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Optimization of fine-grained concrete composition for hydraulic structures using chemical admixtures

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Abstract:

This study investigates the improvement of the physical, mechanical, and technological properties of fine-grained concrete intended for use in hydraulic structures. Portland cement M500 D20 produced in the Jizzakh region was used as the binder, while crushed diabase-based material and natural sand were used as mineral aggregates. To regulate the properties of the concrete mixture, Sika 4336 and Sika 908 chemical admixtures were incorporated at dosages of 0.3, 0.5, 0.7, and 0.9% by cement mass. The average density, workability, and compressive strength of the concrete were investigated at curing ages of 3, 7, and 28 days. The experimental results demonstrated the high efficiency of the concrete composition containing Sika 4336. At 28 days, the average compressive strength reached 55.93 MPa, which was 11.5% higher than that of the concrete containing Sika 908. The slump of the concrete mixture containing Sika 4336 reached 24 cm, while its workability was maintained for approximately two hours. Based on the comprehensive analysis of the physical, mechanical, technological, and economic characteristics, the B30 (M400) fine-grained concrete composition was recommended as an optimal composition for hydraulic structures. The obtained results demonstrate the potential of locally available diabase aggregate combined with an effective polycarboxylate-based chemical admixture for producing high-performance fine-grained concrete for hydraulic engineering applications.

Keywords:

fine-grained concrete, hydraulic structures, diabase, Portland cement, superplasticizer, Sika 4336, Sika 908, concrete mixture, compressive strength, density, water permeability, concrete composition

1. Introduction

Hydraulic structures are among the most important elements of water-management infrastructure, and their reliability largely depends on the durability and performance of the concrete used in their construction. Concrete in hydraulic structures is subjected to prolonged exposure to water, moisture, hydrostatic pressure, temperature variations, and other environmental factors. Therefore, ensuring sufficient compressive strength, density, water resistance, frost resistance, and long-term durability is an important requirement for concrete used in hydraulic engineering. The analysis presented in the dissertation indicates that improving the strength, water resistance, and long-term durability of fine-grained concrete for hydraulic structures is one of the relevant directions in modern construction materials technology.

Fine-grained concrete has attracted considerable attention because its properties can be effectively controlled through the selection and optimization of cement, fine aggregate, water-to-cement ratio, mineral fillers, and chemical admixtures. The absence of conventional coarse aggregate or its limited use results in a material whose structure is strongly influenced by the characteristics of the fine aggregate and cement matrix. Consequently, the granulometric composition, density, water absorption, and strength of the aggregate become important factors in determining the physical and mechanical properties of the resulting concrete.

For hydraulic engineering applications, the use of locally available mineral materials is particularly important. The

investigated concrete compositions were prepared using Portland cement, natural sand, and mineral fillers based on diabase. The dissertation research established that diabase aggregates characterized by high density and strength can contribute to improving the physical and mechanical properties of fine-grained concrete. Concrete specimens obtained during the experimental investigations had densities within the range of 2427–2450 kg/m³, confirming the formation of a relatively dense concrete structure.

Another important approach to improving the performance of fine-grained concrete is the application of modern chemical admixtures. Chemical admixtures can modify the rheological properties of fresh concrete, improve workability, reduce water demand, and contribute to the formation of a denser hardened structure. In the present study, Sika 4336 and Sika 908 were selected for experimental investigation. According to the research data, Sika 4336 is a high-performance superplasticizer based on polycarboxylate ether, intended to increase concrete workability and reduce water consumption. Sika 908 was investigated as an additional chemical modifier aimed primarily at improving durability and corrosion resistance of reinforced concrete structures.

The chemical admixtures were introduced into the concrete mixtures at dosages of 0.3, 0.5, 0.7, and 0.9% by cement mass. Their influence on the workability, density, and compressive strength of fine-grained concrete was experimentally evaluated. The experimental results demonstrated that the use of Sika 4336 provided particularly favorable results. At 28 days, the average compressive strength of the concrete containing Sika 4336 reached 55.93

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MPa, exceeding the corresponding result obtained with Sika 908 by 11.5%. Furthermore, the slump of the concrete mixture containing Sika 4336 reached 24 cm and remained almost unchanged for approximately two hours.

The obtained results indicate that the combined optimization of the mineral composition and chemical modification of fine-grained concrete can provide a technically effective material for hydraulic structures. The development of B22.5 (M300), B25 (M350), and B30 (M400) compositions and their comparative evaluation showed that the B30 (M400) composition provided the most favorable combination of strength, workability, and operational characteristics and was therefore recommended for hydraulic structures.

Thus, the purpose of this study was to investigate the effect of diabase-based mineral aggregate and chemical admixtures on the physical, mechanical, and technological properties of fine-grained concrete and to determine an optimal composition suitable for hydraulic structures. The study focuses particularly on the comparative effectiveness of Sika 4336 and Sika 908 and on establishing the optimal admixture dosage for obtaining concrete with improved performance characteristics.

Literature Review. Concrete used in hydraulic structures is exposed to a complex combination of environmental and mechanical actions, including prolonged contact with water, hydrostatic pressure, moisture variation, temperature fluctuations, and freeze–thaw cycles. Therefore, the development of concrete with adequate compressive strength, density, water resistance, and long-term durability is an important research direction in modern construction materials technology. In particular, the optimization of concrete composition is considered an effective approach for improving the performance and service reliability of hydraulic structures.

Fine-grained concrete has received increasing attention because its physical and mechanical properties can be controlled through the rational selection of cement, fine aggregates, water-to-cement ratio, mineral fillers, and chemical admixtures. Unlike conventional concrete containing a significant proportion of coarse aggregate, the structure of fine-grained concrete is strongly influenced by the characteristics and particle-size distribution of the fine aggregate and cement matrix. Consequently, aggregate grading, particle packing, density, water absorption, and strength play an important role in determining the final properties of the concrete.

The use of locally available mineral materials is particularly relevant for the production of construction materials. Local aggregates can reduce transportation costs, increase the economic efficiency of concrete production, and provide an opportunity to utilize regional mineral resources. Dense and strong crushed-rock aggregates can contribute to the formation of a compact concrete structure and improve its mechanical performance. In this context, diabase-based mineral materials are of particular interest because of their suitable physical and mechanical characteristics. The experimental materials used in the present study included diabase-based crushed material and natural sand, which were selected as mineral components of the fine-grained concrete.

Another important approach to improving concrete performance is the incorporation of chemical admixtures. Modern chemical admixtures are widely used to regulate the rheological properties of fresh concrete, increase workability, reduce water demand, and improve the structure

of hardened concrete. Superplasticizers are especially effective because they enable a high level of workability to be achieved at a reduced water content. A lower water-to-cement ratio generally promotes the formation of a denser cementitious matrix, which can contribute to increased compressive strength and improved resistance to water penetration.

Polycarboxylate-based superplasticizers are among the most effective chemical admixtures used in modern concrete technology. Their dispersing action promotes better separation of cement particles and improves the efficiency of water utilization within the concrete mixture. As a result, the required workability can be maintained with a lower water content. However, the effectiveness of a chemical admixture depends not only on its chemical composition but also on its dosage, cement characteristics, aggregate properties, water-to-cement ratio, and overall concrete composition.

The determination of an optimum admixture dosage is therefore an important part of concrete mix optimization. An insufficient dosage may not provide the required improvement in workability or strength, whereas an excessive dosage may negatively affect the stability and setting characteristics of the concrete mixture. For this reason, experimental evaluation of several admixture dosages is necessary to establish the most effective range for a particular combination of cement and aggregates.

For hydraulic structures, high compressive strength alone cannot be considered a sufficient criterion for selecting an optimal concrete composition. The concrete should also possess appropriate density, workability, water resistance, and durability characteristics. Consequently, a comprehensive assessment of physical, mechanical, technological, and operational properties is required when developing concrete mixtures for hydraulic engineering applications.

Previous research approaches indicate that the combined optimization of mineral composition and chemical modification can significantly improve the performance of fine-grained concrete. The use of high-density mineral aggregates together with efficient chemical admixtures provides an opportunity to obtain a compact concrete structure while maintaining adequate workability of the fresh mixture. Such an approach is particularly relevant when locally available mineral resources are incorporated into the concrete composition.

The present study focuses on the comparative evaluation of Sika 4336 and Sika 908 chemical admixtures in fine-grained concrete containing Portland cement, natural sand, and diabase-based mineral materials. The admixtures were investigated at dosages of 0.3, 0.5, 0.7, and 0.9% by cement mass. Their effects on the workability, density, and compressive strength of concrete were evaluated at curing ages of 3, 7, and 28 days.

The experimental program considered B22.5 (M300), B25 (M350), and B30 (M400) concrete compositions. Comparative evaluation of control and chemically modified mixtures made it possible to determine the influence of chemical admixtures on the development of concrete properties. According to the experimental results, the use of Sika 4336 demonstrated particularly favorable performance, including improved workability and increased 28-day compressive strength.

Based on the reviewed approaches and the results obtained in the present investigation, the optimization of



fine-grained concrete for hydraulic structures should be based on the integrated consideration of aggregate characteristics, cement content, water demand, chemical admixture dosage, workability, and strength development. The combination of locally available diabase-based mineral materials with an effective chemical admixture represents a promising approach for producing dense and high-performance fine-grained concrete suitable for hydraulic engineering applications.

2. Research methodology

The experimental investigation was carried out using Portland cement, fine mineral aggregates, natural sand, water, and chemical admixtures. M500 D20 Portland cement was used as the main binder. The physical and mechanical properties of the cement were determined in accordance with the relevant standard requirements, including GOST 310.2-76, GOST 310.3-76, GOST 310.4-81, and GOST 31108-2020, which are included among the standards used in the research.

Diabase-based mineral material was used as the principal mineral component. The crushed diabase aggregate and diabase screening material were selected because of their suitable physical and mechanical characteristics. The aggregate properties were evaluated using methods specified in GOST 8267-93 and GOST 8269.0-97.

Natural sand from two local sources was investigated. The first was sand supplied by "NEW NERUD" LLC, with a fineness modulus of 1.8 and bulk density of 1603 kg/m³. The second was sand supplied by "ZARHAL QUM" LLC, with a fineness modulus of 2.6 and bulk density of 1598 kg/m³. The particle-size distribution, moisture content, clay and dust content, and bulk density of the sands were determined according to GOST 8735-88 and GOST 8736-2014.

Two chemical admixtures, Sika 4336 and Sika 908, were used to modify the concrete mixtures. The admixtures were introduced at dosages of 0.3, 0.5, 0.7, and 0.9% by cement mass. The influence of the admixtures on fresh concrete workability and hardened concrete strength was subsequently evaluated.

The experimental compositions were developed for concrete classes B22.5 (M300), B25 (M350), and B30 (M400). The compositions were adjusted according to cement consumption and the required design strength.

For the B30 concrete composition containing Sika 908, for example, the mixture consisted of 350 kg of cement, 849 kg of diabase screenings (0–5 mm), 212 kg of Chinaz sand, 832 kg of diabase aggregate (5–20 mm), 180 L of water, and 3.15 kg of Sika 908, corresponding to 0.9% of the cement mass. The slump of this mixture was 22 cm.

The experimental program also included concrete specimens without chemical admixtures, which were used as control compositions. This made it possible to determine the relative influence of chemical modification on the development of concrete strength.

Experimental Testing

The fresh concrete mixtures were evaluated primarily in terms of average density and workability. The workability was characterized by the slump of the concrete mixture.

Hardened concrete specimens were tested at 3, 7, and 28 days. Compressive strength was determined using laboratory testing equipment, and the obtained instrumental values were processed using a 0.95 measurement coefficient. The

concrete strength was then classified according to the corresponding strength class.

For the control compositions without chemical admixtures, the measured average 28-day compressive strengths were 46.1 MPa for B22.5 (M300), 55.7 MPa for B25 (M350), and 60.1 MPa for B30 (M400).

For the chemically modified compositions, the corresponding physical and mechanical characteristics were determined under comparable laboratory conditions. The concrete specimens were maintained at laboratory conditions of approximately 21–22°C and 69–72% relative humidity during the experimental period.

The experimental program was based on the relevant standards governing cement, aggregates, concrete mixtures, and chemical admixtures. The principal standards considered in the study included:

GOST 310.2-76 — determination of cement fineness;

GOST 310.3-76 — determination of normal consistency, setting time, and volume stability of cement;

GOST 310.4-81 — determination of cement strength in bending and compression;

GOST 31108-2020 — general construction cements, technical specifications;

GOST 8267-93 — crushed stone and gravel from dense rocks for construction;

GOST 8269.0-97 — methods for physical and mechanical testing of crushed stone and gravel;

GOST 8735-88 — test methods for construction sand;

GOST 8736-2014 — technical specifications for construction sand;

GOST 7473-2010 — concrete mixtures, technical specifications;

GOST 26633-2015 — heavy and fine-grained concrete, technical specifications;

GOST 24211-2003 — admixtures for concrete and construction mortars.

The experimental methodology therefore combined characterization of the initial raw materials, preparation of control and modified concrete mixtures, determination of fresh concrete properties, and evaluation of strength development at different curing ages. This approach allowed the effectiveness of the investigated chemical admixtures to be assessed and the most suitable fine-grained concrete composition for hydraulic structures to be identified.

3. Results and Discussion

The experimental investigation was conducted to evaluate the effect of chemical admixtures on the physical and mechanical properties of fine-grained concrete intended for hydraulic structures. The concrete compositions were prepared using Portland cement, diabase-based mineral aggregates, natural sand, water, and chemical admixtures. The influence of the admixtures was evaluated through the density and compressive strength of concrete specimens at curing ages of 3, 7, and 28 days.

The experimental program included concrete compositions of B22.5 (M300), B25 (M350), and B30 (M400). Both chemically modified and control compositions without chemical admixtures were investigated. The admixtures were incorporated at different dosages, while the experimental results showed that a dosage of 0.5% by cement mass provided favorable strength, density, and water-resistance characteristics.



Properties of Concrete with Chemical Admixture

The results obtained for the concrete specimens containing chemical admixtures are presented in Table 4. The specimens demonstrated average densities in the range of approximately 2380–2422 kg/m³, depending on the concrete grade and curing age. The compressive strength increased considerably with curing age, demonstrating active strength development between 3 and 28 days.

Table 1

Physical and mechanical properties of concrete specimens with chemical admixtures

Concrete grade	Age, days	Average density, kg/m ³	Average compressive strength, MPa
B22.5 (M300)	3	2394	21.5
B22.5 (M300)	7	2383	36.7
B22.5 (M300)	28	2396	51.0
B25 (M350)	3	2405	39.4
B25 (M350)	7	2405	48.7
B25 (M350)	28	2402	58.3
B30 (M400)	3	2407	39.6
B30 (M400)	7	2416	51.7
B30 (M400)	28	2416	61.4

The results show that the compressive strength increased systematically with curing age. For the B22.5 composition, the average strength increased from 21.5 MPa at 3 days to 51.0 MPa at 28 days. For B25 concrete, the corresponding increase was from 39.4 to 58.3 MPa, while B30 concrete demonstrated an increase from 39.6 to 61.4 MPa.

The increase in strength with curing age indicates continued development of the cementitious matrix and formation of a denser hardened structure. The B30 composition exhibited the highest 28-day strength among the investigated concrete grades. To evaluate the effectiveness of chemical modification, the obtained results were compared with control concrete specimens prepared without chemical admixtures. The control specimens demonstrated lower compressive strength values at the corresponding curing ages.

Table 2

Compressive strength of concrete without chemical admixtures

Concrete grade	3 days, MPa	7 days, MPa	28 days, MPa
B22.5 (M300)	19.6	33.0	46.3
B25 (M350)	26.8	43.4	55.5
B30 (M400)	33.8	46.1	60.6

The comparison indicates that the chemically modified compositions generally demonstrated higher strength than the corresponding control mixtures. The effect was particularly evident at early and intermediate curing ages.

For example, the B22.5 concrete with chemical admixture reached approximately 36.7 MPa at 7 days, compared with approximately 33 MPa for the control composition. At 28 days, the corresponding values were approximately 51.0 and 46.3 MPa, respectively.

For B25 concrete, the 28-day strength increased from approximately 55.5 MPa for the control composition to approximately 58.3 MPa for the chemically modified composition.

The results therefore confirm that chemical modification contributes to improved strength development of the fine-grained concrete.

Particular attention was given to comparing the performance of Sika 4336 and Sika 908. According to the experimental research, the specimens containing Sika 4336 demonstrated the most favorable overall results.

The average compressive strength of the concrete containing Sika 4336 at 28 days reached 55.93 MPa. This value was reported to be 11.5% higher than the corresponding result obtained for the composition containing Sika 908.

Table 3

Comparative performance of Sika 4336 and Sika 908

Parameter	Sika 4336	Sika 908
Chemical admixture dosage investigated	0.3–0.9%	0.3–0.9%
Selected optimum dosage	0.5%	0.5%
Slump, cm	24	22
28-day average compressive strength, MPa	55.93	Lower by 11.5%
Workability retention	Approximately 2 h	Lower than Sika 4336
Overall assessment	More effective	Effective

The superiority of Sika 4336 was also observed in the fresh concrete properties. The slump of the mixture containing Sika 4336 reached 24 cm, and the mixture retained its workability for approximately two hours.

This characteristic is important for hydraulic construction because maintaining workability during transportation and placement facilitates concrete handling and improves the quality of compaction.

Technical and Economic Assessment. The economic analysis showed that the calculated cost of 1 m³ of concrete containing Sika 4336 was 631,270 UZS, while the corresponding composition containing Sika 908 had a calculated cost of 628,270 UZS.

Table 4

Estimated cost of concrete compositions

Composition	Estimated cost of 1 m ³ , UZS
Concrete with Sika 4336	631,270
Concrete with Sika 908	628,270
Difference	3,000

Although the Sika 4336 composition had a slightly higher calculated cost, its higher mechanical performance and improved workability provide important technical advantages. Therefore, the selection of the optimal



composition should be based not only on initial material cost but also on strength, workability, durability, and expected service performance.

Overall, the experimental results demonstrate that the use of diabase-based aggregate together with Sika 4336 provides a technically effective solution for producing fine-grained concrete for hydraulic structures. The highest efficiency was obtained with the B30 (M400) composition, which demonstrated high strength and favorable workability characteristics.

4. Conclusion

The experimental investigation demonstrated that the performance of fine-grained concrete for hydraulic structures can be significantly improved through the combined optimization of mineral aggregates and chemical admixtures. The main conclusions of the study are as follows:

Diabase-based mineral aggregate proved to be suitable for producing dense and high-strength fine-grained concrete due to its favorable physical and mechanical characteristics.

The incorporation of Sika 4336 and Sika 908 chemical admixtures improved the technological and mechanical properties of the investigated concrete mixtures. The admixtures enabled better control of fresh concrete workability and contributed to strength development.

The Sika 4336-based concrete demonstrated the most favorable overall performance. Its average compressive strength at 28 days reached 55.93 MPa, which was 11.5% higher than that of the concrete containing Sika 908.

The use of Sika 4336 significantly improved the workability of the fresh concrete mixture. The slump reached 24 cm, while the mixture retained its workability for approximately 2 hours, providing favorable conditions for transportation, placement, and compaction.

The experimental program resulted in the development and evaluation of B22.5 (M300), B25 (M350), and B30 (M400) fine-grained concrete compositions. Comparative analysis showed that the B30 (M400) composition provided the most favorable combination of strength and technological performance for hydraulic engineering applications.

The optimal dosage of Sika 4336 was determined to be 0.5% of the cement mass, providing an effective balance between concrete workability and mechanical performance.

The obtained results confirm that the combined use of locally available diabase aggregate and Sika 4336 chemical admixture is a promising technological approach for producing high-performance fine-grained concrete for hydraulic structures.

The developed concrete composition can be considered a technically effective material for hydraulic engineering structures where high strength, dense structure, improved workability, and reliable long-term performance are required.

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O. Khamidov, Sh. Samatov, B. Gayratov, A. Djuraev

Improving the reliability of the TD802 direct-current traction generator of the ChME3 shunting diesel locomotive through insulation replacement.....118

U. Turdialiev, D. Boykishieva

Assessing the impact of integrating lean manufacturing methods into the quality management system on the efficiency of a mechanical engineering enterprise.....125

B. Sobirov, N. Botirova

Use of mineral fillers for PVC-based linoleum production and investigation of their physical and mechanical properties.....130

G. Uzakov, M. Majidova

Development of an artificial intelligence-based adaptive digital twin method for early fault detection and energy loss reduction in solar photovoltaic systems.....133

U. Khamrokulov

Precast-monolithic frame building system based on permanent reinforced concrete shell formwork: Analysis of world practice and experimental substantiation.....138

Z. Kurbonov, S. Bozorboev

Mechanically induced surface modification of diabase aggregate for high-performance concrete.....144

Z. Kurbonov, S. Bozorboev, I. Egamberdiev

Optimization of fine-grained concrete composition for hydraulic structures using chemical admixtures.....149

D. Bekmirzaev, I. Mirzaev, R. Yuldoshev

An automated system for assessing the seismic resistance of buildings and structures using regulatory documents.....155