Comparative analysis of methods of introducing fine perlite into cement composition

Irina Kozlova[1*], *Olga* Zemskova[1], *Nikita* Lekanov[1], *and Daniil* Gavryutin[1]

[1]Moscow State University of Civil Engineering, Yaroslavskoe sh., 26, 129337 Moscow, Russia

Abstract. The article presents a comparative analysis of the methods of introducing fine perlite into the the cement systems. The first method is dry mixing of the additive with cement, followed by mixing with water with a polycarboxylate plasticizer. The second method is based on mixing cement powder with a stabilized suspension of finely dispersed perlite instead of mixing water. Before the introduction of a fine perlite suspension into the cement, studies of its aggregation and sedimentation stability were carried out. It was found that suspensions with 1-3% of perlite and 0.3-0.5% of polycarboxylate plasticizer after ultrasonic processing, have the greatest aggregation and sedimentation stability. There is an increase in the compressive strength of modified samples by more than 2 times at 1 day age and by 56% at 28 days age compared with non-modified cement. When compared with a sample with polycarboxylate plasticizer, there is an increase in the strength of the modified sample by 47% at 1 day age and by 19% at the at 28 days age. Thus, a comparative analysis showed that the method of obtaining a stabilized perlite suspension using an integrated approach and its introduction into the cement composition instead of mixing water, allows to obtain higher mechanical parameters.

1 Introduction

Currently, special attention is paid to the development of new technologies for the production of construction materials as well as to the study of structure formation processes in the designed materials. The production of high-quality building materials is a priority direction nowadays. Special attention is paid to the use of non-deficient raw materials of natural and industrial origin. Perlite is a widespread component used for the production of building materials for various purposes. It is a kind of volcanic glass, a product of volcanic activity [1-4]. In Russia, there are deposits of perlite in Primorsky Krai, Buryatia, Kamchatka.

Perlite has low density, a porous spongy material can be obtained from it at of 850-1200°C, which is used in the production of heat- and sound-insulating building materials [5-8].

Perlite demonstrate high adsorption and fire resistant properties, radiation protective and disinfecting characteristics [9-13], which expands the scope of its use in the production of building materials. The use of perlite in the composition of concretes, magnesia binders,

* Corresponding author: iv.kozlova@mail.ru

 https://doi.org/10.1051/e3sconf/202341304001

dry building mixes, as a raw material component in the production of cement clinker and various types of composite materials is noted [7, 14-18]. The scientists study perlite as a finely dispersed component to the cement systems and its influence to the structure formation in the cement system [19-21].

According to the information mentioned above, we can consider perlite as a promising component in the production of building materials.

This paper studies finely dispersed perlite and the possibility of its introduction into the cement system. Authors [22-24] noted difficulties in the distribution of a finely dispersed component in the cement structure, and some methods to solve this problem were found. Based on these studies, this article consider methods of introducing finely dispersed perlite into the composition of cement matrix and analysis of the results of the study.

2 Experimental

The object of present research is the finely dispersed perlite of the Mukhor-Tala deposit (Buryatia river). The technological scheme for obtaining fine perlite is shown in Figure 1, the chemical and granulometric composition of perlite are presented in Tables 1 and 2.

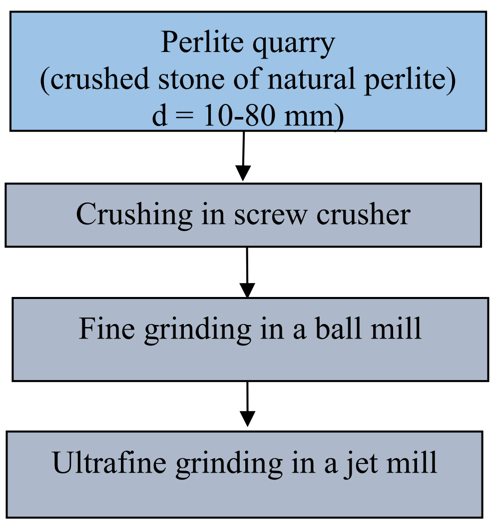


Fig.1. Technological scheme for obtaining fine perlite

Table 1. Chemical composition of amorphous perlite

Components	Content, %	Components	Content, %
SiO_2	70.4	MgO	0.3
Al_2O_3	14.7	TiO_2	0.1
Fe_2O_3	0.7	K_2O	3.9
FeO	0.4	Na_2O	3.4
CaO	0.8	H_2O	5.3

Table 2. Granulometric composition of fine perlite

Particles size, μm	Fraction content, mass.%	Particles size, μm	Fraction content, mass.%

 https://doi.org/10.1051/e3sconf/202341304001

0-1	8	7-10	10
1-3	36	10-15	8
3-5	14	15-20	7
5-7	13	20-30	4

Table 2 demonstrates that the finely dispersed perlite obtained in a laboratory jet mill is a polyfraction composition with a predominant particles size of 1-3 microns, which was determined using the Mastersizer 3000 laser diffraction particle size analyzer.

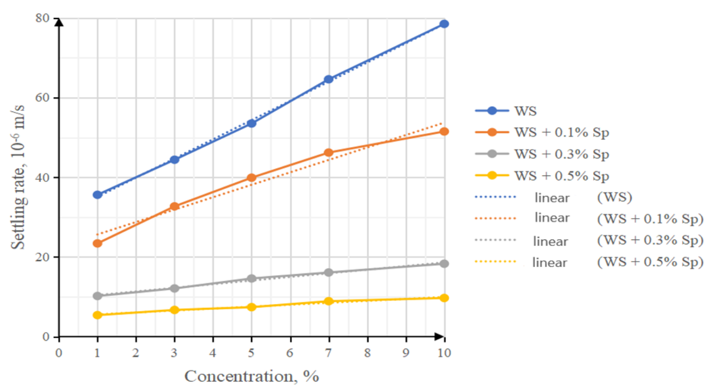
Cement samples of 20x20x20 mm were prepared from Portland cement (OPC) CEM I 42.5N (Podolsk-Cement, JSC), finely dispersed perlite was introduced into the cement system in the form of a dry component and as a stabilized suspension in quantities 1, 3, 5, 7, 10 % from the content of Portland cement.

To achieve stabilization of finely dispersed perlite particles, ultrasonic processing on the UZDN-I device was used as well as the introduction of a polycarboxylate superplasticizer (Sp).

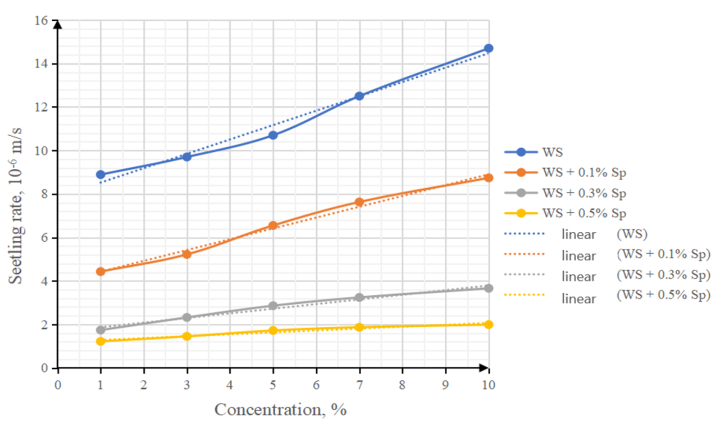
3 Evaluation

Fine particles of perlite with size of 1-3 microns considered as submicron particles, therefore they have tendency to aggregation process. To examine the aggregation and sedimentation stability, the prepared water suspensions (WS) were transferred into cylinders V = 100 cm^3 and the sedimentation process was observed. It is established that the sedimentation of perlite particles occurs in three stages. At first stage large particles of perlite settle intensively, at the second stage the dispersion medium is clarified; at the third stage the process of sedimentation of perlite is completed. Based on this data, graphs "particles settling rate - concentration of fine perlite" were constructed (Fig. 2).

a)



b)



c)

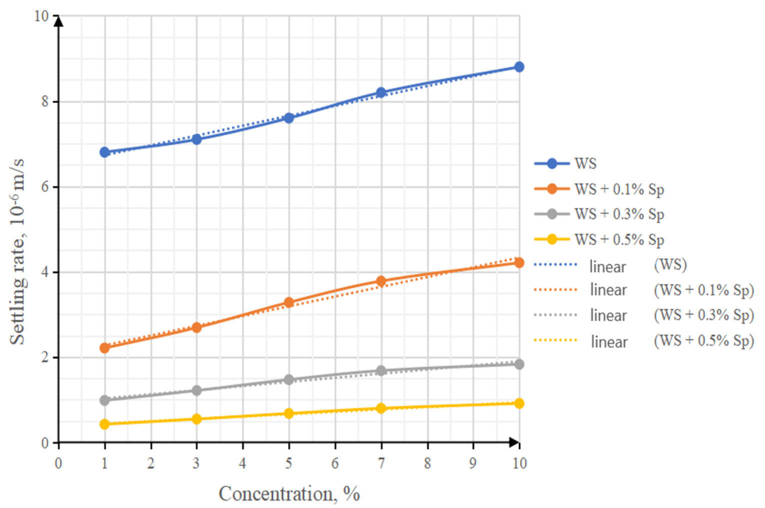


Fig.1. Dependance of settling rate of particles from the concentration of fine perlite: a) I period of settling of particles; b) II period of settling of particles; c) III period of settling of particles

As it follows from the results shown above, the suspensions with 1-3% of fine perlite stabilized with 0.3-0.5% of a plasticizer are the most stable. The stability of suspensions with plasticizer after ultrasonication increased almost 2 times at all settling periods, which confirms the effectiveness of homogenization and stabilization methods.

In this case, the homogenization of the suspension is achieved by ultrasonication, and the stabilization of perlite is achieved by fixing of functional groups of polycarboxylate on the surface of its particles. Stabilizer's non-polar groups form a viscous layer between the surface of perlite particles and the dispersed medium. The polar groups contribute to the formation of electric double layer (EDL), which promotes the micelle formation of perlite particles.

Polycarboxylate ether molecules concentrate on the surface of perlite particles to form dense and elastic gel-like films of the main chain radicals, which contribute to structural, mechanical and hydrodynamic factors of stability, resulting in stabilization of perlite fine particles. When perlite particles get close, the films prevent them from sticking, promoting structural and mechanical factors of aggregation stability.

To conduct a comparative analysis of the methods of introducing finely dispersed perlite into the cement system, the following samples were prepared:

- dry mixtures composed of cement and finely dispersed perlite mixed with water and water with polycarboxylate plasticizer;
- cement powder mixed with perlite water suspensions and stabilized perlite suspensions.

The obtained results are presented in Tables 3 and 4.

Table 3. Properties of cement mortar

Method of introduction of perlite admixture	Perlite content, %	Normal consistency, %	Setting time, h-min	
			Initial	Final
-	-	25.00	2-20	3-20
0.5% of Sp	-	21.00	0-50	1-40
Dry mixture of cement and fine perlite	1	25.00	2-30	3-30
	3	25.00	2-40	3-40
	5	25.50	2-55	3-50
	7	25.50	3-10	4-10
	10	26.00	3-20	4-20
Dry mixture of cement and fine perlite mixed with water + Sp	1	20.00	1-00	1-50
	3	20.50	1-20	2-00
	5	21.00	1-30	2-10
	7	21.50	1-50	2-40
	10	22.00	2-20	3-10
Cement mixed with water suspension of fine perlite	1	25.00	2-25	3-25
	3	25.00	2-35	3-35
	5	25.00	2-45	3-45
	7	25.50	2-55	3-50
	10	25.50	3-10	4-00
Cement mixed with stabilized suspension of fine perlite	1	20.00	0-50	1-40
	3	20.50	1-00	1-50
	5	20.50	1-20	2-00
	7	21.00	1-40	2-20
	10	21.00	1-50	2-50

Table 4. Mechanical and structural characteristics of cement stone

Sample	Method of introduction perlite admixture	Compressive strength, MPa				Hydration degree, %	
		1day	3 days	7 days	28 days	1 day	28 days

OPC	-	23.3	38.5	49.5	81.5	52.8	69.2
OPC+1% perlite	Dry mixing	27.4	44.3	61.5	95.9	66.6	74.6
OPC+3% perlite		33.3	51.1	69.9	101.3	68.2	79.2
OPC+5% perlite		34.7	52.2	69.4	99.5	68.8	78.5
OPC+7% perlite		33.1	50.3	67.2	96.4	67.2	77.6
OPC+10% perlite		32.2	48.4	65.4	93.2	66.0	76.0
OPC+1% perlite	Mixing with water suspension	34.5	47.2	65.8	102.6	67.6	78.5
OPC+3% perlite		37.8	54.5	71.2	105.7	70.2	84.0
OPC+5% perlite		38.2	53.7	72.3	104.5	72.2	85.2
OPC+7% perlite		36.8	52.8	70.7	103.4	72.0	84.9
OPC+10% perlite		35.1	49.7	69.4	101.3	71.7	84.3
OPC+ 0.5% Sp	-	36.9	68.2	78.3	106.9	69.3	83.2
OPC+1% perlite + 0.5% Sp	Dry mixing	43.2	75.7	83.6	113.5	75.6	86.4
OPC+3% perlite + 0.5% Sp		44.4	77.9	89.2	118.1	78.3	88.7
OPC+5% perlite + 0.5% Sp		45.2	80.7	91.4	119.5	78.0	88.1
OPC+7% perlite + 0.5% Sp		43.6	77.2	88.6	117.3	77.2	87.4
OPC+10% perlite + 0.5% Sp		41.7	75.5	84.4	115.3	76.1	86.5
OPC+1% perlite + 0.5% Sp	Mixing with water suspension	48.2	79.4	88.6	120.5	79.9	90.3
OPC+3% perlite + 0.5% Sp		54.4	84.4	95.6	126.6	82.5	92.2
OPC+5% perlite + 0.5% Sp		54.2	85.5	95.9	127.5	82.7	92.5
OPC+7% perlite + 0.5% Sp		53.8	84.1	93.4	124.4	81.8	91.7
OPC+10% perlite + 0.5%		50.2	81.1	91.4	122.7	80.6	90.8

Sp							

The results shown in Table. 3 demonstrate that the introduction of fine perlite slightly increases the water demand of cement paste and does not increase the viscosity of the system. The plasticizer exhibits water-reducing effect, thereby reducing the water demand of cement paste by 16%. The introduction of 1-5% of complex admixture (perlite+Sp) leads to a decrease of the normal consistency by 18-20%.

When fine perlite is introduced into the cement composition, a slowdown in the setting time is observed. The greater the amount of the admixture, the more noticeable the slowdown in setting time. When a stabilized suspension of perlite is introduced into cement system (after ultrasonic processing and after ultrasonic processing with Sp), the slowdown is less than for dry composition of cement and perlite mixed with water and water + Sp. Probably, both due to ultrasonication and the complex effect of ultrasonication with Sp the particles in the suspension retained their size and were uniformly distributed all over the dispersed medium. Consequently it provides the uniform distribution of components in the cement system.

The study of mechanical and structural properties of cement stone (Table. 4) demonstrate that various methods of introduction of finely dispersed perlite into the cement composition provides an increase in compressive strength and the hydration degree of the samples.

The results show that the highest characteristics are reached with 3-5% of fine perlite in the cement composition.

When dry mixing is applied, the strength of the samples at 1 day age increased from 23.3 to 34.0 MPa (by 46%), the hydration degree increased by 30%; at 28 days age the strength of the samples increased from 81.5 MPa to 100.4 MPa (by 23%), the hydration degree increased by 14%.

When finely dispersed perlite was introduced into cement system in the form of water suspension instead of mixing water, the strength of the samples at 1 day age increased from 23.3 to 38.0 MPa (by 63%), the hydration degree increased by 35%; at 28 days age the strength of the samples increased from 81.5 MPa to 105.1 MPa (by 29%), the hydration degree increased by 22%;

When a polycarboxylate-based plasticizer is introduced into a non-additive OPC, an increase in the mechanical and structural characteristics of the cement stone is noted: at 1 day age the compressive strength increased from 23.3 to 36.9 MPa (by 58%), the hydration degree increased by 31%. At 28 days age, the compressive strength increased from 81.5 to 106.9 MPa (by 31%), the hydration degree increased by 20%.

When dry composition of cement with perlite is mixed with water + Sp, an increase in compressive strength is noted at 1 day age from 23.3 to 44.8 MPa (by 93%) compared to non-additive OPC, the hydration degree increased by 48%. In comparison with OPC+Sp samples, the strength of perlite+Sp samples increased from 36.9 to 44.8 MPa (by 21%), the hydration degree increased by 13%.

At 28 days age, there is an increase in compressive strength from 81.5 to 118.8 MPa (by 46%), the hydration degree increased by 28% compared to the additive OPC. When comparing these samples with OPC+Sp samples, it was found that at 28 days age compressive strength of perlite + Sp samples increased from 106.9 to 118.8 MPa (by 11%), the hydration degree increased by 6%.

When OPC is mixed with a stabilized perlite suspension, there is an increase in compressive strength at 1day age from 23.3 to 54.3 MPa (by 2.33 times), the hydration degree increased by 56% compared OPC. At 28 days age, there is an increase in compressive strength from 81.5 to 127.05 MPa (by 56%); the hydration degree increased by 33%.

The compressive strength of samples with a stabilized perlite suspension increased from 36.9 to 54.3 MPa (by 47%) at 1 day age compared to OPC + Sp sample; the hydration degree increased by 19%. At 28 days age, the compressive strength increased from 106.9 to 127.05 MPa (by 19%), the hydration degree increased by 11%.

The comparative analysis confirms that samples obtained after mixing cement with suspension containing 3-5% perlite stabilized with a polycarboxylate plasticizer and ultrasonic processing demonstrate the highest characteristics. The introduction of finely dispersed perlite into the cement system in the form of a stabilized suspension ensures uniform distribution of its particles throughout the material and provides the formation of the final product with increased characteristics.

4 Conclusions

The study of the aggregation and sedimentation stability of fine perlite suspensions show that maximum homogenization and stabilization is provided due to the complex effect of ultrasonic processing and the introduction of a polycarboxylate plasticizer. Suspensions containing 1-3% perlite and 0.3-0.5% polycarboxylate plasticizer are the most stable.

It is noted that introduction of finely dispersed perlite into the cement system in a form of dry mixture of OPC with perlite and subsequent mixing with water + Sp as well as in the form of a stabilized suspension provides an increase in the hydration degree and mechanical characteristics of cement stone.

However, mixing with a stabilized suspension is the most effective way to introduce fine perlite into the cement composition, since the most uniform distribution of the admixture in the cement system is ensured. There is an increase in the compressive strength of samples mixed with stabilized perlite suspension by more than 2 times at 1 day age and by 56% at 28 days age compared with non-additive OPC. When compared to OPC+Sp sample, there is an increase in compressive strength by 47% at 1 day age and by 19% at 28 days age.

References

1 Ja. Lexa, P. Varga, P. Uhlik, P. Koděra, A. Biroň, M. Rajnoha, Perlite deposits of the Central Slovakia Volcanic Field (Western Carpathians): Geology and properties, Geologica Carpathica, **72(3)**, 253-281 (2021) DOI: 10.31577/GeolCarp.72.3.5.

2 F. S. Başar, B. Acartürk, Perlit Katkılı Seramik Bünye Özelliklerinin Araştırılması, Cilt: 22 Sayı, **5**, 1149 - 1156 (2022) DOI: 10.35414/akufemubid.1115439

3 G. Tsintskaladze, T. Kordzakhia, T.Sharashenidze, M. Zautashvili, G. Beridze, I. Javakhishvili, Volcanic glasses on the territory of Georgia and prospects for their use, Volcanic glasses on the territory of Georgia and prospects for their use, 87-88 (2020)

4 B. Tarhan, M. Tarhan, Utilization of perlite as an alternative raw material in the production of ceramic sanitaryware, Journal of Thermal Analysis and Calorimetry, **147(3)**, 3509-3518 (2022) DOI: 10.1007/s10973-021-10784-5.

5 A. B. Toturbiev, V. I. Cherkashin, B. D. Toturbiev, U. D. Toturbieva, Perlitovyj teploizoljacionnyj material na nanodispersnom polisilikatnatrievom vjazhushhem, Promyshlennoe i grazhdanskoe stroitel'stvo, **3**, 20-24 (2016)

6 O. Benjeddou, G. Ravindran, M. A. Abdelzaher, Thermal and Acoustic Features of Lightweight Concrete Based on Marble Wastes and Expanded Perlite Aggregate, Buildings, **13(4):992**, (2023) DOI: 10.3390/buildings13040992.

7 A. Madadi, Effect of perlite powder on properties of structural lightweight concrete with perlite aggregate, Structural Engineering & Mechanics, **84(3)**, 393-411 (2022) DOI: 10.12989/sem.2022.84.3.393.

8 R. Alyousef, O. Benjeddou, Ch. Soussi, A. Khadimallah, M. Jedidi, Experimental Study of New Insulation Lightweight Concrete Block Floor Based on Perlite Aggregate, Natural Sand, and Sand Obtained from Marble Waste, Advances in Materials Science and Engineering, **1(1-14)** (2019) DOI: 10.1155/2019/8160461

9 M. A. Vysockaja, M. Ju. Fjodorov, D. A. Kuznecov, Adsorbcionnaja i strukturirujushhaja aktivnost' perlita kak napolnitelja dlja asfal'tobetona, Izvestija vysshih uchebnyh zavedenij. Stroitel'stvo, **7-8(643-644)**, 21-26 (2012)

10 R. S. Al-jadiri, M. A. Al-w. Ali, Q. Ja. Frayyeh, Study some Mechanical and Thermal Properties of reinforced Perlite Concrete, Key Engineering Materials, **924**, 233-242 (2022) DOI: 10.4028/p-9os233.

11 S. N. Terehin, G. L. Shidlovskij, Ju. M. Tihonov, Ognezashhitnye kompozity na osnove vermikulita, perlita i voloknistyh napolnitelej, Problemy upravlenija riskami v tehnosfere, **3(35)**, 41-44 (2015)

12 N. V. Gurgenjan, K. Pjuskjuljan, I. B. Hachanova, Radiacionnye harakteristiki perlitov, Himicheskaja tehnologija, **16(6)**, 352-357 (2015)

13 N. P. Fadeeva, M. V. Pavlov, I. A. Harchenko, M. M. Simunin, K. A. Shabanova, V. F. Pavlov, I. I. Ryzhkov, Vysokoprochnye keramicheskie podlozhki na osnove perlita i penosilikatov dlja fil'tracionnyh membran, Membrany i membrannye tehnologii, **12(3)**, 192-199 (2022)

14 S. Top, H. Vapur, M. Altıner, D. Kaya, A. Ekicibil, Properties of fly ash-based lightweight geopolymer concrete prepared using pumice and expanded perlite as aggregates, Journal of Molecular Structure, **1202(2)**, 127236 (2019) DOI: 10.1016/j.molstruct.2019.127236.

15 S. Hassanabadi, S. M. Sadrameli, Preparation, characterization and thermal properties of surface-modified expanded perlite/paraffin as a form-stable phase change composite in concrete, Journal of Thermal Analysis and Calorimetry, **144**, 61-69 (2021) DOI: 10.1007/s10973-020-09440-1.

16 L. P. Chernjak, N. A. Dorogan', D. K. Glushhenko, Primenenie perlita kak komponenta syr'evoj smesi dlja izgotovlenija cementnogo klinkera, Colloquium-Journal, **6-1(17)**, 57-62 (2018).

17 S. G. Maxineasa, *The use of perlite in civil engineering applications*, IOP, Mater. Sci. Eng., **1242**, 012022 (2022) DOI 10.1088/1757-899X/1242/1/012022.

18 G. Yan, M. Z. Al-Mulali, A. Madadi, I. Albaijan, H.E. Ali, H. Algarni, B. N. Le, H. Assilzadeh, Effect of perlite powder on properties of structural lightweight concrete with perlite aggregate, Structural Engineering and Mechanics, **84(3)**, 393-411 (2022) DOI: https://doi.org/10.12989/sem.2022.84.3.393.

19 N. I. Kozhuhova, R. V. Chizhov, I. V. Zhernovskij, V. I. Loganina, V. V. Strokova, Osobennosti strukturoobrazovanija geopolimernoj vjazhushhej sistemy na osnove perlita c ispol'zovaniem razlichnyh vidov shhelochnogo aktivatora, Stroitel'nye materialy, **3**, 61-64 (2016)

20 E. Kapeluszna, Ł. Kotwica, W. Pichór, W. Nocuń-Wczelik, Cement-based composites with waste expanded perlite - Structure, mechanical properties and durability in

chloride and sulphate environments, Sustainable Materials and Technologies, **24**, e00160 (2020) DOI: 10.1016/j.susmat.2020.e00160.

21 V. Hrbek, V. Koudelková, P. Padevět, P. Šašek, Microscopic features of cement paste modified by fine perlite, Acta Polytechnica CTU Proceedings, **7(12)** (2016) DOI: 10.14311/APP.2017.7.0012.

22 S. Samchenko, I. Kozlova, O. Zemskova, D. Zamelin, A. Pepelyaeva, Complex Method of Stabilizing Slag Suspension, Advances in Intelligent Systems and Computing, **983**, 817-827 (2019) DOI: 10.1007/978-3-030-19868-8_80.

23 S. Samchenko, I. Kozlova, O. Zemskova, T. Nikiporova, S. Kosarev, Method of Modifying Portland Slag Cement with Ultrafine Component, Advances in Intelligent Systems and Computing, **983**, 807-816 (2019) DOI: 10.1007/978-3-030-19868-8_79.

24 S. Samchenko, I. Kozlova, O. Zemskova, D. Potaev, D. Tsakhilova, Efficiency of stabilization of slag suspensions by polycarboxylate, E3S Web of Conferences, **91**, 02039 (2019) DOI: 10.1051/e3sconf/20199102039.