В роботі визначено закономірності впливу кількості відходів збагачення залізних руд при раціональному зерновому складі компонентів на міцність бетонів з мінімальною витратою цементу. Бетони, які мають малу міцність, застосовуються в неармованих конструкціях, тому на них не поширюється вимога до мінімальної витрати цементу для забезпечення захисту арматури від корозії. Суттєве зменшення витрати цементу в бетонах низької міцності при забезпеченні необхідної її величини можна здійснити за рахунок раціонального зернового складу компонентів бетонної суміші, що характеризується співвідношенням крупних, середніх та дрібних компонентів, яке дорівнює 52:23:25. У таких складах бетону необхідна кількість дрібнозернистої складової забезпечується введенням дрібнозернистих компонентів, наприклад, вторинних продуктів промисловості, зокрема, відходів збагачення залізних руд.

В результаті проведених досліджень встановлено, що при забезпеченні раціонального зернового складу компонентів бетонної суміші забезпечується необхідна низька міцність бетону при значно меншій витраті цементу, ніж для бетонів, склад яких визначається за іншими методиками. Встановлено, що в якості дрібнозернистої добавки доцільно використовувати відходи збагачення залізних руд, введення яких в раціональній кількості забезпечує значне підвищення ефективності використання цементу в бетонах низької міцності. Застосування бетонів пропонованих складів, які можуть використовуватися для тимчасових конструкцій – бетонної підготовки для влаштування перекриттів при безопалубочному формуванні, дозволяє економити значну кількість цементу, утилізувати вторинні продукти промисловості. Дослідженнями також встановлено, що застосування пластифікуючих добавок дозволяє отримати бетони з раціональним зерновим складом необхідної легкоукладальності

Ключові слова: бетон, міцність, зерновий склад заповнювачів, цемент, відходи збагачення залізних руд

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DETERMINING THE RATIONAL COMPOSITIONS OF LOW-STRENGTH CONCRETES

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1. Introduction

Cement concretes are among the main building materials for the erection of various structures. In such concretes, cement is the most energy-intensive component, hence its amount in concretes crucially affects the cost and energy intensity of concretes. Therefore, the main area of research in the field of improving the technology and properties of cement concretes is to resolve a task on achieving the necessary critical physical-mechanical characteristics at a minimally required cement consumption. This issue is especially important for the low-strength concretes with an average strength of less than 15 MPa whose specific cement consumption, required to achieve the unit of strength, is 1.5 to 2 times higher than that in concretes whose average strength is 25 MPa and larger.

Low-strength concretes are used in non-reinforced structures, so they are not subject to the requirement for a minimal cement consumption to ensure the protection of reinforcement against corrosion. A significant reduction in cement consumption for the low-strength concretes, while maintaining the required strength, can be ensures by the rational grain composition of the concrete mixture components. In such formulations, the required amount of a fine-grained component is ensured by introducing the fine-grained components made, for example, from the secondary products of industry, specifically, the iron ore dressing waste (tailings). Disposing of term in concretes could solve an important environmental issue, as they occupy large areas and significantly pollute the environment. However, it is important to determine patterns in a change in the strength of such concretes due to the amount of cement and fine-grained components made from the secondary products of industry.

Concretes of an average strength from 10 to 15 MPa and less are much needed in the construction of buildings and public facilities. For example, when installing a monolithic reinforced concrete foundation slab with a thickness of 0.6–0.8 meters, it is necessary to arrange a concrete cap with a thickness of 0.1 meters from the concrete of average strength of about 10 MPa. The walls of basements at such buildings are constructed from non-reinforced foundation wall blocks made from concrete of average strength of about 10–15 MPa. When building underground parking facilities using the formwork-free technology "top-down", below each floor slab and each covering slab with a thickness of 0.2–0.3 meter is a concrete cap made from concrete with a average strength of about 10 MPa with a thickness of 0.1 meter, which is destroyed after erecting the floor slab. At industrial facilities, when constructing reinforced concrete floors, below them is a concrete cap made from concrete of average strength of about 10 MPa with a thickness of 0.1 meter.

Thus, given that the volumes of concrete with an average strength of 10–15 MPa amount to about one per cent of the total annual volumes of concrete used, that makes up tens of thousands of cubic meters. If the efficiency of cement utilization in them could be close to the efficiency demonstrated by concretes with a higher strength, one would save thousands of tons of cement annually.

There are no standard requirements to the physical-mechanical characteristics of concrete for such a concrete cap. However, given that this concrete must not break down under the action of load from workers that move at its surface and a concrete mixture laid on it, its standard strength at 95 % reliability may not exceed 5 MPa. Acting norms in Ukraine regulate the rules for determining rational formulations of concretes, starting at the class of concrete compressive strength C8/10 and above. For the concrete of class C8/10, it is recommended that the cement with an activity of 30 MPa should be used. As for concretes of lower classes when using highly active cements, it is recommended to introduce a variety of mineral additives in order to reduce cement consumption provided the physical-technical characteristics of the concrete mixture and concrete are maintained. Industry does not produce cements with an activity below 30 MPa. Therefore, any of the cements used, including that with an activity of 30 MPa, is highly active for concretes with a standard strength of 5 MPa. Therefore, to design the formulations for such concretes, it is important to determine a pattern for determining the rational amount of mineral additives, ensuring the improved efficiency of cement utilization to the efficiency that would equal the effectiveness of its use in concretes of higher strength.

Producing a ton of the Portland cement of grade M400 requires about 289 kg of fuel equivalent, and the extraction of 1 m^3 of fillers requires only 5–6 kg of fuel equivalent. In this case, out of 100–200 kg of fuel equivalent needed to produce 1 m^3 of heavy concrete, up to 70 % is used for cement production. The fuel for annealing and obtaining the clinker includes gas, fine-shredded coal, sometimes fuel oil. These are the non-renewable energy sources whose cost constantly increases in proportion to a decrease in their reserves in nature and due to complexity of mining technology. When they are burned, a significant amount of carbon dioxide is emitted into the atmosphere (according to some estimates, up to one and a half tons per a ton of cement), which results in additional environmental damage.

One of the techniques to reduce the consumption of cement in concretes is the use of a mineral additive made from the fine-grained secondary products of industry. It is advisable to use predominantly the silicon-containing products as such a mineral additive, for example the iron ore dressing waste or fly ash from thermal power plants, which take up large areas and lead to the environmental pollution. At their rational introduction to a composition of concretes as a mineral supplement, it becomes possible to successfully solve environmental problems by utilizing these products in concretes thereby decreasing cement consumption in the latter.

Therefore, it is a relevant task to determine the rational granulometric compositions of concrete mixtures in order to obtain concretes of low strength while minimizing consumption of the Portland cement and maximizing possible amount of local secondary iron-containing products from industry in these compositions.

2. Literature review and problem statement

Paper [2] reports results of the successful partial replacement of a fine filler with the iron-containing waste from iron ore dressing in heavy concretes, in which the Portland cement was applied as a binder. However, the authors did not take into consideration the effect of the amount of large filler. Study [3] confirmed the effectiveness of introducing into the composition of heavy concretes a certain portion of only the finely dispersed components from the iron ore dressing waste. In addition, this study established a positive effect of the iron ore dressing waste, introduced to the composition of concretes as a fine filler, on the physical-technical properties of hardened concrete based on a cement-gypsum- pozzolanic binder. However, the authors did not take into consideration the joint influence of all fractions in fillers, both fine and large. Efficiency of utilization of the iron ore dressing waste in concretes was estimated by research results reported in [4]. An important feature of this work is the results of studying the influence of surface-active chemicals on the properties of concretes based on the Portland cement and the finely dispersed tailings of iron ores. However, the effect of a granulometric composition of the filler, taking into consideration the presence of iron ore dressing waste is not investigated. The positive impact of the introduction of different mineral complexes to the structures of concrete mixtures on the properties of cement concrete is described in [5–8]. The obtained regularities are very important to test the possibility of using differently dispersed industrial wastes containing iron compounds in concretes. Including the tailings of iron ores. However, the influence of a granulometric composition of the filler, taking into consideration the presence of iron ore tailings is not known. Papers [9, 10] revealed important patterns in the influence of plasticizers and superplasticizers on technological characteristics of the modified concrete mixtures and hardened concretes whose composition includes the iron ore dressing waste. However, the influence of a granulometric composition of the filler, taking into consideration the presence of iron ore tailings, was not, similarly for the above works, studied. Interesting results from studying the properties of new formations in cement concretes that use the iron ore dressing waste as a fine filler and surfactants, were obtained in [11]. These results explain the positive influence of iron-containing impurities on the properties of cement concretes. However, the authors did not define the influence of a granulometric composition of fillers taking into consideration the presence of iron-containing fine-grained supplements in concrete.

An analysis of results of available studies has revealed the efficiency of applying the iron-containing fine-grained industrial waste, including the iron ore dressing waste, as a component of concrete. As well as that the combined application of the specified wastes and modern surface-active substances improves the physical-technical properties of concrete mixes and hardened concretes.

However, the lack of optimization of the granulometric composition of fillers in the examined concretes leads to that for such concretes a cement utilization efficiency indicator, defined by the achieved strength per unit of cement consumption, remains considerably less than that for concretes of higher strength.

3. The aim and objectives of the study

The aim of this study is to determine the effect of granulometric composition of the concrete filler, which is represented by a mixture of mineral particles of large, medium, and small size, when using the iron ore dressing waste.

To achieve the set goal, we identified the following task:

to establish the degree of influence of the granulometric composition of components in low-strength concrete on its durability when using the iron ore dressing waste.

4. Materials and methods of this study

4. 1. Materials and equipment used in experiments

When conducting experiments, we used the Portland cement of grade CEM 42.5 from Kryviy Rih as the binder. The large filler used was the granite rubble with a maximal grain size of 20 mm. The fine filler used was quartz river sand with an average rock density of 2,630 kg/m^3, a bulk density of 1,550 kg/m^3, a rock voidness of 41 %, a size module of 1.56. The content of harmful impurities is within the normal range. Sieving results are given in Table 1.

Table 1

Results of sieving the Dnieper River quartz sand

Sieve residue, %	Sieves' hole size, mm					
	2.5	1.25	0.63	0.315	0.14	less 0.14
Partial	1.0	2.4	7.85	37.9	42.05	8.8
Full	1.0	3.40	11.25	49.15	91.2	100

The mineral additive used was the iron ore dressing waste from the Southern ore-dressing and processing enterprise (Ukraine), which met the requirements of regulations. A feature of the iron ore dressing waste from the Southern ore-dressing and processing enterprise is the irregular grain composition, which considerably depends on the location of their selection. These wastes may consist of both larger fractions, belonging to the fine filler (sand), and the finer fractions, belonging to mineral additives fillers. Fractional composition of the iron ore dressing waste from the Southern ore-dressing and processing enterprise (GOK), which was used in our experiment, is given in Table 2, chemical – in Table 3.

Table 2

Granulometric composition of the iron ore dressing waste from the Southern GOK

Content, % by weight of fractions the size of, µm								
less 5	6–10	11–20	21–30	31–40	41–50	51–66	67–100	larger 100
4,13	3.54	7.93	15.71	19.7	12.41	11.48	15.39	9.71

Table 3

Chemical composition of the iron ore dressing waste from the Southern GOK

Chemical composition, %					
SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO	MgO
67.47	1.3	9.06	10.84	4.64	6.69

To modify concretes, specifically to improve the technological properties of the concrete mixture, we used the complex additives PLKP-2, produced locally. These additives are made based on secondary products from coke production. These additives contain mostly thiosulphates, sodium sulphate, radonides, and some other substances. To improve the plasticizing properties, we additionally introduced the additive C-3.

4. 2. Procedure to determine indicators for the properties of concretes

We determined compositions of the examined concrete mixtures based on the requirements of regulations. In accordance with the requirements of regulations, we introduced the iron ore dressing waste to concrete as a mineral additive, whose granulometric composition is given in Table 2, chemical – in Table 3. A concrete mixture was prepared at a lab concrete mixer of forced action with a capacity of 25 liters. The components were dosed by mass; we agitated the dry ingredients first and then with water. Mixing time of a single batch was 3 minutes. We pressed control samples with a side size of 100 mm at a standard laboratory vibratory table with a vibration action frequency of 50 Hz, amplitude 0.35–0.5 mm. The samples hardened under standard conditions at a temperature of (29±2) K at relative humidity (95±5) %; we tested them on day 28 for compressive strength in accordance with the requirements of regulations.

The main objective for determining the rational composition of concrete for a cap under foundations and a floor slab, arranged by the method of formwork-free molding, is to ensure the required compressive strength at a minimum consumption of cement. A generalizing indicator for the efficiency of cement utilization is an appropriate factor ($K_{ef.c}$) that shows the obtained specific strength of concrete per a cement consumption unit in it, determined from formula:

$$K_{ef.c}=10f_{cm}/C, \quad (1)$$

where f_{cm} is the average compressive strength of a concrete sample in the form of a cube with an edge size of 150 mm in MPa, determined according to the test results, needed to ensure the required concrete strength class; C is the cement consumption per a cubic meter of concrete, kg.

The average strength of a concrete sample for compression in the form of a cube with an edge size of 150 mm at a concrete strength variation coefficient C_v=13.5 % is determined from formula:

$$f_{cm}=f_{ck.cube}/0.778, \quad (2)$$

where $f_{ck.cube}$ is the characteristic strength of a concrete sample for compression in the form of a cube with an edge size of 150 mm in MPa.

Characteristic strength of a concrete sample for compression in the form of a cube with an edge size of 150 mm in MPa is determined from formula:

$$f_{ck.cube}=f_{cm}(1-1{,}64C_v), \quad (3)$$

where C_v is the coefficient of concrete strength variation.

Next, determine the water/cement ratio, necessary to ensure the required workability of a concrete mixture and strength of the hardened concrete:

$$W/C=AR_c/(f_{cm}+0{,}5AR_c), \quad (4)$$

where R_c is the activity of the cement used; A is a coefficient whose value shall be taken according to norms.

After determining the required water/cement ratio, they determine the required consumption of cement per a cubic meter of concrete in order to obtain the required concrete strength:

$$C=W/(W/C). \quad (5)$$

The required water consumption (W) per a cubic meter of the concrete mixture is calculated according to norms, depending on the required concrete mixture workability and the maximum grain size of a filler.

Based on standards, the minimum concrete class implied is C8/10, so designers apply this class of concrete for structures where high strength is not required. When the concrete of this class is provided, the average compressive strength of a concrete sample in the form of a cube with an edge size of 150 mm (f_{cm}) must be 12.85 MPa. For a concrete cap under a floor slab, arranged by the formwork-free technology, the average compressive strength of 5–7 MPa would suffice.

5. Results of research into the strength of concrete and the required cement consumption

To solve the task set in this work, we calculated the required consumption of cement for several types of heavy concrete based on the granite rubble with a 20 mm fraction (Table 4).

Table 4

Cement consumption per a cubic meter of concrete and its strength

Composition No.	$f_{ck.cube}$, MPa	f_{cm}, MPa	W/C	C, kg/m^3	$K_{ef.c}=10f_{cm}/C$
Rc=30 MPa; OK=5–7 cm; *A*=0.6; W=200 dm^3/m^3					
1	5	6.43	1.16	172.4	0.37
2	10	12.85	0.82	243.9	0.53
3	15	19.28	0.64	312.5	0.62
4	20	25.71	0.52	384.6	0.67
Rc=30 MPa; OK =5–7 cm; *A*=0.6; W=180 dm^3/m^3					
5	5	6.43	1.16	155.2	0.41
6	10	12.85	0.82	219.5	0.59
7	15	19.28	0.64	281.2	0.69
8	20	25.71	0.52	346.1	0.74
Rc=40 MPa; OK =5–7 cm; *A*=0.6; W=200 dm^3/m^3					
9	5	6.43	1.3	153.8	0.42
10	10	12.85	0.97	206.2	0.62
11	15	19.28	0.77	259.7	0.74
12	20	25.71	0.64	312.5	0.82
Rc=40 MPa; OK =5–7 cm; *A*=0.6; W=180 dm^3/m^3					
13	5	6.43	1.3	138.5	0.46
14	10	12.85	0.97	185.6	0.69
15	15	19.28	0.77	233.8	0.82
16	20	25.71	0.64	281.2	0.91

Table 5 gives the results from testing the samples of hardened concrete.

Part of the concrete compositions given in Table 5 was calculated according to the requirements of regulations and part – based on the patterns, which we established earlier, by maintaining the ratio between large, medium, and small components of 52:23:25.

Table 5

Compositions of concrete filled with the iron ore dressing waste

Composition No.	Materials consumption per m^3, kg						f_{cm}, MPa	$K_{ef.c}=10f_{cm}/C$
	C	H	P	Sh	W	PFS, %		
1	75	425	550	1,175	180	0.5C+0.25H	9.7	1.29
2	75	130	820	1,200	180	0.5C+0.25H	5.3	0.71
3	100	400	550	1,175	180	0.5C+0.25H	14.8	1.48
4	100	130	800	1,200	180	0.5C+0.25H	8.2	0.82
5	125	375	550	1,175	180	0.5C+0.25H	18.4	1.47
6	125	130	775	1,200	180	0.5C+0.25H	12.1	0.97
7	150	350	550	1,175	180	0.5C+0.25H	21.5	1.43
8	150	130	750	1,200	180	0.5C+0.25H	13.9	0.93
9	175	325	550	1,175	180	0.5C+0.25H	24.2	1.38
10	175	130	725	1,200	180	0.5C+0.25H	16.8	0.96

Notes: C – cement; H – filler (iron ore dressing waste); Sh – rubble; P – sand; W – water

Fig. 1, 2 show dependences of cement utilization factor on concrete strength.

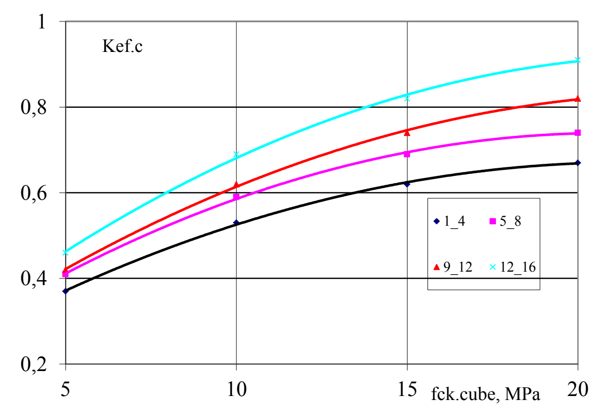

Fig. 1. Dependence of cement utilization factor on concrete strength: 1_4 – concrete compositions No. 1–4 from Table 4; 5_8 – concrete compositions No. 5–8 from Table 4; 9_12 – concrete compositions No. 9–12 from Table 4; 12_16 – concrete compositions No. 12–16 from Table 4.

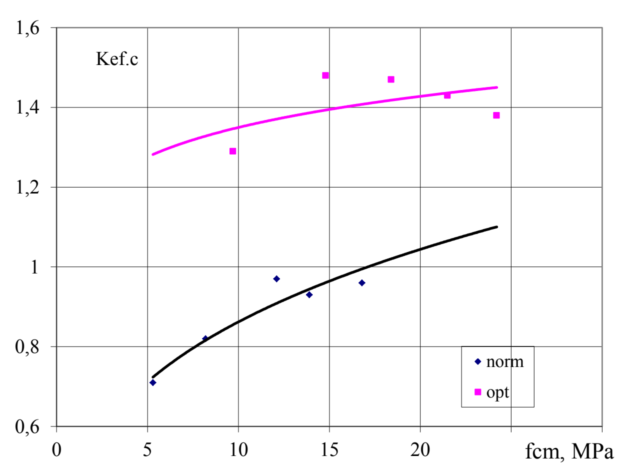

Fig. 2. Dependence of cement utilization factor on concrete strength

6. Discussion of results of studying the strength of concrete

An analysis of the research results given in Tables 4, 5 and shown in in Fig. 1 and 2 has helped establish the following patterns.

When determining the minimum required consumption of cement for such concrete based on conventional procedures (Table 4), a cement utilization efficiency coefficient is almost two times less than that for concretes of higher strength.

The research conducted earlier had established that the reason for such a drastic decline in the cement utilization efficiency coefficient in concrete with low strength is the non-rational grain composition of the concrete mixture components [9]. The established rational granulometric composition of components, which ensures reduced defects in the concrete's structure, and, consequently, the effective use of Portland cement, is the composition with a ratio between large, medium, and small components of 52:23:25 by weight [9]. At a deviation from a given ratio by each of the components within 2–3 parts, the cement utilization efficiency, expressed by the respective factor, determined from formula (1), almost does not change. The average grain size of large, medium, and small components must be approximately 100:10:1 with a possible change within 10–15 %.

The introduction of an additives-filler made from the iron ore dressing waste, as well as the rational amount of a plasticizer, ensures a significant improvement in the strength of hardened concrete. As well as, accordingly, in the cement utilization efficiency coefficient compared to the predicted, defined based on the requirements of norms (compositions 1, 5, 9, 13 from Table 4 and compositions 7–10 from Table 5). Introduction of the recommended amount of the iron ore dressing waste improves by 1.4–1.8 times the efficiency of cement application compared with the compositions that containing the maximum recommended amount according to the requirements of regulations.

In order to obtain the concrete of class C8/10 for strength when introducing the standards-recommended amount of the iron ore dressing waste of 130 kg/m^3 and the rational amount of a plasticizing additive, about 125 kg/m^3 of cement would suffice (composition 6 from Table 5). This is considerably less than the norm-based calculated amount of the same cement (compositions 10, 14 from Table 4) without the iron ore dressing waste. However, concrete of the same class of strength can be obtained at a strength margin of 15 % at a cement consumption of 100 kg/m^3 and the introduction of 400 kg/m^3 of iron ore dressing waste, ensuring the rational grain composition of the concrete mixture components.

Concrete of strength of about 10 MPa can also be obtained at a cement consumption of 75 kg/m^3 of the concrete mixture and 425 kg/m^3 of the secondary products from iron ore dressing waste, ensuring the rational granulometric composition of the concrete mixture components (composition 1 from Table 5).

However, at such a low cement consumption, one requires a very thorough agitation of the concrete mixture components in order to ensure the uniform distribution of a binder.

Visual observations have helped establish a good uniformity, cohesion, non-stratification, and a good compaction of mixtures with the rational grain composition of components (compositions 1, 3, 5, 7, 9 from Table 5).

Concretes with a cement consumption of 300–45 kilograms and mineral additives of up to 130 kg per a cubic meter of concrete, whose compositions are determined based on the requirements of regulations, practically meet the requirements, which we defined, for the rational grain composition of components. Therefore, in order to ensure the improved cement utilization efficiency coefficient in the low-strength concretes, it is necessary to purposefully ensure that the rational, previously defined, grain composition of components should be 52:23:25.

When designing a concrete mixture composition with the rational granulometric composition of components, a large filler should include grains the size exceeding 5 mm, medium – from 5 mm to 0.14 mm, small – from 0.14 mm and less. Therefore, if the composition contains rubble of fractions 5–0.14 mm in the amount of 97–98 %, it can be attributed to the large fraction. Based on the fractional composition of sand presented in Table 1, 92 % should be attributed to the medium fraction, and 8 % – to small. In the granulometric composition of iron ore dressing waste (Table 5), about 90 % belong to the small fraction (mineral additives fillers), and about 10 % – to the medium fraction. The small fraction also includes all cement with grains less than 0.1 mm (100 µm).

The composition of a cubic meter of heavy concrete includes dry components in the amount of 2,200–2,250 kg. To determine consumption of each of them based on the above condition for ensuring the rational granulometric composition of components, we accept their total consumption to be 2,200 kg per a cubic meter of concrete mixture. Since the content of small fractions in the composition of sand is about the same as in the iron ore dressing waste, we can determine the content of each component based on the ratio between large, medium, and small fractions equal to 52:23:25 without any amendments to the content of other fractions. Hence, based on our procedure, it is required for the newly designed compositions: rubble (Sh) Sh= =2,200·0.52=1,144 kg; sand (P) P=2,200·0.23=506 kg; cement (C) and a mineral additive from the iron ore dressing waste (H) C+H=2,200·0.25=550 kg.

The results of our study make it possible to decrease by 15–20 % the consumption of cement when making concretes of low strength. However, one should take into consideration a variability in the granulometric composition of the iron ore dressing waste. This entails the necessity to strictly control properties of the specified waste and to operatively adjust, if necessary, the compositions of concretes.

The results of our research make it possible to increase the utilization of iron ore dressing waste, which would lead to the improvement of ecological situation at the regions of mining and processing of iron ores. A scope of application of the research results described in this work is the monolithic construction of buildings and facilities, first and foremost for a concrete cap under slabs when constructing underground parking facilities based on the technology "top-down".

The present study is part of a multi-year research into opportunities and application of the iron ore dressing waste for the production of building materials and in the search for ways to reduce cement consumption during concrete production.

The results of this study could become the basis for improving the rational compositions of concretes by applying hyper-plasticizers, using a micellar catalysis, and other current solutions in the field of construction materials science.

7. Conclusions

1. We have determined the degree of influence of a granulometric composition of the low-strength concrete components on its strength. It has been confirmed that the optimal composition for a filler is the one based on the ratio between large, medium, and small components of 52:23:25 by weight.

2. We have determined the degree of influence of the amount of iron ore dressing waste on strength of the low-strength concretes, which ensures an increase in the cement utilization efficiency coefficient in these concretes by 1.4 times to the level of the high-strength ones.

References

1. Vil'man Yu. A. Tekhnologiya stroitel'nyh processov i vozvedeniya zdaniy, sovremennye i progressivnye metody. Moscow, 2014. 336 p.
2. Wondolowski A. G., Chaika V. M. Strength properties a particulary fine-grained concrete on the waste of mining and beneficiatian plants as the filler // Zbirnyk naukovykh prats UkrDUZT. 2016. Issue 160. P. 17–24.
3. Shishkin A., Shishkina A., Scherba V. Features of the use of wastes of mining and processing combines in the production of building materials // Visnyk DNABA. 2013. Issue 1. P. 8–12.
4. Ashok P., Sureshkumar M. P. Experimental Studies on Concrete Utilising Red Mud as a Partial Replacement of Cement With Hydrated Lime // IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 2013. P. 1–10.
5. Study of the use of waste iron ore flotation for blended cement / Shapovalov N. A., Zagorodnyuk L. K., Tikunova I. V., Schekina A. Y., Shiryaev O. I., Krayny A. A. et. al. // Fundamental research. 2013. Issue 10. P. 1718–1723.
6. Powder concretes with technogenic materials / Tolstoy A., Lesovik V., Zagorodnyuk L., Kovaleva I. // Vestnik MGSU. 2015. Issue 11. P. 101–109. doi: https://doi.org/10.22227/1997-0935.2015.11.101-109
7. Erdem T. K., Kırca Ö. Use of binary and ternary blends in high strength concrete // Construction and Building Materials. 2008. Vol. 22, Issue 7. P. 1477–1483. doi: https://doi.org/10.1016/j.conbuildmat.2007.03.026
8. Swamy R. N., Sakai M., Nakamura N. Role of Superplasticizers and Slag for Producing High Performance Concrete // The Fourth CANMET/ACI International Conf. on Superplasticizers and Other Chemical Admixtures in Concrete: ACI SP-148-1. Proceedings. Detroit (USA), 2006. P. 1–26.
9. Shetty K. K., Nayak G., Vijayan V. Effect of red mud and iron ore tailings on the strength of self-compacting concrete // European Scientific Journal. 2014. Vol. 10, Issue 21. P. 168–176
10. Shishkin A., Netesa M., Scherba V. Effect of the iron-containing filler on the strength of concrete // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 5, Issue 6 (89). P. 11–16. doi: https://doi.org/10.15587/1729-4061.2017.109977
11. Shishkina A., Shishkin A. Research into effect of complex nanomodifiers on the strength of fine-grained concrete // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 2, Issue 6 (92). P. 29–33. doi: https://doi.org/10.15587/1729-4061.2018.127261