RESEARCH RESULTS OF SCIENTISTS AND SPECIALISTS

Discussion paper
https://doi.org/10.15828/2075-8545-2023-15-5-494-503

Modeling the Kinetics of Cement Composite Processes Modified with Calcium-Containing Additives

Lilia V. Ilina[1], Svetlana V. Samchenko[2], Mikhail A. Rakov[1*], Dmitry A. Zorin[2]

[1] Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, Russia
[2] National Research Moscow State University of Civil Engineering, Moscow, Russia

* Corresponding author: e-mail: westcoast89@mail.ru

ABSTRACT: Introduction. Rock wastes from dust collection systems can be used as mineral additives for making artificial conglomerates based on mineral binders. At the same time, the size of waste particles allows them to be used without additional grinding. Such materials may include fine powders of calcium-containing rocks such as limestone, wollastonite, diopside. Waste rock from dust collection systems can be used as mineral additives for manufacturing artificial conglomerates based on mineral binders. The particle size of the waste allows their utilization without additional grinding. Such materials can include finely dispersed powders of calcium-containing rocks, such as limestone, wollastonite, and diopside. **Methods and materials.** We used Portland cement CEM II/A-W 32.5F was used as a binder in the study. The selection of additives was determined through a comparative analysis of their thermodynamic properties with those analogous to clinker minerals. Standard research methods were used to study cement composites, as well as mercury porometry, X-ray phase analysis and electron microscopy. **Results.** The addition of calcium-containing additives makes it possible to strengthen the structure of cement materials. The greatest increase in strength during the initial hardening period can be achieved by adding 2% of limestone. In the late period of strength gain (in 14 days), the greatest hardening of the stone was obtained with the addition of 9% wollastonite or 7% diopside. **Discussion.** The results of cement stone diffractogram of the control composition and with the use of additives are given. With the addition of additives, there is a decrease in the intensity of calcium hydroxide reflexes and an increase in the intensity of calcium hydrosilicates reflexes. The study of the macrostructure revealed a significant difference in the structure of the stone. The porosity analysis showed that when calcium-containing additives are added into the system, the total pore volume decreases, the number of small pores increases (size 0.003–1.2 μm). **Conclusion.** The increase in strength up to 48% is due to the close chemical composition and thermodynamic characteristics of the binder and calcium-containing additives. Wollastonite, due to its fibrous structure, creates micro-reinforcement of the system, and diopside, in its turn, having the highest hardness and elastic modulus of the presented additives, leads to the greatest hardening of the stone.

KEYWORDS: cement composites, calcium-containing additives, strength characteristics, porosity.

ACKNOWLEDGMENTS: The study was carried out with the financial support of NRU MGSU in the framework of 2023 contest for basic and applied researches (R&D) by scientific teams of member organizations and strategic partners of the Construction and Architecture Industry Consortium (contract No. NSUACE/K-23 dated 30.06.2023) for the implementation of the NRU MGSU Development Program for 2021-2030 as part of the Strategic Academic Leadership Program "Priority-2030."

FOR CITATION: Ilina L.V., Samchenko S.V., Rakov M.A., Zorin D.A. Modeling the Kinetics of Cement Composite Processes Modified with Calcium-Containing Additives. *Nanotechnologies in construction.* 2023; 15(5): 494–503. https://doi.org/10.15828/2075-8545-2023-15-5-494-503. – EDN: WVIFWH.

INTRODUCTION

Obtaining fast-hardening high-strength cement composites is the most important task in the development of materials science. In case fillers from dense and coherent rocks are used in construction composites based on mineral binders', the strength of which is several times higher than their strength, then the matrix of the binder is responsible for the strength of the composite. At the same time, the phase composition and structure of crystalline hydrates in the hydrated binder and artificial composite do not differ significantly [1–5]. The use of fine mineral wastes from mining and mining processing facilities as additives can increase the strength of artificial composites by strengthening the matrix of the hydrated mineral binder. At the same time, the addition of these wastes can reduce the consumption of expensive mineral binder [6–12].

Dogmatic documents require finding rational ways to use waste from mining and mining processing facilities in construction in the Russian Federation. The statements of the Innovative Development Strategy of the Russian Federation for the period up to 2030 (approved by Order of the Government of the Russian Federation dated 08.12.2011 No. 2227-р (amended by 18.10.2018)), the Strategy for the Development of Building Materials Industry for the Period up to 2020 and the Future further until 2030 (approved by Order of the Government of the Russian Federation dated 10.05.2016 N 868-р) are aimed at expanding the use of waste in materials science. Thus, the expediency of fine man-made or natural raw materials utilization in the manufacture of artificial composites based on mineral binders is due to the task of improving their quality and to the utilization requirement of multi-tonnage waste from mining processing facilities [13]. In the Russian Federation, over 3500 thousand tons of such wastes are generated every year. At the same time, the building materials industry currently processes only 4% of the annual volume of these wastes. [14–17].

Fine rock wastes from dust collection systems can be used as mineral additives to make artificial stone materials based on mineral binders. At the same time, the size of the powders of these wastes allows them to be used without additional grinding. Such powders can include finely dispersed powders of calcium-containing rocks such as limestone, wollastonite, diopside [4, 18–20]. Fine mineral powders of rocks can participate in the process of crystalline hydrates formation and the structure of artificial stones on a cement basis. The interaction of mineral powder particles with hydrated matrix of cement occurs mainly along the plane of their contact. When selecting mineral wastes of rocks, it is necessary to pay attention to the type of their chemical bond and the proximity of their energy indicators (entropy and enthalpy of formation) with clinker minerals [8, 9, 18, 21, 22]. Russian scientists believe [8, 9, 21, 22] that calcium-containing wastes can be the most effective of those fine rock wastes that can be used to improve the properties of cement systems. At the same time there is necessary energy compatibility between finely dispersed powders of rocks (mineral additives) and hydrate innovations of cement.

Since the greatest hardening of the cement matrix can be achieved with the smallest porousness between the particles of the additive and the binder, a number of scientists indicate the need to control the dimension of their grains [8, 23, 24].

Thus, the objective of the work is to study the degree of influence of calcium-containing mineral additives on the kinetics of hardening and increasing the strength of the cement matrix, and to establish the factors affecting this process.

METHODS AND MATERIALS

Portland cement CEM II/A-SH 32,5F Iskitimcement JSC (Iskitim, Novosibirsk Region), manufactured in accordance with GOST 31108-2020, was used as a binder in the work. The main characteristics of the binder are shown in Table 1.

The additives used in the work were selected based on the comparison of their thermodynamic characteristics with similar characteristics of clinker minerals (Table 2).

The comparison of thermodynamic characteristics (enthalpy and entropy of formations) showed their close values (differences of no more than 9%).

Calcium-containing additives were used in the work that is the powders of natural stone materials, which are man-made products: diopside, wollastonite and limestone. The chemical composition of these additives is shown in Table 3.

Table 4 shows the hardness of the test additives on the Mohs scale.

Clinker hardness is quite high and is 6–7 on the Mohs scale. However, the hardness of hydrate neoplasms is much lower and, as a rule, does not exceed 3.5–4.0.

Thus, the choice of calcium-containing additives (wollastonite, diopside, limestone) adopted in the study is determined by the proximity of their thermodynamic characteristics and chemical composition with clinker minerals, and, therefore, the possibility of these additives to act as supports for crystallization of hydrated new-growths.

In addition, the choice of mineral additives is due to their hardness, and therefore, the modulus of elasticity. If the modulus of elasticity of mineral additives and hydrated cement differs, then, when external forces act on the system, the stresses will redistribute towards the component with the largest modulus of elasticity.

In this case, the additives that have a fibrous structure will micro-strengthen the cement matrix of artificial composites.

Calcium-containing additives were added to portland cement in an amount of 2 to 11% weight. The mixture was stirred dry. Standard density cement dough was prepared from the resulting modified binder and the samples were then formed. Water under the requirements of GOST 23732 was used to cure the modified binder during experimental studies.

The strength characteristics of the cement system were determined on cubes with a 20 mm rib. Five batches of samples were manufactured, which gained strength under steam curing conditions and under standard conditions. Curing mode: 4 hours – preliminary curing at a temperature of 20 ± 2°C; 3 hours – temperature rise to 80°C, 8 hours – curing at this temperature; 3 hours – temperature decrease. Under standard conditions (temperature 20 ± 2°C, humidity – not less than

Table 1
Portland Cement Specification

No.	Indicator	Required value	Actual value
	Chemical composition		
1	Content SiO_2, %	not rated	22.64
2	Content Al_2O_3, %	not rated	6.24
3	Content Fe_2O_3, %	not rated	3.48
4	Content CaO, %	not rated	59.50
5	Content MgO, %	not rated	2.89
6	Content of potassium and sodium oxides in terms of Na_2O (Na_2O+0.658K_2O)	not rated	0.84
7	Insoluble residue content, %	not rated	0.47
8	Content SO_3, %	not more 3.5	2.59
9	Content Cl^-, %	not more 0.10	0.02
	Estimated mineralogical composition of clinker		
10	Content C_3S, %	not rated	67.0
11	Content C_2S, %	not rated	11.0
12	Total contentC_3S и C_2S, %	not less 67.0	78.0
13	Content C_3A, %	not rated	6.4
14	Content C_4AF, %	not rated	12.0
15	Content MgO, %	not more 5.0	1.57
	Physical characteristics		
16	Fineness, %	not rated	8.1
17	Specific surface area, m^2/kg	not rated	304
18	Initial set, min Final set, min	not early 75 not rated	192 235
19	Soundness	not more 10	0.4
20	Water-need, %	not rated	25
	Strength characteristics		
21	Bending strength, MPa, age: – at 2 days – at 28 days	 not rated not rated	 3.8 7.5
22	Compressive strength, MPa, when hardening: – under curing – under normal conditions 2 days – under normal conditions 28 days	 more 30.0 not less 10.0 from 42.5 to 62.5	 31.4 17.2 43.6

Table 2
Specific thermodynamic characteristics of compounds

Compound description	Enthalpy of formation (ΔH^o_{298}), kJ/g	Entropy of formation (S^o_{298}), J/(g • K)
Tricalcium silicate ($3CaO \cdot SiO_2$)	–12.83	0.74
Dicalcium silicate (ß-$2CaO \cdot SiO_2$)	–13.40	0.74
Tricalcium aluminate ($3CaO \cdot Al_2O_3$)	–13.29	0.76
Diopside ($CaO \cdot MgO \cdot 2SiO_2$)	–14.80	0.66
Wollastonite ($CaO \cdot SiO_2$)	–14.10	0.71
Limestone ($CaCO_3$)	–12.06	0.88

Table 3

Chemical composition of calcium-containing additives (according to the manufacturer)

Additives	Chemical composition, % мас.							
	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	R_2O	TiO_2	Loss on ignition
Diopside	26.23	53.44	17.91	0.19	0.08	0.12	0.11	1.90
Wollastonite	34.72	53.43	0.30	3.06	2.34	–	–	6.24
Limestone	54.7	0.5	0.5	0.2	0.1	–	–	40.4

Table 4

Hardness of compounds

Compound	Mohs' hardness
$CaO \cdot MgO \cdot 2SiO_2$ (diopside)	6.5
$CaO \cdot SiO_2$ (wollastonite)	5.0
$CaCO_3$ (limestone)	3.0

95%), the samples were tested at the ages of 1, 3, 7 and 28 days, respectively.

X-ray diffraction pattern of hydrated portland cement of the control composition and with calcium-containing additives were taken on a D8 Advance powder diffractmeter (Bruker AXS, Germany).

The microstructure of the cement stone was studied with the use of Hitachi TM 1000 Hitachi Science Systems Ltd scanning electron microscope. The degree of increase of the microscope is from 20 to 10 000.

The structural characteristics of the hydrated stone were examined with the use of automated mercury porometer (porosimeter) AutoPore IV 9520 from Micromerics (USA).

RESULTS

The results of the calcium-containing additives impact on the strength characteristics of the modified cement stone are shown in Figures 1, 2.

DISCUSSION

The analysis of the obtained experimental data shows that the addition of even a small amount (2%) of the studied calcium-containing additives (wollastonite, diopside, limestone) leads to a significant hardening of the modified cement.

The obtained experimental dependencies on the effect of the type and amount of calcium-containing additives on the kinetics processes of cement composites show that during the initial period of strength gain the greatest strengthening of the material can be achieved by adding limestone. The addition of 2% crushed limestone strengthens the cement stone hardened for 1–3 days up to 20%. In the late periods of strength gain (7–28 days), the greatest hardening of the stone was obtained when wollastonite and diopside were added. The optimal amount of wollastonite from the point of view of strengthening effect was 9%, diopside – 7%. Modification of Portland cement with 9% wollastonite increases the strength to 27.5%. The addition of 7% diopside results in more hardening (up to 48%). The addition of calcium-containing additives in excess of the optimum amount results in the strength decrease of the modified cement stone.

The strengthening effect when wollastonite and diopside are added is associated with the redistribution of stresses in the cement stone under the external forces, which is due to their greater hardness and a greater modulus of elasticity than the hydrated stone.

The hardness of limestone is lower than that of hydrated cement. That is, the effect of the additive is due to other reasons. The addition of limestone is revealed in the process of hydration of the binder by forming a contact zone between the additive particles and the hydrated cement. To do this, X-ray phase analysis of cement stone of a non-filler composition and composition with the addition of limestone was carried out, and their microstructure was also studied.

The diffractograms of cement stone with the most characteristic interplane distances of hydrate phases are shown in Figures 3–4.

The diffractograms of the hydrated stone of the control and limestone modified composition confirmed its impact on the process of crystalline hydrates formation. When modifying cement stone with limestone, the intensity of calcium hydroxide reflexes decreases (d = 0.493; 0.262; 0.192; 0.179; 0.169; 0.148 nm), and the intensity of calcium hydrosilicates reflexes increases (d = 0.310; 0.302; 0.288; 0.277; 0.260 nm). In addition, calcium hydrocarboaluminate reflexes were found in the diffractograms of the modified stone (d = 0.302; 0.288; 0.277; 0.227 nm) and calcium hydrocarbosilicate (d = 0.349; 0.311; 0.288; 0.262; 0.228 nm).

To identify further the strengthening factors of hydrated stone, both the macro and microstructure of cement stone, both non-additive and additive were studied during

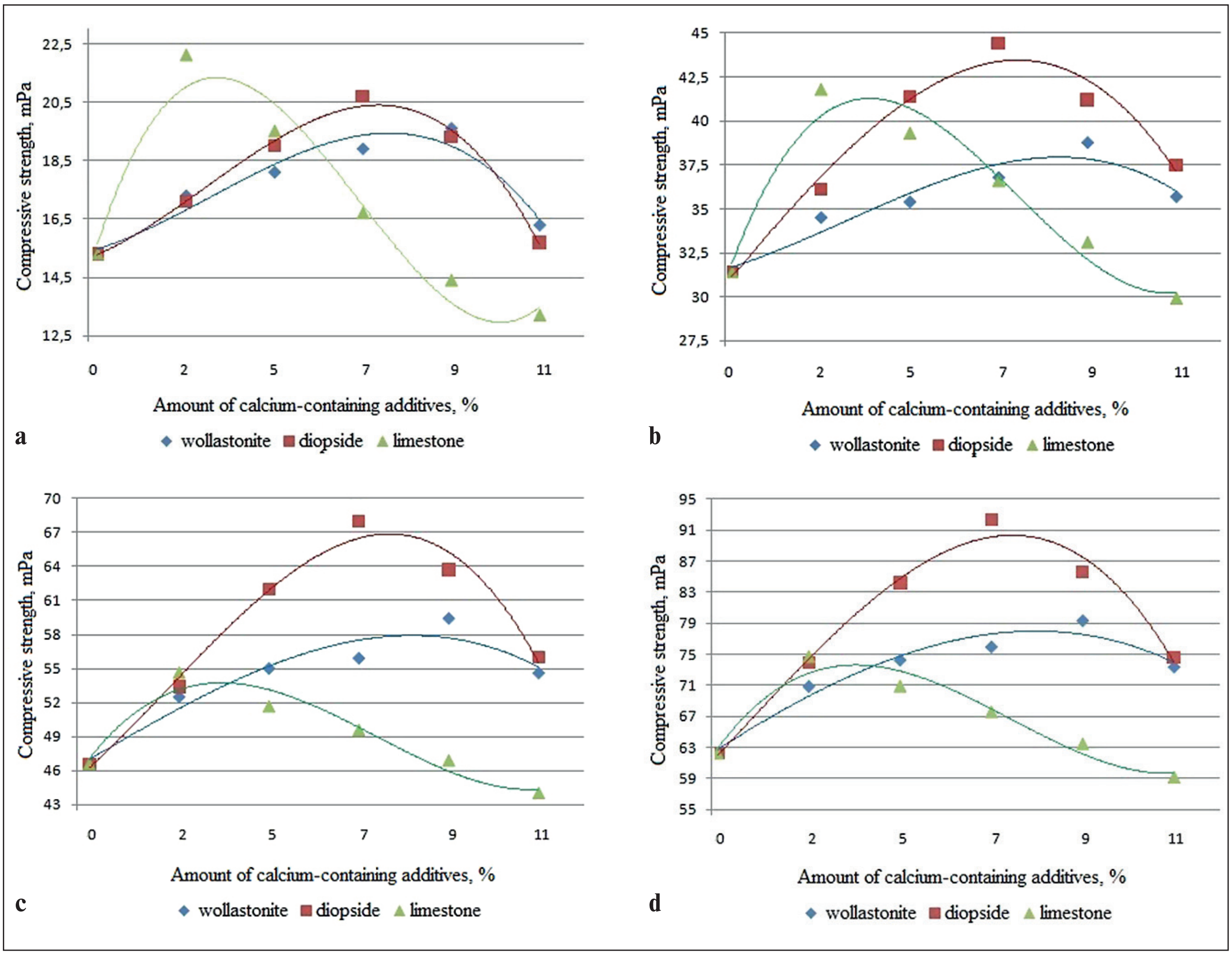

Fig. 1. **Change of cement stone strength at addition of calcium-containing additives. Hardening under regular conditions within the duration of:** a) 1 day; b) 3 days; c) 7 days; d) 28 days

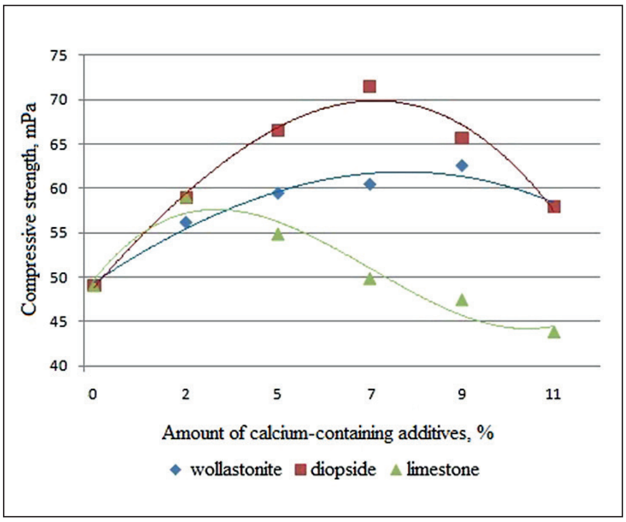

Fig. 2. **Change of cement stone strength at addition of calcium-containing additives. Hardening under steam curing**

the addition of dispersed additives. The macrostructure was evaluated by the nature and pore size of the formed samples. The results are shown in Tables 5 and 6.

The structure of cement stone without additives is porous, it contains a large number of large pores (up to 50 microns in size). Crystalline hydrates are mainly highly basic hydrosilicates with a pore size of 10–15 μm and large ettringite crystals.

The structure of the stone with the additive is denser, homogeneous and finely crystalline. The pore sizes of the modified stone are significantly smaller (0.15 μm or less).

The analysis of the structure porosity showed that when calcium-containing additives are added into the system, the total pore volume decreases, the pore content increases by a size of 0.003–1.2 μm. In this case, the structure of the pores themselves changes, the characteristic length of the pores increases markedly and the tortuosity of the pores significantly decreases. The main part of the pore volume (more than 95%)

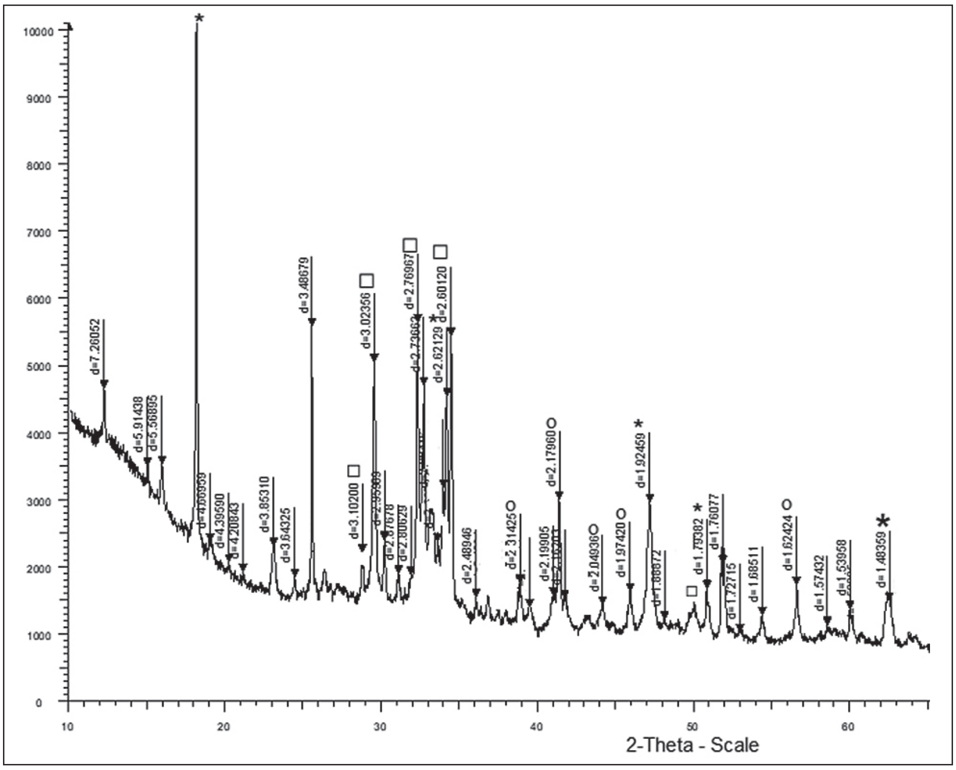

Fig. 3. **Diffractogram of cement stone of plain composition:**
* – $Ca(OH)_2$; □ – C–S–H; ○ – C–A–H; ● – $C_3A \cdot CaCO_3 \cdot 12H_2O$

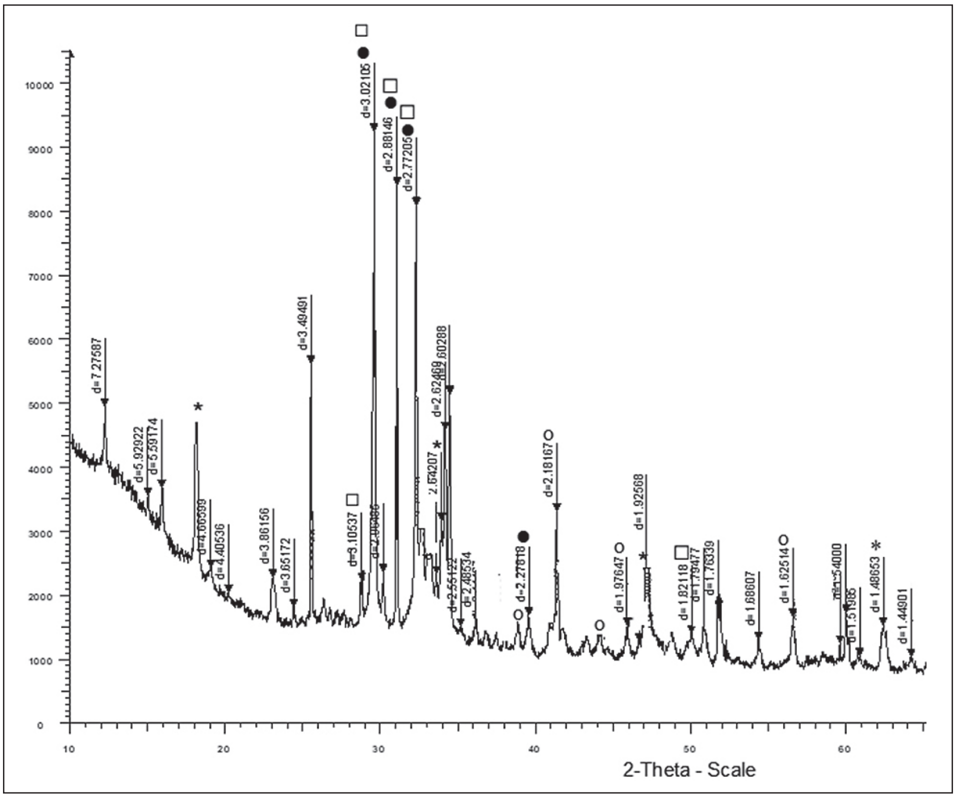

Fig. 4. **Diffractogram of cement stone containing limestone:**
* – $Ca(OH)_2$; □ – C–S–H; ○ – C–A–H; ● – $C_3A \cdot CaCO_3 \cdot 12H_2O$

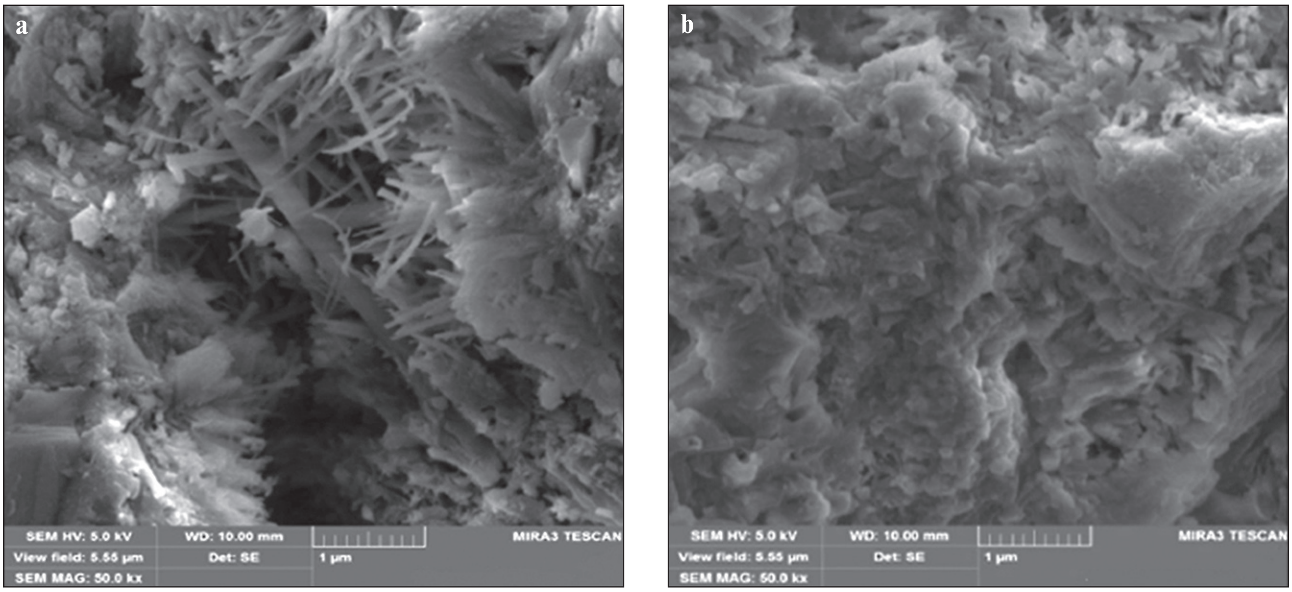

Fig. 5. **The structure of cement stone hardened for 7 days with an increase of 10,000 times:**
a — cement stone of plain composition; b — cement stone with limestone addition

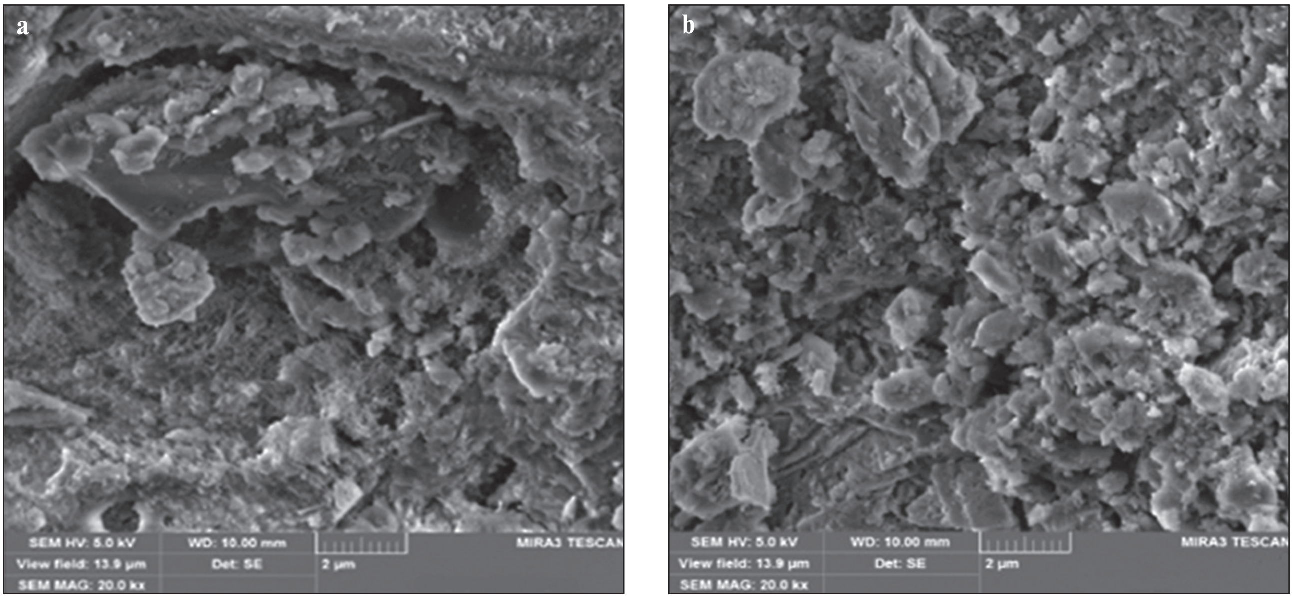

Fig. 6. **The structure of the cement stone hardened for 28 days with an increase of 10,000 times:**
a — cement stone of plain composition; b — cement stone with limestone addition

falls on pores smaller than 0.15 µm. The water in such pores will be in a membranous state, which in turn can lead to an increase in frost resistance of modified cement composites.

Since the modified cement composite has a characteristic pore length that increases and decreases the pore tortuosity, more favorable conditions are created when part of the water is moved to the nearest air inclusions. During the freezing of the liquid, the pressure will not increase inside the concrete.

CONCLUSION

Thus, the following conclusions can be drawn:

1. The increase in stone strength by 20–48% with the addition of the studied calcium-containing additives (limestone, wollastonite, diopside) is due to the proximity of their thermodynamic characteristics and chemical composition with clinker minerals.

2. The greater strengthening effect of diopside addition (up to 48%) is due to the greater hardness and modulus

Table 5

Characteristics of porous structure of hydrated stone

Average pore diameter, μm	Characteristics of porous structure of hydrated stone depending on binder composition							
	Portland cement		Portland cement with 9% wollastonite weight		Portland cement with 7% diopside weight		Portland cement with 1% limestone weight	
	pore volume, ml/g	pore area, m^2/g	pore volume, ml/g	pore area, m^2/g	pore volume, ml/g	pore area, m^2/g	pore volume, ml/g	pore area, m^2/g
73.1–361.0	0.1275	0.003	0.0919	0.002	0.0903	0.002	0.1108	0.003
15.4–73.1	0.0146	0.003	0.0115	0.002	0.0131	0.002	0.0162	0.003
1.2–15.4	0.0164	0.033	0.016	0.029	0.0138	0.026	0.0165	0.031
0.05–1.2	0.036	0.741	0.041	0.944	0.043	0.958	0.039	0.872
0.05–0.15	0.031	4.281	0.035	4.806	0.037	4.824	0.033	4.232
0.003–0.05	0.088	22.456	0.101	24.939	0.105	25.012	0.090	21.865
Total	0.3128	27.517	0.2968	30.722	0.3026	30.824	0.3051	27.006

Table 6

Cement porosity characteristics (summarized data)

Characteristics	Binder composition			
	Portland cement	Portland cement with 1% limestone weight	Portland cement with 9% wollastonite weight	Portland cement with 7% diopside weight
Total pore volume, ml/g	0.3128	0.3051	0.2968	0.3026
Pore volume with diameter less than 0.15–1.2 μm, %	16.4	18.4	19.9	20.3
Pore volume with diameter less than 0.003–0.15 μm. %	32.9	34.6	39.9	41.0
Average pore diameter. μm	0.0571	0.0485	0.0450	0.0407
Characteristic pore length. μm	1.681	6.892	7.634	7.673
Pore tortuosity. rel. units	183.28	33.356	28.498	28.279

of diopside elasticity compared to wollastonite and limestone. The strength at the addition of which increases by 20–27%.

3. Wollastonite having a fibrous structure results in greater hardening of the stone compared to limestone by stone micro-reinforcing.

REFERENCES

1. Akhverdieva TA, Jafarov R. Influence of finely ground mineral additives on concrete properties. Construction materials. 2019;(3):73-6. https://doi.org/10.31659/0585-430X-2019-768-3-73-76

2. Vernigorova VN, Sadenko SM. On non-stationary physical and chemical processes occurring in a concrete mixture. Construction materials. 2017;(1-2):86-9.

3. Nguyen DVK, Bazhenov YuM, Alexandrova OV. Effect of quartz powder and mineral additives on the properties of high-strength concrete. Bulletin of MGSU. 2019;14(1 (124)):102-17. https://doi.org/10.25686/2542-114X.2020.3.7

4. Hafizova EN, Panchenko YuF, Panchenko DA. The use of rock crushing process waste in the development of cement concrete compositions. Bulletin of the Siberian State Automobile and Road University. 2021;18(6 (82)):790-9. https://doi.org/10.26518/2071-7296-2021-18-6-790-799

5. Samchenko SV. Formation and genesis of cement stone structure: monograph. Moscow: Moscow State University of Civil Engineering, IPR Media, EBS DIA; 2016. URL: http://www.iprbookshop.ru/49874.html

6. Rakhimov RZ. Construction complex, ecology and mineral binders. Proceedings of higher educational institutions. Construction. 2022;(2 (758)):5-15. https://doi.org/10.32683/0536-1052-2022-758-2-5-15

7. Berra M, Mangialardi T, Carassiti F, Paolini AE. Effects of nanosilica addition on workability and compressive strength of Portland cement pastes. Construction and Building Materials. 2012;35:666-75. DOI:10.1016/j.conbuildmat.2012.04.132

8. Ilina LV, Mukhina IN, Semenova MM. Hardening cement conglomerates by mining industries waste. Solid State Phenomena. 2021;(316):1061-6. https://doi.org/10.4028/www.scientific.net/SSP.316.1061

9. Ilina L, Mukhina I, Teplov A. Modeling of Cement Activity Increase by Dispersed Mineral. AIP Publishing. Advanced Materials in Technology and Construction. 2016; 1698(070001). DOI: 10.1063/1.4937871

10. Stefanidou M, Papayianni I. Influence of nano-SiO_2 on the cement pastes. Composites Part B: Engineering. 2012;43(6):2706-10. DOI:10.1016/j.compositesb.2011.12.015

11. Nadeem A., Memon S.A., Lo T.Y. Mechanical performance, durability, qualitative and quantitative analysis of microstructure of fly ash and Metakaolin concrete at elevated temperatures. Construction and Building Materials. 2013;38:338-47. https://doi.org/10.1016/j.conbuildmat.2012.08.042

12. Kozlova I.V. Experience in the use of nanoscale particles in the production of building materials. Technique and technology of silicates. 2021;28(3):81-7. Available from: https://tsilicates.ru/2021_tts3

13. Ministry of Natural Resources of Russia. State Report "On the State and Environmental Protection of the Russian Federation in 2018". NIA-Nature. Corporate author. 2019;847.

14. Ilina L., Mukhina I. Dry Building Mixture with Complex Dispersed Mineral Additives. AOP IOP Conference Series: Materials Science and Engineering. 2020;953:012036. https://doi.org/10.1088/1757-899X/953/1/012036

15. Lesovik V.S., Fedyuk R.S., Liseitsev Y.L., Panarin I.I., Voronov V.V. Influence of composition on properties and structure of modified cement composites. Construction materials. 2022;(9):39-49. https://doi.org/10.31659/0585-430X-2022-806-9-39-49

16. Kharchenko A.I., Alekseev V.A., Kharchenko I.Y., Bazhenov D.A. Structure and properties from fine-grained concretes based on composite binders. Bulletin of MGSU. 2019;14(3):322-31. https://doi.org/10.22227/1997-0935.2019.3.322-331

17. Khozin V.G., Tsyganova E.A. The role of the construction industry in the implementation of the federal project "Closed cycle economics". Expert: theory and practice. 2023;1(20):147-159. https://doi.org/10.51608/26867818_2023_1_147

18. Volodchenko A.A., Zagorodnyuk L.H., Prosolova E.O., Akhmed A.A., Kulik N.V. The problem of rational nature management. Bulletin of Belgorod State Technological University named after VG Shukhov. 2014;(6):7-10.

19. Kopanitsa N.O., Demyanenko O.V., Kulikova A.A. Complex additives based on secondary resources for modifying cement compositions. Proceedings of Tomsk Polytechnic University. Georesource engineering. 2023;334(1):136-44. https://doi.org/10.18799/24131830/2023/1/4045

20. Trofimov B.Y., Mahmudov A.M. The structure and properties of hardened cement paste with modifiers. IOP Conference Series: Materials Science and Engineering. 2020;962:022011. https://doi.org/10.1088/1757-899X/962/2/022011

21. Shahova L.D., Chernositova E.S., Schelokova L.S., Uhaneva N.G. Influence of technological additives on the characteristics of cement powders. In: Digital Technologies in Construction Engineering. Selected Papers. Lecture Notes in Civil Engineering. 2022. p. 259-65. https://doi.org/10.1007/978-3-030-81289-8_33

22. Kozlova V.K., Wolf A.V., Manoha A.M., Kishitsky A.A. The role of carbonate additives in the processes of hydration and hardening of composite portland cement. Polzunovsky almanac. 2021;(1):74-6.

23. Ilina L., Kudyakov A., Rakov M. Aerated dry mix concrete for remote northern territories. Magazine of Civil Engineering. 2022;(5):11310. https://doi.org/10.34910/MCE.113.10

24. Samchenko S.V., Kaprielov S.S., Dykin I.V. Optimization of the structure and properties of powder-activated concrete by using portland cement of various dispersity. Technique and technology of silicates. 2022;29(1):64-74. Available from: https://tsilicates.ru/2022_tts1

INFORMATION ABOUT THE AUTHORS

Lilia V. Ilina – Dr. Sci. (Eng.), Professor, Department of Construction Materials, Standardization and Certification, Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, Russia, nsklika@mail.ru,
https://orcid.org/0000-0002-8520-4453

Svetlana V. Samchenko – Dr. Sci. (Eng.), Professor, Head of the Department of Construction Materials Science, National Research Moscow State University of Civil Engineering, Moscow, Russia, samchenko@list.ru, https://orcid.org/0000-0002-3523-593X

Mikhail A. Rakov – Cand. Sci. (Eng.), Associate Professor, Department of Construction Materials, Standardization and Certification, Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, Russia, westcoast89@mail.ru, https://orcid.org/0000-0001-9032-8138

Dmitry A. Zorin – Cand. Sci. (Eng.), Associate Professor, Department of Construction Materials Science, National Research Moscow State University of Civil Engineering, Moscow, Russia, kafSM@mgsu.ru, https://orcid.org/0000-0001-5464-2314

CONTRIBUTIONS OF THE AUTHOR

Lilia V. Ilina – scientific guidance, concept development and development of the research methodology; processing and analysis of experimental data; systematization of experimental data; drawing up final conclusions; literature review.

Svetlana V. Samchenko – participation in the development of a scientific concept; processing and analysis of experimental data; finalization of the text.

Mikhail A. Rakov – conducting the experimental part; graphical and tabular representation of the study results; processing and analysis of experimental data using machine learning methods.

Dmitry A. Zorin – concept development and development of the research methodology.

The authors declare no conflicts of interests.

The article was submitted 02.09.2023; approved after reviewing 04.10.2023; accepted for publication 09.10.2023.