engineering proceedings

Proceedings

Study of Physical and Mechanical Properties of Fiber Concretes with Different Compositions †

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Abstract: The article touches upon the development of dispersed reinforced concrete components and the improvement of their physical and mechanical properties, which can be used in road and defense structures, bridges, and takeoff and landing zones. Multifunctional micro-reinforced fine-grained concrete compositions have been developed based on basalt fiber, where the limit of compression strength varies from 65.6 to 78.35 MPa, flexural strength from 6.4 to 9.1 MPa, and water permeability from 3.7 to 1.8%. Among the compositions of micro-reinforced concrete with basalt fiber, the best strength result was recorded in the case of 2% basalt fiber and 10% microsilica, with compression and flexural strengths of 78.35 and 9.1 MPa, respectively. The best water absorption result of 1.8% was obtained only with basalt fiber concrete when the fiber content was increased to 3.2%. As a result, water absorption was reduced by 62% compared to the initial concrete. The increases in flexural and compression strengths were 42.19% and 13.8%, respectively.

Keywords: basalt fiber; fine-grained fiber concrete; micro-reinforcement; physical and mechanical properties; mineral and chemical additives

1. Introduction

Modern construction demands strict requirements for the physical and mechanical properties of the concrete used: crack resistance, high resistance to dynamic strokes, and durability. Dispersed-reinforced concrete can fully meet the mentioned requirements, the application rates of which are currently increasing. In the West, this composite has proven itself for a long time [1–8], and is used in road and airport construction [9–13]. Among the materials used for dispersed-reinforced concrete, basalt fiber is singled out; the effectiveness of its use is determined by the availability and distribution of the raw material base necessary for its production, eco-friendly production, as well as high physical, mechanical, and operational properties. The technical challenges in basalt fiber uniform distribution in a concrete cement matrix and engineering methods for calculating fiber-concrete structures [14–18] contribute to the difficulties in using the mentioned material for dispersed reinforcement.

Fiber-reinforced concrete has limited use in our country. Meanwhile, the RA has a rich raw material base and extensive experience in basalt fiber production. It has been determined by theoretical and experimental studies [1, 4, 19–21], that concrete reinforced with basalt fibers has high values for physical and mechanical characteristics. We can increase cement activity by selecting the filler composition and grain size, enhancing the filler's physical and mechanical qualities, using chemical methods, and using other techniques to produce a high dynamic strength index.

However, the concrete composites produced by this method cannot meet the requirements for the safe operation of defensive structures when using modern striking methods,

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

which cause high exposure to the supporting and enclosing structures. In this regard, fiber concrete can be an effective material for defense structure construction, as it has a high potential for impact resistance [22–25].

In this research, basalt fibers were used due to the availability of raw materials and local production, and due to their properties, which include a significantly smaller fiber diameter (17 microns), which ensures adhesion with cement stone.

2. Materials and Methodology

2.1. Raw materials

The investigated fiber concrete was made using 42.5-grade Portland cement. The strength increase at the macro level was ensured by introducing basalt fibers with a diameter of 17 microns, a length of 10–12 mm, and a tensile strength of 2000 MPa.

The main physical, mechanical, and chemical characteristics of the above-mentioned Portland cement were determined according to GOST EN 196-1-2002, 196-2-2002, and 196-3-2002 standards, and the data are given in Tables 1 and 2.

Table 1. Physical and chemical characteristics of cement.

Characteristics						Unit		Indicators
Water consumption						%		31
Real density						g/cm3		3.1
Chemical composition (% by mass)								
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.i.	Free CaO	Insoluble residue
28.2	3.21	1.25	52.19	5.1	2.9	3.7	1.13	2.1

River sand with a grain size of 5...0.16 mm and a size modulus of M_K=3.1 was used as a fine aggregate. The main characteristics are presented in Table 2 (GOST 8735-88).

Table 2. Physical and chemical characteristics of river sand.

Bulk density				1525			kg/m^3		
Real density				2.49			g/cm^3		
Chemical composition (% by mass)									
SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O+K_2O	SO_3	Los in ign.
57,26	0,56	14,63	6,22	-	8,31	4,80	-	-	4,56

The characteristics of basalt fibers are shown in Table 3.

Table 3. Characteristics of basalt fiber and microsilica.

Fiber length	10...12	mm
Fiber diameter	17	μm
Specific surface area of microsilica	20	m2/g
Microsilica average grain size	0,1	μm

2.2. Specimen preparation

The fiber concrete mixture was prepared in an E-905 Matest-type mixer by adding pre-sieved and proportioned river sand and 42.5-grade Portland cement. After mixing the components, water and a chemical additive known as "Mapefluid N200" were added to improve the mixture's operating characteristics. Then, basalt fiber of 10–12 mm length and 17 μm in diameter was gradually added in small portions. When using a mineral additive, which was 10% by weight of Portland cement, it was pre-mixed with cement, after which the process continued in the same sequence. After homogenization, the mixtures were moulded into 40×40×160 mm moulds. After 24 hours, they were removed from the moulds and transferred to a cell (C 302-12 Matest type) for hardening under normal conditions (GOST EN 196-1, at a temperature of 20±10C in water). The samples' flexural and compressive strength limits were determined on Matest S337 and C089 compression machines according to standards.

2.3. Analytical methods

The water absorption of the samples was determined according to GOST 12730.3-2020 standard (Concrete. Method for determining water absorption).

The flexural strength (F) of 4x4x16sm specimens was tested by 50 kN Unitronic Compression testing machine within the limits of its max. 50kN capacity and standard test method for flexural strength of cement-based materials. Prism specimen was subjected to three-point bending at a loading rate of 0.05kN/s. The load is applied by hydraulic testing machine that is driven by a motor brushless with closed loop through optic encoder and controlled by a microprocessor. Stroke electric end switches are applied to the load piston to save the machine from accidental handlings.

Compressive strength (R_{com}) was determined for the specimen in accordance with EN 196-1 (Methods of Testing Cement Part 1: Determination of Strength). Compressive tests were carried out on an automatic testing machine (Concrete compression machine 2000 kN automatic, Servo-Plus Progress C089, Matest) with a loading rate of 0.6 kN/s at the age of 7 days and 28 days.

3. Results and discussion

3.1. Flexural and Compressive strength and Water absorption testing

Fiber-concrete compositions were made with 1.8...2.15% fiber content by cement mass, 1.17...1.23% superplasticizer, and a 0.379...0.395 w/c ratio (fig. 1, 2, 3).

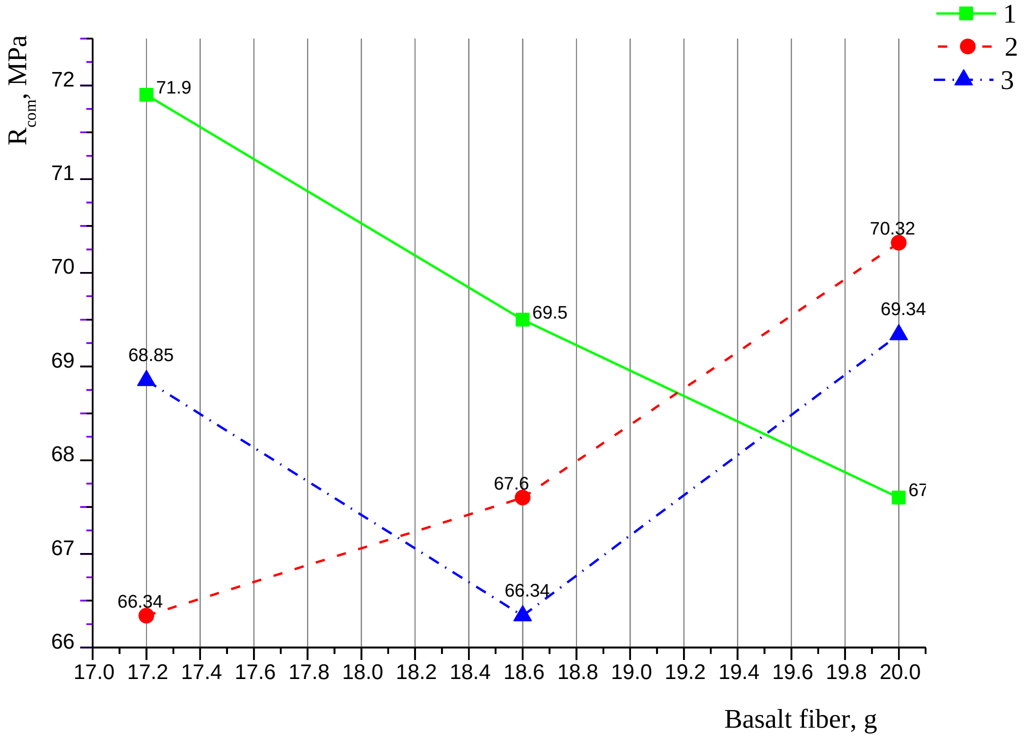

Figure 1. The relation between the compressive strength and the amount of basalt fiber at maximum (1), average (2), and minimum (3) values of superplasticizer and w/c.

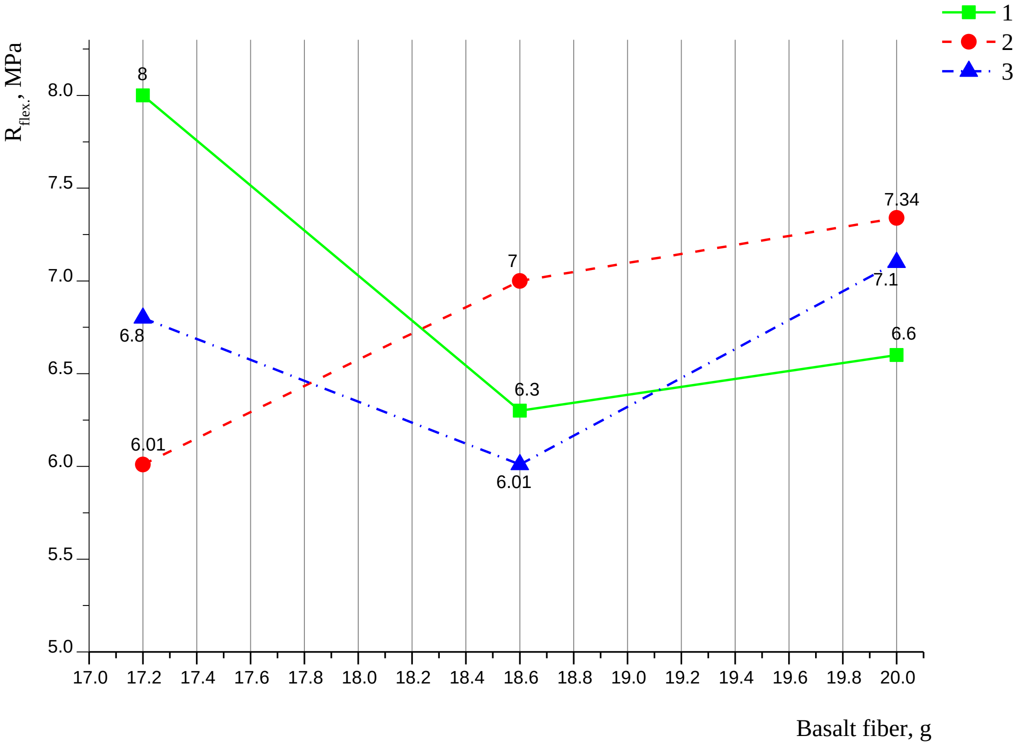

Figure 2. The relation between the flexural strength and the amount of basalt fiber at maximum (1), average (2), and minimum (3) values of superplasticizer and w/c.

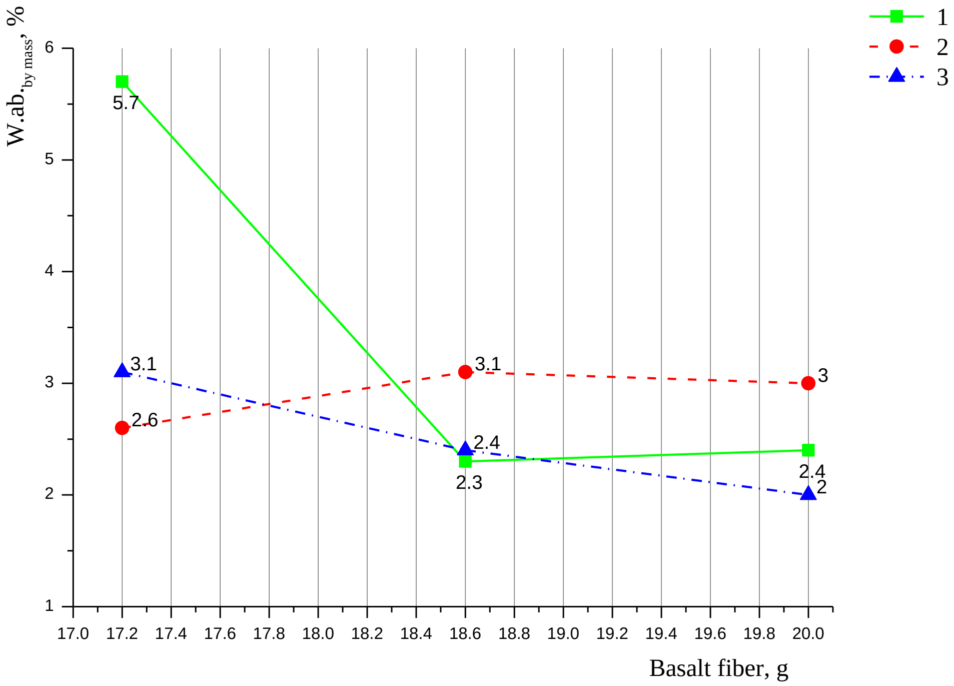

Figure 3. The relation of water absorption to the amount of basalt fiber at maximum (1), average (2) and minimum (3) values of superplasticizer and w/c.

For micro-reinforced and non-micro-reinforced concrete samples, with and without additives, the test results are presented in Table 1. By analyzing the test results, it was found that, during micro reinforcement, an increase in concrete's compressive strength by 9% and flexural strength by 14% was observed, compared to the initial concrete (composition 1). After introducing a superplasticizer into the concrete mixture, the compressive strength of the concrete increased by 6% and the flexural strength by 12.5%.

Table 4. The composition, physical and mechanical properties of the concrete mix.

№	**Consumption of materials in the concrete mixture, g**					**w/c**	**MPa $R_{com.}$**	**MPa $R_{f.}$**	**Water adsorption, %**
	Binder		**Super-plasticizer Mapefluid N200**	**River sand (Mk=3.1)**	**Basalt fiber**				
	Portland cement	**Micro-silica**							
1	930	-	-	2310	-	0,387	68,8	6,4	4,7
2	930	-	-	2310	18,6	0,387	74,9	7,3	3,7
3	930	-	11,2	2310	18,6	0,387	65,6	7,17	3,5
4	930	-	11,2	2310	-	0,387	72,8	7,2	4,0
5	837	93	-	2310	18,6	0,387	78,35	9,1	3,4
6	837	93	-	2310	-	0,387	70,5	6,6	2,4
7	930	-	-	2310	30	0,387	68,83	8,2	1,8

3.2. Discussion

By introducing an active pozzolanic component into the mortar, such as microsilica, it is possible to bind the $Ca(OH)_2$ generated by cement hydration and thereby reduce the decomposition of basalt fiber in the hardening cement. The 10% of the 930 g of Portland cement was replaced with microsilica. The test samples were prepared with pozzolanic Portland cement (the 930 g initial dosage of the binder was preserved). Meanwhile, the pozzolanic reaction of microsilica increases the hydration process of calcium silicate and causes a distinct change in porosity in the concrete structure, reducing the capillary porosity and increasing gel formation, as a result of which the concrete acquires two main properties: increased strength and increased impermeability.

As an active mineral additive, the positive effect of microsilica on the properties of concrete is shown in Fig. 4. The best results were obtained by adding 10% micro-silica to the 2% basalt fiber-reinforced concrete mix.

The best compressive and flexural strengths we reached by using microsilica-basalt fiber combination, which are 78.35 MPa and 9.1 MPa respectively. Compared to microsilica concrete, there are 38% increase in flexural and a 11.14% increase in compressive strengths. The best water absorption rate of 1.8% was obtained in the initial mix with 3.2% basalt fiber, providing a 62% reduction in water absorption.

4. Conclusion

Because RA has a rich raw material base and extensive experience in basalt fiber production, the objective was to develop micro-reinforced, fine-grained composite components with high physical and mechanical properties using local raw materials. For the problem solution, fine-grained dense fiber concretes were developed based on basalt fibers with a compressive strength of 78.35 MPa, a flexural strength of 9.1 MPa, and a water permeability of 1.8%.

If we choose concrete mixture without basalt fibers, the initial concrete mix containing 10% microsilica increased the compressive strength by 2.47% and the flexural strength by 3.13%, then the same concrete mixture, as a result of the introduction of basalt fibers, recorded an increase of 38% in flexural and 11.14% in compression strengths and an increase of 42.19 and 13.88% over the initial concrete.

Acknowledgments: The work was carried out within the framework of the Project no. 21DP-2F008 "Design and production of defensive structures based on new generation composite concretes with addition of basalt fibers and metal-carbon nanostructured additives".

All authors have read and agreed to the published version of the manuscript.

The authors declare no conflict of interest.

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