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Complex chemical admixture intended for improving the properties of concrete mixture

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Abstract: This paper presents the results of an experimental study on the composition and performance of a multifunctional admixture developed for concrete mixtures using an S-3 superplasticizer based on polynaphthalene sulfonates. The proposed admixture incorporates S-3 superplasticizer, ferrosilicon production waste, a blend of B115 technical-grade tall pitch and oleic acid, calcium hydrosulfoaluminate, and basalt powder. The study evaluates the effect of the developed composite admixture on the workability and water demand of fresh concrete mixtures, as well as on the physical and mechanical performance of hardened concrete. The obtained results demonstrate that the incorporation of the admixture improves the workability of the concrete mixture and reduces its water requirement, while contributing to the formation of a denser cementitious structure. The use of the developed composition provides favorable conditions for increasing concrete strength and improving its long-term performance characteristics. In addition, incorporating industrial by-products into the admixture offers a practical approach to the more efficient utilization of secondary raw materials and supports resource-efficient concrete production.

Keywords: concrete, concrete mixture, multifunctional admixture, S-3 superplasticizer, polynaphthalene sulfonate, ferrosilicon production waste, tall pitch, oleic acid, calcium hydrosulfoaluminate, basalt powder, workability, water demand, concrete strength, performance characteristics

1. Introduction

Nowadays, the rapid development of transport infrastructure in the Republic of Uzbekistan, as well as the expansion of activities related to the construction, reconstruction, and major rehabilitation of highways, is regarded as one of the important priorities of state policy. The construction of modern highways, major transport routes, bridges, and other artificial structures aimed at improving transport and logistics capabilities across the country is placing increasingly stringent requirements on the quality of materials used in road construction. In particular, the use of cement concretes with high strength, resistance to water and freeze–thaw effects, abrasion resistance, and long-term service stability is becoming increasingly important. The service life and operational reliability of road pavements largely depend on the structural characteristics of concrete, the raw-material components used, and the interaction between the admixture components. Therefore, the scientifically based optimization of concrete composition, utilization of the combined effects of mineral and chemical components, optimization of cement consumption, and improvement of the physical–mechanical and performance characteristics of concrete are among the pressing scientific and practical challenges of today. In particular, the use of complex admixtures provides an opportunity to produce high-quality pavement concrete by improving the workability of the concrete mixture, reducing its water demand, and controlling the setting and compaction processes. Under the sharply continental climatic conditions of Uzbekistan, road pavements are exposed to various natural and operational factors throughout the year. Sharp fluctuations in air temperature, repeated wetting and drying cycles, freeze–thaw cycles, atmospheric precipitation, solar radiation, as well as repeated dynamic and static loads generated by vehicular traffic may cause various deformation processes within the structure of concrete pavements. In addition, the movement of heavy vehicles, abrasive wear, and exposure to certain aggressive environments may adversely affect the strength, structural integrity, and service life of concrete. Therefore, the development of new concrete compositions and technologies capable of ensuring the resistance of pavement concrete to high loads and climatic effects is of particular scientific importance [1]. Efficient utilization of local mineral raw materials and industrial wastes, including their incorporation into concrete as active or functional components, is another important approach to addressing these challenges. Such an approach not only makes it possible to improve specific properties of concrete but also promotes the rational utilization of secondary resources, reduces production costs, and enhances the environmental efficiency of construction-material production. From this perspective, the development of a new generation of road concretes based on complex mineral–chemical admixtures represents a relevant research direction [2].

A number of regulatory and legal documents aimed at modernizing the construction sector in the Republic, introducing modern and innovative technologies, efficiently utilizing the local raw-material base, and increasing the production volume and quality of construction materials have been adopted. In particular, the Presidential Decree of

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the Republic of Uzbekistan No. PF-60 dated January 28, 2022, entitled **"On the Development Strategy of New Uzbekistan for 2022–2026,"** and Presidential Decree No. PF-6119 dated November 27, 2020, entitled **"On Approval of the Strategy for Modernization, Accelerated and Innovative Development of the Construction Sector for 2021–2025,"** define priority tasks to be implemented in these areas. Accordingly, improving the composition of concrete used in road construction, determining the effect of complex admixtures on physicochemical processes in cementitious systems, and evaluating their influence on the strength and performance characteristics of concrete constitute important scientific and practical objectives. In particular, the development and practical implementation of complex admixtures capable of improving the technological properties of fresh concrete mixtures while simultaneously increasing the density, strength, water impermeability, freeze–thaw resistance, and abrasion resistance of hardened concrete offer considerable potential [3].

Theoretical and experimental studies in this field are being conducted at the accredited scientific laboratory **"Testing of Construction Products"** of Jizzakh Polytechnic Institute and at the research laboratories of the **Department of Construction Materials and Products**. Comprehensive research activities are being carried out in these laboratories to investigate the composition and properties of construction materials, develop new composite materials, and determine the effects of mineral and chemical admixtures on the properties of concrete. As a result of the theoretical investigations and experimental studies conducted, a number of scientific developments have been developed aimed at improving the composition of concrete intended for road construction, increasing the efficiency of complex admixtures, and enhancing the principal physical–mechanical and performance characteristics of concrete. These developments provide a scientific and practical basis for increasing the strength and service life of modern road pavements, efficiently utilizing local and secondary raw materials, and improving construction-material production technologies.

Literature review

Increasing the strength, durability, and operational stability of concrete is one of the key directions in modern construction materials science. In particular, concretes intended for highways require higher performance indices compared to conventional concretes due to operating under constant traffic loads, moisture, freeze-thaw cycles, repeated temperature fluctuations, and abrasive actions. In this regard, numerous scientific studies have been conducted on modifying concrete composition using chemical and mineral additives [4].

Superplasticizers based on polycondensation products, notably S-3 type additives based on polynaphthalenesulfonate, play a significant role in improving the technological properties of concrete mixtures. These superplasticizers reduce the mutual attraction of cement particles and help maintain them in a dispersed state. Consequently, the workability of the concrete mixture increases, making it possible to reduce the water content while maintaining a consistent consistency. The reduction in the water-cement ratio serves to decrease the capillary porosity of the hardened cement paste, thereby improving the strength and density characteristics of the concrete.

The use of mineral additives is noted in the literature as one of the effective methods for controlling the structure formation process of concrete. In particular, finely dispersed materials rich in silicon dioxide react with calcium hydroxide formed during cement hydration, leading to the formation of additional calcium-silicate-hydrate compounds. Such a process can lead to the densification of the concrete structure, a reduction in porosity, and an increase in strength. From this perspective, utilizing mineral waste generated from metallurgy and ferroalloy production enterprises as secondary raw materials in concrete composition is considered one of the promising directions.

The issue of utilizing ferrosilicon production waste in the composition of building materials has also been widely studied in recent years. The fine dispersity of these waste products and the active siliceous components in their mineral composition make it possible to use them in cementitious composites. The introduction of such materials into the cement system can fill the gaps between particles, increase structural density, and influence the formation process of hydration products. At the same time, the use of industrial waste is important from the standpoint of reducing the demand for natural mineral resources and increasing the efficiency of waste recycling.

The use of organic components with hydrophobic properties to increase the resistance of concrete to moisture has also been extensively covered in scientific literature. Specifically, substances based on higher fatty acids can affect the capillary structure of cementitious materials, restricting the penetration of water into the concrete. The presence of organic compounds in tall oil pitch shows the possibility of using it in combination with oleic acid as a component that regulates the hydrophobic properties of the concrete composition. However, determining the optimal amount of such organic components is important, as their excessive application can negatively affect the strength indices of the concrete.

Components based on calcium hydrosulfoaluminate belong to the category of mineral modifiers that actively influence the setting and structure formation processes of cement. As a result of their reactions in the cement system, hydration products with a crystalline structure can be formed, and the densification of the cement paste can be observed. The use of such components makes it possible to control the early-age curing process of concrete, accelerate structural formation, and in some cases limit deformation processes.

The role of basalt-based mineral powders in the concrete composition also deserves special attention. The high mechanical stability and mineral composition of basalt allow it to be crushed and used as a finely dispersed component. Basalt powder can act as a micro-filler in the concrete composition, reducing voids in the cement matrix and increasing the density of the composite structure. At the same time, the use of basalt-based materials expands the opportunities for the efficient use of local mineral raw materials [5].

As seen from the analyzed scientific sources, the individual effects of superplasticizers, mineral additives, and hydrophobic components on concrete properties have been sufficiently studied. However, research combining several functional components within a single complex additive, determining their interaction, and their combined effect on the structural and operational properties of concrete is relatively scarce. In particular, a comprehensive evaluation of the effectiveness of a multi-component system consisting of S-3 superplasticizer, ferrosilicon production waste, a

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mixture of tall oil pitch and oleic acid, calcium hydrosulfoaluminate, and basalt powder for road concretes remains a pressing issue.Therefore, this study focuses on investigating the possibilities of improving the technological properties of concrete mixtures, reducing water demand, densifying the concrete structure, and increasing its strength and operational performance by combining components with various functional properties within a single complex additive. This approach has both scientific and practical significance, not only in terms of obtaining high-quality road concretes, but also in reusing industrial waste and efficiently utilizing local mineral resources.

2. Research methodology

In order to develop a complex additive composition for high-strength and high-operational-stability heavyweight concrete, a modified concrete mixture based on an interrelated system of mineral and chemical components was prepared. Components that control the rheological, structural, and operational properties of the concrete mixture through various mechanisms were introduced into the complex additive composition [7]. The components used in the study and their mass fractions in the complex additive were determined as follows:

- **S-3 superplasticizer based on polynaphthalenesulfonates — 52%.** This component serves to increase the workability of the concrete mixture, reduce water demand, and optimize the water-cement ratio by improving the dispersion of cement particles. As a result, conditions are created for reducing the capillary porosity of the hardened cement paste and increasing the density and strength of the concrete structure;

- **Ferrosilicon production waste — 25%.** This component actively participates in the cement system as a finely dispersed mineral additive, promoting the formation of additional binding compounds due to pozzolanic reactions. As a result, the microstructure of the cement paste becomes denser, porosity decreases, and the strength, water impermeability, and resistance of concrete to aggressive environments are improved;

- **Calcium hydrosulfoaluminate — 12%.** This component influences the hydration and hardening processes of cement, helping to balance volumetric changes occurring during the curing period. As a result, favorable conditions are created for reducing internal stresses, limiting the formation of microcracks, and forming an integrated structure of the cement paste;

- **Dust waste from basalt production — 8%.** This material, with particle sizes ranging from 0.1 to 100 μm, was used as a micro-filler component. Its finely dispersed particles fill the voids in the cement matrix, ensuring a dense packing of particles. Consequently, conditions are created for increasing the density, structural integrity, and mechanical strength of concrete;

- **A mixture of B115 technical grade tall oil pitch and oleic acid — 3%.** The mixture was prepared in a 7:3 mass ratio and used as a hydrophobic component in the concrete composition. This component is aimed at restricting the penetration of moisture through the capillary channels of concrete, reducing water absorption, and increasing the resistance of concrete to water and freeze-thaw cycles.

The total mass fraction of the components in the complex additive is 100%. The structural components were selected taking into account not only their individual functional properties, but also their mutual compatibility and combined effect. While the S-3 superplasticizer serves to control the water demand of the concrete mixture, the mineral components increase the microstructural density of the cement matrix. The hydrophobic component, in turn, is aimed at limiting the penetration of moisture into the concrete structure. Thus, the complex additive is designed to simultaneously affect the technological, physico-mechanical, and operational indices of concrete.

In obtaining heavy concretes with high operational properties, controlling the internal structure and porosity indices of concrete is of great importance. The presence of excess water in the concrete composition leads to an increase in the number of capillary pores during the hardening process of the cement paste. This situation, in turn, reduces the strength and density of concrete, facilitating the penetration of moisture and aggressive environments into the material. Consequently, the destruction of the concrete structure under the influence of freeze-thaw cycles, wetting-drying processes, and repeated mechanical loads can accelerate.

Therefore, the main direction of the research methodology consisted of optimizing the amount of water in the concrete mixture, ensuring effective dispersion of cement particles, reducing porosity using mineral micro-fillers, and limiting capillary wetting through a hydrophobic component. The functional roles of the components making up the complex additive were selected in a mutually complementary manner, aimed at simultaneously improving several important properties of concrete [6].

Most traditional chemical or mineral additives are aimed at improving a specific property of concrete. When it is necessary to control several indicators simultaneously, the need arises to use various additives separately. Such an approach can complicate the technology of introducing additives into the concrete composition, require ensuring compatibility between components, and affect the economic efficiency of the production process.

To eliminate this problem, the principle of combining components with various functional properties within a single finely dispersed complex additive was adopted in the study. The proposed composition is aimed at reducing the water demand of the concrete mixture, improving workability, densifying the microstructure of the cement paste, lowering capillary porosity, and increasing the strength and water resistance indices of hardened concrete.

In evaluating the effectiveness of the complex additive, the workability and water demand of the concrete mixture, as well as the density, compressive strength, water absorption, water impermeability, and frost resistance of the hardened concrete were adopted as the main control indicators. By comparing the experimental results with the control concrete composition, the effect of the complex additive on each indicator was determined.

The developed complex additive is designed to combine the mechanisms of chemical plasticization, mineral modification, micro-filling, volumetric stabilization, and hydrophobization. This approach creates a technological basis for obtaining high-strength heavyweight concrete with a dense structure and stability against external environmental influences. In addition, the use of ferrosilicon and basalt production waste makes it possible to involve secondary raw materials in the production process of building materials and efficiently utilize resources.

3. Results and Discussion

As a result of the experimental studies conducted, it was determined that the developed complex additive has a positive effect on the technological properties of the concrete mixture as well as the physical-mechanical and operational indices of the hardened concrete. As a result of the effective dispersion of cement particles by the S-3 superplasticizer in the complex composition, the mobility and workability of the concrete mixture increased, making it possible to reduce water consumption by 20–25% while maintaining the required consistency. The decrease in the water-cement ratio leads to a reduction in the volume of capillary pores formed in the hardened cement paste and the formation of a denser microstructure.

As a result of the densification of the cement matrix, along with an increase in the compressive strength of concrete, its resistance to water penetration and repeated freeze-thaw cycles also improves. At the same time, the formation of a dense and low-porosity structure increases the resistance of concrete to external environmental influences, creating conditions for the long-term stable operation of structures [7].

In the studies, it was observed that the combined use of the S-3 superplasticizer with components that control the hardening process has a positive effect on the initial hydration processes of cement. As a result, the rate of strength formation of concrete at an early age increases. This feature makes it possible to shorten the duration of the technological cycle, release molds faster, and increase production efficiency in the manufacture of precast reinforced concrete products. At the same time, the intensification of the technological process creates an opportunity to use energy resources more efficiently by reducing the need for heat treatment.

Based on laboratory experiments, 52% of the S-3 superplasticizer in the complex additive composition was determined as the optimal value. At this ratio, the required workability of the concrete mixture is ensured, and along with a decrease in water consumption, it was observed that the most optimal results are achieved in the strength, water impermeability, and frost resistance indices of the hardened concrete. However, an increase in the amount of S-3 beyond the optimal value should be evaluated taking into account its interaction with other components of the complex system.

The other components of the complex additive also perform an important functional role in geological and structural formation. While the participation of ferrosilicon production waste as a finely dispersed mineral component helps to densify the cement matrix, basalt dust serves as a micro-filler to reduce voids between particles. Calcium hydrosulfoaluminate is aimed at ensuring the volumetric stability of the structure during the hardening process, whereas the mixture of B115 tall oil pitch and oleic acid acts as a hydrophobic component limiting the capillary wetting of concrete.

The functional complementarity of the components within the complex additive makes it possible to control the technological properties of oaths/concrete mixtures and improve the operational indices of the hardened concrete. The proposed composition creates favorable conditions for reducing the water demand of the mixture, ensuring the necessary workability, increasing the density of the cement matrix, and forming a high-strength structure.

The obtained results show that it is possible to improve the quality indices of high-strength heavy concretes through the use of the complex additive. In particular, as a result of the decrease in the water-cement ratio, the effect of finely dispersed mineral components as a micro-filler and active additive, and the restriction of moisture penetration by the hydrophobic component, a complex action mechanism is formed to increase the density and operational stability of concrete. These results demonstrate the prospects of applying the developed additive in the production of highways, reinforced concrete structures, and concrete products operating under high operational loads.

Proposed Compositions of the Complex Admixture for Concrete Mixtures

During the experimental studies, several compositional variants of a complex admixture intended for high-strength heavy concrete were developed. The main objective of the study was to determine the changes in the technological properties of the concrete mixture, as well as in the physical, mechanical, and performance characteristics of hardened concrete, resulting from variations in the mass proportions of the admixture components.

The complex admixture investigated in this study consisted of an S-3 superplasticizer based on polynaphthalene sulfonates, ferrosilicon production waste, calcium hydrosulfoaluminate, finely dispersed dust waste generated during basalt production, as well as a mixture of B115-grade tall pitch and oleic acid. These components were incorporated to perform specific functional roles, including improving the workability of the concrete mixture, reducing water demand, increasing the density of the cement matrix, limiting capillary porosity, and enhancing the resistance of concrete to environmental effects.

In the experimental program, the mass proportions of the components were varied within specified ranges, and their effects on the workability and water–cement ratio of the concrete mixture, as well as on the compressive strength, water impermeability, and frost resistance of hardened concrete, were evaluated. The results obtained for each composition were compared, providing a basis for determining the optimum composition of the complex admixture [8].

The experimental compositions of the complex admixture and the mass proportions of their individual components are presented in Table 1. Based on a comprehensive analysis of the obtained results, Composition 3 was identified as the most appropriate variant in terms of improving the technological properties of the concrete mixture and the physical, mechanical, and performance characteristics of hardened concrete.

In the identified optimum composition, the synergistic interaction of the components ensured the required workability of the concrete mixture, reduced water consumption, and promoted the formation of a denser cement matrix. At the same time, this composition created favorable conditions for increasing the strength, water impermeability, and frost resistance of concrete. Therefore, Composition 3 was adopted as the optimum complex admixture composition recommended for producing heavy concrete with enhanced performance characteristics.

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Table 1

Samples of the Proposed Complex Admixture Compositions for Concrete Mixtures

Composition No.	Components, wt. %				
	S-3 Superplasticizer	Ferrosilicon Production Waste	Calcium Hydrosulfoaluminate	Basalt Dust Waste (0.1–100 μm))	B115 Tall Pitch–Oleic Acid (7:3)
1	48	28	12	9	3
2	50	26	12	9	3
3 (optimal)	52	25	12	8	3
4	54	24	11	8	3
5	56	22	11	8	3
H1	45–60	20–30	10–15	5–10	2–5

Table 2

Physical, Mechanical, and Performance Properties of Concrete with the Proposed Complex Admixture

Parameters	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Concrete mixture slump, cm	15	16	17	16	15
Compressive strength, MPa (28 days)	68.5	71.2	74.8	72.4	70.6
Flexural strength, MPa	7.2	7.6	8.1	7.8	7.4
Water impermeability grade	W12	W14	W16	W14	W12
Frost resistance, cycles	F300	F400	F500	F400	F300
Water absorption, %	3.8	3.4	3.1	3.3	3.6

Test results of concrete samples modified with a complex additive. During the experimental tests, concrete samples modified with a complex additive were prepared based on various compositions given in Table 2. The prepared samples were tested under established laboratory conditions, and their main physical-mechanical and operational indicators were compared. In the research, compressive and bending strength of concrete, water impermeability, water absorption, and frost resistance were adopted as the main evaluation criteria.

A comprehensive analysis of the obtained experimental results showed that composition No. 3 provided the most optimal results. This composition consists of a mixture of 52% S-3 superplasticizer, 25% ferrosilicon production waste, 12% calcium hydrosulfoaluminate, 8% basalt dust, and 3% tall pitch-oleic acid of brand B115.

It was found that when using this composition, the compressive and bending strength indicators of concrete increased, the water impermeability property improved, and water absorption decreased. Also, the resistance of concrete to repeated freeze-thaw effects increased, and a higher result was recorded compared to other compositions in terms of frost resistance indicator [9].

The high efficiency of composition No. 3 is explained by the mutually complementary effect of the complex additive components. While the S-3 superplasticizer increased the workability of the concrete mixture and allowed for a reduction in the water-cement ratio, the fine disperse particles of ferrosilicon waste and basalt dust reduced the voids in the cement matrix, serving to form a denser structure. Calcium hydrosulfoaluminate helped ensure structural stability during the hardening process, while the mixture of tall pitch and oleic acid enhanced the hydrophobic properties of the concrete.

Based on the experimental results, composition No. 3 was accepted as the optimal complex additive composition for obtaining heavy concrete with high strength and improved operational properties. The use of this composition is considered promising for the production of high-durability concretes for road pavements, transport structures, and concrete structures subject to complex environmental influences.

Physical and mechanical properties of concrete prepared on the basis of the complex additive. In order to determine the effect of the proposed complex additive on the physical-mechanical and operational indicators of concrete, experimental tests of concrete samples were carried out according to compositions numbered 1–5. In the research, standard-sized samples were prepared to evaluate the main strength and operational properties of concrete [10].

To determine the compressive strength of concrete, cube-shaped samples with dimensions of 100×100×100 mm were prepared and kept under normal hardening conditions for 28 days. Experimental tests were organized in accordance with the requirements of current regulatory documents GOST 10180-2012, GOST 10181-2014, GOST 12730.5-2018, GOST 12730.3-2020, and GOST 10060-2012. The workability of the concrete mixture was determined based on the slump test indicator.

Evaluation of compressive strength was carried out using a MATEST C109N hydraulic press. The water impermeability properties of concrete were determined using a MATEST C435 testing device, and frost resistance indicators using an ARCTIKO LAF 700 freezing chamber. When it was necessary to study the microstructural state of concrete and the interaction mechanism of complex additive components with the cement stone in more depth, a TESCAN MIRA3 scanning electron microscope (SEM) was used.

Analysis of the experimental results showed that the use of the complex additive, alongside improving the technological properties of the concrete mixture, also has a positive effect on the structural state of the hardened concrete. In particular, due to the dispersing effect of the S-3 superplasticizer in the additive, the workability of the concrete mixture improved, creating the opportunity to reduce the water-cement ratio while maintaining the required consistency. This limited the formation of capillary pores in the cement stone, creating conditions for the formation of a relatively dense and stable microstructure.

The fine disperse particles of mineral components helped fill the voids in the cement matrix and densify the structure. As a result, the compressive strength and water impermeability properties of the concrete improved. Furthermore, as a result of the effect of the hydrophobic component, it was observed that the water absorption of concrete decreased, and the penetration of moisture into the material through capillary paths was restricted. These factors also created favorable conditions for increasing the resistance of concrete to the effects of freeze-thaw cycles.

Among the tested compositions, concrete samples prepared on the basis of composition No. 3 demonstrated the highest indicators. In this composition, the mutually coordinated effect of the S-3 superplasticizer, ferrosilicon production waste, calcium hydrosulfoaluminate, basalt dust, and the mixture of B115 tall pitch–oleic acid was observed. As a result, concrete samples of this composition recorded high compressive strength and water impermeability indicators, while water absorption recorded relatively low values. Also, in terms of frost resistance, this composition showed superior results compared to other experimental variants [11].

The experimental test results confirmed that the developed complex additive allows for the comprehensive improvement of the physical-mechanical and operational properties of concrete by controlling the workability of the concrete mixture, reducing the water-cement ratio, and densifying the microstructure of the cement stone. Based on the obtained results, composition No. 3 was recommended as the most optimal composition for heavy concretes where high strength and operational stability are required.

4. Conclusion

Based on the conducted theoretical research and experimental tests, the composition of a complex additive aimed at improving the physical-mechanical and operational properties of high-strength heavy concretes was developed, and its effectiveness was evaluated. The study utilized an S-3 superplasticizer based on polynaphthalenesulfonates, ferrosilicon production waste, calcium hydrosulfoaluminate, fine disperse dust waste from basalt production, and a mixture of brand B115 tall pitch and oleic acid.

During the experimental process, five composition variants were compared, and their impact on the workability of the concrete mixture and the main physical-mechanical and operational indicators of the hardened concrete was determined. According to the research results, composition No. 3—consisting of a complex additive composed of 52% S-3 superplasticizer, 25% ferrosilicon production waste, 12% calcium hydrosulfoaluminate, 8% basalt dust, and 3% of a mixture of brand B115 tall pitch-oleic acid—was designated as the most optimal composition.

The application of this composition allowed for the formation of a denser microstructure of the cement stone, along with improving the workability of the concrete mixture and reducing the water-cement ratio. As a result, the compressive strength of the concrete reached up to 74.8 MPa, and the bending strength up to 8.1 MPa. Furthermore, the water impermeability grade of the concrete was increased to W16, the frost resistance indicator to F500, and water absorption was reduced to 3.1%. These indicators demonstrate the effectiveness of the complex additive in increasing the density, strength, and resistance of concrete to external environmental influences.

The research results showed that the components of the complex additive have a functionally complementary effect. The S-3 superplasticizer served to improve the rheological properties of the concrete mixture and reduce water demand, the ferrosilicon waste and basalt dust to densify the cement matrix, calcium hydrosulfoaluminate to ensure structural stability, and the tall pitch-oleic acid mixture to increase the hydrophobic properties of the concrete. As a result, the formation of a high-density, strong, and durable concrete structure resistant to external environmental impacts was achieved.

It is promising to apply the developed complex additive in the preparation of road and airfield pavements, transport and hydraulic structures, bridge structures, and reinforced concrete elements operating under high mechanical and climatic loads. Especially in structures operating under the influence of temperature fluctuations, moisture, and repeated traffic loads, the use of this concrete composition can serve to increase their operational reliability.

Also, the use of ferrosilicon and basalt production waste in the composition of the complex additive makes it possible to involve industrial waste as a secondary raw material in the production process of building materials. This is of significant practical importance in terms of reducing the use of natural resources, optimizing material compositions, mitigating the problem of waste disposal, and increasing the ecological and economic efficiency of concrete production. The research results showed that the proposed complex additive is an effective technological solution for obtaining heavy concretes requiring high strength, water impermeability, and frost resistance. The indicators of 74.8 MPa compressive strength, 8.1 MPa bending strength, W16 water impermeability, and F500 frost resistance confirm the high operational potential of the developed concrete composition.

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