Л.Н. Гумилев атындағы Еуразия ұлттық университетінің ХАБАРШЫСЫ.
ISSN: 2616-7263. eISSN: 2663-1261
ТЕХНИКАЛЫҚ ҒЫЛЫМДАР ЖӘНЕ ТЕХНОЛОГИЯЛАР СЕРИЯСЫ / TECHNICAL SCIENCES AND TECHNOLOGY SERIES/ СЕРИЯ ТЕХНИЧЕСКИЕ НАУКИ И ТЕХНОЛОГИИ

IRSTI 67.09.33
https://doi.org/10.32523/2616-7263-2025-153-4-35-52
Article

Study of the structure of hydration products of cement stone with hyperplasticizer and silica microfillers

I. Abdraimov[1], K. Musa[1], Yu. Pukharenko[2], M. Sailygarayeva[3]*

[1] Mukhtar Auezov South Kazakhstan University, Shymkent, Kazakhstan,
[2] Saint Petersburg State University of Architecture and Civil Engineering, Saint Petersburg, Russian Federation,
[3] Kazakh National Research Technical University, Almaty, Kazakhstan,

E mail: abdraimov_ilyas@mail.ru, tsmm@spbgasu.ru,mariya_23365@mail.ru

Abstract. In this paper, the combined effect of active silica fillers of technogenic and natural origin and polycarboxylate superplasticizer on the structure of the cement matrix was investigated in order to increase its microporosity. It was found that the dispersion of filler particles, the amorphization of the structure and components, are due to the effect of chemical energy on the molecular and surface crystallization structure of binder particles. Studies on the combined introduction of silica and plasticizer in the composition of mortar mixtures make it possible to increase the content of the pozzolanic additive to 15% of the binder weight, which helps to reduce cement consumption, while simultaneously optimizing the microstructure of the cement stone and further obtaining concrete with high construction and technical characteristics. As part of the study, a detailed microstructural study of the cement stone was carried out to analyze the hydration products in the presence of polycarboxylate plasticizers and active silica fillers. The obtained results show that the introduction of 10-15% of plasticizer and silica filler into the mortar mixture leads to a decrease in the content of portlandite in the cement system, a decrease in the size of its crystals, filling of the intergranular space, as well as compaction and strengthening of the structure of the cement stone. Thus, the proposed approach ensures the effective use of pozzolanic additives, increasing the operational properties of concrete and reducing the consumption of expensive cement.

Keywords: hyperplasticizer, silica microfillers, hydration products, cement stone, cement structure.

Received 10.02.2025. Revised 8.04.2025.Accepted 15.05.2025.Available online 30.12.2025

* the corresponding author

Introduction

Increasing the durability and improving the operational reliability of cement stone are among the priority areas of modern research in the field of materials science. These goals can be achieved by reducing the microporosity of the structure to minimize water filtration through cavitation channels. In this regard, an active search for effective materials continues, including polymer compositions with high resistance to aggressive environmental influences. However, the use of the proposed polymer compositions is often associated with the use of expensive chemical components, which limits their widespread implementation in the construction industry [1]. One of the most accessible and promising areas for regulating the construction and technical properties of concrete, as well as reducing material and energy costs, is the introduction of various additives into their composition, which are often considered in the scientific literature as modifiers of the structure and properties of cement systems. The optimal dosage of such additives is determined by their minimum amount, ensuring the achievement of the required regulatory indicators [2] and technological or technical efficiency without deterioration or with an acceptable decrease in other quality characteristics of concrete or mortars. Depending on their origin and functional purpose, additives are divided into chemical and mineral.

Chemical additives, including organic and inorganic compounds, are introduced into cement systems (concretes and mortars) in relatively small quantities (usually within 0.02–2% of the cement mass). However, despite the low concentration, they have a significant effect on the hydration processes of clinker minerals and the structure formation of cement stone. The use of such additives allows for targeted modification of the properties of hardened mortars and concretes, ensuring their compliance with specified operational requirements [3].

Mineral additives are dispersed inorganic materials of natural, technogenic, or artificial origin, which are introduced into concrete and mortar mixtures in quantities from 5 to 20% or more. Using them allows cement consumption and aggregate consumption to be reduced, and the production of high-density concrete to be produced with minimal binder consumption. In addition, mineral additives increase the resistance of concrete to external influences and serve as an effective means of recycling industrial waste, such as ash and slag from thermal power plants, ash and slag from the combustion of solid municipal waste, blast furnace granulated slag and other industrial by-products [4].

It should be noted that complex modifying additives containing various organic and mineral components not only provide wide controllability of the rheological and technological properties of mortar and concrete mixtures, but also help to optimize the microstructure of cement stone. This, in turn, makes it possible to obtain concrete with improved construction and technical characteristics, including strength, durability and resistance to external influences. [5].

Studies devoted to the combined effect of amorphous silica and superplasticizer in the composition of powder concrete [6] are of particular interest. These concretes are characterized by high compressive strength (up to 150 MPa), as well as increased crack resistance and water resistance. According to P.A. Rebinder, the presence of surface-active substances (SAS) contributes to an increase in the filler activity. The dispersion of its particles, amorphization of the structure and components are due to the influence of chemical energy on the molecular and surface crystallization structure of the binder particles. The introduction of SAS into the system prevents the aggregation of highly dispersed microfiller particles, protecting the structure from the aggressive effects of the external environment and helping to maintain the activity of the material during storage. [7].

The purpose of this study was to investigate the microporous structure in the cement-filler system and the effect of active silica fillers of technogenic and natural origin on the structure of the cement matrix. As part of the work, an analysis of the influence and mutual action of a complex modifier in various percentage ratios in filled cement systems was carried out. The calculated content of the mineral component of the solution mixture was determined with the identification of factors contributing to the formation of a densely packed structure of the material and, accordingly, an increase in its performance characteristics. It has been established that the increase in the density of cement composites at the optimal level of filling with mineral components is due to a number of factors. These include the orienting effect of filler particles on cement hydration products in the presence of polycarboxylate chains and the formation of cluster structures, the use of materials with a similar crystal-chemical structure, the formation of additional chemical bonds when introducing pozzolanic additives, and a reduction in the porosity of the material [8].

Table 1. Chemical composition of portland cement (according to LLP Shymkentcement [9])

Cement brand	Manufacturer	Chemical composition, wt.%						
		Na_2O	SO_3	MgO	Fe_2O_3	CaO	Al_2O_3	SiO_2
CEM I 42.5N	Shymkentcement LLP	0.57	0.65	0.92	4.05	64.79	5.11	23.91

Portland cement grade CEM I 42.5N, which meets the established requirements [9], was used as a hydraulic binder. Cement was produced by Shymkentcement LLP, located at the following address: Shymkent, St. Koikeldi Batyr St., 22. The characteristics of the cement used and the results of experimental tests of its properties are shown in Tables 1–2.

Table 2. Mineral composition of Portland cement clinker (according to LLP Shymkentcement [10])

Cement brand	Mineral content in clinker, %			
	C_4AF	C_3A	C_2S	C_3S
CEM I 42.5N	10.56	6.86	11.69	60.99

Analysis of the obtained test results showed that the studied cement complies with the requirements of [10]. Natural sand mined in the Akdala quarry, located at the following address: Asar-2 microdistrict, Syrym Batyr Street, 175/2, was used as fine aggregate for the mortar part. The properties of the sand were tested using the methods described in [11]. The results of the fine aggregate tests are presented in Table 3, and the chemical composition is presented in Table 4. Interms of clay and dust impurity content, granulometric composition and radiatio n-hygienic assessment, this sandmeets the established requirements [11]. Mixing water meets the requirements of [12]. The water does not contain sulfates over 2700 mg/l (in terms of SO_4), all salts over 5000 mg/l, oil sludge and scale, organic matter content less than 12 mg/l, pH 7.7 and no color

Table 3. Sand test results (according to Akdala quarry [11])

Manufacturer	Sand characteristics				
	True density, kg/m^3	Fineness modulus	Bulk density, kg/m^3	Specific effective activity of natural radionuclides, Bq/kg	Content of clay and dust particles, %
Quarry "Akdala"	2610	2.45	1470	71.3	1.7

The products of NEOCHIM LLP, located at the address: Shymkent, Enbekshinsky district, block 264, building, were used as a superplasticizer. In terms of its consumer properties, the additive "NEOCHIM" meets the requirements [13].

Table 4. Chemical composition of sand (according to LLP Joint Venture "Southern Mining and Chemical Company" [11])

Manufacturer	Main oxides, %								
	SiO_2	Al_2O3	Fe_2O3	CaO	MgO	SO_3	K_2O	Na_2O	p.p.p.
Limited Liability Partnership "Joint Venture "Southern Mining and Chemical Company"	70.9	16.37	2.68	2.49	0.69	0.01	3.29	2.77	1.09

The additive "NEOCHIM" is a plasticizing and water-reducing additive based on a mixture of polyoxylene derivatives of polycarboxylic acids, surfactants. The standardized physical and chemical indicators are presented in Table 5.

Table 5. Physicochemical properties of the additive (according to NEOCHIM LLP [13])

Name of the indicators	Hyperplasticizer "NEOCHIM"
Appearance	homogeneous aqueous solution of light brown color
Density at 20˚C, g/cm^3, not less than 1.05	1.05
Hydrogen ion activity index (pH), not less than 4.2	4.2
Mass fraction of chlorine ions, %, not more than 0.1	0.1

It is used for the production of self-compacting commercial concretes that harden under normal conditions or with the use of electric heating. Dust waste (MKU-95) produced by LLP "Tau Ken Temir", registered at the address: Karaganda, Oktyabrsky district, accounting quarter 018, Building 133, was used as a reaction-chemical pozzolanic additive.

This dust from electrostatic precipitators of ferrosilicon production has particle sizes of 5-50 microns. Under the influence of high temperature, silica microparticles are transformed into glassy amorphous dust. The qualitative characteristics of microsilica MKU-95 are presented in Table 6.

Table 6. Qualitative characteristics of microsilica grade MKU-95 (according to LLP "Tau Ken Temir"[14])

Name of indicators	Qualitative characteristics
Mass fraction of silicon dioxide, %, not less than (SiO_2)	95.06
Mass fraction of phosphorus oxide (P_2O_5), %, not more than, %	0.12
Mass fraction of magnesium oxide (MgO), %, not more than	0.6
Mass fraction of aluminum oxide (Al_2O_3), %, not more than	0.17
Mass fraction of iron oxide (Fe_2O_3), %, not more than	0.19
Mass fraction of sulfuric anhydride (SO_3), %, not more than	0.41
Mass fraction of calcium oxide (CaO), %, not more than	0.41
Mass fraction of free alkalis (Na_2O, K_2O), %, not more than	1.71
Mass fraction of water, %, not more than	0.29

In terms of its properties, microsilica "MKU-95" meets the requirements of [14].

Opoka containing silica particles from the Taskalinskoye deposit was studied as the second active filler. The opoka from this deposit has the following chemical composition (Table 7).

Table 7. Chemical composition of opoka from the Taskalinskoye deposit (according to Taskalinskoye deposit [15])

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Opoka	87.02	10.58	3.84	4.73	2.45	1.90

Amorphous-siliceous opoka is composed in the overwhelming majority of amorphous silica, provided in the form of globules and spicules of sea sponges, radiolarians, shells, etc. The characteristics of opoka, which opoka must meet as an additive-filler, are indicated in Table 8.

Table 8. Characteristics of the flask (according to the Taskalinskoye deposit [15])

Indicator	Indicator Value		
	Minimum	Maximum	Average
Specific weight, N/m^3	$22.27 \cdot 10^3$	$24.13 \cdot 10^3$	$23.15 \cdot 10^3$
Density (in a piece), kg/m^3	1050	1665	1240
Water absorption, %	15.34	41.00	25.00
Compressive strength, MPa, in the state:			
Dry	6.239	14.09	9.49
Water-saturated	44.9	11.47	6.61
Frost resistance	25	37	31

ISSN: 2616-7263. eISSN: 2663-1261

In terms of its properties, the Opoka of the "Tascalinskoye deposit" meets the requirements of [15]. The Opoka selected for testing was subjected to preliminary grinding until a specific surface of 1700-1850 cm2/g was achieved in a laboratory ball mill BS-BALLMILL-I with a rotation range of up to 200 rpm.

The methodology

A series of tests were conducted using Professor Okamura's method to determine the cone spread with an initial water to binder ratio of 0.4 and 1% superplasticizer from the amount of binder with different dosages of mineral additives. The ratio was obtained experimentally by determining the cone spread of cement paste with different Water/MDS ratios. The dependence of the cone spread and the Water/MDS ratio is expressed through the ratio of the "final" spread area to the "initial" area, called the "relative" spread area. (Figure 1).

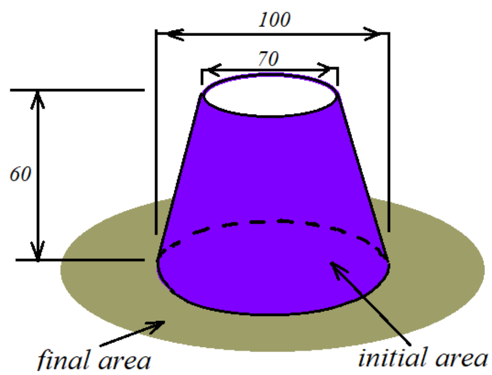

Figure 1. Truncated cone for determining the spread of cement paste (Okamura H., Ozava K. Mix design for self-compacting concrete // Concrete Library of the JSCE. 1995. № 2. P. 107-120)

The task was to obtain a mixture of water, binder, and superplasticizer, which during testing would show a flow cone of 244-246 mm, the flow time through the funnel of 9-11 seconds [16].

Table 9. Effect of the amount of microsilica additive MKU on the rheology of cement-sand mixture

Main composition *	Cement, kg	Quantity of microsilica from cement mass, %	Quantity of microsilica from cement mass, kg	Quantity of superplasticizer, kg	Flow (mm)	Flow time, sec
Sand-900 kg, Water-0.4 from cement	600	0	0	6	265	7
	570	5	30	6	261	8
	540	10	60	6	253	9
	510	15	90	6	245	10
	480	20	120	6	237	12
	420	30	180	6	231	14

*All data are given based on the number of components per 1 m^3 of concrete or mortar mixture

Microstructure study:

To analyze the microstructure of the material, studies were carried out on grinding samples aged for 28 days. The study was carried out using a ZEISS Axio Vert.A1 microscope (Germany) using the reflectivity microphotography method at a magnification of ×500. In addition, X-ray phase analysis (XRD) was used to study the phase composition of the cement stone hydration products and assess the content of minerals. The analysis was carried out on a D2 PHASER powder X-ray diffractometer from Bruker, made in the USA. The analysis was decoded using DIFFRAC.EVA software, which provides tools for rapid analysis of one-dimensional and two-dimensional diffraction data. It supports all Bruker detectors and X-ray scanning types. EVA functionality covers a wide analytical spectrum from data processing, basic scan evaluation and presentation, detailed peak analysis, phase identification and quantitative analysis to crystallinity and crystallite size determination [17].

Table 10. Effect of the amount of flask additive on the rheology of cement-sand mixture

Main composition*	Cement, kg	Quantity of opoka from cement mass, %	Quantity of opoka from cement mass, kg	Quantity of superplasticizer, kg	Flow (mm)	Flow time, sec
Sand-900 kg, Water-0.4 from cement	600	0	0	6	265	7
	570	5	30	6	246	9
	540	10	60	6	232	12
	510	15	90	6	227	14
	480	20	120	6	213	17
	420	30	180	6	205	20

*All data are given based on the number of components per 1 m^3 of concrete or mortar mixture

Table 11. Compressive strength indices of mortar samples with microsilica MKU and opok O at the ages of 1 day and 28 days

Cement	Quantity of filling, %	Quantity of filling, kg	MKU-1day	MKU-28 days	O-1 day	O-28 days	Without additive-1	Without additive-28
600	0	-	-	-	-	-	11.2	37.7
570	5	30	-	-	11.5	38.1	-	-
540	10	60	-	-	-	-	-	-
510	15	90	12.8	40.7	-	-	-	-

Generalized data on the rheological properties of the solution using different quantities of two silica fillers are given in Tables 9-10.

From the tables reflecting the rheological characteristics of the obtained solutions, it is evident that the best effect is achieved by replacing 15% of the cement with microsilica.

Then, from the mortar mixtures that showed the required values of cone spread and flow through the funnel, samples were formed, which were tested for compressive strength according to [18] after 1 day and 28 days. The results of the compressive strength tests of mortar samples with microsilica, opokal and metakaolin at the ages of 1 day and 28 days are presented in Table 11.

The strength characteristics of the mortar samples show that the best effect is achieved by replacing part of the cement with 15% microsilica, which is consistent with the studies of Kaprielov S.S. and Sheinfeld A.V., where the recommended consumption of microsilica is 15–20% of the mass of the binder per 1 m^3 of concrete [19].

Findings/Discussion

As a result of studying the microstructure of the samples using a ZEISS Axio Vert.A1 electron microscope using the reflection method, the following data were obtained.

Figure 2 shows an image of the fracture microstructure of a control sample made of pure cement.

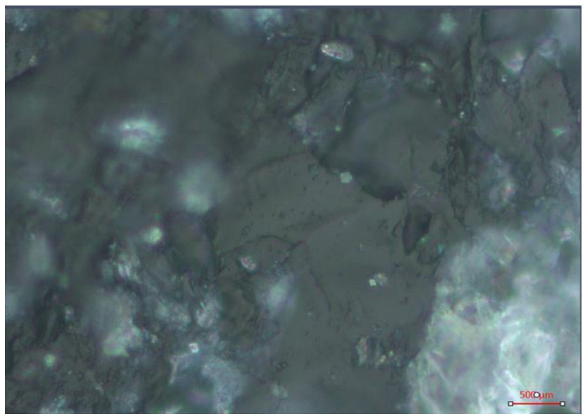

Figure 2. Microstructure of the fracture of a control sample made of pure cement

Figure 2 shows that the structure of cement stone is not monolithic and has a block structure. It is represented by weakly crystallized layers of highly basic metastable hydrosilicate particles ($CaO\ SiO_2\ H_2O$) with molar ratios $CaO/SiO_2 > 1.5$ (C_2SH_2).

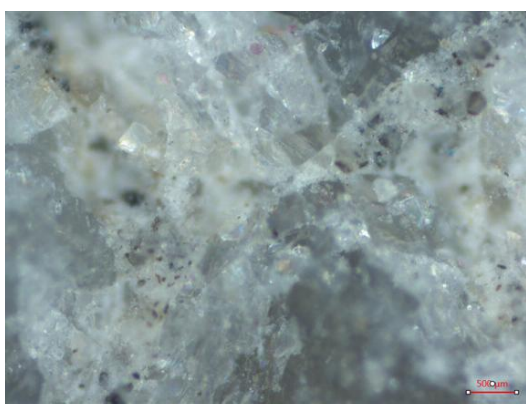

Figure 3. Microstructure of a fracture of a cement stone sample containing Opoku from the "Tascalinskoye deposit."

These new formations, which have increased basicity, are prone to coagulation; water molecules retained by adsorption processes are located inside their structure. Evaporation of both adsorbed water and water located in the crystal lattice is accompanied by shrinkage of the system,

which corresponds to the data presented in [20]. Figure 3 shows that the hydraulic activity of the opal-chalcedony gaize causes chemical interactions of the amorphous silica included in its composition with the hydroxide components formed during cement hydration as a result of hydrolysis of $3CaO\ SiO_2$ according to the equation:
$2(3CaO\ SiO_2) + 6H_2O \rightarrow 3CaO\ 2SiO_2\ 3H_2O + 3Ca(OH)_2$.

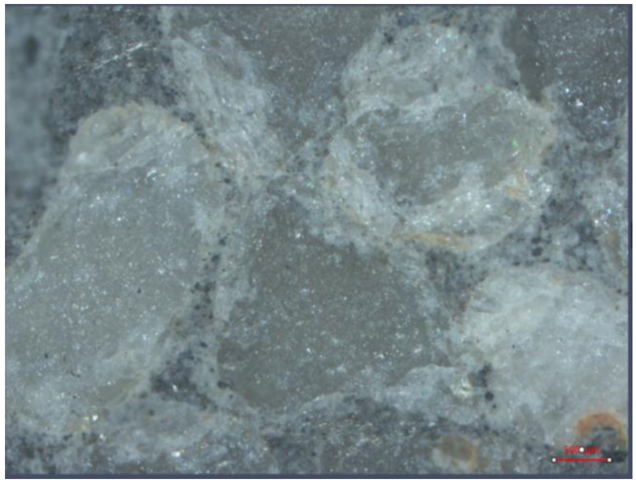

Figure 4. Microstructure of a fracture of a cement stone sample containing microsilica MKU-95

As a result, low-basic calcium hydrosilicates of the C-S-H (B) type, hydroaluminates 3CaO*Al2O3*6H2O and calcium hydroferrites CaO*Fe2O3 *nH2O are formed. The new formations have the appearance of thin fibers, plates and petals of irregular shape [21].

Figure 4 shows that cement stone with the addition of microsilica MKU-95 has a pronounced homogeneous structure in comparison with cement stone without additives. The reaction of the hydration products of clinker minerals and active microsilica is a compound of $Ca(OH)_2$ with active SiO_2, resulting in the formation of a structure composition with the densest packing of crystals, forming elements of low-basic calcium hydrosilicates of the CSH (B) type, for example ($Ca_5(OH)_2Si_6O_{16}$•$4H_2O$ ($CaO/SiO_2 < 1.5$)), which is confirmed by the theoretical provisions set out in [22].

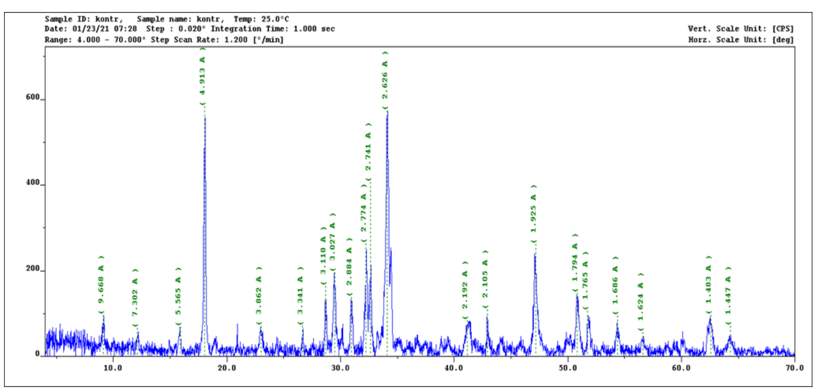

Figure 5. Control sample without mineral additive

Next, to assess the influence of mineral additives on the phase composition of cement stone hydration products, the X-ray phase analysis (XPA) method was used using a D2PHASER powder X-ray diffractometer from Bruker, manufactured in the USA (Fig. 5-7).

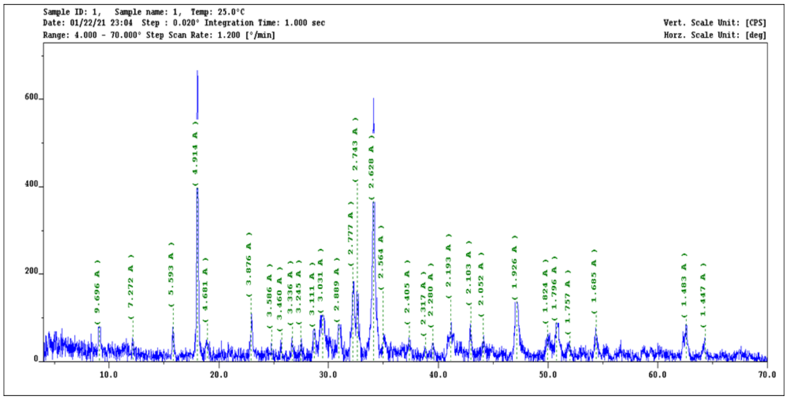

Figure 6. Sample with replacement of part of the cement with microsilica MKU

Using the DIFFRAC.EVA software, an analysis of the obtained diffraction patterns was performed, which confirmed the formation of low-basic hydrosilicates present in the studied samples, as shown in Tables 12-13.

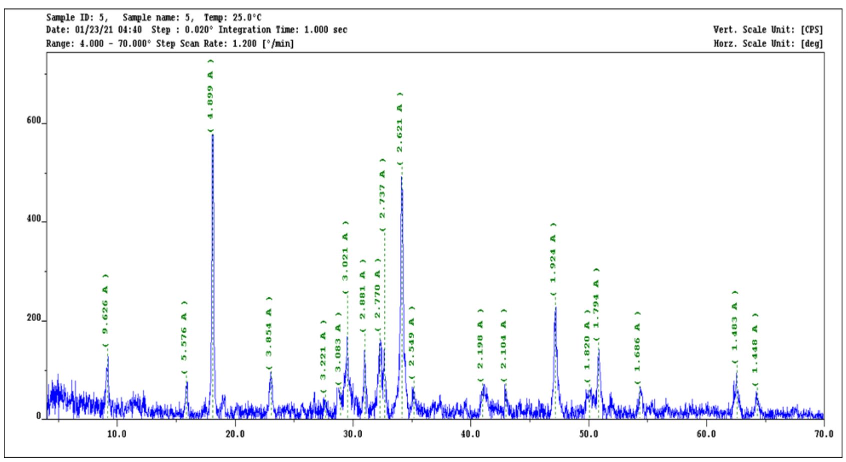

Figure 7. Sample with replacement of part of the cement of the Opoka of the “Tascalinskoye deposit”

Table 12. Phase composition of cement stone at the age of 28 days of normal hardening

Composition No	Cement stone	Phase composition of cement stone, %			
		C_3S	C_2S	$Ca(OH)_2$	Degree of hydration
1	Control	19.6	8.8	21.6	75
2	PC+MKU	14.7	7.4	16.8	82
3	PC+O	14.2	7.2	16.3	78

ISSN: 2616-7263. eISSN: 2663-1261

Analysis of the phase composition showed that partial replacement of cement with microsilica (composition 2) promotes the intensification of hydration processes and the binding of the resulting Ca $(OH)_2$ hydroxide with microsilica. As a result, a decrease in the content of minerals C_3S and C_2S is observed compared to composition 1, with this degree of hydration increasing from 70% to 82%. When replacing part of the cement, the flask (composition 3) occupies an intermediate position between the control composition 1 and composition 2 in terms of the degree of hydration and phase composition of new formations. This also indicates a reduced content of minerals C_3S and C_2S, which leads to compaction of the structure of the cement stone and an increase in its strength [23].

Analysis of the diffraction pattern shows the general theory outlined in [24] and [25] that a significant amount of highly stable low-base hydrosilicates and hydroaluminates are formed when using active mineral additives. A special feature is that in the control sample No. 1, containing only cement, the formation of only three low-base hydrosilicates was recorded, whereas in the samples with active mineral additives (No. 2 and 3) their number increased to 5–6 (Table 13).

Table 13. Content of calcium hydrosilicates in the studied samples of modified cement stone at the age of 28 days of normal hardening

Sample	Conventional designation	Calcium hydrosilicates
Control	1	Tobermorite $Ca_2H_3O_{11}Si_3$ Klinotobermorite $Ca_5H_8O_{21}Si_6$ Katoite $Al_2Ca_3H_{12}O_{12}Si_3$
PC+MK	2	Gergeyite $Ca_5H_2K_2O_{25}S_6$ Katoite $Al_2Ca_3H_{12}O_{12}Si_3$ Tobermorite $Ca_2H_3O_{11}Si_3$ Klinotobermorite $Ca_5H_8O_{21}Si_6$ Killalaite $Ca_2H_6O_{11}Si_3$ Phoshagite $Ca_4H_2O_{11}Si_3$
PC+O	3	Katoite $Al_2Ca_3H_{12}O_{12}Si_3$ Calcium hydroferrite $4CaOFe_2O_3n+3H_2O$ Lumontite $Al_4Ca_2H_{18}O_{33}Si_8$ Klinotobermorite $Ca_5H_8O_{21}Si_6$ Rosenhanite $Ca_3H_210Si_3$

This indicates an intensification of hydration processes in the cement stone, as well as a more active crystallization of the colloidal system in the active components SiO_2 and $Al_2O_3{\cdot}2SiO$.

Conclusion

Based on the results of the tests, the following conclusions can be made:

1) The mixture with partial replacement of cement with opal-chalcedony opoka is the least homogeneous structure, which contains both calcium hydrosilicates and hydroaluminates and hydroferrites, which is confirmed by the data of differential thermal analysis (DTA) and microstructural studies. The revealed heterogeneity can negatively affect the operational reliability of concrete and lead to a decrease in its strength characteristics due to the uneven distribution of hydration products and a possible increase in local zones of increased porosity.

2) The mixture with microsilica demonstrated a more homogeneous microstructure, and low-basic hydrosilicates of the CSH(B) type are widely represented here. This effect is due to the complex influence of the microfilling of the system, which leads to optimization of the grain composition and a decrease in the defectiveness of the structure, as well as high pozzolanic activity of microsilica. It binds calcium hydroxide, $Ca(OH)_2$, and increases the degree of hydration of cement minerals, which contributes to the formation of a denser and stronger structure of cement stone. 3) The introduction of active mineral fillers leads to an increase in the number of fine particles in the cement paste, which contributes to the formation of a denser microcapillary structure of cement stone and a significant decrease in the volume of micropores, reducing its permeability. During the hydration process, capillary pores are gradually filled with new formations, which allows for an increase in the volume of gel pores while simultaneously reducing the total pore space and average pore diameter. As a result, the viscosity of the concrete mixture increases, which has a beneficial effect on its workability. In addition, the use of active mineral additives helps to increase the compressive strength of concrete, reduce the number and size of large portlandite crystals at phase boundaries, and moderately reduce the total porosity, which can ultimately improve the performance characteristics of concrete.

The contribution of the authors.
Abdraimov Ilyas – concept, methodology, resources
Musa Kuttybay – data collection, testing
Yuri Pukharenko – modeling, analysis, visualization
Mariya Sailygarayeva – interpretation, drafting, editing

References

1. Gesoglu, M; Güneyisi, E.; Oznur Oz, H.; Taner, Y.; Taha, I. Durability and Shrinkage Characteristics of Self-Compacting Concretes Containing Recycled Coarse and/or Fine Aggregates. August 2015. Advances in Materials Science and Engineering. DOI: https://doi.org/10.1155/2015/278296 Surname A and Surname B 2009 Journal Name 23 544.
2. Usanova, K.; Barabanshchikov, Y.; Krasova, A.; Akimov, S.; Belyaeva, S. Plastic Shrinkage of Concrete Modified by Metakaolin. Magazine of Civil Engineering 2021, 103, 1–15, doi:10.34910/MCE.103.14
3. Cheah, C.B.; Chow, W.K.; Oo, C.W.; Leow, K.H. The Influence of Type and Combination of Polycarboxylate Ether Superplasticizer on the Mechanical Properties and Microstructure of Slag-Silica Fume Ternary Blended Self-Consolidating Concrete. Journal of Building Engineering 2020, 31, https://doi.org/10.1016/j.jobe.2020.101412 /
4. Güneyisi, E.; Gesoglu, M; Booya, E.; Mermerdas, K. Strength and permeability properties of self-compacting concrete with cold bonded fly ash lightweight aggregate. Construction and Building Materials. Volume 74, 15 January 2015, P. 17-24 https://doi.org/10.1016/j.conbuildmat.2014.10.032
5. Aitcin P.C. High-Performance Concrete. – London: E&FN SPON. – 1998. – 364 p. https://ru.scribd.com/document/618856021/High-Performance-Concrete
6. Kalashnikov V.I. Fine-dispersed rheological matrices and powder concrete of new generation. Collection of articles of the International Scientific and Practical Conference "Composite

Building Materials. Theory and practice". - Penza. - 2007. - p. 9-18. https://engstroy.spbstu.ru/userfiles/files/2012/8(34)/07.pdf
7. Utepov, Y.; Akhmetov, D.; Akhmatshaeva, I. Effect of Fine Fillers from Industrial Waste and Various Chemical Additives on the Placeability of Self-Compacting Concrete. Computers and Concrete 2020, 25, 59–65, https://doi.org/10.12989/cac.2020.25.1.059
8. Elyamany, H.E.; Abd Elmoaty, A.E.M.; Mohamed, B. Effect of Filler Types on Physical, Mechanical and Microstructure of Self Compacting Concrete and Flow-Able Concrete. Alexandria Engineering Journal 2014, 53, 295–307, https://doi.org/10.1016/j.aej.2014.03.010
9. EN 197-1:2011 Cement - Part 1: Composition, Specifications and Conformity Criteria for Common Cements; 2011; p. 38; https://standards.iteh.ai/catalog/standards/cen/64d327b1-d5ac-45e3-8b04-fafec9e0698e/en-197-1-2011?srsltid=AfmBOooXnn984NiZaAXeFnksHAMxfxU4Ifjp6W-1tiQia-eN1iPIZizr
10. EN 196-2:2013 Method of Testing Cement - Part 2: Chemical Analysis of Cement; 2013; p. 73; https://standards.iteh.ai/catalog/standards/cen/47283941-90a2-43dc-8b2c-dea6208712a6/en-196-2-2013?srsltid=AfmBOoq9kREAKPll32Qt5eE3eVjcRb0XftnRfXMs_3KZCwMLn7dlSDYZ
11. GOST 8736-2014. Sand for Construction Works. Specifications; 2014. https://files.stroyinf.ru/Data2/1/4293767/4293767502.pdf
12. ST RK GOST R 51232-2003. WATER. General requirements for organization and methods of quality control. 2003 г. https://online.zakon.kz/Document/?doc_id=30015745&pos=2;-112#pos=2;-112
13. GOST 30459-2008. Admixtures for Concretes and Mortars. Determination and Estimate of the Efficiency; 2008. https://files.stroyinf.ru/Index2/1/4293818/4293818440.htm
14. EN 13263-1:2005+A1:2009 Silica Fume for Concrete—Part 1: Definitions, Requirements and Conformity Criteria; 2009; p. 23; https://www.intertekinform.com/preview/98703412427.pdf?sku=870053_SAIG_NSAI_NSAI_2068874&srsltid=AfmBOooIG83UBYye4Z51wFzcbv5KTCkVkPvvbXjGN6v6mRiBHJBWh9x3
15. GOST R 56593-2015 "Mineral additives for concrete and mortars" https://meganorm.ru/Data2/1/4293759/4293759239.pdf
16. Okamura, H.; Ouchi, M. Self-Compacting Concrete. ACT 2003, 1, 5–15, http://dx.doi.org/10.3151/jact.1.5
17. Bruker. X-Ray Diffraction. https://www.bruker.com/en/products-and-solutions/diffractometers-and-x-ray-microscopes/x-ray-diffractometers/diffrac-suite-software/diffrac-eva.html
18. Riad, D.; Mohamed Larbi, M. Acceleration of the Hardening of Concrete Made with Mineral Admixtures by Using a Heat Treatment Process. Journal of Materials Science and Engineering 2014, A4, 164–171. https://www.researchgate.net/publication/267152418_Acceleration_of_the_Hardening_of_Concrete_Made_with_Mineral_Admixtures_by_Using_a_Heat_Treatment_Process
19. Kaprielov S.S., Sheinfeld A.V., Kardumyan G.S. New modified concretes // Moscow: Paradise. - 2010. - 258 p. https://doi.org/10.37538/2224-9494-2024-1(40)-92-104
20. Abdraimov, I.; Kopzhassarov, B.; Kolesnikova, I.; Akhmetov, D.A.; Madiyarova, I.; Utepov, Y.

Frost-Resistant Rapid Hardening Concretes. Materials 2023, 16, 3191, https://doi.org/10.3390/ma16083191
21. Su, Y.; Luo, B.; Luo, Z.; Huang, H.; Li, J.; Wang, D. Effect of Accelerators on the Workability, Strength, and Microstructure of Ultra-High-Performance Concrete. Materials 2021, 15, 159, https://doi.org/10.3390/ma15010159 .
22. Yu, R.; Spiesz, P.; Brouwers, H.J.H. Effect of Nano-Silica on the Hydration and Microstructure Development of Ultra-High Performance Concrete (UHPC) with a Low Binder Amount. Construction and Building Materials 2014, 65, 140–150, https://doi.org/10.1016/j.conbuildmat.2014.04.063
23. Zhakipbekov, S.; Aruova, L.; Toleubayeva, S.; Ahmetganov, T.; Utkelbaeva, A. The Features of the Hydration and Structure Formation Process of Modified Low-Clinker Binders. doi:10.34910/MCE.103.2
24. Shannag, M.J. High Strength Concrete Containing Natural Pozzolan and Silica Fume. Cement and Concrete Composites 2000, 22, 399–406, https://doi.org/10.1016/S0958-9465(00)00037-8
25. Revilla-Cuesta, V.; Skaf, M.; Ortega-Lopez, V.; M.Manso, J. Multi-parametric flowability classification of self-compacting concrete containing sustainable raw materials: An approach to real applications. Nov 2022. Journal of building engineering 63 (4):105524. http://dx.doi.org/10.1016/j.jobe.2022.105524

И.Абдраимов[1], К.Муса[1], Ю.Пухаренко[2], М.Сайлыгараева[3*]

[1] Мұхтар Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан
[2]Санкт-Петербург мемлекеттік сәулет-құрылыс университеті, Санкт-Петербург, Ресей Федерациясы
[3]Қазақ ұлттық аграрлық зерттеу университеті, Алматы, Қазақстан

Гиперпластификатормен және кремнеземдік микротолтырғыштармен цемент тасының гидратация өнімдерінің құрылымын зерттеу

Аңдатпа. Бұл жұмыста техногендік және табиғи тексті белсенді кремнеземдік толтырғыштардың және поликарбоксилатты суперпластификатордың цемент матрицасының құрылымына оның микрокеуектілігін арттыру мақсатында бірлескен әсері зерттелді. Толтырғыш бөлшектердің дисперсиясы, құрылымы мен компоненттерінің аморфизациясы байланыстырушы материал бөлшектерінің молекулалық және беттік кристалдану құрылымына химиялық энергияның әсерінен болатыны анықталды. Ерітінді қоспаларының құрамына кремний диоксиді мен пластификаторды біріктіріп енгізу бойынша зерттеулер пуццоландық қоспаның құрамын байланыстырғыш массасының 15% дейін арттыруға мүмкіндік береді, бұл цемент шығынын азайтуға көмектеседі, сонымен бірге цемент тасының микроқұрылымын оңтайландыруды және кейіннен жоғары құрылыс және техникалық сипаттамалары бар бетонды өндіруді қамтамасыз етеді. Зерттеу аясында поликарбоксилатты пластификаторлар мен белсенді кремнеземдік толтырғыштардың қатысуымен гидратация өнімдерін талдау мақсатында цемент тасын егжей-тегжейлі микроқұрылымдық зерттеу жүргізілді. Алынған нәтижелер ерітінді қоспасының құрамына 10-15% пластификатор мен кремнеземді толтырғышты енгізу цемент жүйесіндегі портландит мөлшерінің төмендеуіне, оның кристалдарының мөлшерінің азаюына, түйіршікаралық кеңістіктің толтырылуына, сонымен қатар цемент тасының құрылымын нығыздауға және нығайтуға әкелетінін көрсетеді. Осылайша, ұсынылған тәсіл пуццоландық қоспаларды тиімді пайдалануды, бетонның пайдалану қасиеттерін жақсартуды және қымбат цементті тұтынуды азайтуды қамтамасыз етеді.

Түйін сөздер: гиперпластификатор, кремнеземдік микротолтырғыштар, гидратация өнімдері, цемент тасы, цемент құрылымы.

И.Абдраимов[1], К.Муса[1], Ю.Пухаренко[2], М.Сайлыгараева[3*]

[1] Южно-Казахстанский университет имени М. О. Ауэзова, Шымкент, Казахстан
[2]Санкт-Петербургский государственный архитектурно-строительный университет, Санкт-Петербург, Российская Федерация
[3]Казахский Национальный Аграрный Исследовательский университет, Алматы, Казахстан

Изучение структуры продуктов гидратации цементного камня с гиперпластификатором и кремнеземистыми микронаполнителями

Аннотация. В данной работе исследовано совместное влияние активных кремнезёмистых наполнителей техногенного и природного происхождения и поликарбоксилатного суперпластификатора на структуру цементной матрицы с целью повышения её микропористости. Установлено, что диспергирование частиц наполнителя, аморфизация структуры и компонентов обусловлены воздействием химической энергии на молекулярную и поверхностную кристаллизационную структуру частиц вяжущего материала. Исследования по совместному введению кремнезёма и пластификатора в составе растворных смесей позволяют увеличить содержание пуццолановой добавки до 15% от массы вяжущего, что способствует снижению расхода цемента, одновременно обеспечивая оптимизацию микроструктуры цементного камня и дальнейшее получение бетонов с высокими строительными и техническими характеристиками. В рамках исследования было проведено детальное микроструктурное исследование цементного камня с целью анализа продуктов гидратации в присутствии поликарбоксилатных пластификаторов и активных кремнеземистых наполнителей. Полученные результаты показывают, что введение 10–15% пластификатора и кремнеземистого наполнителя в состав растворной смеси приводит к снижению содержания портландита в цементной системе, уменьшению размеров его кристаллов, заполнению межзернового пространства, а также к уплотнению и упрочнению структуры цементного камня. Таким образом, предложенный подход обеспечивает эффективное использование пуццолановых добавок, повышая эксплуатационные свойства бетона и снижая потребление дорогостоящего цемента.

Ключевые слова гиперпластификатор, кремнеземные микроволны, продукты гидратации, цементный камень, цементная структура.

References

1. Gesoglu, M; Güneyisi, E.; Oznur Oz, H.; Taner, Y.; Taha, I. Durability and Shrinkage Characteristics of Self-Compacting Concretes Containing Recycled Coarse and/or Fine

Aggregates. August 2015. Advances in Materials Science and Engineering. DOI: https://doi.org/10.1155/2015/278296 Surname A and Surname B 2009 Journal Name 23 544.
2. Usanova, K.; Barabanshchikov, Y.; Krasova, A.; Akimov, S.; Belyaeva, S. Plastic Shrinkage of Concrete Modified by Metakaolin. Magazine of Civil Engineering 2021, 103, 1–15, doi:10.34910/MCE.103.14
3. Cheah, C.B.; Chow, W.K.; Oo, C.W.; Leow, K.H. The Influence of Type and Combination of Polycarboxylate Ether Superplasticizer on the Mechanical Properties and Microstructure of Slag-Silica Fume Ternary Blended Self-Consolidating Concrete. Journal of Building Engineering 2020, 31, https://doi.org/10.1016/j.jobe.2020.101412 /
4. Güneyisi, E.; Gesoglu, M; Booya, E.; Mermerdas, K. Strength and permeability properties of self-compacting concrete with cold bonded fly ash lightweight aggregate. Construction and Building Materials. Volume 74, 15 January 2015, P. 17-24 https://doi.org/10.1016/j.conbuildmat.2014.10.032
5. Aitcin P.C. High-Performance Concrete. – London: E&FN SPON. – 1998. – 364 p. https://ru.scribd.com/document/618856021/High-Performance-Concrete
6. Kalashnikov V.I. Fine-dispersed rheological matrices and powder concrete of new generation. Collection of articles of the International Scientific and Practical Conference "Composite Building Materials. Theory and practice". - Penza. - 2007. - p. 9-18. https://engstroy.spbstu.ru/userfiles/files/2012/8(34)/07.pdf
7. Utepov, Y.; Akhmetov, D.; Akhmatshaeva, I. Effect of Fine Fillers from Industrial Waste and Various Chemical Additives on the Placeability of Self-Compacting Concrete. Computers and Concrete 2020, 25, 59–65, https://doi.org/10.12989/cac.2020.25.1.059
8. Elyamany, H.E.; Abd Elmoaty, A.E.M.; Mohamed, B. Effect of Filler Types on Physical, Mechanical and Microstructure of Self Compacting Concrete and Flow-Able Concrete. Alexandria Engineering Journal 2014, 53, 295–307, https://doi.org/10.1016/j.aej.2014.03.010
9. EN 197-1:2011 Cement - Part 1: Composition, Specifications and Conformity Criteria for Common Cements; 2011; p. 38; https://standards.iteh.ai/catalog/standards/cen/64d327b1-d5ac-45e3-8b04-fafec9e0698e/en-197-1-2011?srsltid=AfmBOooXnn984NiZaAXeFnksHAMxfxU4Ifjp6W-1tiQia-eN1iPIZizr
10. EN 196-2:2013 Method of Testing Cement - Part 2: Chemical Analysis of Cement; 2013; p. 73; https://standards.iteh.ai/catalog/standards/cen/47283941-90a2-43dc-8b2c-dea6208712a6/en-196-2-2013?srsltid=AfmBOoq9kREAKPll32Qt5eE3eVjcRb0XftnRfXMs_3KZCwMLn7dlSDYZ
11. GOST 8736-2014. Sand for Construction Works. Specifications; 2014. https://files.stroyinf.ru/Data2/1/4293767/4293767502.pdf
12. ST RK GOST R 51232-2003. WATER. General requirements for organization and methods of quality control. 2003 г. https://online.zakon.kz/Document/?doc_id=30015745&pos=2;-112#pos=2;-112
13. GOST 30459-2008. Admixtures for Concretes and Mortars. Determination and Estimate of the Efficiency; 2008. https://files.stroyinf.ru/Index2/1/4293818/4293818440.htm
14. EN 13263-1:2005+A1:2009 Silica Fume for Concrete—Part 1: Definitions, Requirements and Conformity Criteria; 2009; p. 23;

https://www.intertekinform.com/preview/98703412427.pdf?sku=870053_SAIG_NSAI_NSAI_2068874&srsltid=AfmBOooIG83UBYye4Z51wFzcbv5KTCkVkPvvbXjGN6v6mRiBHJBWh9x3
15. GOST R 56593-2015 “Mineral additives for concrete and mortars” https://meganorm.ru/Data2/1/4293759/4293759239.pdf
16. Okamura, H.; Ouchi, M. Self-Compacting Concrete. ACT 2003, 1, 5–15, http://dx.doi.org/10.3151/jact.1.5
17. Bruker. X-Ray Diffraction. https://www.bruker.com/en/products-and-solutions/diffractometers-and-x-ray-microscopes/x-ray-diffractometers/diffrac-suite-software/diffrac-eva.html
18. Riad, D.; Mohamed Larbi, M. Acceleration of the Hardening of Concrete Made with Mineral Admixtures by Using a Heat Treatment Process. Journal of Materials Science and Engineering 2014, A4, 164–171. https://www.researchgate.net/publication/267152418_Acceleration_of_the_Hardening_of_Concrete_Made_with_Mineral_Admixtures_by_Using_a_Heat_Treatment_Process
19. Kaprielov S.S., Sheinfeld A.V., Kardumyan G.S. New modified concretes // Moscow: Paradise. - 2010. - 258 p. https://doi.org/10.37538/2224-9494-2024-1(40)-92-104
20. Abdraimov, I.; Kopzhassarov, B.; Kolesnikova, I.; Akhmetov, D.A.; Madiyarova, I.; Utepov, Y. Frost-Resistant Rapid Hardening Concretes. Materials 2023, 16, 3191, https://doi.org/10.3390/ma16083191
21. Su, Y.; Luo, B.; Luo, Z.; Huang, H.; Li, J.; Wang, D. Effect of Accelerators on the Workability, Strength, and Microstructure of Ultra-High-Performance Concrete. Materials 2021, 15, 159, https://doi.org/10.3390/ma15010159 .
22. Yu, R.; Spiesz, P.; Brouwers, H.J.H. Effect of Nano-Silica on the Hydration and Microstructure Development of Ultra-High Performance Concrete (UHPC) with a Low Binder Amount. Construction and Building Materials 2014, 65, 140–150, https://doi.org/10.1016/j.conbuildmat.2014.04.063
23. Zhakipbekov, S.; Aruova, L.; Toleubayeva, S.; Ahmetganov, T.; Utkelbaeva, A. The Features of the Hydration and Structure Formation Process of Modified Low-Clinker Binders. doi:10.34910/MCE.103.2
24. Shannag, M.J. High Strength Concrete Containing Natural Pozzolan and Silica Fume. Cement and Concrete Composites 2000, 22, 399–406, https://doi.org/10.1016/S0958-9465(00)00037-8
25. Revilla-Cuesta, V.; Skaf, M.; Ortega-Lopez, V.; M.Manso, J. Multi-parametric flowability classification of self-compacting concrete containing sustainable raw materials: An approach to real applications. Nov 2022. Journal of building engineering 63 (4):105524. http://dx.doi.org/10.1016/j.jobe.2022.105524

Information about the authors:

Abdraimov Ilyas – PhD student, Mukhtar Auezov South Kazakhstan University, Tauke Khan Ave 5, Shymkent, Kazakhstan

Musa Kuttybay – PhD student, Mukhtar Auezov South Kazakhstan University, Tauke Khan Ave 5, Shymkent, Kazakhstan

Yuri Pukharenko – Professor, Saint Petersburg State University of Architecture and Civil Engineering, St. Krasnoarmeyskaya, 2nd, 4, Saint Petersburg, Russian Federation

Mariya Sailygarayeva – corresponding author, PhD, senior lector, The Kazakh National Agrarian Research University, Abay Ave., 8, Almaty, Kazakhstan

Абдраимов Ильяс – PhD студент, Южно-Казахстанский университет имени М. О. Ауэзова, просп. Тауке хана 5, Шымкент, Казахстан

Муса Куттыбай – PhD студент, Южно-Казахстанский университет имени М. О. Ауэзова, просп. Тауке хана 5, Шымкент, Казахстан

Пухаренко Юрий – профессор, Санкт-Петербургский государственный архитектурно-строительный университет, 2-я Красноармейская ул., 4, Санкт-Петербург, Российская Федерация

Сайлыгараева Мария – автор по корреспонденции, PhD, старший преподаватель, Казахский Национальный Аграрный Исследовательский университет, проспект Абая, 8, Алматы, Казахстан

Абдраимов Ильяс – PhD студент, Мұхтар Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан, Тәуке хан даңғылы 5, Шымкент, Қазақстан

Муса Куттыбай – PhD студент, Мұхтар Әуезов атындағы Оңтүстік Қазақстан университеті, Шымкент, Қазақстан, Тәуке хан даңғылы 5, Шымкент, Қазақстан

Пухаренко Юрий – профессоры, 2Санкт-Петербург мемлекеттік сәулет-құрылыс университеті, 2-ші Красноармейская көш., 4, Санкт-Петербург, Ресей Федерациясы

Сайлыгараева Мария – хат-хабар авторы, PhD, аға оқытушы, 3Қазақ ұлттық аграрлық зерттеу университеті, Алматы, Қазақстан, Абай даңғылы, 8, Алматы, Қазақстан