Technobius, 2022, 2(3), 0024, DOI: https://doi.org/10.54355/tbus/2.3.2022.0024

Technobius

https://technobius.kz/

e-ISSN
2789-7338

Article

Potential applicability of tailings as fine aggregate for concrete paving slabs

Zulfiya Aubakirova[1,*], Aldiyar Temirbekov[1], Monika Kulisz[2], Gulnaz Zhairbaeva[1]

[1]School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
[2]Department of Management, Lublin University of Technology, Lublin, Poland
*Correspondence: aubakirova.zulfiya@mail.ru

Abstract. Statistics of recent years shows an annual increase in the volume of technogenic waste (in particular "tailings") of mining and metallurgical enterprises of Kazakhstan by about 1.5 billion tons, which at the current time is already about 4.7 billion that entails certain environmental and economic consequences. This article proposes the potential use of the tailings of the enterprises as a fine aggregate to partially replace the consumption of cement in the concrete mixture for the manufacture of paving slabs. Carbonate tailings of Kazzinc LLP enterprise were used. To determine the optimum composition of concrete mix with the use of tailings were made control and 4 experimental compositions with the replacement of part of the cement waste in the amount of 5, 10, 15, 20% respectively. Samples of concrete mixtures were tested for compressive strength, flexural tensile strength, abrasion, frost resistance, and resistance to wetting and drying. According to the test results, it was found that as the concentration of tailings increases, the physical-mechanical and operational indicators of the concrete mixture and concrete for the manufacture of paving slabs improve.
Keywords: technogenic waste, tailings, aggregates, concrete, paving slabs.

1. Introduction

The application in processing of technogenic raw materials in warehouses, waste mines, mining and processing plants (MPPs) is a secondary resource for use in modern global production, since it ensures the release of occupied tailings ponds, warehouses, land and vehicles from toxic technogenic waste. Thus, environmental pollution is reduced, the ecological situation in the area of mining enterprises' management significantly improves, and the degraded ecosystems of entire regions are restored. This trend is observed in most industrially developed countries: the USA, Italy, Canada, Great Britain, Poland, as well as in South Africa, Spain, Portugal, and other countries. For example, in the USA aluminum accounts for 20 % of technogenic waste, iron – 33 %, lead and zinc – 50 %, copper – 44 %, while in Kazakhstan and abroad these figures do not exceed 15%. Thus, the share of building sector of Kazakhstan in use of technogenic waste does not exceed 1,5 - 2 % [1].

Almost half of the total mass of ore during enrichment forms a special type of technogenic waste - "tailings", which are quartz-iron sand consisting of particles of 0.14-0.63 mm. The presence of a large amount of iron compounds in the composition of these wastes causes their higher density than the natural sand [2].

Different chemical composition, physical and chemical parameters and properties of the technogenic waste formed during mining and concentration of ores determine the variety of construction materials obtained on their basis. The basic direction of recycling of this group of wastes is the production of non-metallic materials, first of all, aggregates of concrete and mortars, road-building materials, cobble-stone, etc. The cost of aggregates from technogenic waste, including tailings, is usually lower than that of natural materials. For example, in the conditions of the East Kazakhstan oblast the fractionated wastes of ore dressing plants are 6-10 times cheaper than sand. The use of technogenic wastes reduces the cost of concrete products by 10-15 %.

Mineral extraction all over the world is characterized by an increase in the volume and area of mining operations due to the dynamic development of the needs of human society, which causes significant harm to the environment. For example, the total amount of technogenic waste from mining and metallurgical enterprises in Kazakhstan increases by approximately 1.5 billion tons per year. At the current moment, the total reserves of enrichment production wastes already amount to 4.7 billion tons and occupy an area of 164.14 square kilometers. The waste from enrichment plants is a finely ground product with the grain size of 0.074 mm in the volume of 40-80 % and 0.15 mm in the volume of 10-15%. The chemical composition is mainly represented by silica (67-72 %), alumina (11-12 %), calcium oxide (2.6-4.5 %) [3].

Continuous growth of the volume of waste production, raises the question of the need to find effective ways of their practical application. In this regard, the authors of this study proposed the possibility of replacing part of the cement introduced into the concrete mixture by tailings wastes from 5 to 20 %. The purpose of the experiment was to obtain a concrete mixture for the production of paving slabs. To achieve the goal, tests were carried out to determine the optimal composition of the concrete mixture, satisfying the requirements for compressive strength, bending tension, abrasion, frost resistance, and resistance to wetting and drying.

2. Methods

In order to obtain the optimal composition of the concrete mixture were made control and experimental samples (Table 1).

Table 1 – Test sample compositions

Samples	Percentage of cement replacement, %	Material consumption per 1 m^3 of mixture			
		Cement, kg	Sand, kg	Tailings, kg	Water, l
Reference:	0	594.4	1634	-	171.2
Experimental:					
No. 1	5	564.7	1634	29.7	171.2
No. 2	10	535.0	1634	59.4	171.2
No. 3	15	505.2	1634	89.2	171.2
No. 4	20	475.6	1634	118.8	171.2

To select the optimal composition of the concrete mixture in the experiment was used:

- Cement grade M400 D0 [4] produced by UCG Company (Almaty), in Ust-Kamenogorsk;
- Quartz sand with particle size modulus of 2.5 microns according to [5] and [6] produced by LLP "Polypak S" (Karaganda);
- Water for concrete mixture mixing according to [7].

The procedure for determining the properties of cement was:

- Determination of cement fineness according to [8] and [9];
- Determination of normal density and setting time of cement dough [9].

Procedure for determining the properties of sand:

- Determination of the coarseness modulus of sand according to [10];
- Determination of the content of dust and clay particles in the sand according to [10];
- Determination of the true density of sand according to [10];
- Determination of bulk density of sand according to [10];
- Determination of hollowness according to [10].

For the purposes of the experiment, the tailings of Kazzinc LLP's mining and processing plants were used. The composition of enrichment tails was determined by quantitative elemental analysis of the studied material using mass spectrometry and atomic emission spectrometry. The analysis revealed that the "tailings" are of carbonate nature and are a finely ground product, which does not require additional grinding before use. The granulometric composition of the waste is as follows: grains smaller than 85 microns are 25-30 %, 85-200 microns – 55-65 % microns, and larger than 200 microns – 10-15 %.

The main minerals in the tailings are: dolomite 50-60 %; limestone 10-15 %; barite 10-20 %; clay matter 5-8 %; ore minerals 2-3 % [11]. Analysis for radiation pungent odor was also conducted. Radiation pungent odor is moderate, i.e., safe. Chemical composition of enrichment tails used during the experiment is shown in Table 2.

Table 2 – Chemical composition of tailings

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$BaSO_4$	FeS_2	PbS	$PbSO_4$	$PbCO_3$	Calcination losses
Content, wt. %	4.2	0.9	2.5	26.8	14.5	12.7	4.8	0.14	0.03	0.09	33.34

Tests of tailings for radionuclides were carried out in accordance with [12]. The results of these tests are given in Table 3 below.

Table 3 – Results of waste testing for radionuclides

The indicator to be determined	Unit	Value of the characteristic		
		according to [12]	during testing	errors
Radionuclides:				
thorium-212	Bq/kg	< 370	9.4	± 2.64
cesium-137	Bq/kg	< 370	9.2	± 2.76
strontium-90	Bq/kg	< 370	9.7	± 2.61

Samples from the concrete mixture for the experiment were prepared in the following sequence:

- All components of the mixture were weighed;
- Dosed sand, Portland cement and tailings were loaded into the mixer, which were then stirred for 2 minutes, then incubated for 50 minutes (Figure 1);
- Indicators of dry mixture were determined according to [8], the values of which are: bulk density 1100 kg/m^3; true density 3155 kg/m^3; normal density 25.5 %; specific surface 2500 cm^2/g; porosity 58 %;
- The mixture was mixed with the addition of water;
- From the resulting concrete mixture samples were made, which are subjected to heat and moisture treatment at 80-85 º C and then tested for compressive and flexural strength [13], abrasion [14], frost resistance [15] and resistance to wetting-drying [16].

To determine the compressive strength, specimens-cubes with dimensions of 15×15×15 cm were prepared, and for tensile strength, prism specimens with dimensions of 10×10×40 cm were prepared.

Figure 1 – Preparation of concrete samples for the experiment

3. Results and Discussion

The properties of the obtained samples of concrete mixture for the manufacture of paving tiles according to the test results are presented in Table 4.

Table 4 – Results of an experimental study of the properties of concretes

Samples	Portland cement replacement rate, %	Physical and mechanical indicators				
		Compressive strength, MPa	Tensile strength at bending, MPa	Abrasion resistance, g/cm^2	Frost resistance, cycles	Wetting-drying resistance, cycles
Reference	0	25.2	3.2	0.282	25	520
No. 1	5	29.3	3.7	0.281	35	650
No. 2	10	32.2	3.9	0.276	50	680
No. 3	15	34.5	4.2	0.275	55	690
No. 4	20	39.4	4.3	0.273	65	720

The results of tests on the compressive strength of samples showed that the highest index was obtained for sample No. 4 (Figure 2), this is the sample with the highest percentage of replacement of Portland cement with waste (20 %). It is evident that the compressive strength increases as the percentage of replacement increases. This appears to be due to an increase in the proportion of ore minerals, catalytic and modifying elements contained in the tailings.

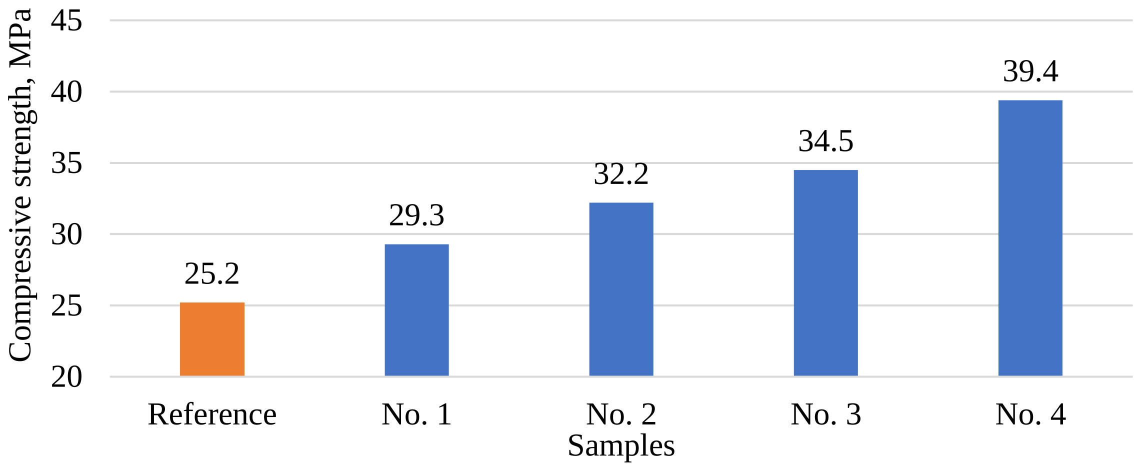

Figure 2 – Compressive strength test results of the specimens

The highest bending tensile strength value was also obtained for specimen No. 4 (Figure 3).

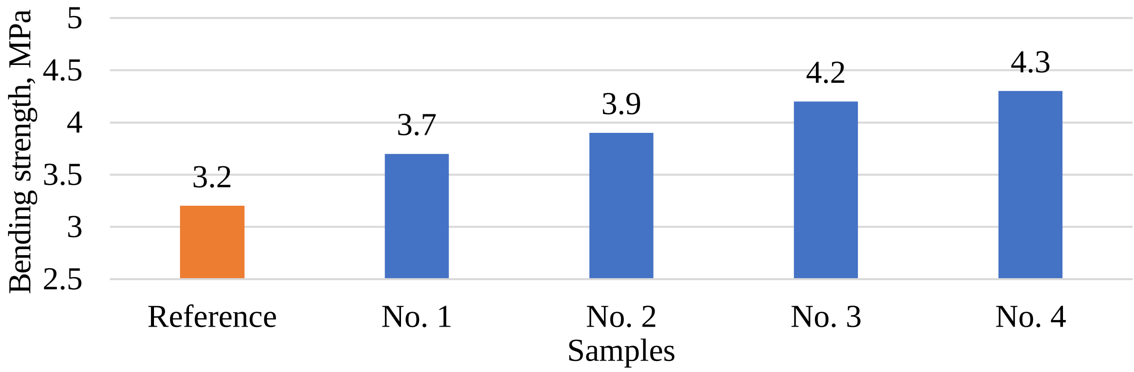

Figure 3 – Results of bending strength test of specimens

Figure 3 shows that the flexural strength class of the introduction of tailings to replace part of the cement increases as the proportion of replacement increases.

The obtained data confirm the suggested assumption that the inclusion of dolomite tailings at lower content of Portland cement and, consequently, clinker provides the maximum convergence of deformation characteristics of cement-slag stone and slag aggregate in concrete, as well as the highest values of their cohesion (adhesion) [17].

In particular, this is due to the formation in the contact zone of crystallization structures, firmly fused with the slag and cement stone in their physical and chemical interaction [18].

Obviously, the role of the addition of dolomites and calcite in the system is to enhance hydration of fine particles of tailings and the interaction of cement with it. All this causes an increase in the deformation-structural homogeneity of the concrete mixture, and, consequently, its durability, as well as an increase in the tensile strength of the sample at bending [19].

Abrasion tests of the samples showed that the abrasion of the material decreases as the proportion of replacement of Portland cement with waste (Figure 4).

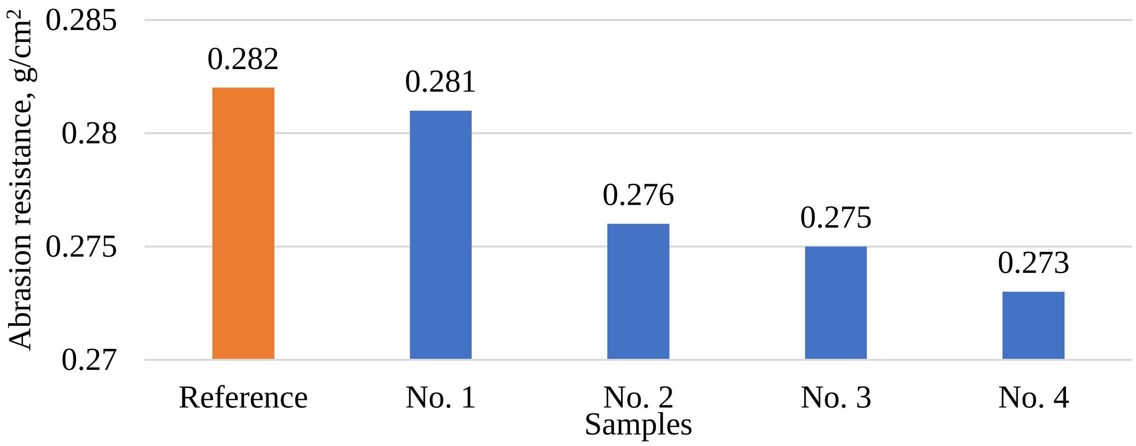

Figure 4 – Results of abrasion tests on samples

This means that the introduction of enrichment tails insignificantly reduces the abrasion resistance of the material compared to the indicator of the control sample.

Regarding the index of frost resistance, we can conclude that the experimental samples have a much higher index than the control sample (Figure 5).

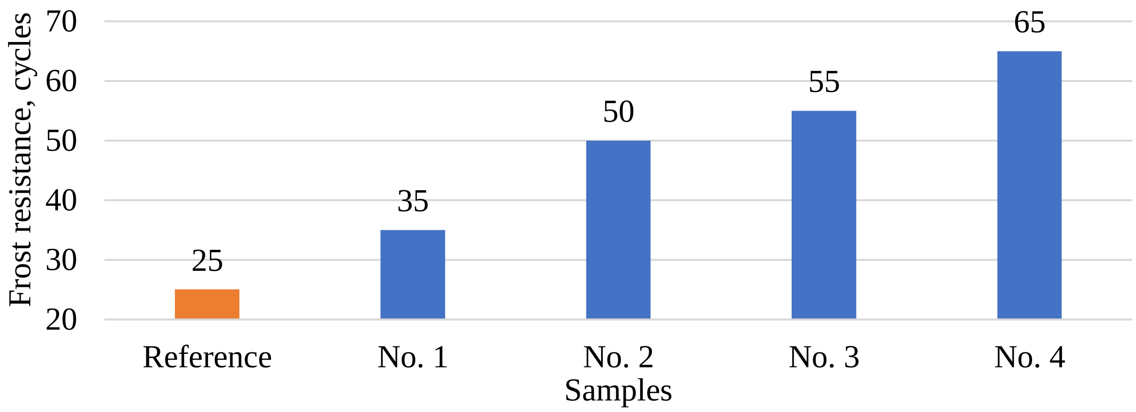

Figure 5 – Test results of samples for frost resistance

Figure 5 shows that the inclusion of polymetallic ore tailings in the composition of concrete instead of part of the cement allows to obtain material withstanding from 35 to 65 cycles.

The study of durability of samples during moistening-drying showed that the experimental samples durability index is much higher than that of the control sample, and the number of cycles increases with increasing the share of technogenic waste – polymetallic ore tailings in the experimental samples (Figure 6).

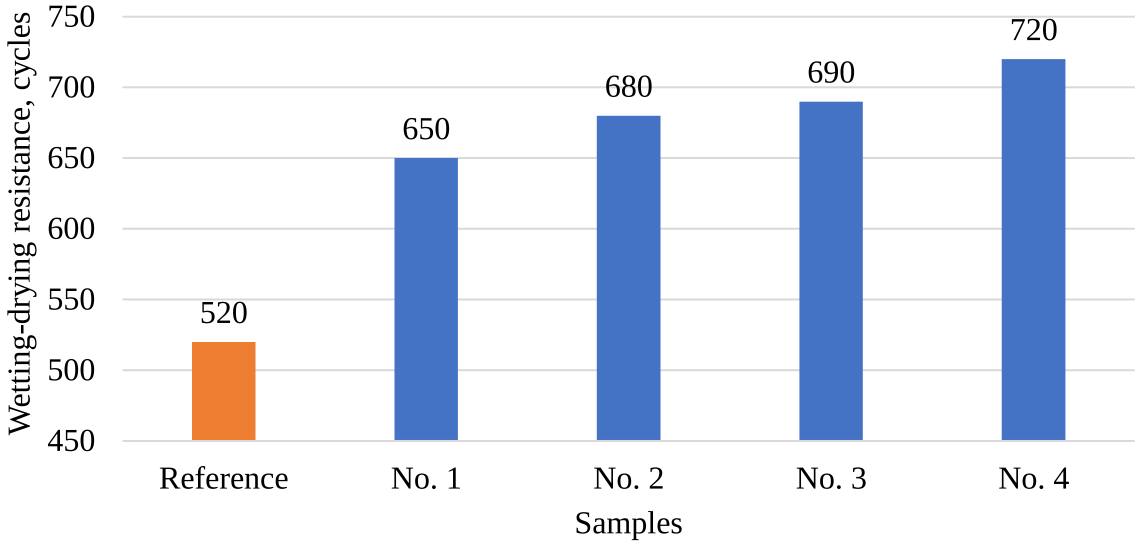

Figure 6 – Resistance test results for wetting and drying

Thus, tests of experimental samples for compressive strength, bending tensile strength, abrasion, frost resistance and resistance to wetting-drying were carried out.

Analysis of the experimental results showed that the introduction of enrichment tails instead of part of the cement allows you to get materials with improved physical and mechanical properties.

The results obtained are consistent with the available empirical data on the problem of research.

In particular, in [20] it is shown that the volume of formed crystalline calcite depends on the calcium released during slag dispersion. In the development of cements with given properties, hydrate compounds or anhydrous minerals morphologically homogeneous with slag-alkali stone hardening products serve as crusts for crystallization of secondary phases.

In [21] it is shown that drying cracks in the hydrated amorphous phase when the aqueous soda solution is removed are not typical for the modified slag-alkali stone because the reaction of interaction of slag with aqueous soda solution proceeds more completely with introduction of additives. The fine-grained structure of the artificial stone, which provides damping of internal stresses during structure formation and higher resistance to external stresses during operation, probably, among other factors, predetermines higher strength of cements in comparison with unadded ones.

It was shown in [22-23] that limestone can be used as a mineral additive in the clinker of Portland cement. In Portland cement with carbonate fillers the active structure-forming role of fine limestone particles in the forming cement stone is primarily determined by chemical interaction of calcium and magnesium carbonates with hydration products of aluminous clinker phases.

From the above empirical data, it follows that the joint grinding of Portland cement with the addition of carbonate fillers will allow its active use in the composite cement, and additives from carbonate rocks can be used as a filler. Mineral additives of metallurgical technogenic raw materials used in the production of mixed cements and their participation in the formation of artificial cement stone is based on pozzolanic nature of hardening, appearing through acid-base interaction in aqueous solution of structural elements of Portland cement clinker and additive [24].

It should be noted that the above studies emphasize that the receipt of mixtures based on the tailings of polymetallic enterprises allows to obtain products with high physical, technical and operational characteristics.

Thus, during the experiment concrete samples were made with the introduction of various proportions of tailings (from 5 to 20 %). Five samples (one control and four experimental) under laboratory conditions were tested for compressive strength, bending tensile strength, abrasion, frost resistance and resistance to wetting-drying.

The best indices were obtained for sample No. 4, as the best indices of frost resistance, abrasion resistance, resistance to wetting and drying, bending strength and compressive strength were obtained for this composition.

4. Conclusions

For the purposes of the experiment were made one control and 4 experimental compositions (with replacement of part of the cement waste 5, 10, 15, 20%) of the concrete mixture. The control sample consisted of Portland cement and silica sand and was mixed with water.

During the experiment, samples were tested for: compressive strength; tensile strength at bending; abrasion; frost resistance; resistance when wetting-drying.

The best indicators were obtained for specimen No. 4, as the best indicators of frost resistance, abrasion resistance, resistance to wetting and drying, bending strength and compressive strength were obtained for this composition.

Experimental study showed that as the weight of the added enrichment tails in the sand-concrete mixture increases, the physical-mechanical and operational indicators of the mixture samples for sidewalk slabs are improved.

Thus, experimentally proved the possibility of using tailings as a substitute for a certain amount of cement in the manufacture of small concrete products (paving slabs) with high performance and physical-mechanical characteristics.

It has been proved that obtaining concrete mixtures with the addition of tailings of polymetallic enterprises allows obtaining products with high physical-technical and operational characteristics.

References

1. Razrabotka tehnologij izgotovleniya stenovyh blokov s primeneniem mineralnyh dobavok na osnove tehnogennogo syrya predpriyatij g. Ust-Kamenogorska / V.A. Magerova. — Ust-Kamenogorsk, Kazakhstan: 2011. — 20 p.
2. Tehnogennye mestorozhdeniya: ot ispolzovaniya imeyushihsya – k sozdaniyu bolee sovershennyh / V.D. Evtekhov // Geology and Mineralogy Bulletin of Kryvyi Rih National University. — Vol. 9, No. 1. — P. 19–25.
3. Tehnogennoe mineralnoe syre rudnyh mestorozhdenij Kazahstana / MIID RK. — Almaty, Kazakhstan: — 122 p.
4. GOST 31108-2016 Common cements. Specifications [Electronic resource] / Meganorm // Meganorm. — [2017]. — Mode of access: https://meganorm.ru/Index2/1/4293751/4293751392.htm (accessed date: 10.09.2022).
5. GOST 8736-2014 Sand for construction works. Specifications [Electronic resource] / Meganorm // Meganorm. — [2015]. — Mode of access: https://meganorm.ru/Index2/1/4293767/4293767502.htm (accessed date: 10.09.2022).
6. GOST 2138-91 Moulding sands. General specifications [Electronic resource] / Meganorm // Meganorm. — [1993]. — Mode of access: https://meganorm.ru/Index2/1/4294832/4294832221.htm (accessed date: 10.09.2022).
7. GOST 23732-79 Water for concretes and mortars. Specifications [Electronic resource] / Meganorm // Meganorm. — [1980]. — Mode of access: https://meganorm.ru/Index/31/31616.htm (accessed date: 10.09.2022).
8. GOST 30744-2001 Cements. Methods of testing with using polyfraction standard sand [Electronic resource] / Meganorm // Meganorm. — [2002]. — Mode of access: https://meganorm.ru/Index2/1/4294847/4294847911.htm (accessed date: 10.09.2022).
9. GOST 310.2-76 Cements. Methods of grinding fineness determination [Electronic resource] / Meganorm // Meganorm. — [1978]. — Mode of access: https://meganorm.ru/Index/34/34110.htm (accessed date: 10.09.2022).
10. ST RK 1217-2003 Sand for construction work. Testing methods [Electronic resource] / KazLaws // KazakhstanLaws. — [2005]. — Mode of access: https://www.kazakhstanlaws.com/p-22202-st-rk-1217-2003.aspx (accessed date: 10.09.2022).
11. Uranium Association with Iron-Bearing Phases in Mill Tailings from Gunnar, Canada / G. Othmane, T. Allard, G. Morin, M. Sélo, J. Brest, I. Llorens, N. Chen, J.R. Bargar, M. Fayek, G. Calas // Environmental Science & Technology. — 2013. — Vol. 47, No. 22. — P. 12695–12702. https://doi.org/10.1021/es401437y
12. GOST 30108-94 Building materials and elements. Determination of specific activity of natural radioactive nuclei [Electronic resource] / Meganorm // Meganorm. — [1995]. — Mode of access: https://meganorm.ru/Index2/1/4294853/4294853068.htm (accessed date: 10.09.2022).

13. GOST 10180-2012 Concretes. Methods for strength determination using reference specimens [Electronic resource] / Meganorm // Meganorm. — [2013]. — Mode of access: https://meganorm.ru/Index2/1/4293782/4293782275.htm (accessed date: 10.09.2022).
14. GOST 13087-2018 Concretes. Methods of abrasion test [Electronic resource] / Meganorm // Meganorm. — [2019]. — Mode of access: https://meganorm.ru/Index2/1/4293730/4293730304.htm (accessed date: 10.09.2022).
15. GOST 10060-2012 Concretes. Methods for determination of frost-resistance [Electronic resource] / Meganorm // Meganorm. — [2014]. — Mode of access: https://meganorm.ru/Index2/1/4293782/4293782220.htm (accessed date: 10.09.2022).
16. GOST 31383-2008 Protection against corrosion of concrete and reinforced concrete constructions. Test methods [Electronic resource] / Meganorm // Meganorm. — [2010]. — Mode of access: https://meganorm.ru/Index2/1/4293822/4293822418.htm (accessed date: 10.09.2022).
17. Compositional slag-alkaline binders, mortars and concretes on their base / N.R. Rakhimova // Russian Journal of Building Construction and Architecture. — 2008. — Vol. 12, No. 4. — P. 110–118.
18. Optimization of Cement-Based Mortar Containing Oily Sludge Ash by Response Surface Methodology / M.U. Kankia, L. Baloo, N. Danlami, W.N. Samahani, B.S. Mohammed, S. Haruna, A.H. Jagaba, M. Abubakar, E.A. Ishak, K. Sayed, N. Amila Bt Wan Zawawi // Materials. — 2021. — Vol. 14, No. 21. — P. 6308. https://doi.org/10.3390/ma14216308
19. Study of cement binders applicable for modified cast-in-place concrete / K. Khonjo, Y. Toleuov, A. Azbergenova, A. Urumbayeva // Technobius. — 2022. — Vol. 2, No. 3. — P. 0022. https://doi.org/10.54355/tbus/2.3.2022.0022
20. The composition and structure of the slag-alkaline composite binder stone with an addition of used moulding mixture / N.R. Rakhimova // News of higher educational institutions. Construction. — 2008. — Vol. 589, No. 1. — P. 45–49.
21. The use of man-made waste in the production of building materials / F. Yuldashev, G. Begzhanova // Universum:Technical sciences. — 2022. — Vol. 97, No. 4–10. https://doi.org/10.32743/UniTech.2022.97.4.13504
22. Investigation of binder compositions using waste from the production of ferrous metallurgy / T.B. Akhmetzhanov, B.S. Ashimova, E.T. Ashimova // Epoha nauki. — 2019. — No. 20. — P. 110–115. https://doi.org/10.24411/2409-3203-2019-12019
23. Optimization of the structure of the concrete of a high specific weight using fine-grained admixture / S.P. Gorbunov // Vestnik Yuzhno-Uralskogo gosudarstvennogo universiteta. Seriya: Stroitelstvo i arhitektura. — 2012. — Vol. 17, No. 14. — P. 30–35.
24. Slag Substitution as a Cementing Material in Concrete: Mechanical, Physical and Environmental Properties / M.E. Parron-Rubio, F. Perez-Garcia, A. Gonzalez-Herrera, M.J. Oliveira, M.D. Rubio-Cintas // Materials. — 2019. — Vol. 12, No. 18. — P. 2845. https://doi.org/10.3390/ma12182845

Information about authors:

Zulfiya Aubakirova – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, aubakirova.zulfiya@mail.ru
Aldiyar Temirbekov – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, asira92@bk.ru
Monika Kulisz – PhD, Associate Professor, Department of Management, Lublin University of Technology, Lublin, Poland, m.kulisz@pollub.pl
Gulnaz Zhairbaeva – MSc, School of Architecture and Construction, Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan, gulnaz.w@mail.ru

Author Contributions:

Zulfiya Aubakirova – concept, methodology, funding acquisition.
Aldiyar Temirbekov – analysis, resources, visualization.
Monika Kulisz – interpretation, editing.
Gulnaz Zhairbaeva – data collection, testing modeling, drafting.

Received: 03.07.2022
Revised: 31.08.2022
Accepted: 01.09.2022
Published: 30.09.2022