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COMPLEX LABORATORY STUDIES OF MODIFIED ADDITIVE INFLUENCE ON CONCRETE PHYSICAL AND MECHANICAL PROPERTIES

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ABSTRACT: The article presents a complex of laboratory studies of the influence of a complex modified additive (CMA), exactly the effect of the variable composition of additive components on the physical and mechanical properties of concrete. This work shows the methodology of making samples, the selection of additive composition at different percentage ratios of components, and the comparative analysis of the obtained results. The work is devoted to solving the problem of increasing the performance characteristics of concrete by adding the composition of CMA. In this work, the authors used the developed CMA including alkali (caustic soda NaOH), post-alcohol bard (alcohol production wastes), and hardening accelerator (gypsum) in different percentages. Studies can identify the impact of additives on the properties of concrete during their production. Thus, the addition of CMA to the composition of heavy concrete can increase the strength at 28 days of hardening by 4.56-39.08% compared to the reference sample. The analysis suggests that CMA provides a reduction of water saturation in concrete by 2-4 times. The obtained concrete with CMA withstood 200 cycles of tests for frost resistance. The experimental data indicate that the studied additive forms the optimal structure reduces water saturation and increases the strength properties of concrete. This makes it possible to expect higher operational properties of heavy concrete - frost resistance, therefore, increasing its durability.

Keywords: Heavy concrete, Complex modified additive, Compressive strength, Water saturation, Frost resistance

1. INTRODUCTION

The main task in the modern construction sector is to reduce the time required to produce concrete and reinforced concrete products and to accelerate the achievement of the standard strength of concrete [1]. Several articles [2, 3] discuss these problems in detail and analyze existing solutions. Nevertheless, the problem of accelerating the standard task of concrete strength and maintaining high-strength properties is relevant [4].

In global construction practice, modified heavy concrete firmly occupies one of the leading positions as a versatile material that allows the solution of a wide range of engineering problems and provides modern quality and competitiveness of construction products. Because of its quality, this type of concrete is the most common in industrial and civil construction [5].

By using concrete admixtures appropriately and according to the purpose, concrete plant engineers can modify the properties of fresh concrete and monolithic concrete according to the various tasks of the construction industry. At the same time, high-quality and durable concrete can be produced in different climatic conditions [6]. The most important quality of concrete structures is their high quality and durability in the future. For this reason, the use of additives in concrete is important, and this method has become indispensable for all concrete technology [7].

Because of the abundance of domestic and imported chemical additives, it is difficult to make a choice. Concrete producers seek to reduce cement consumption, reduce energy consumption in the production of reinforced concrete and improve its properties by modification while minimizing the cost of additives under stable quality conditions. This is quite a difficult task, which can be solved by using various wastes and byproducts of many industries as mineral and chemical modifiers for concrete [8, 9].

In most cases, the properties of concrete are corrected with the help of chemical additives. At the same time, optimal properties, such as strength, workability, etc., are achieved at a certain critical amount of chemical modifiers, after which the effects are reduced [10, 11].

It is known that the main purpose of plasticizing additives is to improve workability and reduce energy and labor costs for laying. On the other hand, using such additives can significantly increase the strength and durability of the product by reducing the water-cement ratio, while maintaining the mobility of the mixture. In addition, the introduction of plasticizers can affect the time and speed of hardening of cement, increase the strength, frost resistance, and water resistance of concrete by reducing the amount of water and even reduce cement consumption and energy costs for the production of concrete and mortar. Thus, the development of compositions of modified heavy concrete for general construction purposes with improved technical parameters due to the use of effective modifying additives is relevant [12].

To improve the technical characteristics of the mortar mixture is added a special additive - a surface-active substance with plasticizing (post-alcohol bard) action. The use of these wastes generated during the operation of alcohol production factories remains an urgent problem [13]. Any scientific research should be focused on obtaining quality and reliable results [14, 15].

This research aims to develop a complex modified additive (CMA) and influence research on concrete physical and mechanical properties. Within the framework of this study, a set of laboratory tests was carried out to assess the physical and mechanical properties of experimental samples with subsequent comparative analysis of changes in the qualitative characteristics of concrete and the influence of the complex modifier on it.

The main evaluation parameters were: compressive strength, water saturation, and frost resistance.

To achieve the goal, the following tasks were solved:

1. Selection of the optimal composition of the additive at different percentages of its components;
2. Preparation of samples of variable composition of additive components in laboratory conditions;
3. Laboratory research of physical and mechanical properties of experimental samples.

2. RESEARCH SIGNIFICANCE

Most of the transformative process of concrete as a building material falls on the development and use of additives that improve the performance qualities of concrete. The research significance lies in the establishment of the optimal ratio of the developed additive, allowing obtaining concretes with high physical and mechanical properties. The tests of the developed compositions of heavy concrete with complex modified additives are effective, therefore the interest in the development of new, competitively capable additive accelerators does not weaken. The research results allow for recommending the proposed composition of modified concrete for the production of building products and structures.

3. MATERIALS AND METHODS

Cement. Portland cement M400 type CEM I 42.5 N have adopted «Kokshe-Cement» products.

Fine and coarse aggregate. As a fine aggregate was used sand. A coarse aggregate (i.e. 10 mm) for concrete was taken from crushed stone.

As a complex modified additive was used: - modifying additive - post-alcohol bard (the main component of the additive) alcohol production waste, in the amount of 2.5%, 5.0%, 7.5%, 10%, a multiple of 2.5%. Supplied in liquid form, producer - JSC «Aydabul distillery»; - sodium compounds (NaOH) were used in small quantities, just enough to obtain a neutral medium, i.e., to stabilize the pH of the additive, in the amount of 5%; - hardening accelerator - gypsum, which will accelerate the process of hardening, in the amount of 1%, 1.5%, 2.0%, 2.5%, a multiple of 0.5%.

The laboratory research methodology consisted of several consecutive operations on the creation of compositions, preparation of concrete mixtures, molding standard (100x100x100 mm) cube samples shown in Fig. 1, and testing the obtained samples for comparative analysis of different types of concrete.

Fig. 1 Test samples–concrete cube samples

After curing, the following tests were performed on the concrete samples:

1) To determine the compressive strength (adopted to GOST 10180-2012 [16] and BS EN 12390-Part 3 [17]) shown in Fig. 2, six cubes (100x100x100 mm) for each mixture were cast and tested after 3, 7, 14, 21 and 28 days of curing, in the laboratory conditions using the equipment Press Automatic Pilot, total compressive load 500 kN (50 tons);

2) The samples for the water saturation test (adopted to GOST 12730.3-2020 [18] and ASTM C642-21 [19]) shown in Fig. 3, were placed in a container filled with water (water level over samples - 60 mm, water temperature - 21˚C). The samples were weighed every 24 hours until constant weight. Calculated values such as: 1) average and saturated dry density, g, 2) water saturation, %;

Fig. 2 Compressive strength tests

Fig. 3 Frost resistance tests

Fig. 4 Water saturation tests

3) Methods for determining frost resistance - by the first basic method of repeated freezing and thawing. Frost resistance was tested by comparing the strength characteristics and mass loss of the basic (with an additive) and reference samples after alternate freezing and thawing. The number of cycles is 100, 150, and 200 (adopted to GOST 10060-2012 [20] and BS EN 12390-Part 9 [21]) shown in Fig. 4

Water-cement ratio for the reference composition (Type 1) was w/c = 0.56.

The consumption of raw materials (required for measurements of compressive strength, water saturation, and frost resistance) is shown in Table 1.

Table 1 The composition of the concrete types compared

No	Type	Cement	Sand	Crushed stone	Gypsum	Post-alcohol bard	NaOH	Water
1	Reference sample	350	840	1200				196
2	Type 2-1	346.5	840	1200	3.5	8.75	0.4375	186.8125
3	Type 2-2	346.5	840	1200	3.5	17.5	0.875	177.625
4	Type 2-3	346.5	840	1200	3.5	26.25	1.3125	168.4375
5	Type 2-4	346.5	840	1200	3.5	35	1.75	159.25
6	Type 3-1	344.75	840	1200	5.25	8.75	0.4375	186.8125
7	Type 3-2	344.75	840	1200	5.25	17.5	0.875	177.625
8	Type 3-3	344.75	840	1200	5.25	26.25	1.3125	168.4375
9	Type 3-4	344.75	840	1200	5.25	35	1.75	159.25
10	Type 4-1	343	840	1200	7	8.75	0.4375	186.8125
11	Type 4-2	343	840	1200	7	17.5	0.875	177.625
12	Type 4-3	343	840	1200	7	26.25	1.3125	168.4375
13	Type 4-4	343	840	1200	7	35	1.75	159.25
14	Type 5-1	341.25	840	1200	8.75	8.75	0.4375	186.8125
15	Type 5-2	341.25	840	1200	8.75	17.5	0.875	177.625
16	Type 5-3	341.25	840	1200	8.75	26.25	1.3125	168.4375
17	Type 5-4	341.25	840	1200	8.75	35	1.75	159.25

4. RESULTS AND DISCUSSION

The choice of additive was determined based on the main mechanism of their action. The compound-complex modified additive includes gypsum, post-alcohol bard, and caustic soda (NaOH). During the work two types of concrete samples with different cement rates were made, the first type without using an additive (Type 1-reference sample) and the second type with CMA (16 Types). The developed compositions differed in % content of the introduced complex modified additive. When developed the mixes required to obtain a higher class of concrete, the water consumption was reduced, due to the addition of CMA. The effect was achieved by lowering the water-cement ratio (w/c = 0.56).

4.1 Compressive Strength

After the addition of the additive in heavy concrete, the most important indicator is to determine the strength of the concrete.

Fig. 5-8 shows a diagram of the change in compressive strength of the samples as a function of curing time. According to these results, it is possible to give a comparative characteristic of concrete samples made with the use of CMA and control compositions without additives (Type 1 reference sample).

Reference samples showed lower strength at all curing times (3, 7, 14, 21, and 28 days). At the same time, the individual points of average strength ranged from 25.1 to 39.4 MPa.

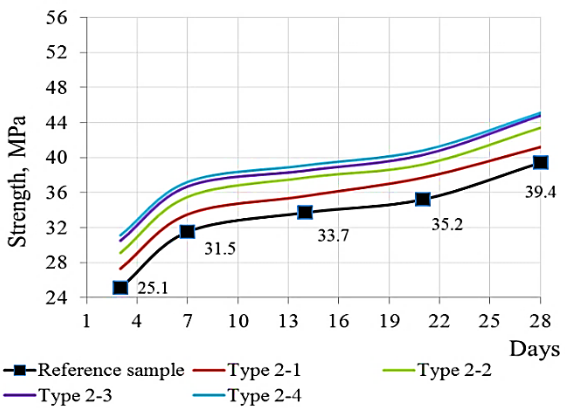

Fig. 5 Comparison of Type 1 with Types 2-1 – 2-4

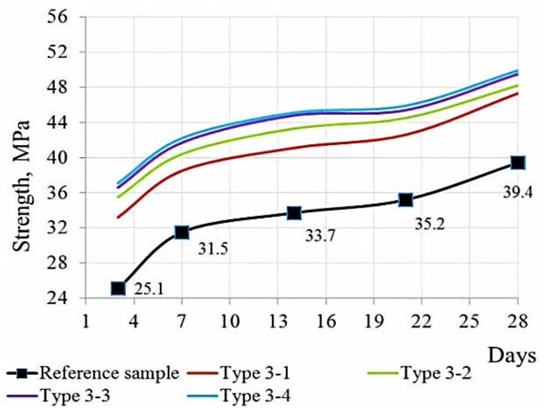

Fig. 6 Comparison of Type 1 with Types 3-1 – 3-4

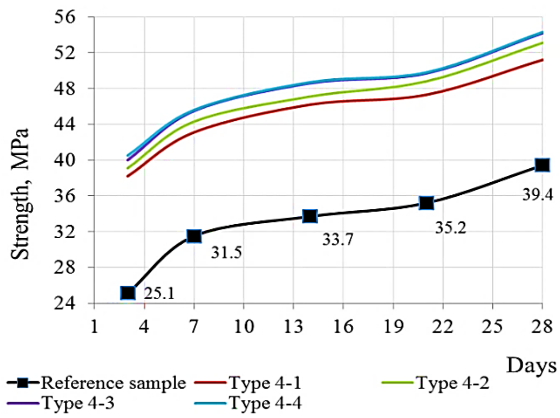

Fig. 7 Comparison of Type 1 with Types 4-1 – 4-4

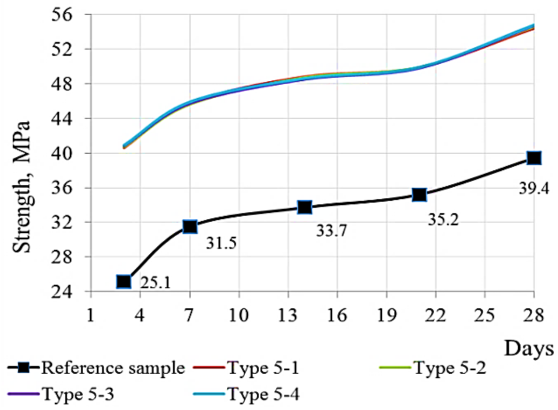

Fig. 8 Comparison of Type 1 with Types 5-1 – 5-4

Samples using the additive (CMA) showed high strength at all curing times (3, 7, 14, 21, and 28 days). At the same time, the individual points of average strength ranged from 27.9 to 54.8 MPa.

According to Fig. 5-8 can observe how the set strength of heavy concrete when using CMA, it is one of the main properties of this type of additive improvement of physical and mechanical characteristics. It is observed an increase of strength with CMA compared with the reference sample without modifiers on day 3 - 8.7-62.94%, 7 day - 6.34-45.7%, 14 day - 5.63-44.21%, 21 day-7.1-44.76%, and 28 day - 4.56-39.08%. Concrete strength indicators at the expense of the additive (post-alcohol bard) 2.5-10% (in terms of dry matter) differ from each other, so always find the necessary dosage, as lack or excess will not produce the desired results. The additive showed itself best when used at 2.5-7.5% of the cement mass, which led to a rapid set of strength on the first day, and on the 28 days the percentage of the set, was 4.56-39.08% more compared to the reference sample.

Analysis of the experimental results showed that the Type 2-1 - 5-4 compressive strength is in the range 41.2-54.8 MPa (28 days), and for the reference, the sample is 39.4 MPa, that is, this parameter is 1.5 times higher. Thus, the use of CMA allows getting the strength of concrete higher than the reference sample in all periods of hardening, respectively, developed CMA is an effective accelerator of hydration and hardening. When comparing the indices of strength prepared on the sample, equal to 39.4 MPa, with the proposed compositions, which ranged from 41.2-54.8 MPa, is possible to say that the sample Types 2-1 - 5-4 are of higher quality. Achieve a rapid set strength, helps to achieve such a property of the additive, as an influence on the hydration of the binder. The use of CMA makes it possible to obtain highly workable plasticized mixtures using an additive (post-alcohol bard) in an amount of 2.5-7.5% without lowering the strength in the specified periods of normal hardening.

A further increase in the dosage of the additive leads to a decrease in the project strength and slows down the growth kinetics of strength. Adding one of the additive components (post-alcohol bard) to the concrete mixture reduces the water consumption by 8.75-35% and also reduces the cement consumption by 1-2.5% when adding gypsum. According to the results, the hardening process occurs not only in the initial stages, but also continues to gain strength evenly in the subsequent time and to a greater extent increases the strength, which is positively characterized by samples using CMA. This is where the modified structure has a higher resistance to fracture. The increase in strength points is since the action of the plasticizing additive in the concrete mixture reduces the volume of intergranular space and provides closer contact between the shells of hydrate products on the surface of neighboring cement grains, which helps to combine them more dense and strong conglomerate.

4.2 Water Saturation

Studies of samples on water saturation by mass showed the effective hydrophobicity of the used CMA in the structure of concrete. Data on water saturation of concrete samples by mass after 28 days of normal curing are shown in Fig. 9-11. As can be seen from the data provided, the content of CMA leads to a decrease in water saturation by 2-4 times, which indicates a decrease in porosity.

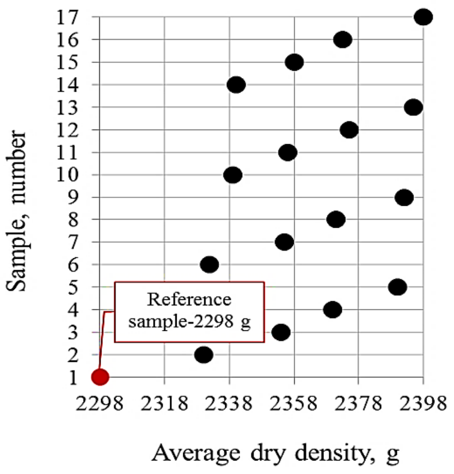

Fig. 9 Average dry density results

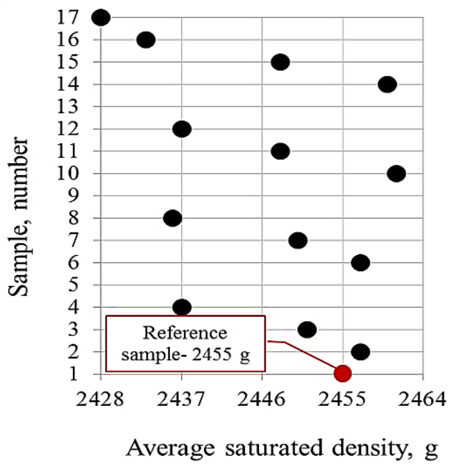

Fig. 10 Average saturated density results

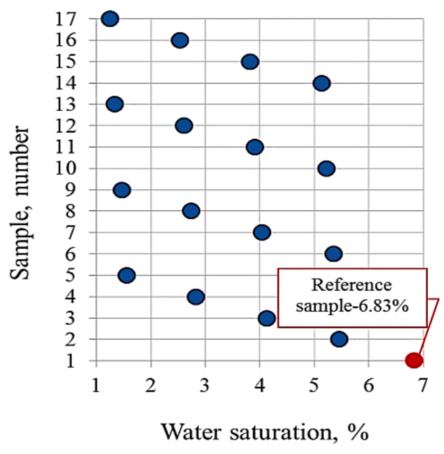

Fig. 11 Water saturation test results

Such an indicator was achieved due to plasticizing action of the post-alcohol bard. And also the use of CMA gives a higher influence, as a post-alcohol bard in its structure has plasticizing components, reducing the water saturation of samples, thereby creating a hydrophobic shell in the concrete structure, forming a barrier to the penetration of water into the pores. High water saturation has a negative influence on the frost resistance of concrete. Analysis of the results shows that the water saturation of concrete samples ranged from 1.251-6.832%, depending on the composition of concrete and additive consumption.

The water saturation of Type 1 samples has the highest point, equal to 6.832%, while the lowest water saturation was observed in Type 5-4 samples - 1.251%. It was found that by increasing the amount of additive introduced the water saturation of concrete decreased by 81.6%. At the maximum consumption of additive in the studies, the water saturation of concrete by mass does not exceed its normative point (for heavy concrete with coarse aggregate Wm≤5%) and reference samples without additive.

4.3 Frost resistance

In the following experiment, the results of the frost resistance tests on concrete were analyzed, as shown in Fig. 12. The frost resistance tests were performed on normal-curing concrete samples, and a total of 150 samples were tested. Fig. 13-18 shows the average point of change in mass and strength of concrete samples with different compositions as a function of the number of freeze-thaw cycles.

Determination of frost resistance led to the following results:

Type 1 reference sample. The lowest values of frost resistance showed samples of concrete without additives - F150, which were made with increased consumption of cement and water, without changing the w/c to ensure equal workability of the concrete mixture. The average mass loss of the samples was 1.31%, and the loss of strength of the samples was 18.38%.

Samples with additive. The addition of a complex modified additive regulating the character of the structure of concrete significantly changes the frost resistance of concrete up to F200. The mass loss of samples was 2.33-4.12% and the loss of strength of samples was 14.7-24.5%. Consequently, the additive is an effective way to increase the frost resistance of concrete. Testing the concrete up to 200 cycles revealed that the results met the criterion of frost resistance. The decrease in mass reached 2.11-3.93% and the strength loss of the samples was 18.7-25.6%. At 150 cycles of alternate freezing and thawing, visible signs of destruction (cracking, peeling) were not observed.

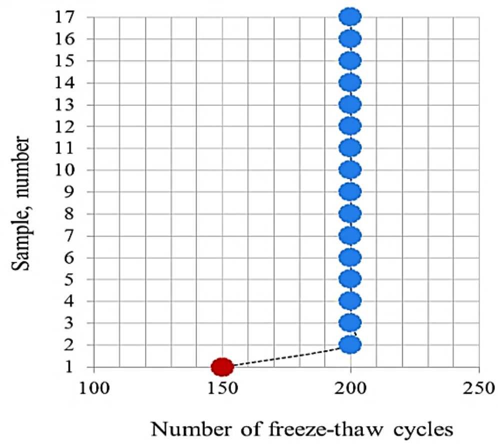

Fig. 12 Frost resistance test results

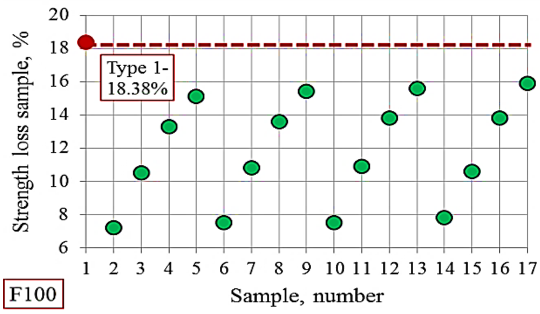

Fig. 13 Strength loss of samples at 100 cycles

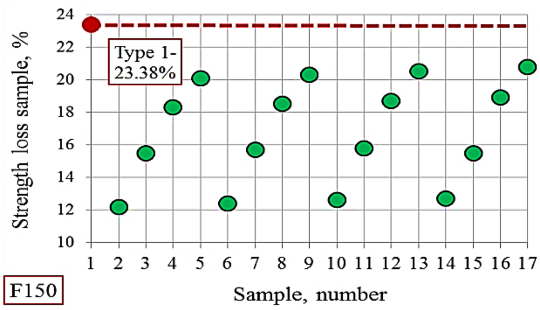

Fig. 14 Strength loss of samples at 150 cycles

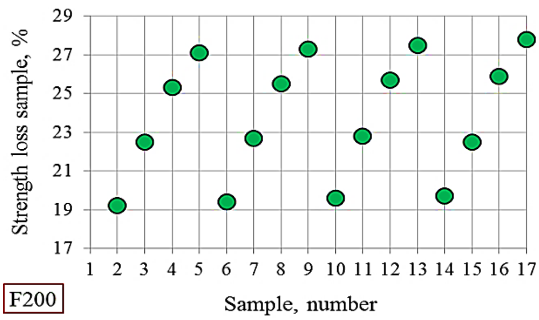

Fig. 15 Strength loss of samples at 200 cycles

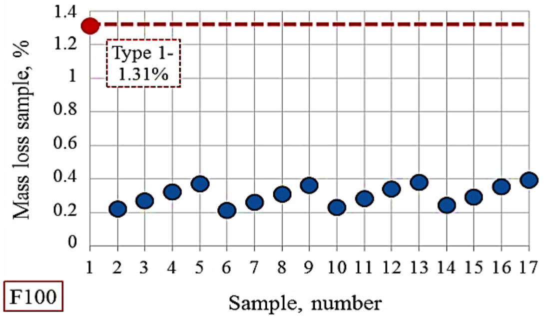

Fig. 16 Mass loss of samples at 100 cycles

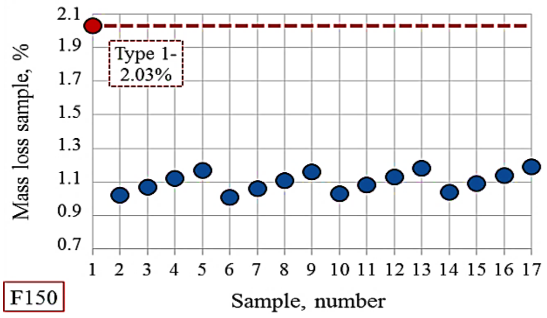

Fig. 17 Mass loss of samples at 150 cycles

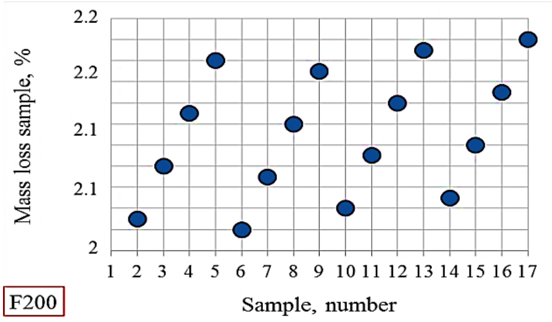

Fig. 18 Mass loss of samples at 200 cycles

At 100 cycles, the concrete lost virtually no mass or strength. After testing the concrete at 150 cycles, it was found that the lower limit of the strength confidence interval was 20% higher than the lower limit of the confidence interval for the control sample. That is, the 150-cycle test results of the concrete met the frost resistance criteria in terms of strength. The decrease in mass of the reference sample was a total of 2.03% and in the sample with the addition of the additive was 1.01 to 1.19%, no flaking of the surface of the sample was observed. In the final test of the additive-added sample consisting of 200 cycles, it was found that the strength was reduced by 5% and the lower limit of the confidence interval of the reference sample was lower than the criterion for frost resistance strength. In addition, the amount of mass reduction at 200 cycles was more than 2%, and the peeling of the sample surface was negligible, so it was necessary to complete the test. As a result, the freeze-thaw resistance grade of concrete with the additive is equivalent to F200, the resulting concrete can be attributed to medium frost resistance. CMA can be added to increase the frost resistance of concrete. Thus, the addition of CMA increases the frost resistance of concrete to grade F200. Compositions without additives have frost resistance class F150 (150 test cycles, strength loss of 13%). Thus, the results of frost resistance tests of concrete, show that the most stable structure of cement stone is formed in the presence of a complex modified additive.

The addition of additives in the composition of concrete significantly increases the frost resistance, and the amount of additives does not harm this indicator. On the contrary, the frost resistance of the concrete improved in comparison with the reference composition of the concrete (Type 1). Thus, the results of the study confirmed that the resulting modified concrete to withstand 200 cycles and belongs to the class of medium frost resistance.

5. CONCLUSION

Analysis of the obtained data shows that compared to the reference sample of concrete (Type 1), the modified concrete has technical efficiency in the following indicators: compressive strength, water saturation, and frost resistance.

The addition of CMA in the composition of heavy concrete can increase the strength at 28 days of hardening by 4.56-39.08% compared to the reference sample. As can be seen from the data provided, the content of CMA leads to a decrease in water saturation by 2-4 times, indicating a decrease in porosity. The use of CMA gives a higher effect, as a post-alcohol bard in its structure has plasticizing components, reducing the water saturation of samples, thereby creating a hydrophobic shell in the structure of concrete, forming a barrier to the penetration of water into the pores. Experimental studies have shown that the frost resistance of concrete with CMA, compared with conventional concrete, increased by 1.5 times, so the effectiveness of the additive in terms of improving frost resistance is obvious.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Ngugi H.N., Mutuku R.N., and Gariy Z.A, Effects of sand quality on compressive

strength of concrete: A case of Nairobi County and Its Environs, Kenya, Open Journal of Civil Engineering, Vol. 04(03), 2014, pp. 255-273.

[2] Gora J., and Piasta W., Impact of mechanical resistance of aggregate on properties of concrete, Case Studies in Construction Materials, Vol. 13, 2020, pp. 200-215.

[3] Hong L., Gu X., and Lin F., Influence of aggregate surface roughness on mechanical properties of interface and concrete, Construction and Building Materials, Vol. 65, 2014, pp. 338-349.

[4] Barannikov M.V., Polyakov I.V., Vinogradova L.A., and Polyakov V.S., A multifunctional additive for heavy concretes, Vestnik MGSU, Vol. 17, No 6, 2022, pp. 720-726.

[5] Shamshygaiyn T., Talgat Akhmetzhanov, G.B., Tanirbergenova A., and Yeleussinova A., Effect of complex additive on exothermic kinetics and hydration stages of cement systems, GEOMATE Journal, Vol. 19(75), 2020, pp. 184–190.

[6] Q. Huy Vu, G. Pham, and A. Chonier., Impact of different climates on the resistance of concrete to natural carbonation, Construction and Building Materials, Vol. 216, 2019, pp. 450-467.

[7] Nagrockiene D., Girskas G., and Skripkiunas G., Properties of concrete modified with mineral additives, Construction and Building Materials, Vol. 135, 2017, pp. 37-42.

[8] Jingjing F., Shuhua L., and Zhigang W., Effects of ultrafine fly ash on the properties of high-strength concrete, Journal of Thermal Analysis and Calorimetry, Vol. 121, 2015, pp. 1213–1223.

[9] Havlikova I., Bilek V., Topolar L., Simonova H., Schmid P., and Kersner Z., Modified Cement-Based Mortars: Crack Initiation and Volume Changes, Materials in Technology, Vol. 49, 2015, pp. 557–561.

[10] Lukuttsova N., Lesovik V., and Postnikova O., Nano-disperse additive based on titanium dioxide, International Journal of Applied Engineering Research, Vol. 9(22), 2014, pp. 16803-16811.

[11] Yoo D.Y., Banthia N., and Yoon Y.S., Predicting service deflection of ultra-high-performance fiber reinforced concrete beams reinforced with GFRP bars, Composites, Vol. 99, 2016, pp. 381–397.

[12] Altynbekova A., Lukpanov R., Dyussembinov D., Askerbekova A., and Tkach E., Effect of a complex modified additive on the setting time of the cement mixture, Kompleksnoe Ispolzovanie Mineralnogo Syra, Vol. 325(2), 2022, pp. 29–38.

[13] Lukpanov R., Dyussembinov D., Altynbekova A., and Zhantlesova Z., Research of foam concrete components in the regional production conditions of Nur-Sultan, Technobius, Vol. 2(3), 0023, 2022, pp. 1-7.

[14] Nadirov K.S., Zhantasov M.K., Bimbetova G.Z., Kolesnikov A.S., Sadyrbayeva A.S., Orynbasarov A.K., Kutzhanova A.N., Turemuratov R.S., Botabaev N.E., and Zhantasova D., Examination of optimal parameters of oxy-ethylation of fatty acids with a view to obtaining demulsifiers for deliquefaction in the system of skimming and treatment of oil: a method to obtain demulsifier from fatty acids, Chemistry today, Vol. 34, № 1, 2016, pp. 72-77.

[15] Nadirov K.S., Zhantasov M.K., Sakybayev B.A., Orynbasarov A.K., Bimbetova G.Z., Sadyrbayeva A.S., Kolesnikov A.S., Ashirbayev H.A., Zhantasova D.M., and Tuleuov A.M, The study of the gossypol resin impact on adhesive properties of the intermediate layer of the pipeline three-layer rust protection coating, International Journal of Adhesion and Adhesives, Vol. 78, 2017, pp. 195-199.

[16] Interstate Standard GOST 10180-2012, Concretes. Methods for strength determination using reference specimens, 2013, pp 1-26.

[17] BS EN 12390, Testing hardened concrete – Part 3: Compressive strength of test specimens, 2019, pp. 1-19.

[18] Interstate Standard GOST 12730.3-2020, Concretes. Method of determination of water absorption, 2021, pp. 1-3.

[19] ASTM C642-21, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, Annual Book of ASTM, 2022, pp. 1-3.

[20] Interstate Standard GOST 10060-2012, Concretes. Methods for determination of frost-resistance, 2014, pp. 1-19.

[21] BS EN 12390, Testing hardened concrete – Part 9: Freeze-Thaw resistance-Scaling, 2016, pp. 1-32.