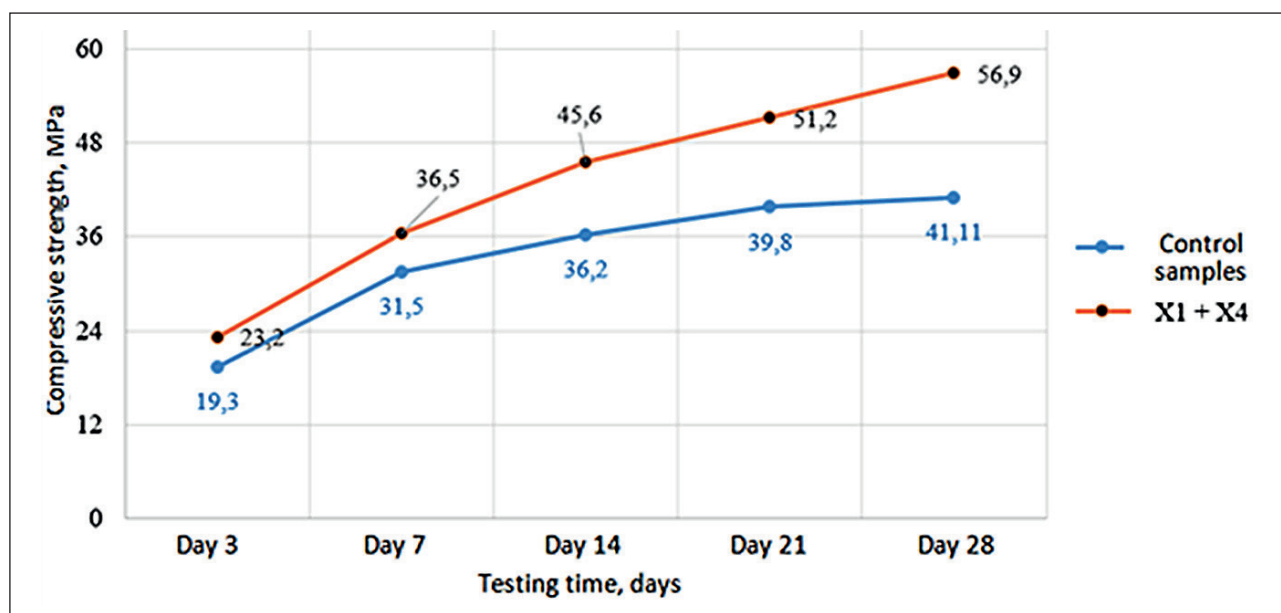


Fig. 6. Diagram of the maximum indicators of the kinetics of cement stone hardening according to non-destructive impact-echo control data for combination No. 3 (X1+X4)

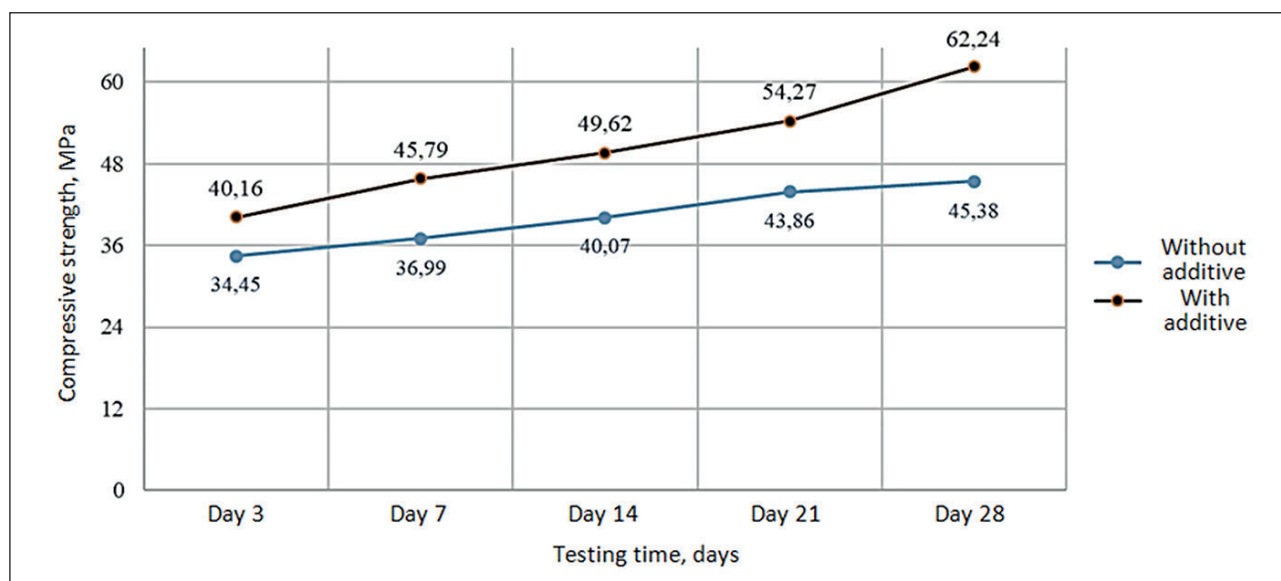
the early stages of hardening (up to 14 days) and at the later stages (up to 28 days). In this regard, samples made with the use of additive combination No. 2 were tested for compressive strength by destructive testing (Fig. 7).

The analysis of the processed data allowed for the determination of patterns in the change of cement stone strength during various stages of hardening. The graphical representation of the results provided a clear understanding of the dynamics of strength growth and identified criti-

cal periods when the intensity of strength gain was greatest or least. This allowed for the optimization of storage and maintenance regimes for the samples.

## DISCUSSION

The hardening kinetics diagrams provided a foundation for subsequent optimization of concrete mixture formulations. These diagrams corroborated the hypothesis



**Fig. 7.** Kinetics of cement stone hardening with the addition of combination No. 2 according to destructive control data

regarding the beneficial influence of the investigated additives on accelerating the hydration process and enhancing cement stone quality. Such investigations are essential for advancing innovative approaches in the construction industry and for strengthening the competitiveness of Russian products in the international market.

The experimental data confirm an increase in cement stone compressive strength exceeding 30%, irrespective of the assessment method employed: both non-destructive testing and direct (destructive) testing demonstrated this enhancement with the addition of combination No. 2. Analysis of the strength development dynamics of the cement stone over the interval from 3 to 28 days yielded average strength gains with the proposed additive: non-destructive testing data indicated a strength increase of 38.57%, and destructive testing indicated a corresponding value of 37.15%.

Through testing, it was also established that the optimal dosage rate of the additive per 1 m<sup>3</sup> of concrete is approximately 0.01–0.011 of the total concrete mass. A calculation of economic indicators (technical and economic efficiency) for the produced additive is not required due to the insignificance of the associated costs.

Theoretical and experimental analysis demonstrates the principal characteristics of the proposed additive, which is a mixture of fluoroborate and fluorosilicate nanopowders. Its high efficacy combined with the minimal required dosage renders this innovation promising for further investigation and implementation in industrial production. An additional advantage of the proposed additive is its versatility. It is compatible with most cement types and can be adapted to various climatic conditions, which expands its application scope. The capability to

adjust dosage according to specific requirements will allow achieving superior performance even in complex production situations.

## CONCLUSION

The conducted research successfully achieved all established objectives and accomplished the corresponding tasks, thereby enabling the identification of the optimal ratio of nanoscale additive components and the investigation of cement stone hardening kinetics.

Based on the obtained results, the application of the optimal composition (combination No. 2) yielded an average increase in concrete strength of approximately 38% as determined through both non-destructive and destructive testing methods. The quantity of nanocomponents required for the recommended additive formulation corresponds to approximately 0.0141% of the total weight of the initial concrete.

The accumulated theoretical and experimental evidence demonstrating the effectiveness of the developed complex additive, comprising a mixture of nanopowders of silicon carbide and ammonium hexafluorosilicate, supports a preliminary conclusion regarding the considerable advantages of this formulation.

The adoption of novel composite materials incorporating nanopowders will enable Russian construction enterprises to advance to an enhanced technological level, thereby achieving competitiveness with international counterparts. This development demonstrates substantial potential in both civil construction applications and infrastructure projects, including the construction of bridges, roadways, and industrial facilities.

## REFERENCES

1. Rogozhina M.I., Mishcherina E.Yu., Lapidus A.A. Main aspects of heavy-weight concrete technology for the construction of monolithic structures. *Technology and organization of construction production*. 2018; 2:14-17.
2. Endzhievskaya I.G., Demina A.V., Endzhievsky A.S., Dubrovskaya S.D. Evaluation of the interaction of additives in concrete. *Bulletin of Tomsk State University of Architecture and Civil Engineering*. 2022; 24(3):128-137. <https://doi.org/10.31675/1607-1859-2022-24-3-128-137>
3. Ksenofontova T.K., Smolonogova V.S. On the issue of designing buildings from monolithic reinforced concrete on the shelf of large water bodies. *Bulletin of the Scientific and Methodological Council for Nature Management and Water Use*. 2020; 18:42-47.
4. Zabavina V.V. Design of Monolithic Reinforced Concrete Structures with Changes in the Functional Purpose of the Building. *Academic Journalism*. 2017;11:16-22.
5. Yukhnevsky P.I. On the Permissible Content of Ammonium Ions in Chemical Additives for Concrete. *Science and Technology*. 2021;5(20):420-426. <https://doi.org/10.21122/2227-1031-2021-20-5-420-426>
6. Alarkhanova Z.Z. Chemical Additives for Concrete and Mortars: Nomenclature, Classification, Main Effect of Action. *Bulletin of the KNI RAS. Series: Natural and Technical Sciences*. 2022;1(9):31-39. <https://doi.org/10.34824/VKNIIRAN.2022.9.1.003>
7. Mamytov S.M., Sarbaeva N.M. Influence of chemical additives on the properties of concrete. *Science and Innovative Technologies*. 2023;1(26):172-177. <https://doi.org/10.33942/sit042262>
8. Kurnikov T.D., Tlekhusezh M.A. Chemical additives and their influence on the properties of concrete. *Trends in the development of science and education*. 2023;104-11:139-141. <https://doi.org/10.18411/trnio-12-2023-629>
9. Kurylev V.S., Timokhin D.K. Modified antifreeze additives and their influence on concrete characteristics. *Resource-energy efficient technologies in the regional construction complex*. 2017;8:128-134.
10. Tarakanov O.V., Ilyina L.V., Gichko N.O. Influence of negative temperatures on the microstructure, hardening kinetics and strength of cement materials. *Regional architecture and construction*. 2024;4(61):63-72. [https://doi.org/10.54734/20722958\\_2024\\_4\\_63](https://doi.org/10.54734/20722958_2024_4_63)
11. Talipov L.N., Velichko E.G., Semenov V.S. Study of the synergistic effect of a complex anticorrosive additive based on polycarboxylates in a concrete pore fluid model. *Vestnik MGSU*. 2020;6(15):824-833. <https://doi.org/10.22227/1997-0935.2020.6.824-833>
12. Kozaderov O.A., Shevtsov D.S., Potapov M.A., Zartsyn I.D., Grushevskaya S.N., Kruzhilin A.A., Ilyina E.A., Tkachenko K.A., Shikhaliev H.S. Evaluation of the inhibitory effect of some derivatives of long-chain carboxylic acid salts on pitting corrosion of reinforcing steel in concrete. *Condensed Matter and Interfaces*. 2023;3(25):445-453. <https://doi.org/10.17308/kcmf.2023.25/11396>
13. Konovalova V. Influence of chloride-containing media on the protective properties of concrete. *Lecture Notes in Civil Engineering*. 2021;95:260-265. [https://doi.org/10.1007/978-3-030-54652-6\\_39](https://doi.org/10.1007/978-3-030-54652-6_39)
14. Konovalova V.S., Rummyantseva V.E., Strokin K.B., Galtsev A.A., Novikov D.G., Monastirev P.V. Degradation of concrete cement stone under the influence of aspergillus niger fungi. *Corrosion and Materials Degradation*. 2024; 4(5):476-489. <https://doi.org/10.3390/cmd5040022>
15. Polonina E.N. Technology of concrete modified with a complex additive of hydrothermal nanosilica and multi-walled carbon nanotubes. *Bulletin of Brest State Technical University*. 2021;2(125):27-34. <https://doi.org/10.36773/1818-1212-2021-125-2-27-34>
16. Zimakova G.A., Solonina V.A., Zelig M.P. High-performance concretes using complex additives and local raw materials. *Architecture, Construction, Transport*. 2021;1:38-46.
17. Belov V.V., Barkaya T.R., Kulyaev P.V. Creep of fine-grained carbonate concretes with a complex additive. *Chemistry, Physics and Mechanics of Materials*. 2022;1(32):62-75.
18. Malyuk V.V. Concept of a model of frost action on concrete of offshore structures. *Construction and Reconstruction*. 2024;1(111):78-87. <https://doi.org/10.33979/2073-7416-2024-111-1-78-87>
19. Travush V.I., Kuzevanov D.V., Kapriyelov S.S., Volkov Yu.S. Concrete as an environmental factor in reducing the carbon footprint in the environment. *Concrete and Reinforced Concrete*. 2022;3(611):10-14. <https://doi.org/10.31659/0005-9889-2022-611-3-10-14>
20. Fedosov S.V., Roumyantseva V.E., Loginova S.A., Goglev I.N. Experimental research of the process bio-corrosion of cement concrete for inspection of building structures. *Lecture Notes in Civil Engineering*. 2021;147:168-175. [https://doi.org/10.1007/978-3-030-68984-1\\_25](https://doi.org/10.1007/978-3-030-68984-1_25)
21. Fedosov S.V., Roumyantseva V.E., Konovalova V.S., Loginova S.A. Mathematical modeling of diffusion processes of mass transfer of “free calcium hydroxide” during corrosion of cement concretes. *International Journal for*

*Computational Civil and Structural Engineering*. 2018;3(14):161-168. <https://doi.org/10.22337/2587-9618-2018-14-3-161-168>

22. Fedosov S.V., Aleksandrova O.V., Nguyen D.V.K., Fedoseyev V.N., Loginova S.A. Physical and mathematical substantiation of theoretical and engineering surveys for the development of corrosion-resistant materials for buried structures in coastal zones. *Silicate Engineering and Technology*. 2022;1(29):45-54.

23. Ho V.Ha., Ngo V.M., Vu V.T. Bond strength of a steel bar in concrete reinforcing with shape memory alloy fibers. *Science Journal of Transportation*. 2024;3(19):44-57.

24. Krishan A.L., Narkevich M.Yu., Sagadatov A.I., Rimshin V.I. Investigation of the influence of post-alcohol distillers' grains on the strength of concrete used in a two-component modified additive. *Механика и технологии*. 2024;3(85):188-200. <https://doi.org/10.55956/ZSWL8979>

25. Sokolov P.E. Results of the study of the influence of a complex additive on the rate of strength gain and the strength of fine-grained concrete. *Bulletin of Eurasian Science*. 2024;2(16):15-21.

26. Travush V.I., Karpenko N.I., Erofeev V.T., Erofeeva I.V., Bondarev B.A., Bondarev A.B. Cyclic strength of new generation concretes. *Construction Materials*. 2020;1-2:88-94. <https://doi.org/10.31659/0585-430X-2020-778-1-2-88-94>

27. Pshenichny G.N. Strength drops in cement concretes and their practical significance. *Concrete Technologies*. 2020;5-6(166-167):51-59.

28. Bulgakov A.G., Erofeeva I.V., Ishutin A.A., Afonin V.V., Moiseev V.V. Flexural tensile strength of new-generation concrete. *Expert: Theory and Practice*. 2022;2(17):21-27. [https://doi.org/10.51608/26867818\\_2022\\_2\\_21](https://doi.org/10.51608/26867818_2022_2_21)

29. Dimitriev V.S. Strength testing of concrete at sub-zero temperatures using complex additives to concrete mix. *Science Bulletin*. 2025;5(86):1707-1713.

30. Rummyantseva V.E., Konovalova V.S., Gal'tsev A.A., Strokin K.B., Narmaniya B.E. Strength and crack resistance of concrete with a calcium stearate-based additive. *Modern problems of civil protection*. 2024;3(52):71-82.

31. Vishtorsky E.M., Belov I.V., Tkachev A.A. Experimental and statistical model of changes in the strength of hydraulic concretes using complex modifying additives. *Modern construction and architecture*. 2025;6(61). <https://doi.org/10.60797/mca.2025.61.2>

32. Chernyshov E.M., Fedosov S.V., Rummyantseva V.E. Development of methods for predicting the durability of building structures based on the development of the theory and models of concrete corrosion, taking into account the phenomena of heat and mass transfer and the formation of gradient states. *Academia. Architecture and construction*. 2023;1:89-100. <https://doi.org/10.22337/2077-9038-2023-1-89-100>

33. Fedosov S.V., Fedoseyev V.N., Zaitsev I.S., Zaitseva I.A. Tools for implementing information modeling of the life cycle of construction projects: domestic and foreign experience. *Modern Science-Intensive Technologies. Regional Supplement*. 2023;2(74):101-104. <https://doi.org/10.6060/snt.20237402.00011>

#### ADDITIONAL INFORMATION

The authors declare that generative artificial intelligence technologies and technologies based on artificial intelligence were not used in the preparation of the article.

#### INFORMATION ABOUT THE AUTHORS

**Svetlana A. Loginova** – Cand. Sci. (Eng.), associate Professor of the Institute of Civil and Transport Engineers, Yaroslavl State Technical University, Yaroslavl, Russia, [loginovasa@ystu.ru](mailto:loginovasa@ystu.ru), <https://orcid.org/0000-0001-6025-8968>

**Maxim V. Tanchev** – Cand. Sci. (Eng.), associate Professor of the Institute of Civil and Transport Engineers, Yaroslavl State Technical University, Yaroslavl, Russia; Associate Professor of the Department of Transport and Highways, Ivanovo State Polytechnical University, Ivanovo, Russia, [maxt\\_ivanovo@mail.ru](mailto:maxt_ivanovo@mail.ru), <https://orcid.org/0009-0002-4421-3692>

**Ilya N. Goglev** – PhD candidate, Ivanovo State Polytechnical University, Ivanovo, Russia, [azidplumbum00@mail.ru](mailto:azidplumbum00@mail.ru), <https://orcid.org/0000-0002-4956-323X>

#### CONTRIBUTIONS OF THE AUTHORS

**S.A. Loginova** – development of the study concept and methodology; analysis of study results.

**M.V. Tanchev** – data processing, preparation of the article for publication.

**I.N. Goglev** – literature review; conducting the experiment.

#### The authors declare no conflicts of interests.

The article was submitted 20.10.2025; approved after reviewing 01.12.2025; accepted for publication 04.12.2025.