Management of initial structuring in connection zones of concrete fillers in hydrotechnical construction

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Abstract. In the article, the stages of formation of joint zones during the natural hardening of hydraulic concrete, the connections between cement stone and filler surface, and the influence of the mineralogical composition of fillers and external surface parameters on the structuring of cement stone in joint zones are studied by conducting laboratory tests. The development of high-performance technologies that accelerate the structuring of cement stone in the contact zones of hydraulic concrete fillers is considered urgent, and it is considered urgent to conduct scientific and practical research on the management of the spatial structuring mechanism arranged in the contact zones of fillers. The purpose of scientific and practical research is to study the possibilities of ensuring that hydraulic concrete strength reaches 70% within two days and to study the mechanisms affecting the kinetics of structuring in the contact zone.

1 Introduction

In Uzbekistan, 28.4 thousand km in the water management system. 66% of main and inter-farm irrigation canals, i.e., 18,700 km long, are earthen, and 34%, i.e., 9,700 km, are covered with concrete. In the concept, by 2030, the share of concrete-lined canals will be 13,100 km. or 46% is planned. In addition to canals, irrigation systems use 54,432 different hydrotechnical structures and 70 reservoirs and flood reservoirs with a total volume of 19.4 billion cubic meters.

The goal of the reforms in the field of water management and large-scale constructions using hydraulic concrete is to increase the efficiency of the irrigation system and irrigation networks from 0.63 to 0.73 in the future, to introduce water-saving irrigation technologies in agriculture and to increase the amount of water supplied per hectare of irrigated area. It is planned to increase water productivity by reducing its volume by 20% [1];

In modern water management construction, covering irrigation systems with monolithic concrete against water absorption is a more common method than other anti-leakage measures. This is explained by the long-term performance, reliability, and full mechanization of the preparation process of the hydrotechnical concrete coating, as well as the possibility of carrying out construction work regardless of the season. According to its

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structural preparation, coverings can be divided into non-reinforced monolithic, reinforced monolithic, prefabricated reinforced concrete, and shotcrete concrete reinforced types.

The main physico-mechanical properties of hydraulic concretes are usually determined by their three structural elements: strength of cement stone, type and size of aggregates, and properties of connecting layers between them. The integrity, waterproofing, cold resistance, water resistance, and resistance to cracking of hydraulic concretes largely depend on the main classification of the connecting layer of the contact zone.

Large fillers used to prepare hydraulic concrete are one of the main components. According to the analysis of our many years of laboratory work, statistical data, and current international regulatory documents, the number of fillers can be up to 80% of the volume of concrete [2, 5]. Especially in hydraulic concrete, their technical and operational classification depends on many aspects [8].

In the normative documents determining the basic standards of cements for the preparation of the heavy concrete composition and 1 m^3 concrete mixture, cement consumption is given for a crushed stone with a size of 40 mm. If the diameter of the large aggregate is changed from 40 mm to 70 mm, the cement consumption is reduced by 3% based on the standard, and it is set to be reduced by 2-9% when the type is changed to gravel. Therefore, as the quality and quantity of fillers in the concrete mixture increases, the amount of cement paste in it decreases, and the basis for reducing the consumption of cement, which is the main component of concrete, is created [5].

Suppose hydraulic concrete is considered a multi-component artificial stone material, like ordinary heavy concrete. In that case, it is appropriate to study its main properties into the following three structural elements: cement stone, fillers, and the physical and mechanical properties of the connecting layers between them. Bonding layers begin to form during the preparation of the concrete mixture in the form of a mixture of hydrated cement, sand, and plasticizer with the surface parameters of each large aggregate [3].

In this case, the surface of the fillers should be well moistened with a water-cement solution for the cement paste to bond well with the surface of the filler. Fillers need to be hydrophilic [6, 9]. This condition was achieved mainly by cleaning fillers from other organic-inorganic compounds.

Comparing the compaction of concrete mixtures with other technologies, relatively intensive compaction in the multi-parameter, modulated wave vibration transmission process, the aggregates rapidly approach each other, the cement paste that covers their outer surfaces is compacted between the aggregate particles and moves them to fill the voids formed during mixing [10]. The amount of cement paste in the concrete mixture should be sufficient for this. This condition is especially important for hydraulic concretes because the formation of open spaces in hydraulic concretes drastically reduces their frost resistance and waterproofing. As a result, it causes the service life of hydrotechnical structures to decrease. According to the results of scientific research, it is justified that the optimal thickness of the cement paste between the small filler grains in the concrete is 0.040...0.1mm [6].

Hydraulic concrete, which is widely used in the construction of irrigation systems, is considered a multi-component artificial stone material, like ordinary heavy concrete. Its physical-mechanical and operational properties depend on the quality indicators of the components of heavy concrete (binding fillers, water, and various chemical additives) and the chemical, directly depends on mechanical processes. Although the main properties of the components included in hydraulic concrete have been sufficiently studied in general terms, chemical modification (*lat.* Modification- *setting an event, changing, giving a different property*), adhesion (*lat.* adhaesio - *mechanical or intermolecular joining of two different surfaces*) cohesion (*lat.* sohaesus - *strength due to the force of gravity of connected, united molecules, atoms, ions*) and the processes of mechanical structuring formed under the influence of multi-parameter, modulated vibration have not been sufficiently studied. If the effects of vibration on fillers are analyzed, they can be conditionally divided into "volumetric" and "surface" effects. Volumetric forces are gravity, and inertial forces depend on the volume of fillers and the law of change is characterized by the dimension "d^3". The forces acting on the surface of the aggregates-dry friction, adhesion, frictional force, etc., depend on the dimension "d^2" that characterizes the surface of the aggregates.

As a result, the increase in particle diameter in the aggregate fraction determines the rapid growth of volume effects compared to surface effects. Clearly, it shows the difference between large aggregates and sand. Especially in local conditions, in the preparation and pouring of hydrotechnical concrete used in the construction of hydromelioration systems, it was accepted as the main goal of the scientific research to study their main properties into three structural elements (parameters of cement stone, fillers, and connecting layers between them).

2 Materials and Methods

It is produced in large quantities in Uzbekistan as a binder for conducting research *CEM 0 30N* Oxhangaron portland cement, according to Russian State Standard GOST 31108-2020, was used. The chemical, mineralogical composition, and physical-mechanical parameters of cement are given in Tables 1 and 2 below.

Table 1. Mineralogical and chemical composition of brand Oxangaron Portland cement CEM 0 32.5N

Cement brand	Mineralogical composition			
	$C_3.S$	C_4,S	C_3,A	C_4,AF
CEM 0 32.5N GOST 31108-2020	52	22	4.8	12.2

Continuation of table № 1.

Cement brand	Chemical composition					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	NagO K_2O
CEM 0 32.5N GOST 31108-2020	21.3	6.1	4.30	64.3	1.87	0.84

During the construction of hydrotechnical structures of irrigation systems and their reconstruction in the future, it is required to carry out large-scale concrete and reinforced concrete works. This mainly includes applying chemical additives and using multi-parameter modulated wave vibration in compaction, which creates the possibility of dramatically improving the technological and operational properties of hydraulic concrete [10]. Therefore, the reliability, service life, and safety of hydraulic structures depend to a large extent on the rheological, physical-mechanical, and operational properties of the hydraulic concretes used in their construction during the mixing period and after hardening [9, 11, 12].

Table 2. Physico-mechanical indicators of Oxangaron Portland cement CEM 0 32.5N

№	The main classifications of cement	Unit of measure	Pointer quantity
1	Normal dryness of cement paste	%	26,2
2	Deadlines: - the beginning - ending	 hour hour	 2.58 5.47
3	Comparison surface		3.04
4	Resistance to compression according to the limits (GOST30744-2001) after 3 days after 7 days after 28 days	MPa	 22.8 28.6 38.7

In a series of theoretical and laboratory experimental studies conducted to obtain hydraulic concrete with a strong and dense composition, the deformation of a heavy concrete mixture with a cement-sand mixture was studied (Figure 1) [13].

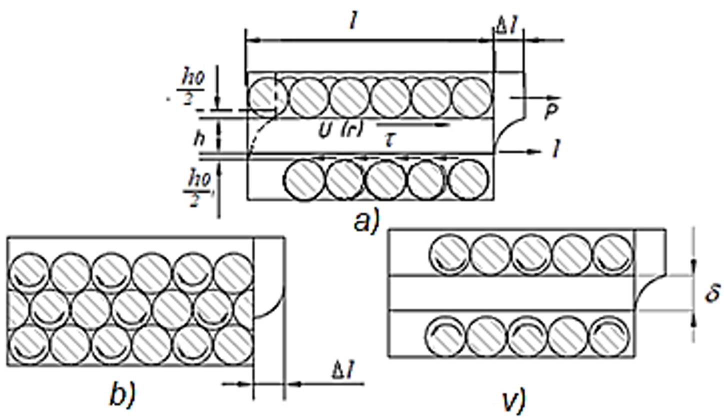

Fig. 1. Shear deformation structural scheme: *a* is for cement-sand paste; *b* is for single concrete mix; *v* is for plastic concrete mix.

The consistency of the concrete mixture and the viscosity of the cement-sand mixture (viscosity) can be expressed by various formulas (1,2) as a function of the composition of their constituents. The cement-sand mixture is considered a two-phase, liquid cement paste and a solid phase-sand particle dispersed system. Such a structure differs from cement paste by its complex structure, especially since these properties manifest under vibration. Our previously published scientific works proved that the solid particles of sand in the mixture themselves are transmitters of vibration energy [14]. On the surface of each grain filler, depending on its size, a zone of vibration influence is formed, which differs from the vibration energy of the average speed. As a result, the thixotropic liquefaction of cement paste in this zone is greater, and its viscosity decreases from the average viscosity of the mixture [14].

The viscosity (η_ρ) for the cement-sand mixture is as follows:

$$\eta_\rho = \eta_{tc} \cdot e^{ax} \tag{1}$$

where, e^{ax} is plasticity index is a function of saturation of predetermined cement paste and concrete mixture to fine aggregate (depending on sand properties) (2); η_{tc} is normal initial viscosity of cement paste without chemical additives.

$$G=ax+by-cZ \quad (2)$$

here, G is sec, concrete mixture uniformity; *a, b, c* are qualimeters of sand, gravel, and cement, respectively (*lat.* qualis and metron - *a complex characteristic of quality indicators expressed in numbers*); *x, y*- indicators of saturation of cement paste with sand and gravel; *Z* is the fluidization index of cement paste.

Local fillers consisting of quartz, feldspar, and calcite minerals were used for the research. The mineralogical composition and main classifications of these fillers are presented in Table 3.

Table 3. Mineralogical composition and main classifications of local fillers

№	Names of minerals	Content	Hardness, according to Moos	Density $gr/cent^3$	Explanation
1	Quartz	SiO_2	7	2,65	Durability, MPa - to squeeze -1920; - to stretch -50;
2	Feldspar	CaO-Al_2O_2-2SiO_2	6	2,73	Durability, MPa - to squeeze -160;
3	Calcite	$CaCO_3$	3	2,70	Soluble in hydrochloric acid

The physico-mechanical properties of the main components (portland cement, fine and large aggregates) used in the study of the structuring of hydraulic concrete fillers in the contact zones were determined based on current international standards, and the composition of hydraulic concrete was designed based on the method of absolute volumes [17, 18].

Before conducting the research, the published scientific research on the topic was systematized, the main classifications of hydraulic concrete were tested based on the standard methods presented in the current regulatory documents, and the obtained results were compared.

3 Research results and analysis

In preparing the hydraulic concrete mixture, the quality of cement paste with the outer surface of large aggregates is caused by many factors. One of the main ones is the water-cement ratio (W/Ce) in the concrete mixture. With an increase in the water-cement ratio, the plasticity of the cement paste increases, and in the process of compacting the concrete mixture with the help of vibrotitrators, the layering of the cement paste occurs due to the transfer of vibration energy of the gravel fractions with an additional volumetric effect depending on the "d^3" parameter (this process was proven in the composition of the mixture).) is observed to release gravitational water [14]. As a result, the released water takes away with it the smallest colloidal particles of the rotating cement, causes a decrease in the concentration of the cement paste located at the bottom of the large filler grains, and creates the basis for the weakening of the hydrate derivatives that are formed during the formation of the cement stone.

Suppose the W/C ratio is significantly large in preparing hydraulic concrete mixtures. In that case, layering of the concrete mixture occurs, and a decrease in the concentration of the above cement paste occurs over the entire surface of the large aggregate grains. During the solidification process, the crystallization of cement stone, which occurs on the inert surfaces of the large aggregates in the concrete mixture and unites it into a new artificial whole conglomerate, serves as a base or crystallization center. This situation has been confirmed many times in the results of some scientific studies. During the solidification process of cement, the degree of formation of new crystallization phases of various shapes in a very thin layer surrounding the outer surface of large aggregates that do not participate in its hydration depends largely on the adsorptive and hydrophilic properties of the surface of the aggregates [19]. The uniform distribution and porosity of the crystals formed in a very thin layer surrounding these aggregates' outer surface determine the hydraulic concrete's properties after hardening.

It is known from the results of scientific research that the process of emergence of new formations formed on the surface of quartz grains in the concrete mixture is observed a little earlier than those that are in the mixture but moved at least $h_0/2$ from the surface of the filler [20]. That is, the centers of crystallization are first formed on the surface of the filler, and the rate of increase in their number is inversely proportional to the distance away from the surface.

According to the results of the study, during the first 6 hours of cement hardening, an increase in the number of crystals formed as a result of the interaction of C_3S suspension with quartz grains was observed, that is, the number of new derivatives [$n \cdot CaO \cdot SiO_2 \cdot (H_2O + Ca(OH)_2 \quad n = 1,2,3,4$] numerically, it was found that the formation rate is greater than the crystal growth rate.

If the mixture on the quartz grains is highly saturated with $Ca(OH)_2$ the basicity of the resulting calcium hydrosilicate is 2.4-2.5. However, over time, this indicator decreased to 1,65. In this case, the basicity level of calcium hydrosilicate formed in the composition of the mixture was 1.83.

This situation Yu.M. Booth and W.V. When analyzed by the Timashevas, in their opinion, crystallization properties occur only in cases where there are siloxane bonds (-Si-o-Si-) on the surface of quartz grains [10]. If the mineralogical composition of the fillers in the preparation of the concrete mixture consists of feldspar, the growth of crystallization products and calcium hydrosilicate crystals on their surface will be significantly slower since their hydrophilicity and adsorption properties are somewhat weaker.

Due to the release of $Ca(OH)_2$ on the surface of quartz grains, the rate of growth of crystals in these phases is faster than the rate of growth of calcium hydrosilicate crystals.

Analyzes show that crystals of new derivatives appear faster on the surface of fillers that do not react with an alkaline environment. In this case, mainly calcium hydrosilicates are of great importance, and their sizes increase faster than the sizes of calcium hydrosilicates in the mixtures located between filler particles. This situation causes an increase in the density of the cement stone in the joint zones. But at the same time, the basis for increasing internal tensions is created. In addition, the above processes cause a change in the properties of the cement stone in the joint zones. As a result, as the cement stone's density increases, the cement stone's compressive strength also increases.

Since the strength resulting from the adhesion of fillers to the surface is less than the cohesive strength, dangerous microcracks may appear in the cement stone layer during the process of macrostructural crystallization on its surface, depending on the amount and geometrical parameters of the large filler in the mixture. It is also possible to control this process, that is, to drastically reduce the size of microcracks, which are formed due to the effect of high-speed vibration in the compaction of the mixture, and then the strength of the hardening cement paste overcomes the stress arising from the input deformations. The microhardness of the cement stone can judge this condition. As the crystals in the cement stone grow larger and the defects in their structure increase, the tensile strength of the cement stone decreases. This condition can be determined by measuring the degree of adhesion of cement stone to the aggregate surface. A cement: sand mixture with a ratio of 1:4 was prepared to determine the microfinesse of the cement stone in the joint zone. In this case, the distance between the quartz grains was changed from 30 microns to 200 microns, and the microhardness of the cement stone was determined after it hardened in its natural state (figure 2).

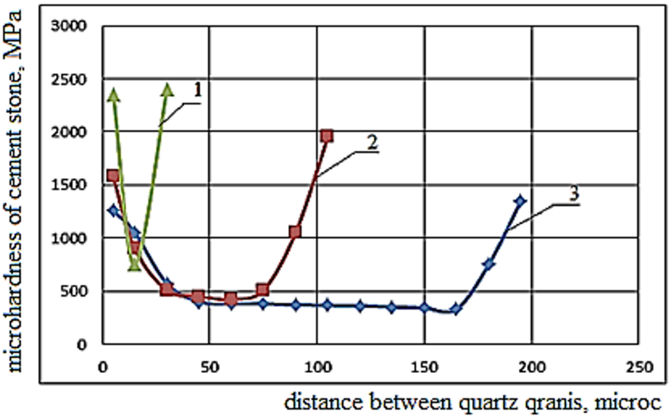

Fig. 2. Graph of variation of microhardness of cement stone in 1:4 ratio sand-cement mixture as a distance function: *1*-the distance between quartz grains is 30 microns; *2*-the distance between quartz grains is 100 microns; *3*-the distance between quartz grains is 200 microns.

Based on the graph in figure-2, it should be noted that the microhardness of the cement stone directly attached to the surface of the quartz grains (30 microns) is relatively large; its value reaches 2250 MPa. It was observed that the microhardness of cement stone 3 times away (100 microns) from the surface of quartz grains decreases to almost 400-430 MPa (up to 5 times). Maximum durability is ensured when the optimal thickness of the cement stone around the quartz grains in the joint zones is 20-30 microns.

In the formation of joint zones, there is a change in the characteristics of the cement stone and the large aggregates. In this case, on the surface of quartz grains, there are junction zones with a 50-60 microns thickness, and the microhardness of cement stone is relatively smaller (up to 500 MPa) [20]. This indicator of the microhardness of cement stone is 16-18% on the surface of quartz grains, while on the surface of filler grains belonging to the group of feldspar, which is relatively less active, the microhardness remains almost unchanged.

Accordingly, since the microhardness indicators of the surface of the aggregate or cement stone are determined by dipping diamond pyramids into them, they mainly represent the local resistance of the material under consideration. However, these indicators cannot be a sufficient basis for evaluating the strength of hydraulic concrete under different stress conditions. Because the compressive strength of hydraulic concretes is determined by testing samples of concrete mixes molded in standard cubes in special presses.

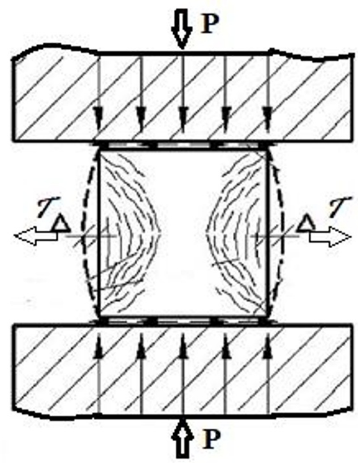

Fig. 3. Diagram of failure of hydraulic concrete strength limit during axial compression testing of cube-shaped concrete samples: P-axial compressive force acting on the cubic specimen, kH; τ is tangential force that produces tensile stresses perpendicular to the direction of the compressive force, kH; Δ is the amount of microstrain at the point of application of the tangential force (τ).

When a concrete sample is compressed in a press, the onset of strength failure occurs under the influence of the tangential τ-force, which creates tensile stresses perpendicular to the direction of the compressive P -force acting on the sample (figure 3).

The joint zones between aggregates and cement stone in hydraulic concrete are also tensile, and the strength of concrete depends on the adhesion strength of cement stone to the surface of the aggregate. So, logically, the stronger the bond between the cement stone and the aggregate, the higher the compressive and tensile strength of the concrete.

From scientific publications, to determine the adhesion indicators between cement stone with polished quartz and other filler particles with much lower activity, octagonal samples with a neck surface of 4 sm^2were prepared, and when they were tested for elongation, the adhesion index was 0.53-1.8 MPa is known to be [13].

To determine the adhesion parameters between several types of local fillers from the Chirchik River basin, which are widely used in the preparation of hydraulic concrete, flat plate-shaped samples were taken from the fillers, and their outer surfaces were polished uniformly. After that, when the surface of the filler samples was observed with a magnifying glass, no open pores were detected. That is, the effect of mechanical adhesion has almost disappeared. After that, eight-shaped samples with different types of mineral plates were prepared on the neck, and they were kept under normal, natural conditions. After 3, 7, 14, 28, and 90 days of curing, the samples were then tested for elongation. The test results are shown in Figure 4.

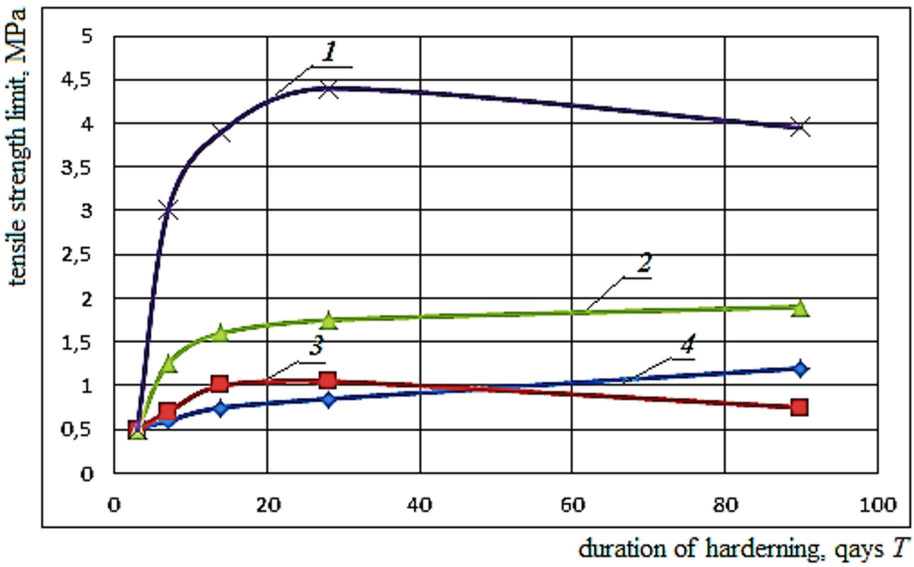

Fig. 4. Degree of bonding of cement stone with surface of various aggregates: *1* is cement stone; *2* is with calcite grains; *3* is with feldspar; *4* is with quartz grains

The results of the research in figure-4 are consistent with the indicators obtained in the research of many authors, and in particular, the tensile strength of cement stone increases rapidly in 14 days under normal conditions and reaches about 90-93% of its maximum strength (4.5 MPa) (4.0 MPa). (graph-*1* in figure-4).

In research, the maximum tensile strength of cement stone was 4.5 MPa in 28 days. But the tensile strength of cement stone with plates of the above filler minerals (quartz, feldspar, and calcite) was 0.7-1.8 MPa in 14 days, respectively. The 14-day tensile strength of samples consisting of quartz and feldspar minerals with very weak chemical activity was 0.85-1.0 MPa, respectively (graphs-*3* and *4* in fig. 4). But in the later stages of the hardening process, that is, from 14 to 90 days, the tensile strength of the samples increases from 0.85 MPa to 1.2 MPa (figure 4), while in feldspar this indicator increases from 1,0 MPa to 0.87 it was observed that it decreased to MPa (graph *3* in figure-*4*). However, based on the graph presented in Figure 4 above, it was observed that the interconnection of cement stone with a plate made of calcite mineral is 1.6-3.1 times larger than the interconnection with plates made of quartz and feldspar minerals (graph *2* in figure *4*). This high degree of bonding can be understood as a result of the chemical interaction of calcite ($Ca\ CO_3$) with the cement stone.

It was found that if the distance between fillers, including quartz sand particles, is reduced to 30-40 μm by compaction under the influence of multi-parameter, modulated wave vibration during the laying of hydraulic concrete mixture, the strength of the cement stone binding the filler particles can increase up to 1.4-1.8 times. When evaluating the effect of vibration on cement stone and, as a result, increasing the strength of hydraulic concrete, it is necessary to proceed from the condition that the composition of the concrete mixture is not layered [23].

4 Conclusions

1. Several types of aggregates from the Chirchik River basin, used in the preparation of hydraulic concrete, have a natural "polished" gravel surface, but the feldspar and mica particles in the granite form a rough microrelief due to the erosion of the particles under the influence of the external environment. Gypsum is bound, and the basis for the increase in strength of hydrotechnical concrete is created.

2. Bond strength resulting from chemical adhesion between cement stone and natural "polished" surface of inert fillers is usually not greater than 1.0 MPa. However, since any defects in the joint zone (incomplete wetting, excessive water content, the density of cement paste, low vibration speed, etc.) can further reduce the bond strength, it is required that when laying the mixture on the body of the structure, its density should reach that specified in the project.

3. The more the external surface of the fillers used in the preparation of hydraulic concretes is free of dust and additives, the greater the share of chemical and mechanical adhesions and positively affects the strength and water resistance of hydraulic concretes. A deep study of mineralogical, physico-mechanical, and chemical properties of local fillers used in the preparation of hydraulic concretes makes it possible to reveal the possibilities of their rational use and, as a result, improves the technical-economic and operational indicators of hydraulic structures, elucidates the effect of technological factors and chemical additives in extending the predicted service life to 200-500 years.

4. As a result of our scientific research, we believe that it has been proven that the quality of water management facilities can be ensured if fillers obtained from the basins of the Chirchik and Ohangaron Rivers, including the quality and mineral content of washed sand, are used in the preparation of hydraulic concrete in the conditions of the construction site.

References

1. Dziewański, J., Brylicki, W., & Pawlikowski, M. Utilization of slag-alkaline cement as a grouting medium in hydrotechnical construction. Bulletin of Engineering Geology & the Environment, 54(1). (1996).
2. Tam, V. W., Butera, A., Le, K. N., & Li, W. Utilising CO2 technologies for recycled aggregate concrete: A critical review. Construction and Building Materials, 250, 118903. (2020).
3. Voilokov, I. A. The use of dispersed reinforcement in the construction of hydraulic structures. Magazine of Civil Engineering, (1), 27-31. (2009).
4. Khomyakov, G. P. Consideration of operating requirements in designing structures and building equipment for hydroelectric power plants located in northern regions. Hydrotechnical Construction, 29, 633-635. (1995).
5. Galitskova, Y. M., & Limarjeva, E. V. (2015). The research of qualitative characteristics of construction materials based on concrete waste. Procedia Engineering, 111, 228-232.
6. Abo-El-Enein, S. A., El-Sayed, H. A., Ali, A. H., Mohammed, Y. T., Khater, H. M., & Ouda, A. S. Physico-mechanical properties of high performance concrete using different aggregates in presence of silica fume. HBRC Journal, 10(1), 43-48. (2014).
7. Klochko, B. G., Goridko, D. V., & Punagin, V. V. Control of structure formation in activated hydrotechnical concrete. Science and progress of transport. Bulletin of the Dnepropetrovsk National University of Railway Transport, (1), 142-148. (2003).

8. Vinogradov, V. N. Influence of fillers on the properties of concrete. Stroiizdat, Moscow. (1979).
9. Yunusova F. R., Muslimov T. D., Some characteristics of water permeability of hydrotechnical concretes. Journal "Irrigation and Melioration", Vol. 1(19) (2020).
10. Muratov, A., & Melikuziev, S. Technology of formation of combined products of meliorative purpose. In IOP Conference Series: Materials Science and Engineering, Vol. 883, No. 1, p. 012060. (2020).
11. Semenova.E.A. Effective modified heavy concrete for hydromelioration construction. "Trends in the development of science and education", No. 36, pp.16-18. (2018)
12. Control system for the composition and properties of hydrotechnical concrete. Science and progress transport. Vol. 5(59), pp.195-204. (2015).
13. Muratov A. R. Improving the technology for the production of prefabricated structures of irrigation and drainage systems using modulated multi-parameter oscillations. (2000).
14. Hughes, B. P., & Ai-Dafiry, H. Impact energy absorption at contact zone and supports of reinforced plain and fibrous concrete beams. Construction and Building Materials, 9(4), 239-244. (1995).
15. Lyubimova.T.Yu., Melenteva.G.G. Kinetics of crystallization and changes in composition of hydrosilicates and dispersions of quartz surface and solution of trechkalsievo silicate. Colloid magazine, (1971).
16. Beck, A. A., Estemesov, Z. A., Suvorov, A. S., Nurpeisova, M. B., & Dadin, A. D. Installation mixtures based on limestone tailings. Proceedings of the National Academy of Sciences of the Republic of Kazakhstan. Chemistry and Technology Series, (1), 11-19. (2022).
17. Muratov A. Innovative technology of vibration compaction of lightweight concrete mixtures. In AIP Conference Proceedingsб Vol. 2612, No. 1. AIP Publishing (2023).
18. Zhao, Y., Liu, Y., Shi, T., Gu, Y., Zheng, B., Zhang, K., & Shi, S. Study of mechanical properties and early-stage deformation properties of graphene-modified cement-based materials. Construction and Building Materials, 257, 119498. (2020).
19. Van Lam, T., Bulgakov, B., Bazhenov, Y., Aleksandrova, O., & Anh, P. N. Effect of rice husk ash on hydrotechnical concrete behavior. In IOP Conference Series: Materials Science and Engineering (Vol. 365, No. 3, p. 032007). (2018).
20. Skutnik, Z., Sobolewski, M., & Koda, E. An experimental assessment of the water permeability of concrete with a superplasticizer and admixtures. Materials, 13(24), 5624. (2020).