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The Influence Of Chemical And Mineral Additives On The Technological Properties Of Fiber Concrete Mixture

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Abstract: The article analyzes the influence of rheological properties on viscosity, workability, fluidity and degree of compaction of concrete mix prepared with the addition of superplasticizer, microsilica, fly ash and basalt fiber in order to create an optimal composition of fine-grained fiber-reinforced concrete (FRC). According to the conclusions made on the basis of the results of the study, it is stated that the use of the specified superplasticizers and additives in optimal quantities improves the rheological properties of fiber-reinforced concrete mix, has a positive effect on the uniformity of distribution of micro-reinforcing elements in the composition of the FRC mix throughout the volume and increases its formability.

Keywords: Fine-grained fiber concrete, superplasticizer, microsilica, fly ash, basalt fiber, workability (viscosity, mobility, fluidity, formability), cavitation, modification.

Introduction

Due to the increasing demand for high quality, long-term durability, environmental safety, and economic efficiency in concrete materials used in the construction industry today, the development of a new generation of concrete mixtures has become an urgent and highly relevant issue. Fine-grained fiber-reinforced concrete (FRC) belongs to the class of modern composite materials that meet these requirements and exhibit high physical and mechanical properties. There is a growing need to further improve the workability, moldability, and flowability of fiber-reinforced concretes by incorporating mineral and chemical additives into their composition. Therefore, the modification of fiber-reinforced concrete, the determination of its optimal composition, and the in-depth study of its production technologies represent an urgent scientific challenge for materials researchers and hold significant scientific and practical importance today.

High flowability and resistance to segregation, uniform distribution of self-compacting mixtures within the volume, and low porosity contribute to superior surface quality, significantly enhancing the physical and mechanical properties of concrete and improving the structural strength of constructions [1]. However, it is acknowledged that the incorporation of self-reinforcing fibers of specific sizes and diameters into the concrete mixture, as well as the uniform distribution of these fibers throughout the overall volume of the mixture, has not been sufficiently studied.

The production of high-quality, efficient, and durable concrete is closely associated with the use of chemical-mineral modifiers, which actively influence the material by integrating components with an optimal particle size distribution in the solid state, a process that is particularly significant during the initial stages of structure formation [2]. However, the impact of variations in the linear dimensions of fibers, particularly basalt fibers, on the moldability of the concrete mixture has not been sufficiently investigated. Therefore, this issue is being identified as a primary focus of current research efforts.

In the preparation of high-strength concrete and fiber-reinforced concrete structures, the ease of placement and mobility of the mixture are crucial factors. In particular, achieving the specified high flowability ensures the uniform distribution of fibers within the concrete mixture, which, in turn, prevents the formation of micro- and macro-cracks in the hardened fiber-reinforced concrete conglomerate. If the fiber-reinforced concrete mixture being placed has low flowability and fails to properly fill the spaces between the reinforcement framework, air voids are formed, negatively affecting the strength and quality characteristics of the structure. Accordingly, fiber-reinforced concrete mixtures with high flowability densely fill the structure and fully conform to its shape without the need for vibration or vibro-compaction methods, thereby ensuring high density and, consequently, increased strength. The use of highly flowable fiber-reinforced concrete mixtures facilitates the easy placement of the material into complex-shaped structures during formwork, enabling fast and efficient concreting [6, 13–16].

Referring to international normative documents recognized as interstate standards, the following requirements and recommendations regarding flowability levels can be observed (Table 1). The convenient placement flowability of the concrete mixture during formwork is determined based on the slump cone test, and the mixture grades are classified according to these indicators [17,18].

Table 1

According to the requirements of GOST 10181-2000, the regulatory standards for adjusting the flowability of concrete mixtures are defined as follows.

Grade	Slump Cone, cm	Recommended Application Area
P-1	1-4	Low flowability; vibration required
P-2	5-9	For conventional concrete structures
P-3	10-15	For moderately complex, densely reinforced structures
P-4	16-20	For densely reinforced structures
P-5	>20	For highly reinforced and complex-shaped structures

In addition to the above parameters, during concrete works, it is essential to consider the requirements related to the segregation of concrete mixtures. For mixtures with flowability grades P-3 to P-5, water separation should not exceed 0.8%, and segregation of the mixture should not exceed 4% [19].

Methods

For the high-strength B60 class fiber-reinforced concrete described in this study, especially when applied in densely reinforced structural frameworks, it is required that the concrete mixture exhibits a placement flowability corresponding to flowability grades P4 or P5.

This requirement, in turn, is met through the incorporation of chemical admixtures (plasticizers, superplasticizers, and hyperplasticizers) and active mineral additives (microsilica, fly ash, and other fine powders) into the proposed fiber-reinforced concrete mixture. In order to investigate the effects of various chemical and mineral additives incorporated into such high-strength concrete, extensive laboratory experimental tests were conducted using the following types of materials:

Portland cement M500 (SEM II/A-I 42.5 MPa, 500 kg/m³) produced by "Qizilqumsement" LLC (Navoi) was used, with a normal consistency of cement paste of 25% and a 28-day compressive strength of 42.5 MPa [21–22].

As a filler, natural granite gravel with a particle size of 5–10 mm, originating from the Sevasoy-1 quarry in Urgut district, Samarkand region, was used. The granulometric composition of the aggregate is presented in Table 2. The processes of crushing the granite stone to the required particle sizes were carried out at "Fortuna-Stone" LLC in Samarkand city, while the determination of its physical and mechanical properties was performed at the Regional Testing Center LLC and in the scientific laboratories of the "Construction Engineering" Department at Samarkand State Architecture and Construction University (SamDAQU). The bulk density was 1.5 g/cm³, the crushability grade was 1000, and the frost resistance grade was F250 [20–21].

Table 2

Granulometric Composition of Granite Gravel from "Fortuna-Stone" LLC

Residue on Sieve, %	Sieve Aperture Size, mm				Passing Through 10 mm Sieve, %
	20	10	5	2,5	
Specific	-	-	72,49	27,51	100
Cumulative			72,49	100	

Additionally, fly ash (zola-unos) from the Angren TPP JSC thermal power plant was used in the experimental work as a mineral microfiller and for modification purposes.

Fly ash is a by-product consisting of fine, spherical, glassy particles formed as a result of the combustion of pulverized coal and possesses pozzolanic or hydraulic activity [19]. Its granulometric composition is presented in Table 3.

Fly ash improves the workability of the concrete mixture and reduces settlement and heat release during the setting of the concrete or mixture. In addition, fly ash slows down the initial setting of the concrete after preparation, reduces its water permeability, and increases its frost resistance. The high dispersion of fly ash has a positive effect on the workability of the concrete mixture [8].

The composition, structure, and properties of fly ash and slag from thermal power plants depend on the type of fuel, combustion conditions, and ash collection methods. They mainly consist of SiO_2, Al_2O_3, and Fe_2O_3, with smaller amounts of CaO, MgO, and other compounds. Such types of fly ash must meet standards for sulfate resistance, volumetric stability, and reactivity when used in concrete production [3].

The true density of the fly ash from "Angren TPP" JSC is 2.21 g/cm³, and its bulk density is 0.87 kg/m³, according to [19]. In addition, the specific surface area is 3516 m²/kg, and its chemical and granulometric compositions are presented in Table 3.

Table 3

Granulometric Composition of Fly Ash from "Angren TPP" JSC

Sieve Aperture Size, mm	Residue on Each Sieve, %
0.3	0.10
0.15	0.20
0.075	42.52
Less than 0.075	57.17

In order to prevent the formation of cracks in the hardened concrete, basalt fiber was used as a reinforcing material [13–16]. The characteristic properties of basalt fiber produced in the Forish district of the Jizzakh region are as follows:

- the diameter of the basalt fibers ranges from 20 to 500 µm, and the fiber length varies from 1 mm to 10 mm;

- tensile strength reaches up to 1200 MPa;

- the thermal conductivity coefficient is $\lambda < 0.46$ W/m·°C;

- density — 2.0 g/cm³;

- elastic modulus, E = 50–55 GPa;

- fire resistance — up to 800°C;

- highly resistant to corrosion and chemical effects.

In addition, to improve the technological properties of the mixture and reduce water consumption, the "Poliplast SP-1" superplasticizer, consisting of a mixture of sodium salts of polymethylenenaphthalene sulfonic acids with various molecular weights, was used [20]. Its characteristics are presented in Table 4.

Table 4

Characteristics of the Superplasticizer "Poliplast SP-1"

Parameter				
Appearance	Density, kg/m³	pH Value	Mass Fraction of Dry Matter, %	Weight of Sample with 8% Moisture in 100 g Solution, g
Brown powder	1185	8±1	35	38,04

Microsilica (MKU-85) was used as a highly active mineral additive. Condensed microsilica is an ultra-dispersed material composed of spherical particles and is formed during the production of silicon-based alloys, including ferrosilicon grades FS 75 and FS 90, as a result of furnace gas purification. The primary particle size of microsilica ranges from 1 µm to 0.01 µm or even smaller.

Condensed microsilica is non-flammable and non-explosive, does not contain radioactive elements, and is classified as a moderately hazardous substance, belonging to hazard class 3 according to [27]. It is considered a highly effective modifier used in the production of cement and concrete. The following table presents its properties and applications as a mineral additive:

Thus, the main component is SiO_2 (silicon dioxide), the content of which exceeds 90% in microsilica. The extremely fine particle size (60–100 nm) and the high specific surface area (4000–10,000 m²/kg) enhance its interaction with the cement matrix. It reduces density and water absorption, thereby improving the quality of concrete.

The water used in the concrete mixture complied with the requirements specified in [26].

Research and Analysis

Concrete compositions and fine-grained fiber concretes were designed for class B60 to enhance their performance and suitability for various applications, and laboratory research and experimental tests were conducted based on these compositions. Their compositions are presented in Table 5.

Table 5

The Influence of the Water-Cement Ratio on the Workability of Fine-Grained Concrete Mix

No.	Name of Components	Workability Grades of Concrete Mix (kg/m³)			
		P-1	P-2	P-3	P-4
1	**Control composition (2392.9 kg/m)**				
1.1	Cement – Sem II/A-I 42.5 N	594	594	594	594

1.2	Crushed granite stone (d > 10 mm)	960	960	960	960
1.3	Quartz sand, M_y = 2.49	648,9	648,9	648,9	648,9
1.4	Water, l	195	207	225	238
1.5	Water–cement ratio	0.33	0.35	0,38	0.4
2.	**Experimental composition 2 (2407 kg/m³)**				
2.1	Cement – Sem II/A-I 42.5 N	505	505	505	505
2.2	Crushed granite stone (d > 10 mm)	960	960	960	960
2.3	Quartz sand, M_y = 2.49	648,9	648,9	648,9	648,9
2.4	Microsilica	89	89	89	89
2.5	Water, l	210	220	230	245
2.6.1	Water–binder ratio *(cement + microsilica)*	0.35	0.37	0.39	0.43
2.6.2	*Water–cement ratio*	*0.41*	*0,43*	*0.45*	*0,48*
3.	**Experimental composition 3 (2407 kg/m³)**				
3.1	Cement – Sem II/A-I 42.5 N	534.6	534.6	534.6	534.6
3.2	Crushed granite stone (d > 10 mm)	960	960	960	960
3.3	Quartz sand, M_y = 2.49	648,9	648,9	648,9	648,9
3.4	Fly ash	59.4	59.4	59.4	59.4
3.5	Water, l	187	198	208	220
3.6.1	Water–binder ratio *(cement + fly ash)*	0.31	0.33	0.35	0.37
3.6.2	Water–cement ratio	0.35	0.37	0,39	0,41
4	**Experimental composition 4 (2412 kg/m³)**				
4.1	Cement – Sem II/A-I 42.5 N	594	594	594	594
4.2	Crushed granite stone (d > 10 mm)	960	960	960	960
4.3	Quartz sand, M_y = 2.49	648,9	648,9	648,9	648,9
4.4	Basalt fiber	4,752	4,752	4,752	4,752
4.5	Water, l	195	207	225	238
4.6	Water–cement ratio	0.33	0.35	0,38	0.4
5	**Experimental composition 5 (2399.97 kg/m³)**				
5.1	Cement – Sem II/A-I 42.5 N	505	505	505	505
5.2	Crushed granite stone (d > 10 mm)	960	960	960	960
5.3	Quartz sand, M_y = 2.49	648,9	648,9	648,9	648,9
5.4	Microsilica	89	89	89	89
5.5	Superplasticizer Poliplast SP-1	3,03	3,03	3,03	3.03
5.6	Basalt fiber	4,04	4,04	4,04	4,04
5.7	Water, l	167	172	178	182
5.8.1	Water–binder ratio *(cement + microsilica)*	0.28	0.29	0.3	0.31
5.8.2	Water–cement ratio	0.33	0.34	0,35	0,36

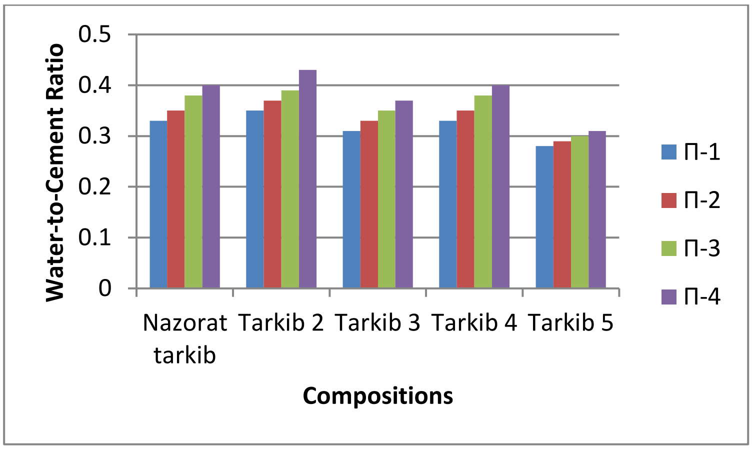

Figure 1. Workability of Fine-Grained Fiber Concrete Mix as a Function of the Water-to-Cement Ratio

As shown in Figure 1, when analyzing the water-to-cement (or water-to-binder) ratios of the compositions corresponding to the workability grades P-1, P-2, P-3, and P-4, it is observed that in the control composition, the water-to-cement ratio increased from 0.33 to 0.40 from grade P-1 to P-4. Consequently, the slump increased from 2 cm to 16 cm due to the additional water content, and the amount of water rose from 195 liters to 238 liters per 1 m³ accordingly. Similarly, in composition 2, the water-to-binder ratio for grade P-1 was 0.35 with a slump of 1.0 cm, while for grade P-4, this ratio increased to 0.43 and the slump reached 16 cm. The water-to-cement ratio rose from 0.41 to 0.48, and the water consumption increased from 210 liters to 245 liters. The significant increase in the water-to-cement (water-to-binder) ratio compared to the control composition can be explained by the microsilica's high water absorption capacity, which reduces the workability of the mixture. Additionally, due to the dense, stiff, and poorly workable nature of the composition 2 concrete mix at workability grade P-1, the water-to-binder ratio was increased to achieve workability grade P-4 in order to improve its technological properties.

When fly ash (zola) was added to composition 3, it was observed that less water was required compared to microsilica at the corresponding workability grades. Specifically, at grade P-1, the water-to-binder ratio was 0.31 with a slump of 3 cm, while at grade P-4, this ratio increased to 0.37 and the slump reached 18 cm. This can be explained by the adsorptive properties of the fly ash, pozzolanic reaction, and the fineness of its fractions, which together reduce water demand while achieving higher workability of the mixture.

The addition of basalt fiber in composition 4 showed almost no difference compared to the control composition indicators. The unchanged water demand can be explained by the relatively smooth surface of the basalt fibers, which do not absorb water. However, it is important to note that when adding basalt fibers to the mix, a specific technological procedure must be followed: the fibers should be thoroughly mixed with the dry aggregate components before adding water. If this procedure is not followed, basalt fibers tend to cluster in the mix, a phenomenon that was particularly noticeable in mixtures of workability grades P-1 and P-2.

During the study of the optimal composition of high-strength fine-grained concrete mixtures, efforts to minimize water content, increase density, and apply other technological approaches led us to develop the fifth composition. In this composition, to reduce the water consumption that deteriorated the technological properties and negatively affected the strength indicators of the concrete mixes in compositions 1, 2, 3, and 4, we conducted relevant studies by adding the superplasticizer Poliplast SP-1 in equal amounts relative to the cement mass for all workability grades. As a result, the following values were recorded for the water-to-binder ratios: 0.28 with a slump of 4 cm for P-1; 0.29 with a slump of 9 cm for P-2; 0.30 with a slump of 14 cm for P-3; and 0.31 with a slump of 19 cm for P-4. (Similarly, the water-to-pure cement ratios varied from 0.33 to 0.36 across the corresponding grades.)

The primary objective of conducting research in this manner was to obtain concrete with high construction-technical properties that is convenient to prepare technologically and practical for use in production. As a result of our research, a concrete mix composition was developed with workability grade P-4, enabling the molding of densely reinforced reinforced concrete structures. Compared to the control composition 1, composition 5 achieved a reduction in water content from 238 liters to 182 liters per cubic meter of concrete mix, and the water-to-cement (water-to-binder) ratio was reduced from 0.40 to 0.31. This, in turn, creates the possibility of producing concrete products and reinforced concrete structures that maintain high technological properties while possessing high strength, durability, and quality operational characteristics.

Results and Conclusions

The research conducted on the workability of the compositions revealed that chemical and mineral additives play a significant role in influencing the technological properties of fine-grained fiber concrete (FGFC) mixes.

Specifically:

- Although the addition of microsilica reduced the workability of the mixture, it improved physical-mechanical properties such as strength and density;

- Fly ash (zola), due to its moderate adsorption capacity and pozzolanic reaction, relatively reduced water demand and optimized workability;

- The incorporation of basalt fibers had minimal impact on water consumption but contributed to improving structural strength and crack resistance through reinforcement effects;

- The addition of the superplasticizer Poliplast SP-1 significantly enhanced the workability of the concrete mixture, reduced water consumption, and enabled the mixture to achieve superior technological characteristics.

According to the research results, a high-workability (P-4) mixture was developed using the composite composition 5 (microsilica, basalt fibers, and superplasticizer), enabling its effective application in densely reinforced structures. This expands future opportunities for producing construction materials that are high-strength, durable, and technologically efficient.

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