Influence of dispersed reinforcement on frost resistance of high-strength basalt concrete

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Abstract. This work is devoted to the study of the influence of various types of dispersed reinforcement of basalt fiber on increasing the frost resistance of high-strength modified basalt concrete. The article presents the results of experimental studies of one composition of coarse aggregate concrete modified with the admixture "Embelit 8-100" and three compositions of basalt fiber concrete. 3 types were considered as dispersed reinforcement: mono-reinforcement with basalt fiber of 24 mm length – soft fiber, mono-reinforcement with basalt micro-reinforcement of 25-40 mm length – stiff fiber, poly-reinforcement with a mixture of soft and stiff fiber in a ratio of 1:1. According to the test results, experimental values of physical and mechanical characteristics of coarse aggregate high-strength concrete and basalt fiber concrete with three types of dispersed reinforcement (at the age of 7, 14, 28 days) were determined: cube strength, concrete compressive strength class, elastic modulus, frost resistance grade concrete. The analysis of the effect of different types of dispersed reinforcement on increasing the strength and frost resistance of coarse aggregate basalt concrete modified with the admixture "Embelit 8-100" was also carried out. The conclusion is made about the prospects of using mono-reinforcement in the form of soft basalt fiber to increase the frost resistance of high-strength basalt concrete.
Keywords: dispersed reinforcement, mono-reinforcement, poly-reinforcement, admixture, fiber-reinforced concrete (FRC), basalt fiber, basalt micro-reinforcement, frost resistance

1 Introduction

High–strength concrete is one of the young and promising materials in the construction industry. It is used in the construction of bridges, roads, skyscrapers, subways and other critical buildings and structures due to its high characteristics (excellent machinability, good mechanical properties and durability compared to conventional concrete). However, some problems limit the use of high-strength concrete, especially in extreme conditions of the far north. Alternating freezing and thawing is the main cause of concrete destruction in cold climatic regions. The expansion of freezing water in the micropores of concrete stone leads

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to the formation of internal microcracks, which gradually expand as the freeze-thaw cycles increase, which seriously impairs the durability, mechanical properties and abrasion resistance of concrete [1-3]. In view of this, special requirements for durability and frost resistance are imposed on objects that are constantly exposed to low temperatures and operated both in the air and in contact with aggressive liquids.

Now many studies are aimed at the active introduction of high-strength concrete in construction [4, 5], standardization of the method of assessing the frost resistance of concrete [6], optimization of the ratio of raw materials in the production of high-strength concrete and prediction of the frost resistance of concrete [7-9]. In addition, many studies are being conducted to improve the durability and mechanical properties of concrete by including various types of fibers, mineral additives and industrial waste in their composition [10-15]. The frost resistance of concrete depends on various parameters: water-to-cementitious materials ratio [16], the porosity and degree of moisture saturation of concrete, the curing time of concrete [17], the amount of freezing water, the freezing rate and the type of filler [16].

Now the use of basalt in the construction industry is rapidly developing as a reinforcing material with high resistance to aggressive environments and strength (compared with fiberglass) [18-21]. This work is devoted to the study of the influence of various types of dispersed reinforcement from basalt fiber on increasing the frost resistance of high-strength modified basalt concrete due to the improvement of new materials with high strength characteristics and the emergence of the need for construction in extreme climatic conditions.

2 Materials and Methods of Research

This work is devoted to experimental studies of high-strength concretes containing the complex organic-mineral admixture "Embelit 8-100" and basalt concretes with different types of reinforcement with soft basalt fiber (Fig. 1, a) and stiff basalt fiber – basalt micro-reinforcement (Fig. 1, b). Experimental studies were conducted in the laboratory "Building Materials and Structures" of the Department of Civil Engineering of RUDN University.

The complex organic-mineral admixture "Embelit 8-100" with expanding components produced by LLC "Enterprise Master Concrete" was used in order to improve the physical and mechanical characteristics of concrete. The admixture "Embelit 8-100" is a powdered multicomponent product in which the content of the plasticizer C-3 is 8%, the content of the expanding component in the mineral part of the modifier is 90-100%.

Wet chopped basalt fiber BS16-24-76 manufactured by LLC "Alliance-Construction Technologies" with a fiber length of 24 mm was used as soft fiber, the diameter of monofilaments is 13-17 microns, the type of oiling is water-compatible (it is necessary for basalt fiber to easily disintegrate into monofilaments in an aqueous environment and to be easily distributed in the concrete matrix).

Basalt micro-reinforcement MKA 1.5-4 was used as a stiff fiber. The length of the fiber is 15-40 mm.

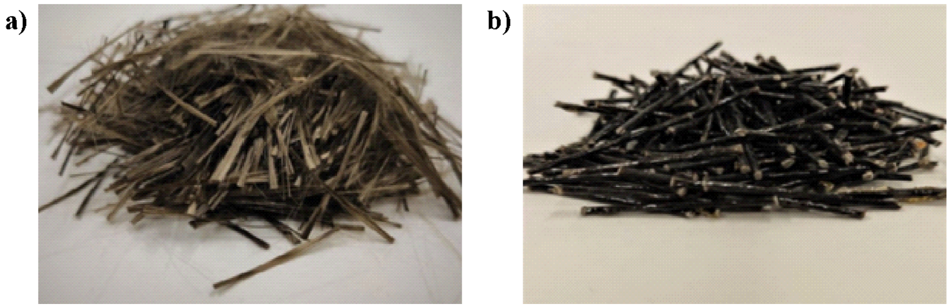


Fig. 1. Dispersed reinforcement: a – basalt fiber BS16-24-76, b – basalt micro-reinforcement MKA 1.5-4.

Laboratory experiment was conducted according to the Interstate Codes for CIS (GOST 10180-2012, 2013; GOST 24452-80, 2005; GOST 53231-2008, 2009; GOST 31914-2012, 2014; GOST 10060.3-95, 2005; GOST 10060.0-2012, 2012; GOST 17624-2012).

The study was carried out with the following concrete composition: binder – Portland cement type I = 700 kg/m^3; coarse aggregate – crushed stone = 524 kg/m^3; concrete admixture "Embelit 8-100" = 56 kg/m^3; river sand with a grain size of 2.7 = 830 kg/m^3 as a fine aggregate; water = 283 l/m^3.

The percentage of basalt fiber reinforcement was assumed to be equal to 2% of the cement mass for basalt concrete compositions.

The studies were carried out on 4 set of samples (Table 1). The test samples were made in the form of cubes with dimensions of 100×100×100 mm. Compressive strength tests were carried out during the curing period for 7, 14, 28 days. The number of samples for determining frost resistance for each set of samples was assumed to be 3, for determining compressive strength for the set C1.00 – 12 samples, for all other sets – 18 samples each in accordance with the experimental plan (Table 1).

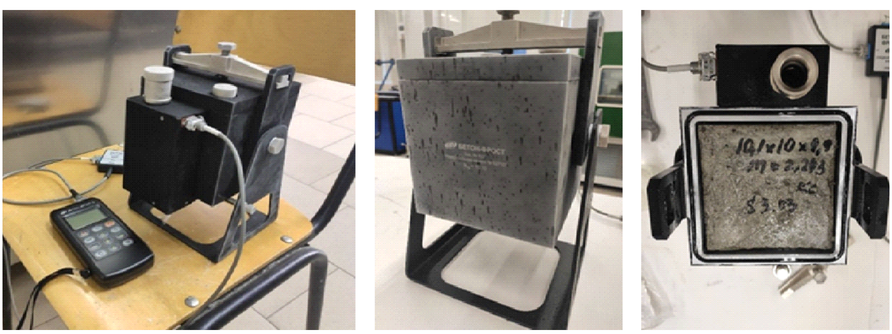
Table 1. Sets of test concrete samples.

Set number	Description	Fiber BS16-24-76, kg	Micro-reinforcement, MKA 1.5-4, kg	Number of samples tested for compression strength	Number of samples tested for frost resistance	Total number of samples tested in the set
C1.00	Concrete without reinforcement (control sample)	-	-	12	3	15
C2.00	Basalt reinforced concrete – poly-reinforcement with soft fiber BS16-24-76 (50%) and micro-reinforcement MKA 1.5-4 (50%)	0.07	0.07	18	3	21

C3.00	Basalt reinforced concrete – mono-reinforcement with micro-reinforcement MKA 1.5-4	-	0.14	18	3	21
C4.00	Basalt reinforced concrete – mono-reinforcement with soft fiber BS16-24-76	0.14	-	18	3	21

The following equipment was used for experimental studies: hydraulic press "Matest CPC040PN167", freezer CM 5/100-80, volumetric deformation measuring device "CONCRETE-FROST", ultrasound device "Pulsar-1".

The frost resistance of the samples was determined by the accelerated dilatometry with a single freezing of water-saturated samples-cubes with dimensions of 100×100×100 mm, using the volumetric deformation measuring device "CONCRETE-FROST" (Fig. 2) in



according to GOST 10060.3-95.

Fig. 2. Volumetric deformation measuring device "CONCRETE-FROST".

3 Results

4 sets of test samples with dimensions of 100×100×100 mm with different types of dispersed reinforcement were tested in order to determine the effect of dispersed reinforcement in the form of basalt fiber on the strength and frost resistance of concrete modified with the expanding admixture "Embelit 8-100" (Table 1):

4 series of test samples with dimensions of 100×100×100 mm with different types of dispersed reinforcement were tested (Table 1) in order to determine the effect of dispersed reinforcement in the form of basalt fiber on the strength and frost resistance of concretes modified with the expanding admixture "Embelit 8-100":

1. Samples of the C1.00 set are made of concrete without reinforcement (control sample). The test samples of this set were designated as C1.01, C1.02, C1.03, C1.04. 12 test samples were tested for strength, 3 samples for frost resistance;

2. Samples of the C2.00 set are made of basalt concrete with a type of poly-reinforcement with soft fiber BS16-24-76 (50%) and rigid fiber micro-reinforcement MKA 1.5-4 mm (50%). The test samples of this set were designated as C2.01, C2.02, C2.03, C2.04, C2.05, C2.06. 18 test samples were tested for strength, 3 samples for frost resistance;

3. Samples of the C3.00 set are made of basalt concrete with the type of mono-reinforcement with rigid fiber – basalt micro-reinforcement MKA 1.5-4 mm. The test samples of this set were designated as C3.01, C3.02, C3.03, C3.04, C3.05, C3.06. 18 test samples were tested for strength, 3 samples for frost resistance;

4. Samples of the C4.00 set are made of basalt concrete with a type of mono-reinforcement with soft fiber BS16-24-76. The test samples of this set were designated as C4.01, C4.02, C4.03, C4.04, C4.05, C4.06. 18 test samples were tested for strength, 3 samples for frost resistance.

The results of study for all four sets of tested samples to determine compressive strength are presented in Table 2 and Figures 3 and 4. The results of study to determine frost resistance are shown in Table 3 and Figure 5.

Table 2. Compression strength test results.

Sample numbe r	**Den-s ity, ρ, kg/m^3**	**Modu-l us of elasti-ci ty, *E*, GPa**	**Compres -sion strength, 7 days, *R7*, MPa**	**Compres -sion strength, *R14*, MPa**	**Compres -sion strength, *R28*, MPa**	**Average compres-sion strength, *R28*, MPa**	**Compres -sion strength grade of concrete, B, MPa**
C1.01	2210	38.90	28.40	51.20	58.90	60.17	C57
C1.02	2170	38.50	30.40	52.39	56.80		
C1.03	2180	38.20	31.60	54.95	63.20		
C1.04	2200	38.00	29.20	50.78	58.40		
C2.01	2230	24.00	30.01	54.02	62.01	57.53	C55
C2.02	2230	21.00	25.68	46.53	51.36		
C2.03	2280	21.00	31.60	50.17	55.19		
C2.04	2310	23.00	27.60	52.13	56.34		
C2.05	2170	23.00	27.81	50.56	55.61		
C2.06	2325	21.50	31.80	50.32	56.14		
C3.01	2280	24.50	31.20	56.26	64.08	58.86	C56
C3.02	2300	21.00	33.45	43.48	62.12		
C3.03	2240	21.00	21.46	46.52	52.92		
C3.04	2330	19.00	27.57	47.93	55.13		
C3.05	2210	22.00	27.06	47.06	54.12		
C3.06	2320	21.00	24.29	42.24	48.57		
C4.01	2200	22.00	27.30	49.10	50.70	50.70	C48
C4.02	2180	23.00	25.53	48.03	48.51		
C4.03	2250	21.00	22.87	42.03	43.46		
C4.04	2240	21.00	26.88	50.57	51.08		
C4.05	2250	19.00	24.74	44.10	44.53		
C4.06	2200	22.00	27.30	49.10	52.50		

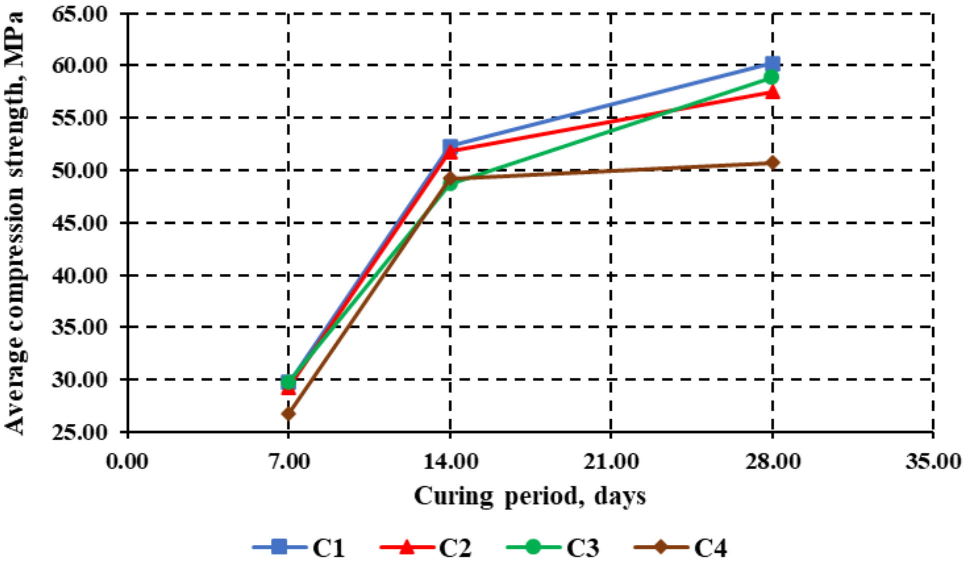


Fig. 3. Compression strength test results.

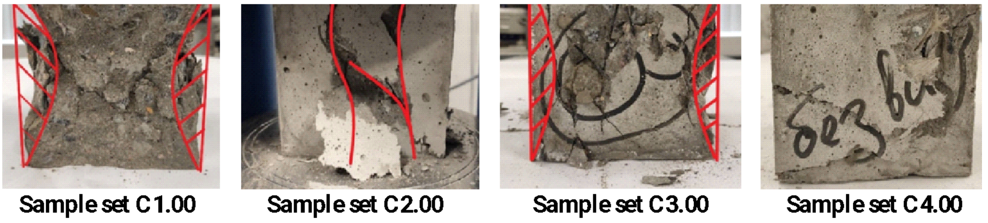


Fig. 4. Fracture pattern of samples under compression.

Table 3. Frost resistance test results.

Set number	Dimensions, mm	Weight, kg		Weight increase of water-saturated samples, %	Value of the coefficient of frost resistance	Frost resistance grade of concrete, F
		Basic	Water-saturated		θ×10^{-3}	
C1.00	100×100×100	2.307	2.324	0.74	0.6374	F200
C2.00	100×100×100	2.286	2.371	3.72	0.5270	F200
C3.00	100×100×100	2.243	2.360	5.22	0.7915	F200
C4.00	100×100×100	2.228	2.300	3.23	0.3583	F300

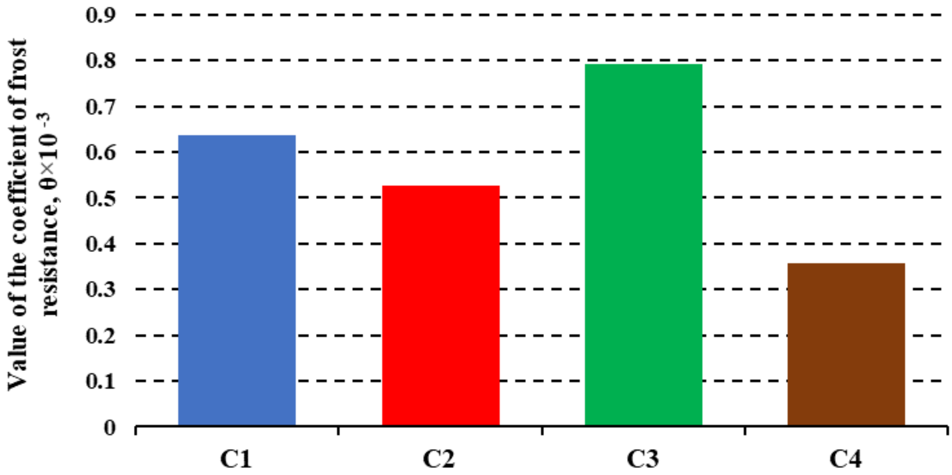


Fig. 5. Frost resistance test results.

4 Discussion

4.1 The effect of dispersed reinforcement on the change in the strength and deformation characteristics of concrete

The following patterns can be seen by analysing the results of tests to determine the compressive strength: the presence of dispersed reinforcement changes the fracture pattern of samples. The mechanisms of destruction of samples are shown in Fig. 4.

The brittle nature of destruction is inherent for set of samples C1.00 without fiber. Angular cracks formed, which opened and destroyed the concrete sample as the load increased during the test.

The destruction is brittle for the poly-reinforced set of samples C2.00. However, vertical cracks parallel to each other are observed. It indicates the occurrence of plastic flow deformations in the fiber-concrete sample due to the inclusion of basalt fibers (both soft fiber and rigid micro-reinforcement) in addition to the appearance of angular cracks as in the control sample.

The load curve and the dynamics of crack development the set of samples C3.00 with mono-reinforcement of rigid fiber clearly indicates the brittle fracture pattern. The fracture pattern is similar to the fracture pattern the set of samples C1.00. However, there is a decrease in the angle of opening of angular cracks, which indicates an increase in the strength characteristics of fiber concrete.

The destruction of fiber concrete samples with soft fiber of the C4.00 set occurs without obvious signs of destruction, which indicates a viscous non-dangerous fracture pattern.

Thus, the most advantageous option of dispersed reinforcement from the point of view of the work of concrete in the structure is the option of mono-reinforcement with soft basalt fiber. The fracture pattern of destruction has changed from brittle to viscous only for set of samples C4.00.

It can be noted that the presence of dispersed reinforcement led to a decrease in compressive strength at the design age of 28 days analyzing the test results presented in Table 2: for samples of the C2.00 set – by 3.5%, the C3.00 set – by 1.75%, the C4.00 set – by 15%.

4.2 The effects of dispersed reinforcement on the frost resistance of concrete

Different types of dispersed reinforcement considered in this study affect the frost resistance of concrete to varying degrees as can be seen from Table 3 and Table 5. The addition of fiber into the composition of concrete increases the porosity of concrete and leads to an increase in the amount of absorbed water during water saturation of samples. The increase in the mass of water-saturated samples differs for different sets: fibro concrete samples of the C 4.00 set have the smallest increase in mass compared to other fibro concrete samples of the C2.00 and C3.00 sets.

According to the indicator of frost resistance – Value of the coefficient of frost resistance (Table 3) fiber concrete samples showed changes compared to control samples without fiber of the C1.00 set:

- samples of the C2.00 set: decrease in the value of the indicator by 17% (indicates an increase in frost resistance);
- samples of the C3.00 set: increase in the value of the indicator by 24.17% (indicates a decrease in frost resistance);
- samples of the C4.00 set: decrease in the value of the indicator by 43.78% (indicates an increase in frost resistance).

These experimental results describe the operation of soft basalt fiber BS16-12-76. Fibers in the body of concrete exhibit a hydrating effect, reduce the amount of water in the pores of fiber concrete, resulting in reduced volumetric deformations inside the body of the test sample, which leads to an increase in the number of freezing and thawing cycles.

The most advantageous type of dispersed reinforcement to increase the frost resistance of concrete was the type using mono-reinforcement with soft basalt fiber BS16-24-76 set C4.00. The most unfavorable type was the type of mono-reinforcement with rigid fiber – basalt micro-reinforcement MKA 1.5-4 mm set C 3.00. The intermediate position is occupied by the type of poly-reinforcement with soft fiber BS16-24-76 (50%) and rigid fiber micro-reinforcement MKA 1.5-4 mm (50%) of the C2.00 set.

5 Conclusions

Based on the conducted studies of samples with different types of dispersed reinforcement with basalt fiber, the following conclusions can be drawn:

1. The most optimal type of dispersed reinforcement for high-strength coarse-grained concrete using the admixture "Embelit 8-100" is a type of mono-reinforcement with soft basalt fiber BS16-24-76, as a percentage of 2% by weight of cement. The samples of this set are characterized by a non-dangerous viscous fracture pattern, and there is also a significant increase in the frost resistance of these basalt concrete samples compared to control samples without fiber. The addition of dispersed reinforcement in the form of soft fiber into the concrete composition made it possible to increase the frost resistance grade of concrete from F200 to F300;
2. The presence of dispersed reinforcement leads to a decrease in compressive strength. Depending on the type of dispersed reinforcement, the compressive strength decreases to varying degrees compared to samples without fiber: for samples mono-reinforced with micro-reinforcement (stiff fiber) by 1.75%, mono-reinforced with soft fiber – by 15%, poly-reinforced with micro-reinforcement and soft fiber – by 3.5%;
3. Dispersed mono-reinforcement of modified coarse-grained concrete with stiff fiber in the form of micro-reinforcement MKA 1.5-4 mm, as well as poly-reinforcement with soft fiber BS16-24-76 (50%) and stiff fiber micro-reinforcement MKA 1.5-4 mm (50%)

does not increase the frost resistance of concrete, the fracture pattern of samples under compression remains brittle and dangerous;

4. Further studies aimed at improving the operational properties of high-strength coarse-grained modified concretes should be conducted for fiber concrete compositions with soft basalt fiber, combining poly-reinforcement options with different lengths of fibers.

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