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HYDROPHYSICAL PROPERTIES OF HEAVY-DUTY CONCRETE WITH A COMPLEX MODIFIER FOR HYDROMELIORATIVE CONSTRUCTION

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Abstract: Heavy concrete is widely used as the main structural material in irrigation and drainage construction, ensuring high reliability and safety of the complexes during operation. The main quality criteria for heavy concrete are their operational characteristics. The binder was Portland cement of class CEM I 42.5N. The dispersed composition, technological and strength characteristics of cement and cement stone obtained from it were determined using sieve analysis, pycnometric method, determination of bending and compressive strength in accordance with standard methods. Natural sand was used as a fine aggregate. Granite crushed stone was used as a coarse aggregate. Water was used to mix the concrete mixture. Melflux 5581 F superplasticizer was used as a plasticizing additive. Microsilica was used as an active mineral additive. Chopped basalt fiber was chosen for dispersed reinforcement of concrete stone. To determine the efficiency of water interaction with the matrix of the developed concrete and, as a consequence, the efficiency of diffusion processes inside the matrix, affecting the destruction of the concrete stone structure and possible moisture loss during irrigation, the porosity of concrete, its water absorption and water resistance were determined. Analysis of the obtained data shows that the introduction of a complex modifier together with basalt fiber reduced the water absorption index by 57.8% compared to the control. The water resistance of the modified concrete in composition 5 increased by 4 loading stages compared to control composition 1. Improvement of hydrophysical properties of modified concrete was established: water absorption decreased by 57.8%; water resistance grade increased by 4 loading stages in comparison with the control composition. After 600 cycles of frost resistance testing, the mass loss was 1.5-1.8%, the strength decrease was 9.1%-10.2%. The proposed modification with a complex additive together with basalt fiber allows obtaining high-quality heavy concrete with improved hydrophysical properties.

Keywords: heavy concrete, irrigation and drainage construction, complex additive, concrete modification

ГИДРОФИЗИЧЕСКИЕ СВОЙСТВА ТЯЖЕЛОГО БЕТОНА С КОМПЛЕКСНЫМ МОДИФИКАТОРОМ ДЛЯ ГИДРОМЕЛИОРАТИВНОГО СТРОИТЕЛЬСТВА

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Аннотация: В качестве основного конструкционного материала при гидромелиоративном строительстве широко используется тяжелый бетон, обеспечивающего высокую надежность и безопасность комплексов при эксплуатации. Основными критериями качества тяжелых бетонов являются их эксплуатационные характеристики. Вяжущим являлся портландцемент класса ЦЕМ I 42,5Н. Дисперсный состав, технологические и прочностные характеристики цемента и получаемого из него цементного камня определяли с использованием ситового анализа, пикнометрического метода, определения прочности на изгиб и сжатие в соответствии со стандартными методиками. В качестве мелкого заполнителя использовали природный песок. В качестве крупного заполнителя использовали гранитный щебень. Для затворения бетонной смеси использовалась вода. В качестве пластифицирующей добавки использовался суперпластификатор Melflux 5581 F. В качестве водорастворимой полимерной добавки использовали «Полидон-А». В качестве активной минеральной добавки применялся микрокремнезём. Для дисперсного армирования бетонного камня было выбрано рубленное базальтовое волокно. Для определения эффективности взаимодействия воды с матрицей разработанного бетона и, как следствие, эффективности диффузионных процессов внутри матрицы, влияющих на разрушение структуры бетонного камня и возможной потери влаги при орошении, проводилось определение пористости бетона, его водопоглощение и водонепроницаемость. Анализ полученных данных показывает, что введение комплексного модификатора совместно с базальтовым волокном снизило показатель водопоглощения на 57,8% в сравнении с контрольным. Водонепроницаемость модифицированного бетона в 5 составе повысилась на 4 ступени нагружения в сравнении с контрольным составом 1. Выводы: установлено улучшение гидрофизических свойств модифицированного бетона: водопоглощение снизилось на 57,8%; марка по водонепроницаемости повысилась на 4 ступени нагружения в сравнении с контрольным составом. После 600 циклов испытания на морозостойкость потеря массы составила 1,5-1,8%, снижение прочности 9,1%-10,2%. Предлагаемое модифицирование комплексной добавкой совместно с базальтовым волокном, позволяет получить тяжелый бетон высокого качества с улучшенными гидрофизическими свойствами.

Ключевые слова: тяжелый бетон, гидромелиоративное строительство, комплексная добавка, модификация бетонов

INTRODUCTION

At present, in the Russian Federation, much attention is paid to the development and quality of irrigation and drainage construction, ensuring food security of the population, and especially to the quality of irrigation and drainage systems and the quality of the system's operation. Heavy concrete is widely used as the main structural material in irrigation and drainage construction, ensuring high reliability and safety of the systems during operation. The main quality criteria for heavy concrete are their performance characteristics: strength (up to 150 MPa and above), frost resistance (F1 = 1000), density (up to 2500 kg/m^3), water resistance (W20), corrosion resistance in aggressive environments. Research is also actively being conducted on modifying concrete, which allows for a given level of quality. Even a small number of modifying components allows for a radical change in the process of structure formation and the production of durable concrete with improved physical and mechanical characteristics [1-2]. Multicomponent modifiers on a chemical-mineral basis are used in hydraulic engineering; their application allows obtaining a dense durable structure [3-7]. To obtain concrete mixtures with optimal rheotechnological indicators and to improve the operational properties of hardened concrete, it is rational and promising to use chemical-mineral modifiers [8-10]. The most important achievements in the field of concrete science are studies that allow expanding the concepts of micro-, submicro- and nanolevels of structure formation processes and provide a significant increase in physical and mechanical characteristics, and above all, strength and durability. Scientifically substantiated patterns of hydration processes of cement clinker minerals and control of structure formation of cement stone and concrete have been obtained, developed and formulated [11-14]. Based on these provisions, effective methods for protecting concrete and reinforced concrete from corrosion and ways to increase its durability have been developed. Modification of concrete with chemical additives is the main direction of development of concrete technology, which is confirmed by scientific research and implemented in the practice of real enterprises. The main means of combating leaching corrosion in cement systems (washing out of calcium hydroxide) is the introduction of active mineral additives and the use of a dense matrix of cement stone. Such conclusions can be reached after studying the practical experience of the authors of scientific papers [15-17], which note that when leaching portlandite in an amount of 20-30% of the total content, the strength of the cement stone decreases by 35-50% or more. The key feature of the recommendations in these works is the use of silica-containing additives, in particular microsilica, which is a by-product containing more than 91% silicon oxide and is formed during the smelting of ferrosilicon, where dust particles of microsilica of 10-50 μm in size are retained on an electrostatic precipitator [18, 19]. Scientific interest is also aroused by the combined capabilities of amorphous silica and superplasticizer, which have an effect that improves the characteristics of the produced heavy concrete [20]. When using these two elements in production, the product gains additional compressive strength of up to 150 Mpa, and also becomes more waterproof and resistant to cracking. Thus, improving the quality of concrete for melioration and hydraulic engineering construction is a problematic issue and requires its development taking into account the technological paradigm being developed at the present stage, which provides for the use of a polydisperse binder in its composition together with a complex modifier.

METHODS

The work used the initial materials with the following characteristics. The binder was Portland cement of class CEM I 42.5N, manufactured by OOO Holcim (Rus) SM (Kolomna). The chemical and mineral composition of the cement was determined using X-ray phase and X-ray fluorescence analysis, the results of which are presented in Table 1.

Table 1. Chemical and mineral composition of Portland cement

<table>
<tr><td rowspan="2">Cement brand</td><td colspan="7">Chemical composition, wt.%</td></tr>
<tr><td>Na_2O</td><td>SO_3</td><td>MgO</td><td>Fe_2O_3</td><td>CaO</td><td>Al_2O_3</td><td>SiO_2</td></tr>
<tr><td rowspan="4">CEM I 42,5 N</td><td>0,83</td><td>0,6</td><td>0,88</td><td>3,9</td><td>64,1</td><td>5,89</td><td>23,8</td></tr>
<tr><td colspan="7">Content of crystalline phases in clinker, wt. %</td></tr>
<tr><td colspan="2">C_4AF ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$)</td><td colspan="2">$C_3A$ ($3CaO \cdot Al_2O_3$)</td><td colspan="2">C_2S ($2CaO \cdot SiO_2$)</td><td>C_3S ($3CaO \cdot SiO_2$)</td></tr>
<tr><td colspan="2">11,46</td><td colspan="2">6,97</td><td colspan="2">11,5</td><td>60,92</td></tr>
</table>

The particle size distribution, process and strength characteristics of cement and cement stone obtained from it were determined using sieve analysis, pycnometric method, determination of bending and compressive strength in accordance with standard methods. To determine the mechanical strength, beam samples measuring 4×4 ×16 cm were made of cement-sand mortar with a water-cement ratio W/C=0.4. After production, the samples were kept in molds for 1 day in a bath with a hydraulic seal, which provided the following conditions: relative air humidity of at least 90% and an ambient temperature of (20±2) °C. After 24 hours, the samples were unmolded and then stored in a bath with water for 27 days, the temperature in which was controlled within (20±2) °C. Upon expiration of the storage period, the beam samples were removed from the bath with water and tested for strength no later than 30 minutes later. The results obtained are presented in Table 2. According to the test results, it was established that the cement meets the requirements of the standard for the standardized indicators: test for uniformity of volume change, the beginning of setting of the cement paste, compressive strength after 2 and 28 days.

Table 2. Results of determining the characteristics of Portland cement grade CEM I 42.5N

Indicator	Requirement GOST 31108-2020	Actual value
Residue on sieve 45 μm, %	-	3.1
Residue on sieve 80 μm, %	-	0.5
Normal density of cement paste, %	-	26.0
Test for uniformity of volume change (Le Chatelier Ring), expansion, mm	10	7
Specific surface (according to Blaine), cm^2/g	-	3500
Start of setting, min	not earlier than 60	175
End of setting, min	-	500
Presence of signs of false setting, yes/no	no	no
Average compressive strength at the age of 2 days, MPa	not less than 10	26.5
Average compressive strength at the age of 28 days, MPa	not less than 42,5	45.5
	not more than 62,5	
True density, kg/m^3	-	3150
Bulk density, kg/m^3	-	1250

Natural sand with a fineness modulus of 2.5 and particle sizes from 0.16 mm to 2.5 mm produced by Khromtsovsky Quarry LLC, located in the village of Khromtsovo, Ivanovo Region, was used as fine aggregate. Granite crushed stone produced by Bogaevsky Quarry LLC, Moscow Region, Ruzsky Urban District, was used as coarse aggregate. It meets the requirements for the content of plate-shaped and needle-shaped grains - 12.0%; dust, silt and clay particles - 0.93%; crushed stone grade for crushability - 1400; crushed stone grade for frost resistance - 300; bulk density - 1385 kg/m^3; specific effective activity of radionuclides (Aeff) - 90 Bq/kg; crushed stone grade for abrasion I-1. The maximum in the crushed stone size distribution was 20 mm. The aggregate under study belongs to the medium-grained type of crystalline structure.

Water was used to mix the concrete mixture. Water does not contain sulfates over 2700 mg/l (in terms of SO_4), all salts over 5000 mg/l, oil sludge and scale, the content of organic matter is less than 15 mg/l, pH 7.8, color is absent.

Melflux 5581 F superplasticizer additive by BASF Construction Additives (Germany) was used as a plasticizing additive, the consumption of which was 0.3% of the binder weight, recommended by the manufacturer.

Polydon-A additive by Orgpolimersintez LLC, St. Petersburg, was used as a water-soluble polymer additive, meeting the requirements of TU 9365-002-46270704-2001. The consumption of this additive was 0.2% of the binder weight.

"Polidon-A" is an aqueous solution of polyvinylpyrrolidone C_6H_9NO, with a density of about 1200 kg/m^3, a viscosity of 3000 to 6000 MPa s at 25 °C, and a melting point of 150-180 °C.

Microsilica grade MKU-95 was used as an active mineral additive. Microsilica was produced by OOO NTC EVEREST, Lipetsk.

The chemical composition of microsilica in terms of basic oxides was determined using X-ray phase analysis using a DRON-3 X-ray machine. The specified microsilica has a high content of amorphous and glassy silicon oxide (up to 95% SiO_2 by weight); the content of other oxides is low. The results of the analysis of the chemical composition of microsilica are presented in Table 3.

Table 3. Qualitative characteristics of microsilica grade MKU-95

Substance	Mass fraction, %
Silicon dioxide SiO_2	not less than 95.0
Phosphorus oxide P_2O_5	not more than 0.09
Magnesium oxide MgO	not more than 0.7
Aluminum oxide Al_2O_3	not more than 0.17
Iron oxide Fe_2O_3	not more than 0.1
Sulfuric anhydride SO_3	not more than 0.43
Calcium oxide CaO	not more than 0.25
Free alkalis Na_2O, K_2O	not more than 1.21
Water	not more than 0.3

Chopped basalt fiber manufactured in accordance with TU 5952-002-13307094-08 was selected for dispersed reinforcement of concrete stone. Unlike steel fiber, basalt fiber has a higher resistance to corrosion. Compared to polymer fibers, basalt fiber has a lower elastic modulus and is not subject to aging. The melting point of basalt fiber is 1450°C, the average length of a fiber section is 12.67 mm, the diameter of an elementary fiber is 16.19 µm, the relative elongation at break is 1.4-3.6%, the tensile strength Rt is 2.8-3.4 MPa·10^3, the true density of the fiber is 2.63 g/cm^3, the modulus of elasticity of the fiber is 100-130 MPa·10^3, and the resistance to alkalis and inorganic acids is high.

RESULTS AND DISCUSSION

When creating trays for irrigation canals in conditions of constant contact with water, concrete must be dense and have good hydrophysical properties: low rates of water absorption, capillary suction, water resistance and high rates of frost resistance and corrosion resistance. In the works [10-17] it is noted that the hydrophysical properties of concrete are improved with the use of modifiers, especially those that include ingredients with a hydrophobic-plasticizing effect of 15-30% or more. To determine the efficiency of water interaction with the matrix of the developed concrete and, as a consequence, the efficiency of diffusion processes inside the matrix, affecting the destruction of the structure of concrete stone and possible moisture loss during irrigation, the porosity of concrete, its water absorption and water resistance were determined. To determine water absorption, the method of successive saturation of samples with water to a constant mass was used in accordance with GOST 12730.3-2020. The cube samples used had a side of 100 mm and were made of concrete mixtures of the developed compositions. The samples hardened under normal conditions for 28 days. The series of samples for testing consisted of 3 cubes plus a control for each of the compositions. Water absorption of a series of samples of each composition was determined as the arithmetic mean of the water absorption values of each sample in the series. The porosity of samples of the developed compositions was determined by assessing the kinetics of water absorption using the discrete weighing method in accordance with GOST 12730.4-2020 "Concrete. Methods for determining porosity parameters." The cube samples had a side of 70 mm, the test series included two samples of each composition. The porosity value was calculated as the arithmetic mean. The water resistance of the developed concrete products was determined using the "wet spot" method in accordance with the requirements of GOST 12730.5-2018 [16]. To determine the water resistance, cylindrical samples with a diameter of 150 mm and a height of 150 mm were made from the developed compositions. According to GOST 24587-81 [17] and the technological conditions for the manufacture of trays, the largest filler size in them should not exceed 15 mm. The cylindrical samples also had a maximum filler size of 15 mm. Six samples of each composition were prepared in the series. Before testing, the samples were kept in a normal curing chamber under normal conditions for 24 hours before testing. Water resistance was determined using the Form + Test WE 6 MMZ installation (Germany). The samples were installed in the landing devices of the installation, the cuffs of which were pre-lubricated with waterproof grease. The water pressure was increased stepwise with subsequent holding (0.2 MPa for 1-5 minutes) and a duration of water exposure under pressure equal to 12 hours at each step. When a "wet spot" appeared, as well as other signs of water penetration into various places of the sample, the test was stopped. The value of the maximum water pressure, at which no water filtration was observed on at least four out of six samples, was taken as an indicator of the sample's water resistance. The first basic method was used to determine frost resistance. The test samples were a series of concrete cubes with an edge of 100 mm, six of which were taken as controls, and twelve had additives introduced into their composition in accordance with the developed experimental plan. The holding time of the samples was 24 hours with immersion to 1/3 of the sample height, 24 hours with immersion to 2/3 of the sample height, and 48 hours with complete immersion. The testing process was continued until the appearance of structural defects in the samples - cracks, chips and peeling, loss of mass and loss of strength of the samples by more than 5% of the required value [12, 14] The results of tests for water absorption and water resistance of concrete are presented in Table 4. Analysis of the obtained data shows that the introduction of a complex modifier together with basalt fiber (composition 6, PV + (0.3% Melflux + 0.2% Polydon-A + 15% MK) + 0.7% BV) reduced the water absorption index by - 57.8%; composition 2 PV + 0.3% Melflux reduced it by 37.8%); composition 3 PV + 0.2% Polydon-A reduced it by 48.9%; composition 4 PV + (0.3% Melflux + 0.2% Polydon-A reduced it by 53.3%. by 55.5% – 5 composition PV + (0.3% Melflux + 0.2% Polydon-A + 15% MK) compared to the control (composition 1). The water resistance of the modified concrete in composition 5 PV + (0.3% Melflux + 0.2% Polydon-A + 15% MK) increased by 4 loading stages compared to the control composition 1 (PC++ 0.3% Melflux). At the same time, the presence of basalt fiber PV + (0.3% Melflux + 0.2% Polydon-A + 15% MK) + 0.7% BV in composition 6 did not affect its water resistance.

Table 4. Results of water absorption and water resistance tests

Sample marking	Water absorption by weight, %	Water resistance, MPa	Concrete grade by water resistance
Composition 1 control factory PC + 0.3% Melflux	4.5	0.6	W6
Composition 2 PV + 0.3% + Melflux	2.8	0.8	W8
Composition 3 PV + 0.2% Polidon-A	2.3	1.0	W10
Composition 4 PV + (0.3% Melflux + 0.2% Polidon-A)	2.1	1.2	W12
Composition 5 PV + (0.3% Melflux + 0.2% Polidon-A + 15% MK)	2.0	1.4	W14
Composition 6 PV + (0.3% Melflux+ 0.2% Polidon-A + 15% MK) + 0.7% BV	1.9	1.4	W14

The results of tests under cyclic alternating freezing and thawing are shown in Table 5.

Table 5. Results of concrete tests under cyclic alternating freezing and thawing

Sample marking	Sample mass loss, %, after cycles						K_{mrz} after cycles					
	200	300	350	400	500	600	200	300	350	400	500	600
Composition 1 control factory PC + 0.3% Melflux	1.18	2.18	3.15	4.32	-	-	0.96	0.91	0.78	0.67	-	-
Composition 2 PV + 0.3% + Melflux	0.47	1.14	1.18	2.2	3.6	5.30	1.0	0.96	0.94	0.92	0.82	0.8
Composition 3 PV + 0.2% Polidon-A	0.32	1.09	1.56	2.0	3.2	4.82	1.02	0.98	0.95	0.94	0.86	0.85
Composition 4 PV + (0.3% Melflux + 0.2% Polidon-A)	0.23	0.98	1.6	1.9	2.9	3.89	1.03	1.01	0.97	0.96	0.94	0.88
Composition 5 PV + (0.3% Melflux + 0.2% Polidon-A + 15% MK)	0.12	0.94	1.2	1.4	1.6	1.80	1.04	1.02	0.98	0.94	0.92	0.91
Composition 6 PV + (0.3% Melflux+ 0.2% Polidon-A + 15% MK) + 0.7% BV	0.1	0.15	0.22	0.36	0.9	1.5	1.1	1.08	1.04	0.99	0.97	0.93

Note. K_{mrz} is the ratio of the strength index of a sample after testing its frost resistance to the strength of a sample of the material in a water-saturated state before determining frost resistance.

The results of tests with cyclic alternate freezing and thawing of cube samples made of concrete of different compositions, presented in Table 5, showed:

- maximum reduction in weight up to 6.32% and cube strength by 26% in control composition 1 (PC + 0.3% Melflux) after 400 cycles of alternate freezing and thawing tests, which exceeds the es-

tablished indicators of the requirements of GOST 10060-2012 (loss of weight and strength of concrete no more than 2% and 15%, respectively).
- high frost resistance characteristics of compositions containing the complex modifier PV + (0.3% Melflux + 0.2% Polydon-A + 15% MK). After 600 test cycles, the mass loss in compositions 5 and 6 was 1.8% and 1.5% with a decrease in strength of 10.2% and 9.1%, respectively, which confirms the sufficient margin of strength and frost resistance of the proposed modified concrete compositions.

CONCLUSION

Based on the presented research results, the following conclusion can be made:
1. An improvement in the hydrophysical properties of the modified concrete was established: water absorption decreased by 57.8%; the water resistance grade increased by 4 loading stages compared to the control composition. After 600 frost resistance test cycles, the mass loss was only 1.5-1.8% and the strength decreased by 9.1%-10.2%.
2. The proposed modification with a complex additive together with basalt fiber allows obtaining high-quality heavy concrete with improved hydrophysical properties: water absorption, water resistance and frost resistance, which makes it possible to recommend it for the production of building products and structures operating in harsh operating conditions.

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