13. Mirza W. H., Al-Noury S. I. Utilisation of Saudi sands for aerated concrete production // International Journal of Cement Composites and Lightweight Concrete. 1986. Vol. 8, Issue 2. P. 81–85. doi: 10.1016/0262-5075(86)90002-3
14. Esmaily H., Nuranian H. Non-autoclaved high strength cellular concrete from alkali activated slag // Construction and Building Materials. 2012. Vol. 26, Issue 1. P. 200–206. doi: 10.1016/j.conbuildmat.2011.06.010
15. Drochytka R., Helanová E. Development of Microstructure of the Fly Ash Aerated Concrete in time // Procedia Engineering. 2015. Vol. 108. P. 624–631. doi: 10.1016/j.proeng.2015.06.189
16. Optimizaciya struktury svyazuyushchey matricy gazobetona s ispol'zovaniem karbonatnogo napolnitelya / Kuryatnikov Yu. Yu., Ali R. A., Vinogradova V. A., Saharova O. V. // Stroitel'stvo i stroitel'nye tekhnologii. URL: http://eprints.tstu.tver.ru/135/1/2.pdf
17. Yang L., Yan Y., Hu Z. Utilization of phosphogypsum for the preparation of non-autoclaved aerated concrete // Construction and Building Materials. 2013. Vol. 44. P. 600–606. doi: 10.1016/j.conbuildmat.2013.03.070
18. Hezhev T. A., Puharenko Yu. V., Hashukaev M. N. Yacheistye fibrobetony na osnove vulkanicheskih gornyh porod // Izvestiya vysshih uchebnyh zavedeniy. Severo-Kavkazskiy region. Tekhnicheskie nauki. 2003. Issue 3. P. 37–39.
19. Sokolova S. N., Mitina N. A Untersuchungen zum Einfluss von Dispersfuellern auf die bautechnischen Eigenschaften von Porenbeton. Ibausil, 2009. P. 1193–1198.
20. Flexural Behaviour of Precast Aerated Concrete Panel (PACP) with Added Fibrous Material: An Overview / Abdul Rahim N. H., Mohamad N., Abdul Samad A. A., Goh W. I., Jamaluddin N. // MATEC Web of Conferences. 2017. Vol. 103. P. 02005. doi: 10.1051/matecconf/201710302005
21. Fomicheva G. N. Matematicheskoe opisanie processa polucheniya gazobetona na al'bitofirovom napolnitele // Novye stroitel'nye tekhnologii. 2005. P. 196–199.
22. Strukturoobrazovanie i svoystva yacheistyh betonov / Martynov V. I., Vyrovoy V. N., Orlov D. A., Vetoh A. M. // Resursoekonomni materialy, konstruktsiyi, budivli ta sporudy. 2006. Issue 14. P. 90–96.

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STUDY OF THE EFFECT OF MICELLAR CATALYSIS ON THE STRENGTH OF ALKALINE REACTIVE POWDER CONCRETE

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За певних умов підвищення швидкості гідратації в'яжучої речовини сприяє підвищенню міцності бетону при стиску. Особливо це стосується реакційних порошкових бетонів.

Вивчений вплив поверхнево-активних речовин, здатних утворювати міцели, на швидкість формування та кінцеву величину міцності при стиску лужних реакційних порошкових бетонів. Особливістю досліджень було вивчення одночасного впливу поверхнево-активних речовин, які утворюють міцели, та реакційного порошку або заповнювача на зміну міцності бетонів. Встановлено, що означені міцелярні розчини та реакційні порошки змінюють характер формування міцності лужних реакційних порошкових бетонів. Збільшується швидкість формування міцності у початкові терміни за рахунок міцелярного каталізу гідратації доменного гранульованого шлаку, та зберігається підвищена їхня міцність при стиску на пізніх стадіях твердіння.

Міцність лужних реакційних порошкових бетонів при застосуванні поверхнево-активних речовин, спроможних утворювати міцели, досягає 260 % від міцності таких бетонів без добавок.

Доведено, що для управління процесами тужавіння в'яжучої речовини, яка складається із доменного гранульованого шлаку та лужного компоненту, й формування міцності отриманого штучного каменя можна використовувати міцелярний каталіз. За рахунок цього зменшується час, для досягнення проектної міцності бетону, та підвищується абсолютна величина міцності при стиску таких бетонів у віці 28 діб

Ключові слова: доменний гранульований шлак, луги, міцелярний каталіз, міцність бетону, порошковий бетон, міцели, поверхнево-активні речовини

1. Introduction

The volume of construction, which uses monolithic concrete that should meet numerous requirements, grows every year. The first requirement is the high rate of strength formation, as well as a high tensile strength depending on the type and conditions of operation.

The main type of binders, which are applied in the technology of monolithic construction, is the Portland cement. Modern scientific developments in the field of concrete engineering are based on using the superplasticized Portland cement and mixes of Portland cement with various reactive-active powders. Microsilica, metakaolin, TPP fly ash, rocks, etc., are used as such powders.

As a result of using the reaction-active powders and super- or hyperplasticizers, it was possible to obtain concretes with a compression strength of 100 to 200 MPa and a tensile strength of 25 50 MPa [1, 2].

It should be noted that such concretes were developed and investigated as the main binding substance of the Portland cement.

At the same time, there is a large group of binding substances that do not contain minerals that are analogous to those of the Portland cement. The basis of such binding substance is the finely-ground granulated blast furnace slag, which is mixed with the aqueous solution of the alkaline component (slag-alkaline concretes) [3].

It is recommended [4] to introduce reactive-active powders to the composition of such concretes, particularly those containing the ions of transitional chemical elements.

The specified concretes have a different nature and the mechanism of hydration than the Portland cement, and the strength of such concretes reaches 100 MPa at the hardening rate, which exceeds the rate of hardening of the Portland cement. However, the current state of development of construction requires further improvement of the properties of traditional binding substances, including based on the blast-furnace granulated slag and the alkaline component by modifying their structure.

One of the ways to modify the structure of concrete is the micellar catalysis, which is applied in the manufacture of dense [5], cellular [6], and other types of concretes based on the Portland cement.

Thus, given the specific effect of micelles from surface active substances, it is a relevant task to perform a study aimed at further improvement and development of the technology of concretes based on the blast furnace granulated slag and the alkaline component.

2. Literature review and problem statement

The use of various cements, fillers, and admixtures (reactive-active powders) in the manufacture of concrete makes it possible to control the duration of its setting and hardening. Therefore, the effect of certain reactive powders on the time of hardening and the rate of concrete strength formation should be considered. Thus, the application of fly ash results in a decrease in water consumption while maintaining the mobility of the concrete mix. In this case, there is the modification of the composition of the products of cement hydration, but the rate of concrete strength formation decreases [7]. When adding the ground granular slag to the Portland cement, the strength of concrete at compression during early stages, similar to the case with fly ash, slows down as well [8]. The acceleration of the hydration of Portland cement containing fly ash or ground granular slag can also be achieved by the introduction of ground limestone [9], metakaolin [10], or mineral complexes containing the ions of transitional chemical elements [11, 12]. However, the result of action of these reaction powders is an increase in the strength of concrete only. The use of metakaolin as a reactive powder ensures an increase in both the strength of concrete and the rate of its formation. However, metakaolin is not an industrial waste, which is why it is rather costly, which limits its utilization.

It was established in particular that an increase in the strength of concrete occurs at the simultaneous introduction to its composition of the mineral complex containing iron and polyalcohols [13]. The application of a polyalcohol in the production of reactive-powder concretes ensures an increase both in the strength of concrete and the rate of its formation. However, polyalcohols are not an industrial waste, which is why they are rather costly, which limits their use.

As far as the alkali-slag concretes are concerned, the introduction of traditional mineral additives to their composition does not change the rate of formation of concrete strength [14], which is a serious concern for the specified concretes.

The available results about the effect on the magnitude of strength and the rate of its formation for reactive-powder concretes allow us to draw a conclusion about the possibility of the existence of such effects for the slag-alkaline concretes.

The lack of research results on the effect of the micellar catalysis on the rate of strength formation at compression and its magnitude for the slag-alkaline reactive-powder concrete necessitates conducting our study.

3. The aim and objectives of the study

The aim of this work is to determine the effect of micellar catalysis on the rate of strength formation and its magnitude for the slag-alkaline reactive powder concrete.

To accomplish the aim, the following tasks have been set:

– to determine the effect of surface-active substances that form micelles on the magnitude of strength at compression for the alkaline reactive powder concrete;

– to determine the influence of surface-active substances that form micelles on the rate of strength formation at compression for the alkaline reactive powder concrete.

4. Materials and methods to study the strength of alkaline reactive powder concrete

4. 1. Examined materials and equipment used in the experiment

To manufacture concrete, we used the ground blast-furnace granulated slag from PJSC "Mittal Steel. Kryviy Rih "(Ukraine); wastes from the ore dressing at the Southern Ore Mining and Processing Enterprise (Kryvyi Rih, Ukraine) were used as a fine filler; a particle size ranges from 0.001 to 0.63 mm. Sodium oleate (Simagchem Corp., China) was used as the surface-active substance that forms micelles (MSAS); liquid glass with a 2.8 silicate module, density 1,340 kg/m^3, was used as an alkaline component (LLC "Novochim Company", Kharkiv, Ukraine).

Sodium oleate was dissolved in water to a concentration of 0.1 %; liquid glass was diluted with water to a density of 1,200 kg /m^3. The water solution of sodium oleate was added in the amount calculated according to the experiment design to the container with a dosage amount of liquid glass.

Blast granular slag was ground at a laboratory ball mill to a specific surface of 250 m^2/kg, which was measured using the T-3 device based on the air permeation rate. The blast granulated slag and a filler (reaction powder) were dosed in the amount calculated according to the experiment design and agitated at a laboratory mixer for 1 min. Next, the prepared liquid glass was added to the mixture; it was agitated at a laboratory mixer for 2 minutes more, ensuring a homogeneous mixture.

The obtained concrete mixture was put into a metal mold with sides the size of 4×4×16 cm. Concrete samples, shaped that way, were hardened for 28 days at an ambient humidity of 70±10 % and an ambient air temperature of 293±2 K. The strength of the concrete was determined by testing the samples at the universal test machine UMM-100.

The composition of concrete was accepted constant in all experiments with the ratio of cement/fine filler =½ at water-cement ratio (W/C) 0.6. In the course of experiments, the amount of the surface-active substance that forms micelles (MSAS) and the amount of the reaction powder were changed.

4. 2. Procedure for determining the indicators of properties of the samples

The estimation of the effect of surface-active substances (MSAS) on the rate of strength formation of the alkaline reactive powder concrete was conducted by determining its strength at compression for different age.

Determining the magnitude of strength limit at compression for samples was conducted in accordance with standard procedures adopted in Ukraine. The strength of samples was determined at the universal machine UMM-100.

Since the structural strength of the cement slurry and concrete mixture characterizes its structure formation, we investigated in the first group of experiments a change in the structural strength of the specified dispersed system depending on the composition of MSAS and its content in the system, the water-cement ratio in it, and the time of its existence.

The structural strength of the concrete mix was determined by defining the area of its cone spread, which most fully meets the conditions of its use. The prepared concrete mix was placed to a standard cone, applied in Ukraine to determine the ease of laying a concrete mix. Compaction was achieved by pressing a metal rod with a diameter of 20 mm. Next, the mold of the cone was removed and we measured the lower diameter of the cone of the concrete mix after its spreading. Using formula

$$S = \frac{\pi \cdot d^2}{4},$$

we determined the area of the cone base of the concrete mix.

Next, the concrete mix, with which the mold (cone) was filled in, was weighed, and its mass P was determined. The magnitude of structural strength was derived from formula

$$\tau = \frac{P}{S},$$

where P is the mass of the concrete mix in the volume of a standard cone; S is the area of the cone base of the concrete mix after spreading.

The data obtained were analyzed and mathematically processed in order to determine general patterns of change in the magnitude of structural strength.

5. Results of studying the indicators of properties of the concrete samples

The research results showed that the content of the filler in the examined concrete mix in the amount of 20 % of the mass of its dispersed phase ensures the maximum magnitude of its structural strength. Increasing the water-cement ratio at any content of the filler within the limits of the experiment reduces the structural strength of the concrete mix.

MSAS, as a surface-active substance, somewhat differently affects the structural strength of the concrete mix (Fig. 1).

Increasing the MSAS content to a certain limit (under conditions of the experiment, up to 0.00004 % of the mass of the blast furnace granulated slag in the examined dispersed system leads to an increase in structural strength.

A further increase in the MSAS content in the system leads to a decrease in its structural strength. This confirms our understanding about a change in the character of the MSAS effect on the surface of the dispersed phase of the system.

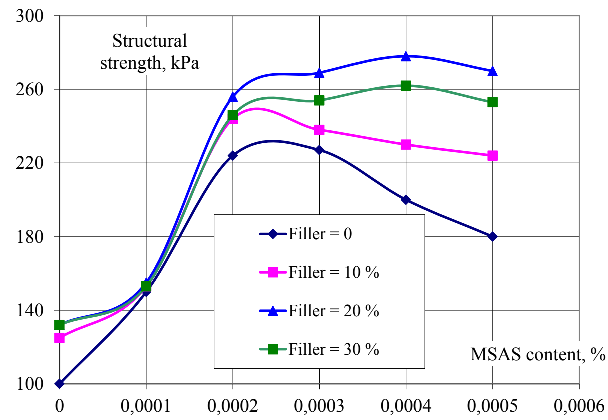

Fig. 1. Structural strength of the dispersed system "blast furnace granulated slag – reaction powder – micelle-forming surface-active substance (MSAS) – alkaline component solution": time – 1.2 hours after obtaining the system

In the course of the performed experiments, it was established that the introduction of the filler (a reactive powder) to the examined system of the reactive powder concrete leads to a sharp increase in the structural strength of the resulting concrete (Fig. 2).

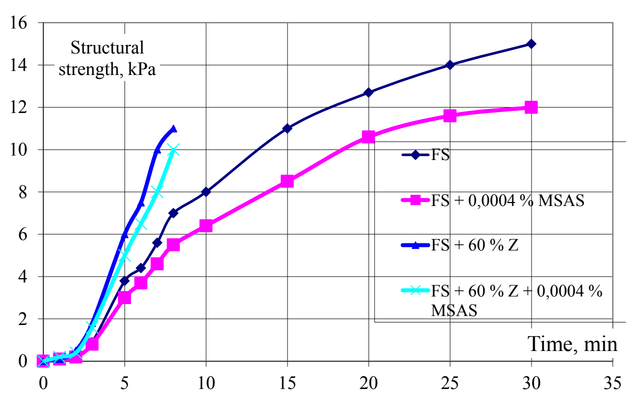

Fig. 2. Structural strength of the dispersed system "Portland cement – complex SAS" (FS – blast furnace granulated slag, Z – reactive powder)

In the process of the conducted experiments, it was established that the introduction to the examined system (reactive powder concrete) of both different reactive powders and MSAS in a certain amount, which depends on the type of the reactive powder, leads to a sharp increase in the strength of the resulting concrete (Fig. 3–5).

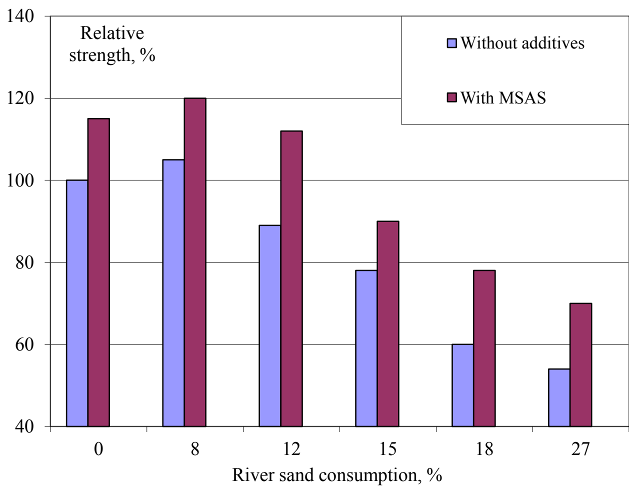

Fig. 3. Strength of alkaline reactive concrete

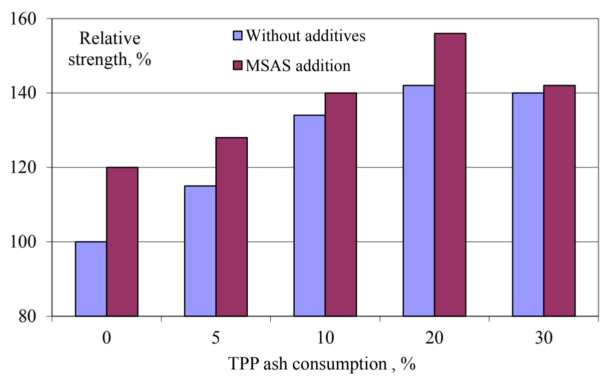

Fig. 4. Strength of alkaline reactive concrete

A general dependence of strength at compression of the alkaline reactive concrete on the consumption of a reactive powder and MSAS is shown in Fig. 6. The kinetics of change in the strength of the examined concrete depending on the content of the reactive powder and MSAS in its composition were determined by defining and comparing the strength of concrete (Fig. 7).

Results of the experiments showed (Table 1) that the use of small particles of the waste of iron ore enrichment, simultaneously with MSAS, as a filler for the examined concrete, leads to a significant increase in the strength of reactive concrete. The particles from the waste of iron ore enrichment had a specific surface area at least 150 m^2/kg.

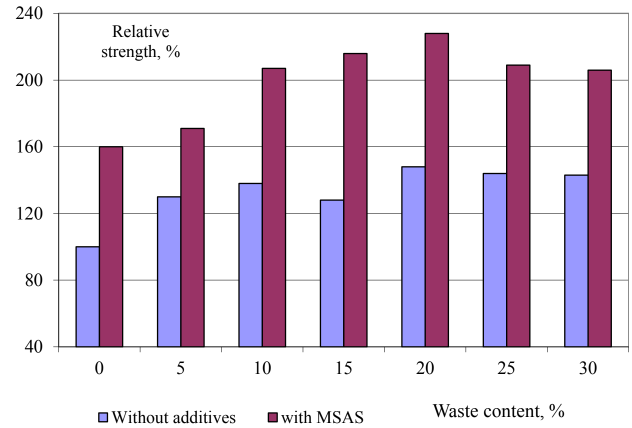

Fig. 5. Strength of alkaline reactive concrete

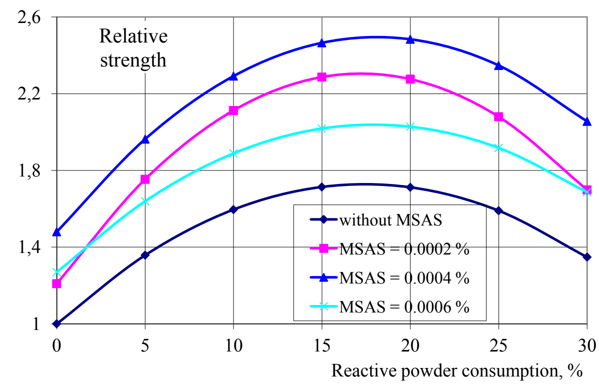

Fig. 6. Effect of MSAS content and reactive powder on the strength at compression of the alkaline reactive concrete (reactive powder is the waste of iron ore enrichment)

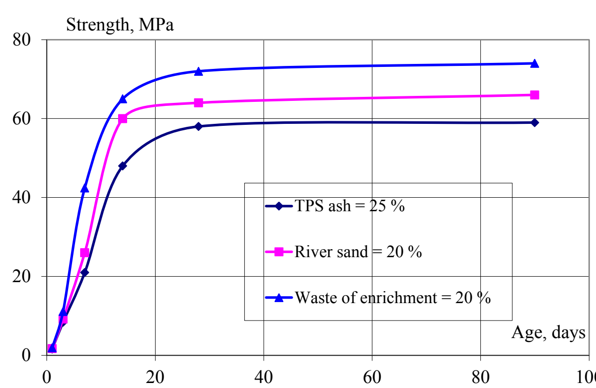

Fig. 7. Change in the strength of concrete over time (MSAS consumption – 0.00004 %)

Thus, it is proved that the use of the reactive powder in the crushed state is the most effective. In other words, the reactive powder is more effective the larger its specific surface.

Table 1

Strength of alkaline reactive concrete

MSAS content, %	Relative concrete strength at compression when retaining the iron-containing powder, %						
	0	5	10	15	20	25	30
0	**1**	1.30	1.38	1.28	1.48	1.44	1.43
0.00002	1.25	1.36	1.59	2.00	2.06	1.86	1.73
0.00004	1.60	1.71	2.07	2.16	**2.28**	2.09	2.06
0.00006	1.33	1.44	1.63	1.78	1.89	1.69	1.68

Note: the strength of concrete without reactive powder and MSAS is 62 MPa

6. Discussion of results of studying the effect of the micelles from surface-active substances on the strength of reactive powder concretes

Adding the micelle-forming surface-active substances to the alkaline reactive powder concrete leads to an increase in the structural strength of the concrete mix (Fig. 1). It should be noted that the amount of MSAS, optimal for the magnitude of structural strength, coincides with the amount of MSAS in such concretes, optimal for the strength at compression.

The magnitude of structural strength depends on the content of MSAS and the reaction powder. MSAS reduces structural strength while the reactive powder increases it.

The type of reactive powder exerts an effect on the magnitude of concrete strength at compression. The highest strength is demonstrated by concretes, which have, as a reactive powder, mineral complexes that contain iron.

In a general case, the content of MSAS in the alkaline reactive concrete, which ensures the maximum strength at compression, is 0.0004 %, and the content of the reactive powder is 10–20 %.

A change in the strength of concrete over time increases with the introduction of MSAS and depends on the type of reactive powder.

An analysis of the research results showed that the most effective reactive powder is the waste of iron ore enrichment, and the least effective one is river sand (Fig. 8, 9).

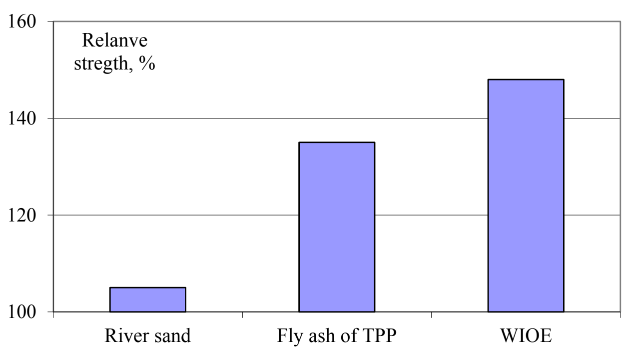

Fig. 8. Effectiveness of the application of a reactive powder (without MSAS, WIOE – waste of iron ore enrichment)

It is obvious that the use of MSAS leads to an increase in the efficiency of reactive powders. In this case, the most effective is to utilize the waste of iron ore enrichment.

The benefits of results of our research are the defined possibility to significantly (larger than by 200 %) increase the strength of powder concrete based on blast-furnace granulated slag and an alkaline component.

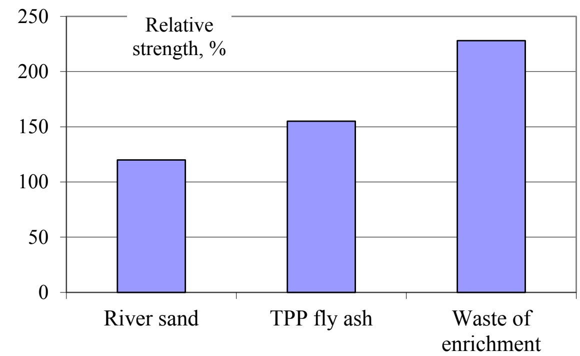

Fig. 9. Effectiveness of the application of a reactive powder in the presence of MSAS

However, there are certain limitations in applying the results of this study. Thus, it is necessary to control duration of concrete setting, which, when applying certain types of the alkaline component, can be quite short.

In the future, in order to extend the scope of application of the examined concretes, it is expedient to study the effect of micellar catalysis on the deformative properties.

7. Conclusions

1. It was established that the introduction of micelle-forming surface-active substances to the composition of the alkaline reactive powder concrete leads to an increase in the structural strength of the concrete mix by 10–15 %.

2. The introduction of MSAS to the composition of the alkaline reactive powder concrete makes it possible to improve the strength of concrete at compression, which reaches 160 % of the strength of concrete, similar in composition, obtained without using MSAS. An increase in the amount of the reactive powder whose specific surface area exceeds 150 m^2/kg leads to an increase in the strength at compression by 48 % of the strength of concrete, similar in composition, obtained without the use of additives. And simultaneous introduction of MSAS and the reactive powder to the alkaline reactive powder concrete leads to an increase in the strength of concrete, which is 230 % of the strength of concrete of similar composition, obtained without the use of additives.

References

1. Falikman V. R. Novye effektivnye vysokofuncional'nye betony // Beton i zhelezobeton. 2011. Issue 2. P. 78–84.
2. 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: 10.1016/j.conbuildmat.2007.03.026
3. Krivenko P. V., Petropavlovskiy O. N., Lakusta S. O. Rol' tekhnologicheskih faktorov v formirovanii struktury i svoystv shlakoshchelochnyh betonov // Visnyk Odeskoi derzhavnoi akademiyi budivnytstva ta arkhitektury. 2015. Issue 57. P. 233–242.
4. Shishkin A. A. Shchelochnye reakcionnye poroshkovye betony // Stroitel'stvo unikal'nyh zdaniy i sooruzheniy. 2014. Issue 2 (17). P. 56–65.

5. Shishkin A. A., Shishkina A. A. Study of the nanocatalysis effect on the strength formation of reactive powder concrete // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 1, Issue 6 (79). P. 55–60. doi: 10.15587/1729-4061.2016.58718
6. Shishkina A. A. Study of the effect of micelle-forming surfactants on the strength of cellular reactive powder concrete // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 2, Issue 6 (80). P. 66–70. doi: 10.15587/1729-4061.2016.63706
7. Cao J., Chung D. D. L. Use of fly ash as an admixture for electromagnetic interference shielding // Cement and Concrete Research. 2004. Vol. 34, Issue 10. P. 1889–1892. doi: 10.1016/j.cemconres.2004.02.003
8. Powder concretes with technogenic materials / Tolstoy A., Lesovik V., Zagorodnyuk L., Kovaleva I. // Vestnik MGSU. 2015. Issue 11. P. 101–109. doi: 10.22227/1997-0935.2015.11.101-109
9. Menéndez G., Bonavetti V., Irassar E. F. Strength development of ternary blended cement with limestone filler and blast-furnace slag // Cement and Concrete Composites. 2003. Vol. 25, Issue 1. P. 61–67. doi: 10.1016/s0958-9465(01)00056-7
10. Increasing concrete durability with high-reactivity metakaolin / Gruber K. A., Ramlochan T., Boddy A., Hooton R. D., Thomas M. D. A. // Cement and Concrete Composites. 2001. Vol. 23, Issue 6. P. 479–484. doi: 10.1016/s0958-9465(00)00097-4
11. Shishkin A. Study of the effect of compounds of transition elements on the micellar catalysis of strength formation of reactive powder concrete // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 2, Issue 6 (80). P. 60–65. doi: 10.15587/1729-4061.2016.63957
12. Sheynich L. A. Special'nye betony i kompozicionnye materialy // Budivelni konstruktsiyi. Mizhvidomchyi naukovo-tekhnichnyi zbirnyk. 2002. Issue 56. P. 367–377.
13. Shishkin A., Shishkina A., Vatin N. Low-Shrinkage Alcohol Cement Concrete // Applied Mechanics and Materials. 2014. Vol. 633-634. P. 917–921. doi: 10.4028/www.scientific.net/amm.633-634.917
14. Effect of fly ash on autogenous shrinkage / Termkhajornkit P., Nawa T., Nakai M., Saito T. // Cement and Concrete Research. 2005. Vol. 35, Issue 3. P. 473–482. doi: 10.1016/j.cemconres.2004.07.010