

Modified high strength lightweight-aggregate concrete based on expanded clay: composition, structure, properties

Kostyantyn Kaverin ¹, Olga Bondarenko², Dmytro Anopko³, Dmytro Levkivskiy⁴,
Tetiana Antoshchuk ⁵

^{1, 2, 3, 4} Kyiv National University of Construction and Architecture,
Povitroflotskyi Avenue, 31, Kyiv, Ukraine 03037,

¹ kaveryn.ko@knuba.edu.ua, orcid.org/0000-0001-9086-5953,

² bondolya3@gmail.com, orcid.org/0000-0002-8164-6473,

³ anopko.dv@knuba.edu.ua, orcid.org/0000-0002-2585-2512,

⁴ levkivskiy.dv@knuba.edu.ua, orcid.org/0000-0003-2964-1605,

⁵ Yuriy Fedkovych Chernivtsi National University,
2 Kotsyubynsky Street, Chernivtsi, Ukraine 58012,

⁵ t.antoshchuk@chnu.edu.ua, orcid.org/0000-0002-1887-2697

Received 01.10.2023, accepted 20.12.2023

<https://doi.org/10.32347/tit.2023.61.0103>

Abstract. The study is devoted to the development of increased strength lightweight concrete based on Portland cement modified with a complex organo-siliceous additive containing a polycarboxylate superplasticizer and an active fine-ground siliceous component. The effect of this complex additive on the physical and chemical characteristics of the hydration and structure formation processes was investigated and it was shown that the high kinetics of the strength gain is provided by directional formation of low-basic calcium hydrosilicates, hydrogranates and plazolite, which are crystallochemically similar to each other, and provide a dense and strength cement stone matrix.

Modification by a complex additive makes possible to obtain concrete mixes with S4 consistency while a portland cement consumption per 1m³ of not more than 330 kg, with a compressive strength of 55 MPa, watertightness up to W8, frost resistance up to F400, corrosion resistance coefficients K_c in the magnesium sulfate, sodium and ammonium solutions by 10 to 24%. The introduction of a complex additive also helps to reduce the relative shrinkage by 16 ... 19% compared to the control composition, which has a positive effect on the durability of the resulting concrete.

Keywords: increased strength lightweight concrete, complex organo-siliceous additive, polycarboxylate superplasticizer, compressive strength, frost resistance, corrosion resistance, relative shrinkage.



Kostyantyn Kaverin
PhD of Technical Sciences,
Associate professor



Olga Bondarenko
PhD of Technical Sciences,
Associate professor



Dmytro Anopko
PhD of Technical Sciences,
Associate professor



Dmytro Levkivskiy
PhD of Technical Sciences,
Associate professor



Tetiana Antoshchuk
PhD of Architectural Sciences,
Assistant of Department of
Architecture and Conservation of
UNESCO World Heritage Sites

INTRODUCTION

As is already known, lightweight concrete based on expanded clay is used in prefabricated residential, transport and hydraulic construction. Also in the construction of port facilities, in shipbuilding, where, along with the reduction in the mass of structures, other positive properties of expanded clay concrete can be used: increased frost resistance, watertightness, resistance to aggressive exposure conditions.

Research in the field of lightweight expanded clay concrete was carried out by G.A. Buzhevich, A.I. Vaganov, V.M. Virovy, V.G. Dovzhik, V.A. Dorf, O.Sh. Kikawa, L.P. Orentlicher, T.M. Shtolle [1-6].

Abroad in this direction where the works of Rossignolo J. A, Morais J.A., Wee Tiong-Huan, Ergul Yasar, Cengiz Duran Atis, Alaettin Kilic, Hasan Gulsen, Jamal Alduaij, Niyazi Ugur Kockal, Ozturan T., Hugo Costa, Eduardo Julio, Lourenjo J. [7-14].

Fine mineral additives (microfillers) are an integral part of modern concrete, because their use allows to reduce the consumption of cement, increase the density, strength, resistance of concrete in aggressive environments, and therefore guarantee their durability. The positive results that are achieved when active mineral additives are introduced include the binding of portlandite, the formation of low-base hydrosilicates, for example, the C-S-H phase, the reduction of the ratio of capillary and gel micropores in the structure of concrete, the intensification of hydration processes, the regulation of temperature and volume deformations of cement compositions.

Examples of the practical implementation of additives in the technology of building materials using nanoscale structural elements are given in the papers of Yu.M. Bazhenov, P.G. Komohov, Yu.V. Pukharenko and others. They've showed significant effects achieved by the introduction of various nanoparticles. The basis of this direction is the work of V.G. Batrakov, S.S. Kaprielov, M.A Sanitcky [15], related to the modification of the structure of the cement stone by the introduction

microsilica into the composition of raw mixtures, whose individual fractions can be classified as nanoparticles. The use of nano- and microsilica allows the use of additives along with the superplasticizer to significantly accelerate the processes of hydration and hardening of cement, to provide a high speed of strength gain and reach 115 ... 150 MPa by 28 days, increasing the durability of artificial stone by almost 2 ... 2,5 times.

But at the same time, questions related to the study of the replacement of the microsilica with its natural analogues and the study of compatibility with the latest class of superplasticizers based on polycarboxylates, polyacrylates and their esters, need further study. Also, the question about the influence of complex organosilicon additives on the processes of structuring high-strength lightweight expanded clay concrete and on their hardened properties remains opened.

The prospects for the use of high-strength lightweight concrete are in manufacturing of reinforced concrete products in industrial and high-rise civil engineering, the construction of road bridges, overpasses and interchanges, as well as in the construction of buildings of special purpose, due to their positive qualities and advantages in relation to heavy concrete. In addition, the reduction in the mass of structural elements of buildings allows to solve complicated architectural problems and extends the scope of use of lightweight concrete as structural and insulation material.

World experience in erection of buildings and structures with the use of structures made of expanded clay (table 1) confirmed their reliability, durability and high performance of these structures.

The main preconditions for the synthesis and durability of high-strength lightweight concrete is the modification of the cement matrix. In recent years, this is usually achieving by the use of various complex additives, modifying both binder and concrete mixture.

In this regard, the development of effective high-strength lightweight expanded clay concrete, modified by complex organomineral additives, is an topical task.

Table 1. Comparison of properties of lightweight concrete used in different countries of the world

Year of implementation	Land	The main characteristics of light concrete		
		Average density of concrete, kg/m^3 (bulk density of expanded clay)	Strength compression for 28 days, MPa	Coefficient of constructive quality (C.C.Q.)
1995	Norway	$\frac{D1700...1950}{(M800...1000)}$	60...79	35...40
1997	USA	$\frac{D1450...1800}{(M400...600)}$	18...46	12...26
2002	Germany	$\frac{D1800}{(M400)}$	14...25	7...14
2003	Brazil	$\frac{D1450...1600}{(M400...600)}$	40...50	27...31
2003	Turkey	$\frac{D1800...1860}{(M600)}$	30...40	17...22
2004	Japan	$\frac{D1800...1850}{(M600...800)}$	47...54	26...29
2007	Russia	$\frac{D1800}{(M600...800)}$	46...61	25...34

Consideration of the basic requirements for such additives, namely: compatibility between the components, availability in the Ukrainian market and the appropriate technical and economic justification for their application, will increase the efficiency of using portland cement. At the same time, the introduction of

modified high-strength lightweight expanded clay concrete in monolithic construction requires the study of the peculiarities of the structure of this concrete, taking into account the effect of the compatibility of the action of silica additives of various nature with organic additives.

THE PURPOSE OF THIS WORK. MATERIALS AND METHODS OF RESEARCH

The purpose of the work is to study lightweight expanded clay mixtures based on Portland cement, modified by complex organosilicon additives, and obtaining on this basis high strength lightweight concrete with high physical, mechanical and operational properties.

To achieve this target, the following tasks must be solved:

- to carry out the analysis of already known information sources on the influence of organic and mineral admixtures on the properties of light concrete mixtures and the processes of structure formation during hardening of concrete;
- develop the composition of a complex organosilicon additive and investigate the compatibility of its components by introducing it into concrete mixtures;
- to optimize mix design of concrete mixtures and to study the properties of concrete mixtures and concrete.

The subject of research is lightweight high strength expanded claylite concrete LC 20/22 ... LC 50/55 (DSTU B V.2.7-176: 2008) on the basis of Portland cement, modified by a complex organo-silica additive. The following materials were used as raw materials: Portland cement, CEM I 42,5 R which complies with the requirements of Governmental Standard of Ukraine 2.7-46: 2010 produced by PJSC "Podilsky cement" (Gumentsi village, Ukraine); Dnieper quartz sand according to DSTU B V.2.7-32-95, with Fineness Modulus = 1,28 (Kiev, Ukraine); expanded clay gravel of different grades, the results of which are given in the table 2.

All used silica additives by specific surface area are very fine dispersed, namely: by-products of the Stakhanov Ferroalloy Plant (Blaine = 36398 cm²/g), OJSC ArcelorMittal Kryviy Rih (Blaine = 9478 cm²/g) and Elkem Microsilica Grade 940-U (Blaine = 24795 cm²/g), SikaFume (Blaine = 8556 cm²/g), thin-melting glass "MHS" (Blaine = 10485 cm²/g), trepelle of the Konoplyansky quarry, ground for 2 hours in a ball mill (Blaine = 21997 cm²/g).

As plasticizers polycarboxylate superplasticizers - "ViscoCrete-5-600UA", "Plast 555W" (produced by TM "Sika", Kiev, Ukraine) and "PowerFlow 3100", "PowerFlow 2695" (produced by TM "MC-Bauchemie ", Berezan, Ukraine) were used. It meet the requirements of DSTU B V.2.7-69-98, DSTU B V.2.7-171: 2008 (EN 934-2: 2001, NEQ).

The mix design procedure of lightweight concrete was carried out in accordance with DSTU B V.2.7-69-98, DSTU B V.2.7-114-2002, DSTU B V.2.7-176: 2008, DSTU B V.2.7-215: 2009 and mathematical experiment planning methods were used.

The rheological properties of concrete mixtures were determined according to DSTU B V.2.7-114-2002, DSTU B V.2.7-176: 2008. The physical and mechanical properties of the mortar (40 x 40 x 160 mm) and concrete (100 x 100 x 100 mm) were determined according to DSTU B V.2.7-187: 2009 and DSTU B V.2.7-214: 2009, respectively. Open porosity, average density, water absorption and watertightness of concrete samples were determined according to the methods given in DSTU B B.2.7-170: 2009.

The degree of dispersion of the siliceous additive was estimated using the laser diffraction method on the laser granulometry Mastersizer 2000 Ver. 5.60 and on the Blaine measurement device according to DSTU EN 196-6: 2007. Microhardness of the contact zone "binder - aggregate" of high-strength concrete was determined using a micro-meter PMT-3. The evaluation of the durability of lightweight concrete was performed by studying the kinetics of the strength set, corrosion resistance (DSTU GOST 27677-2011), frost resistance

(DSTU B V.2.7-49-96) and deformation of concrete shrinkage according to DSTU B V.2.7-216: 2009.

Table 2. Characteristics of expanded clay aggregate

Producer	Bulk density, kg/m ³	Compressive strength (cylinder), MPa	Coefficient of thermal conductivity λ, W/m·K	Grade according to DSTU B V. 2.7 –17–95	
				By bulk density	By strength
JSC "Plant of expanded clay gravel." Novokumol "Belarus	360	1,65	0,092	M400	S75
OJSC "Odessa Keramzite Plant"	460	1,81	0,1	M500	S75
Khmelnitsky Keramzite Gravel Plant Ltd	600	3,03	0,12	M600	S125

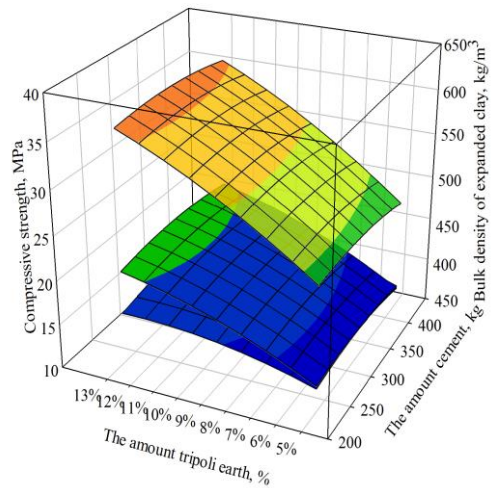
RESEARCH RESULTS

As previous studies show, the use of a complex organosilicon additive can improve the kinetics of strength gain, and the main regulation factor is the amount of fine-ground tripoli earth in the complex additive [16-18]. Optimization of the composition of lightwieghn expanded clay concrete, modified with a complex additive, which includes a fine additive based on ground tripoli earth and superplasticizer, was carried out with the use of three-factor three-level mathematical experiment design (Table 3), in which as a variable factors, the consumption of portland cement (200 ... 400 kg) (X1), the content of fine-ground tripoli (5% ... 15%) (X2) and the bulk density of expanded clay gravel (M400 ... M600) (X3).

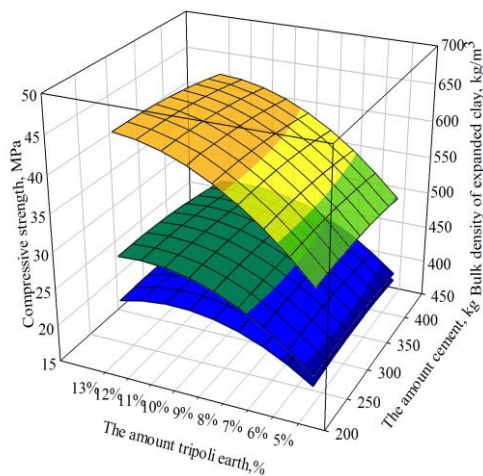
Table 3. Intervals of variation and values of variable factors of concrete mixtures, modified with a complex organic-mineral additive

Factors, type	Coded	Variation levels			Variation intervals
		Upper	Middle	High	
Cement dosage, t	X ₁	0,4	0,3	0,2	0,1
Tripoli earth dosage, %	X ₂	15	10	5	5
Grade of expanded clay by bulk density	X ₃	600	500	400	100

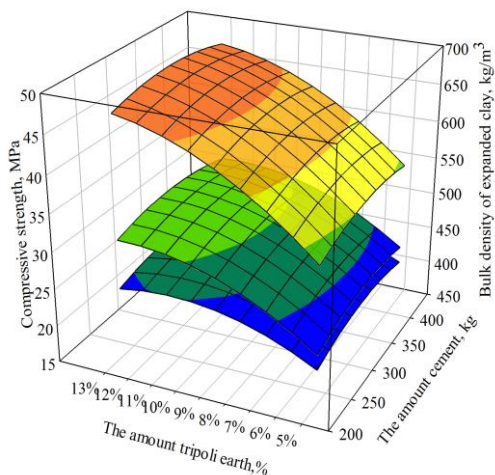
By analyzing isoparametric diagrams (Fig. 1) of the change in compression strength of lightweight expanded clay concrete, it can be noted that the optimal values of the substitution amount is 10% tripoli of the mass of the binder.



a



b



c

Fig. 1. Isoparametric diagrams of compression strength change for samples concrete on the basis of Portland cement, modified by a complex organo-silica additive based on superplasticizer "SikaPlast 555W" in the amount of 1% and fine-ground tripoli earth (5 ... 15%), after hardening in normal conditions during 3 (a), 28 (b) and 365 (c) days

Introduction of complex organic-silica additive with optimal composition and expanded clay M600 and higher makes possible to make lightweight expanded clay concrete with compressive strength of 50 ... 60 MPa.

The effectiveness of the modification of portland cement compositions with a complex organic-silica additive is determined by the nature of the change in the microhardness of the contact zone: "the binder - aggregate", the results of which are shown in Fig. 2

Analysis of the data shows that the microhardness of the samples from unmodified Portland Cement to section width of 20 μm from nominal boundary grain filler is gradually increasing from 1300 MPa (filler) to 2100 ... 2300 MPa (cement stone), which is 20% higher than microhardness of stone mortar parts of concrete (Fig. 2, mix number 1).

The modification of the expanded clay concrete with the addition of the superplasticizer "SikaPlast 555W" (Fig. 2, mix number 2) increases the microhardness at the border with the aggregate to 2450 MPa, which is 24% more than the microhardness of the same control mix.

Introducing a complex organo-silica additive into the lightweight expanded clay concrete (Fig. 2, mix number 3), the value of microhardness on the nominal grain boundary of the aggregate reaches 2770 MPa, which is 32% more than the microhardness of the cement stone on the boundary of the grain and 19% more than the microhardness of the cement-sand mortar in the intergranular space in comparison with the control mix. The compressive strength of such modified concrete increases by 25...30%, compared to the composition without additive.

Modification of Portland cement binder systems with a complex organo-silica additive, accompanied by the intensive formation of hydrated new substances, represented mainly by low-basic calcium hydrosilicates, which contribute to micro-reinforcement of cement stone, while strengthening its structure and improving adhesion to the aggregate, which is one of the prerequisites for obtaining durable

lightweight concrete. with increased operational characteristics.

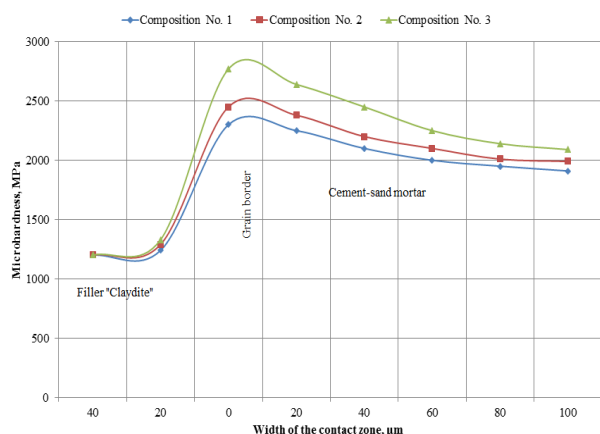
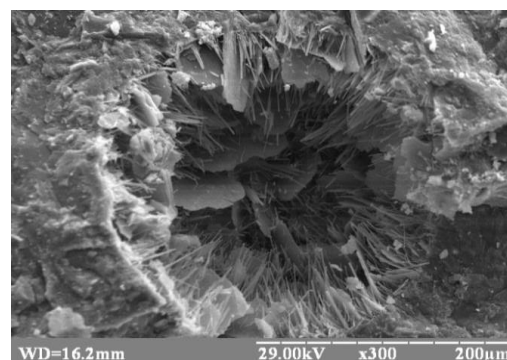


Fig. 2. Change of the microhardness of the contact zone "binding - aggregate" for light concrete: № 1 - control mix; № 2 - modified with superplasticizer "SikaPlast 555W"; No. 3 - modified with a complex organo-silica additive on the basis of this superplasticizer and fine-ground tripoli earth

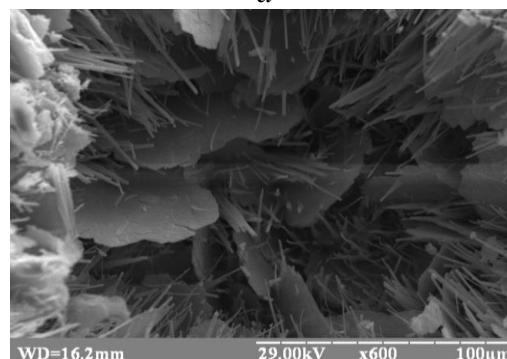
On the photos of the surface of the artificial stone chip on the basis of Portland cement, modified with a complex organo-silica additive, clearly visible fibrous formations and partially recrystallized needle crystals of low-calcium hydrosilicates in the lamellae (Fig. 3), which provides the basis for obtaining high-strength lightweight concrete with a more homogeneous structure.

Thus, when hardening of Portland cement, modified by a complex additive, due to the reduction of B/C in compressed conditions, there is a directed synthesis of crystallochemically similar compounds and layered reinforcement of the cement matrix with lamellar and needle-like new formation based on low-base calcium hydrosilicates of CSH (I), tobermorite 11,3Å together with platyolite and hydrogarnets that are capable of aggregation and contribute to the formation of a more advanced microstructure of cement stone [19].

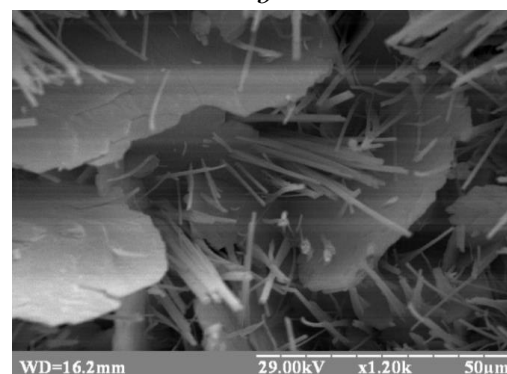
The presence in the structure of claydite gravel of isolated closed and open pores promotes penetration of the Portland cement paste



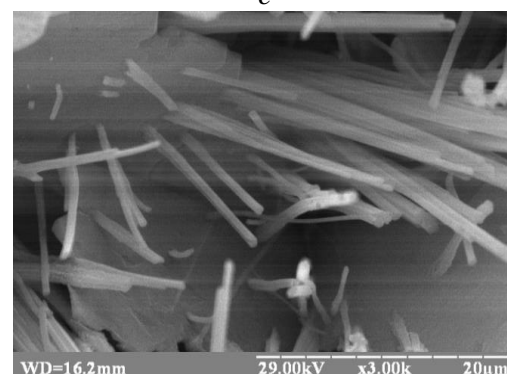
a



b



c



d

Fig. 3. Photographs of microstructure of cement stone, modified with a complex additive containing polycarboxylate superplasticizer "SikaPlast 555W" and ground shaking tripoli earth after 365 days of hardening: increase (a) ×300 times; (b) ×600 times; (c) ×1200 times; (d) ×3000 times

into the structure of the expanded clay (due to the self-immolation effect), resulting in interaction between the aluminosilicate component of claydite and the products of hydration of Portland cement, which causes the formation of a stronger contact zone.

At the same time, it is likely that in the composition of new formation, in addition to low-basic hydrosilicates of calcium will also be present hydroaluminosilicates, for example, hydroglenitis.

To assess the performance of lightweight expanded clay concrete it is necessary to determine its watertightness. Water absorption of concrete, as one of the factors of water resistance, can be reduced by increasing the density of the structure of concrete, which is achieved by reducing the W/C ratio, as well as the introduction into a concrete mix chemical and mineral additives. Concrete test results are given in table 4.

Table 4. Test results of expanded clay aggregate concrete samples tests for water absorption

Mix №	Content of component, mas. %					Average density, kg/m ³	Water absorption, W, %	Open pores, %
	CEM I – 42,5 R	Expanded clay aggregate fraction 5-10, M600	Quartz sand	Superplasticizer «SikaPlast 555W»	Fine-ground tripoli			
1	19,2	23,83	56,97	-	-	1853	3,74	7,04
2	19,14	23,77	56,83	0,26	-	1858	3,2	5,94
3	17,4	23,77	56,83	0,26	1,74	1859	2,52	4,68

The analysis of the data obtained indicates that the complex organo-silica additive developed as a part of lightweight expanded aggregate clay concrete reduces water absorption by 32.6% and reduces volumetric open porosity by 33.5% compared with the additiveless composition, and as a result leads to the formation of optimal structure of concrete.

In the study of lightweight expanded clay concrete watertightness it was established that in case of modification only with superplasticizer provides an increase in watertightness by 13%, while the introduction of a complex organo-silica additive contributes to an increase in watertightness by 37%, compared with the control composition, which corresponds to the grade of watertightness W8

(Table 5).

Table 5. Determination of watertightness of different lightweight expanded clay concrete mixtures

Mix №	Content of component, mas. %					Average density, kg/m ³	Compressive strength, MPa	Water pressure, mean, MPa	Watertightness grade
	CEM I – 42,5 R	Expanded clay aggregate fraction 5-10, M600	Quartz sand	Superplasticizer «SikaPlast 555W»	Fine-ground tripoli				
1	19,2	23,83	56,97	-	-	1891	23,9	0,605	W6
2	19,14	23,77	56,83	0,26	-	1897	34,6	0,688	W6
3	17,4	23,77	56,83	0,26	1,74	1898	43,3	0,832	W8

Increasing watertightness can be explained by the predetermined formation of hydration products and reducing the open porosity of clay concrete, which confirms the effectiveness of using this complex additive.

Assessing the physical and mechanical characteristics of modified expanded clay concrete, it is possible to predict that the developed concrete compositions will have improved special properties such as frost resistance, corrosion resistance, as well as reduced shrinkage deformation rates, which to a certain extent depend on water absorption, watertightness and open porosity.

Tests of modified concrete's frost resistance was carried out in accordance with DSTU B V.2.7-49-96 [20], using an accelerated procedure in a 5% sodium chloride solution at a temperature of -50 ° C. According to the requirements of normative documents, strength loss of specimens that have been under a certain number of cycles of freezing-thawing, should not exceed 5%. The results of studies are presented in Table 6.

The obtained data shows that the control mix of expanded clay concrete on the basis of Portland cement CEM I – 42,5 R provides the frost resistance grade of concrete F200, because the strength loss after 6 cycles of alternating freezing-thawing was 6.82%, exceeding 5%.

Modification of expanded clay concrete with the addition of superplasticizer "SikaPlast 555W" (warehouse number 2, Table 6), provides frost resistance F300: strength loss after

the 10th cycle of alternating freezing-thawing was 5.61%.

Table 6. Comparison of frost resistance of expanded clay concrete of different composition

Mix №	Content of component, mas. %					Strength loss, % after accelerated methodology freezing-thawing cycles			Frost resistance
	CEM I – 42,5 R	Expanded clay aggregate fraction 5-10, M600	Quartz sand	Superplasticizer «SikaPlast 555W»	Fine-ground tripoli	Number of cycles			
						6	10	14	
1	19,2	23,83	56,97	-	-	-6,82	-	-	F200
2	19,14	23,77	56,83	0,26	-	-	-5,61	-	F300
3	17,4	23,77	56,83	0,26	1,74	-	-	-5,00	F400

After modification of the expanded clay concrete with a complex additive based on the superplasticizer "SikaPlast 555W" and fine-ground diatomite (mix number 3, Table 6), there is a rise in frost resistance up to F400, which is confirmed by the results of tests. Loss of strength after the 14th cycle of alternating freezing-thawing was 5%.

The increase of frost resistance of expanded clay concrete on the basis of Portland cement, modified by a complex additive, can be explained by the formation of advanced pore structure and a decrease in the volume of open capillary pores of the material, which provides a smaller amount of ice formed in the pores of concrete at negative temperatures and, accordingly, a decrease in the values of emerging stress forces in the structure of the material.

The evaluation of the corrosion resistance of concrete was carried out according to the method [21-23]. Samples were made in size 10×10×10 cm, which lasted 24 hours under normal conditions, and then in water. After 28 days of storage, samples were immersed in aggressive environments. Test specimens that were in aggressive environments were carried out after 180 days. Corrosion resistance was determined by the coefficient of corrosion resistance K_c , which is equal to the ratio of the strength of the samples after holding in an aggressive solution (R_{agr}) to the strength limit of the control samples that were tested at the moment of immersion of the basic samples in the solution (R_0). According to this technique, samples are corrosion-resistant, if, after testing

at the age of 180 days, the coefficient of corrosion resistance is $K_c \geq 0.8$.

Control samples of expanded clay concrete and comparative samples were selected for corrosion studies, modified only with superplasticizer and also a complex organo-silica additive. Taking into account possible operating conditions, the corrosion resistance of concrete was investigated in saline solutions, namely in 5% by weight sodium sulfate solution, 5% by weight of ammonium sulfate solution and 1% by weight magnesium sulfate solution.

The residual strength of samples after exposure in aggressive environments for 180 days is given in Table 7, and the results of calculations of the coefficients of corrosion resistance of the investigated samples are presented in Fig. 4

The analysis of the results suggests that the expanded clay concrete based on the Portland cement binder composition, modified by the additive based on the SikaPlast 555W polycarboxylate superplasticizer and the fine-ground tripoli earth, have rather high coefficients of corrosion resistance compared to the pure Portland cement compositions (Fig. 4, mix number 3).

The value of K_c of Portland cement clay concrete, modified with a complex additive, in solutions of magnesium sulfate increases by 10 ... 14%, as compared to the additiveless composition. In solutions of sodium sulfate, this indicator rises by 7.5 ... 12.5%, and in solutions of ammonium sulphate - by 15 ... 24%, compared with the additiveless composition.

The increase in the corrosion resistance of expanded clay concrete can be explained by a decrease in the penetration of aggressive sulfate ions inside the specimens by reducing the open porosity and reducing water absorption, which is achieved by compacting the structure of Portland cement stone and predicted synthesis of increased amount of low-basic calcium hydrosilicates.

An important characteristic of concrete is the value of relative shrinkage, which is defined as the arithmetic mean of the reduction in the size of the sample relative to the initial reference [24].

Table 7. Change in the strength of expanded clay concrete after storage in aggressive environments

Mix №	Content of component, mas. %					Compressive strength, MPa of control samples at 28d	Compressive strength, MPa after aggressive environment storage at 180d		
	CEM I – 42,5 R	Expanded clay aggregate fraction 5-10, M600	Quartz sand	Superplasticizer «SikaPlast 555W»	Fine-ground trypoli		1% p-H MgSO ₄	5% p-H Na ₂ SO ₄	5% p-H (NH ₄) ₂ SO ₄
1	19,2	23,83	56,97	-	-	22,9	19,69	18,32	16,03
2	19,14	23,77	56,83	0,26	-	34,9	33,16	30,02	28,27
3	17,4	23,77	56,83	0,26	1,74	38,2	37,44	34,38	33,23

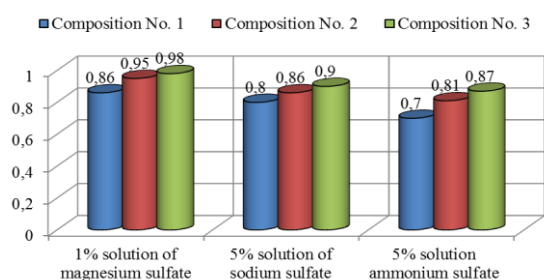


Fig. 4. Comparison of coefficients of corrosion resistance K_s of expanded clay concrete of different composition (according to Table 7) after 180 days aging in aggressive environments: 1% -MgSO₄; 5% -Na₂SO₄ та 5% -(NH₄)₂SO₄

As known, one of the reasons for shrinkage of Portland cement systems are three-dimensional changes in the gel of a cement stone at its drying, which depend on the mineralogical composition of the system, the fineness of cement grinding, conditions and hardening time. At the micro level, the amount of shrinkage depends, first of all, on the ratio of crystalline and gel phases in the products of hydration of the binding composition. The study of the change of relative shrinkage of expanded aggregate clay is given in Table 8 and in Fig. 5.

In the study of changes of relative shrinkage of the expanded clay concrete of the above compositions, it was found that the introduction of the admixture of the polycarboxylate superplasticizer "SikaPlast 555W" leads to a reduction of shrinkage by 10 ... 12%, while the introduction of a complex organo-silica additive reduces this index by 16 ... 19% , compared with the control mix.

Table 8. Comparison of relative shrinkage of expanded clay concrete of different composition

Mix №	Content of component, mas. %					Kinetics of relative shrinkage of clay concrete, $\epsilon(t) \cdot 10^4$, after days						
	CEM I – 42,5 R	Expanded clay aggregate fraction 5-10, M600	Quartz sand	Superplasticizer «SikaPlast 555W»	Fine-ground trypoli	3	7	14	21	28	60	90
1	19,2	23,83	56,97	-	-	1,49	4,98	7,21	7,71	7,71	7,76	7,76
2	19,14	23,77	56,83	0,26	-	0,99	4,95	6,44	6,93	6,93	6,98	6,98
3	17,4	23,77	56,83	0,26	1,74	0,74	4,46	5,94	6,44	6,44	6,49	6,49

As known, according to the normative documents for lightweight concrete shrinkage deformation can reach 1mm/m [24-28]. Thus, the deformation of shrinkage of the additive compositions at the age of 90 days is 0.776 mm/m, whereas modification with a complex additive reduces this index by 16% and is 0.649 mm/m (Table 8 and Fig. 5).

The achieved effect of reducing shrinkage deformation can be explained by the directed formation of low-base calcium hydrosilicates in hydration products.

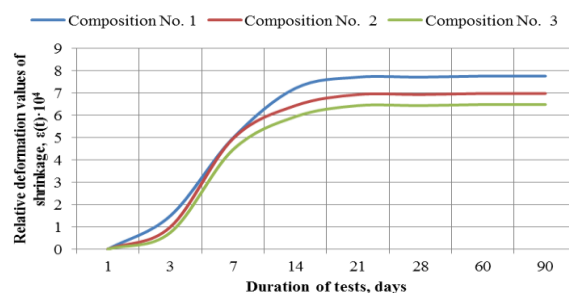


Fig. 5. Comparison of deformations of shrinkage of expanded clay concrete (mixes according to Table 8)

RESULTS DISCUSSION

The influence of various grades of claydite gravel on the strength characteristics of lightweight concrete is investigated and it is shown that the most suitable for monolithic construction is the use of concrete on the basis of expanded clay aggregate M600. It is shown that the highest values of compressive strength increase are characterized by concrete mixtures based on expanded clay aggregate (M600), modified with a complex organo-silica based additive based on a polycarboxylate superplasticizer "SikaPlast 555W" in the amount of

1.5% and a fine-grained tripoli earth in an amount of 10% by weight while the intensification of compressive strength gain by 28 days reaches 66%, and after 1 year to 60%, compared with the control mixtures [16-18, 30].

Analyzing the peculiarities of formation of the contact area "aggregate - binder" it was established that when the complex additive is introduced, the composition, habitus of tumors and the intensity of the process of crystallization in the systems under consideration are changed. The influence of the complex additive on the peculiarities of the formation of the micro-, meso- and macrostructure has been established and a positive role in the synthesis of the strength of crystallochemical low-base calcium hydrosilicates is confirmed, which, in combination with hydroaluminosilicates, which are formed over time, provides a dense bonding and adhesion of the aggregate to the penetrating binder in the pore space of the aggregate grain.

It can also be noted that the use of expanded clay concrete is constantly expanding due to its physical, mechanical and thermal characteristics. For example, the company Cambio combines these properties and has created effective expanded clay concrete blocks for the residential construction, which allows you to reduce the cost of construction by 30% and accelerate the construction time by 3 times [29].

According to the results of research carried out in the batching plant «Budindustriya-1», a production test of total volume of 120 m³ of expanded clay concrete, based on Portland cement modified with a complex organo-silica additive, that was used in the construction of the «Atlant 2» residential complex, was conducted. The full compliance of the properties of expanded clay aggregate based on Portland cement, modified with a complex organo-silica additive, real conditions of production and operation, has been confirmed, which testifies to their high efficiency and functionality in high rise construction. The economic effect of the implementation of the developed concrete composition was UAH 90.25 for 1m³ of concrete.

CONCLUSIONS

Developed warehouses of expanded clay concrete of high strength LC 20/22 ... LC 50/55 (DSTU B V.2.7-176: 2008) on the basis of Portland cement, modified with a complex organo-silica additive. It is shown that the introduction of a complex additive provides increasing in durability of expanded clay aggregate concrete at all stages of curing, increases the watertightness of W6 to W8, increases the frost resistance to F400, increases the coefficient of corrosion resistance Ks by 7.5 ... 24%, compared with the additiveless composition. It was also shown that the introduction of a complex organo-silica additive reduces the relative shrinkage by 16 ... 19%, compared with the control composition, which allows using high strength lightweight expanded clay concrete in residential construction.

REFERENCES

1. **Batnikov V. H.** (1998). Modyfikovani betony. Teoriya y praktyka, yzd. 2-e, pererabotannoe y dopolnennoe. Moscow, 768.
2. **Bazhenov Yu. M., Dem'yanova V. S., Kalashnikov V. I.** (2006). Modyfytirovannyye vysokokachestvennyye betony. Moscow, Yzd-vo ASV, 380.
3. **Dvorkyn L. I., Vyrovoy V. N.** (1991). Tsementni betony z mineralnyy napovnyuvachamy. Kyiv, Budivelnyk publ., 136.
4. **Yvanov Y. A.** (1993). Lehkye betony na shtuchnykh porystykh zapolnytyakh. Moscow, Stroyzdat publ., 182.
5. **Shtol T. M., Kykava O. Sh.** (1986). Tekhnologiya keramzytobetonykh vyrobiv na hor'yachomu zapovnyuvachi. Moscow, Stroyzdat publ., 133.
6. **Orentlykher L.P.** (1983). Betony na porystykh napovnyuvachakh u zbirnykh zhelezobetonykh konstruktsiyakh. Moscow, Stroyzdat publ., 144.
7. **Rossinolo Dzh. A., Ahnesini M. V. S., Morayev Yu. A.** (2003). Vlastyivosti vysokoefektyvnoyi LWAC dlya zbirnykh konstruktsiy z brazyl'skymy lehkymy ahrehatamy. Tsem Kon Compo., Nr.25, 77-82.
8. **Dots. Prof. Vey Tionh-Khuan.** (2005). Nedavni podiyi v lehkykh vysokomitsnykh betonakh z ahrehatamy ta bez nykh ", Tretye mizhnarodna konferentsiya z budivel'nykh ma-

- terialiv: produktyvnist', innovatsiyi ta strukturni naslidky, Universytet Brytans'koyi Kolumbiyi, Vankuver, Kanada, 22-24.
9. **Erhul Yasar, Kenhiz Dyuran Atis, Alaettyn Kilich, Khasan Hul'sen.** (2003). Sylovi vlastyvoli lehkoho betonu, vyhotovleni z bazal'tovoyi pemzy ta lyutserny. *Materialy Lysty*, Nr.57, 2267-2270.
 10. **Dzhamal Alduay, Khalyd Alshalekh, r-n Naseer Khak, Khalid Ellayity,** (1999). Lehkyi beton u haryachykh pryberezhykh rayonakh. *Tsenty ta betonni kompozyty*, Vol.21, Nr.5-6, 453-458.
 11. **Al'-Khayat KH., Khake M.N.** (1998). Vplyv pervynnoho vytryvalosti na ranni syly ta fizychni vlastyvoli lehkoho betonu. *Doslidzhennya tseментu ta betonu*, Vol.28, Nr.6, 859-866.
 12. **Padam Shafih, Mokhd Zamin Yumaat, Khilili Makhmud.** (2011). Oliya pal'mova obolonka v yakosti lehkoho ahrehatu dlya vyrobnytsva vysokomitsnoho lehkoho betonu. *Budivnytsvo ta budivel'ni materialy*, Vol.25, Nr.4, 1848-1853.
 13. **Niyazi Uhur Kokal, Ozutaran T.** (2011). Prochnost ta elastychni vlastyvoli strukturnykh lehkyykh betoniv. *Materialy ta dizayn*, Vol.32, Nr.4, 2396-2403.
 14. **Uhu Kosta, Eduardo Khulio, Lourenko J.** (2012). Novyy pidkhid do prohnozuvannya usadky vysokomitsnoho lehkoho ahrehovanoho betonu. *Budivelni ta budivelni materialy*, Vol.35, 84-91.
 15. **Sannitsky M. A. Poznyak O. R., Marushchak U. D.** (2012). Enerhozberihayuchi tekhnolohiyi v budivnytsvi: navch. Posibnyk. Lviv, Vydavnytsvo Lvivskoyi politekhniki, 236.
 16. **Pushkarova K. K. Honchar O.A., Kaveryn K.O.** (2014). Osoblyvosti modyfikatsiyi tseментnoyi matrytsi dlya otrymannya vysokomitsnykh lehkyykh keramzytobetoniv. *Budivelni materialy, vyroby ta sanitarna tekhnika*, Nr.52, 43-48.
 17. **Kaveryn K. O.** (2015). Vyskomitsni lehki keramzytobetonny, modyfikovani polikarboksyilatnymi superplastyfikatoramy. *Budivelni materialy, vyroby ta sanitarna tekhnika*, Nr.56, 47-54. (ISSN 2413-7693).
 18. **Pushkarova K. K., Kaveryn K. O.** (2016). Vykorystannya vysokomitsnykh keramzytobetoniv u karkasno-monolitnomu budivnytsvi. *Resursokomisni materialy, konstruktsiyi, budivli ta sporudy*, Issue33, 75-83. (ISBN 966-7447-21-9).
 19. **Pushkarova K. K., Kaveryn K. O., Kalatayevs'ky D. O.** (2015). Doslidzhennya vysokomitsnykh tseментnykh kompozytsiy, modyfikovanykh kompleksamy orhanichnykh kremnezemu. *Skhidnoyevropeyskyi zhurnal pidpryyemstv pidpryyemstva*, Vol.5, Issue 5 (77), 42-51. doi: 10.15587/1729-4061.2015.51836.
 20. **DSTU B V.2.7-49-96.** (1997). *Budivel'ni materialy. Betony Metody vyznachennya morozostiykosti. Pryskoreni metody vyznachennya morozostiykosti pry bahatorazovomu zamorozhuvanni ta vidtochenni.* Chynnyy vid 1996-09-01, Kyiv, Derzhkommistobuduvannya Ukrainy, 9.
 21. **Leshchynsky M. Yu.** (1980). *Yspytannya betona.* Moscow, Stroyzdat publ., 360.
 22. **DSTU B V.2.6-145: 2011 (HOST 31384: 2008, NEQ).** (2010). *Zakhyst betonnykh i zalizobetonnykh konstruktsiy vid koroziyi. Zahal'ni tekhnichni vymohy.* Chynnyy vid 2011-07-01. Kyiv, Minrehionbud Ukrainy, 77.
 23. **DSTU B V.2.6-181: 2011 (HOST 31383: 2008, NEQ).** (2011). *Zakhyst betonnykh i zalizobetonnykh konstruktsiy vid koroziyi. Metody vyprobuvan.* Chynnyy vid 2011-01-01. - Kyiv, Minrehionbud Ukrainy, 68. (Derzhavnyy standart Ukrainy).
 24. **DSTU B V.2.7-216: 2009.** (2010). *Budivel'ni materialy. Betony Metody vyznachennya deformatsiy usadky ta skorboty.* Chynnyy vid 2010-09-01. Kyiv: Minrehionbud Ukrainy, 29. (Derzhavnyy standart Ukrainy).
 25. **Solopova H. S.** (2015). *Etapy stanovlennya porystykh zapovnyuvachiv ta betoniv na yikh osnovi.* *Symvol nauky (journal)*, Nr.12, 81-82.
 26. **Karapetyan K. S., Kudzys A. P., Maylyan R. L., Skatynsky V. Y., Aleksandrovs'koho S. V.** (1976). *Osoblyvosti protsesiv kozatstva ta usadok lehkyykh ta inshykh novykh vydiv betoniv. Polzuchest' i usadka betonu ta zhelezobetonnykh konstruktsiy.* Moscow, Stroyzdat publ., 351.
 27. **Moskalkova Yu. H.** (2017). *Povedinka keramzytu na stadiyi utvorennya mikrotrishchyn.* *Nauka ta budivnytsvo*, Nr.3, 40-43.
 28. **Krovyakov S. O., Mishutin A. V.** (2017). *Pidvyshchennya dovhovichnosti lehkyykh konstruktsiyonykh betoniv dlya hidrotekhnichnykh ta transportnykh sporud shlyakhom obrobky poverkhni porystoho zapovnyuvacha.* *Krovyakov, Nauka i budivnytsvo*, Nr.3, 50-58.
 29. **Kholodnyuk V. P.** (2016). *Prymishchennya enerhoefektynykh keramzytobetonnykh blokiv v domostroyu. Al'ternatyva yacheystym blokam.* *Budivelni materialy*, 5-7.

30. **Pushkarova K. K., Kavryn K. O.** (2017). Doslidzhennya osoblyvostey formuvannya kontaktnoyi zony «v'yazhucha rechovyna - keramzytovyy hraviy» ta otsinka yiyi vplyvu na kinetyku naroshchuvannya mitsnosti lehkyykh betoniv. *Keramika: nauka i zhyttya*, Nr.1(34), Kyiv, 32-41.

Модифікований високоміцний легкий бетон на основі керамзиту: склад, будова, властивості

*Костянтин Каверин, Ольга Бондаренко,
Дмитро Аношко, Дмитро Левківський, Тетяна Антошук*

Анотація. Робота присвячена розробці легких бетонів підвищеної міцності на основі портландцементу, модифікованого комплексною органо-кремнеземистою добавкою, що містить полікарбонатний суперпластифікатор та активну тонкодисперсну кремнеземисту складову. Досліджено вплив цієї добавки на фізико-хімічні особливості процесів гідратації і структуроутворення та показано, що висока кінетика набору міцності пов'язана з направленим формуванням низькоосновних гідросилікатів

кальцію, зародків гідрогранатів та плазоліту, що є кристалохімічно подібними між собою, та забезпечують отримання щільної і високоміцної структури цементного каменю.

Модифікування комплексною добавкою дозволяє отримати бетонні суміші рухомістю S4(P4) при витраті портландцементу не більше 330 кг/м³, при цьому міцність бетонів при стиску досягає 55 МПа, водонепроникність збільшується до W8, морозостійкість до F400, підвищуються коефіцієнти корозійної стійкості K_c в досліджених розчинах сульфатів магнію, натрію та амонію на 10...24%. Введення комплексної добавки також сприяє зменшенню деформації усадки на 16...19%, порівняно з контрольним складом, що позитивно впливає на довговічність отриманих бетонів.

Ключові слова: легкий бетон підвищеної міцності, комплексна органо-кремнеземиста добавка, полікарбонатний суперпластифікатор, тонкомелений трепел, міцність при стиску, водонепроникність, морозостійкість, корозійна стійкість, деформації усадки.