Efficient technology of basalt fiber-reinforced concrete for use in monolithic construction

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Abstract. The development and production of basalt fiber-reinforced concrete have been carried out on a large scale recently, driven by the efficiency of using basalt fibers as a micro-reinforcing additive in cement-based concretes. For the successful application of basalt fiber-reinforced concrete in monolithic construction, there must be an accessible and efficient technology for commonly used concrete compositions. This paper presents the results of an analysis of foreign literature sources, which conclude that new experimental research is needed to improve the compositions and technology of basalt fiber-reinforced concrete using local construction materials. The article provides the results of such research and recommendations for an efficient basalt fiber-reinforced concrete technology.The conducted research has shown that introducing basalt fiber into the composition of heavy concrete according to the proposed technology contributes to a 15% increase in compressive strength compared to similar concrete without micro-reinforcement. Additionally, it is possible to save up to 10% or more on cement consumption.

1 Introduction

Based on the results of numerous experimental and theoretical studies [1-4], it is known that the process of concrete failure under load begins with cracks at the interfaces between cement paste and coarse aggregates. These cracks primarily develop along compressive stresses but may have some deviation due to transverse expansion deformations. The failure of a compressible specimen occurs due to the rupture of concrete in the transverse direction, initially microcracks of detachment appear, which subsequently, with increasing load, merge and form visible cracks leading to the destruction of the concrete specimen. The components of concrete in its structure are randomly arranged, without a specific pattern, leading to variations in strength properties. The magnitude of this strength largely depends on various technological factors, among which the ratio of coarse and fine aggregates is of significant importance. An analysis of this ratio for optimal compositions in heavy concretes shows that it varies from 1.5 to 2.5 times. Moreover, as the cement content in the concrete composition increases, the sand consumption usually decreases proportionally. In such cases, the specific content of cement paste tends to increase, and consequently, the sand content in the aggregate mixture decreases. This approach is typical for heavy concretes commonly used in factory

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conditions for the production of precast reinforced concrete structures. However, this adjustment of heavy concrete composition, in our view, is not suitable for basalt fiber-reinforced concrete mixes. This is because it does not create conditions for the quality separation of fiber bundles into individual units and their uniform distribution throughout the volume during the mixing of concrete components. Therefore, a more accessible technology is needed, which can be based on changing the preparation method of such concrete mixes or using nanotechnology. It is worth noting the order of preparing a concrete mixture according to the generally accepted technology, which is described below.

The procedure for preparing a concrete mixture according to the usual technology can be as follows:

1. Add water to the drum.
2. Add cement, then sand.
3. Mix for at least 3 minutes.
4. If necessary, add plasticizers or other additives.
5. Add coarse aggregates and mix the components for 10 minutes.

An important aspect in preparing a concrete mixture according to this procedure, and in general, is the correct determination of the ratio of concrete components, as the quality and strength of concrete largely depend on this. When assessing the quality of a concrete mixture, attention is usually paid to the following indicators:

- Homogeneity of the mixture (if lumps or settling of aggregates are observed, it indicates incorrect and improperly determined proportions of components).
- Appearance of "cement milk" (as a result of vibrating the concrete mixture, a white liquid appears on the surface). This indicates that the concrete composition is properly selected. If "cement milk" appears before vibrating, it means there is a lack of coarse aggregates or sand.
- Water on the surface of the concrete (excessive water consumption, and after 3-5 days of finishing vibration, cracks appear on the surface due to plastic and moisture shrinkage of the concrete).

For fibrous concretes, the above-described concrete mixture preparation technology is used with some adjustments. The components of fibrous concrete (binding fillers and dispersed reinforcement) are usually mixed in two stages using forced-action concrete mixers. In the first stage, the concrete components in dry form are mixed for at least 3 minutes, and in the second stage, after adding water, they are mixed for at least 3 minutes as well. According to the authors [5], such a regime allows basalt fiber bundles to separate into individual units. The use of basalt fibers according to this concrete mixture preparation technology, at its optimal content, according to the author's data, allows increasing the tensile strength of concrete in bending by up to 70% or more compared to similar properties of concrete without dispersed reinforcement.

Aim of the Study: The goal of this study is to conduct experimental and theoretical research to develop proposals for an efficient technology for basalt fiber-reinforced concrete mix based on local construction materials for monolithic construction.

2 Materials and Testing Method

In this study, Portland cement of grade M 400 PO "Ahangarancement" was used, which complies with the requirements of GOST 10178-85 "Portland Cement and Slag Portland Cement. Technical Conditions." According to the manufacturer, the normal density of the cement paste is 27%, specific surface area is 3500 cm2/g, and the cement's strength activity on the test day is 38.5 MPa.

Coarse aggregates for concrete mix preparation were granite gravel with particle sizes ranging from 5 to 20 mm from Kuylyuksky quarry, meeting the requirements of GOST 10260 [6].

Fine aggregates used in the study were river quartz sand from Kuylyuksky quarry, complying with GOST 8736 [7].

Basalt fiber consists of segments of complex basalt fiber of a specified length in the form of scattered monofilaments. The basalt fiber used in the study was produced by "MEGA INVEST INDUSTRIAL." Basalt fiber has the following technical characteristics: color - bronze; density - 2.8 g/cm3; diameter of individual filaments - 13-20 μm; fiber lengths: 5, 10, 15, and 20 mm; operating temperature from -260 to +700°C; melting temperature - 1450°C; tensile strength - 45-55 GPa/tex; resistant to acids and alkalis.

3 Discussion and Proposals for Basalt Fiber-Reinforced Concrete Technology

The properties of basalt fiber provide high performance in concrete when used, as it modifies the concrete matrix and imparts special properties to it, making it resistant to various aggressive influences.

When preparing fibrous concrete mix, the fiber is introduced during the production of the concrete mix, where it serves as a reinforcing component, ensuring compatibility with all chemical additives and rapid distribution of fibers throughout the mix without clumping [5,9,10]. How this technology modifies bundles of basalt fibers into individual fibers is not entirely clear. The fact is that when basalt fiber is added (see Figure 1)

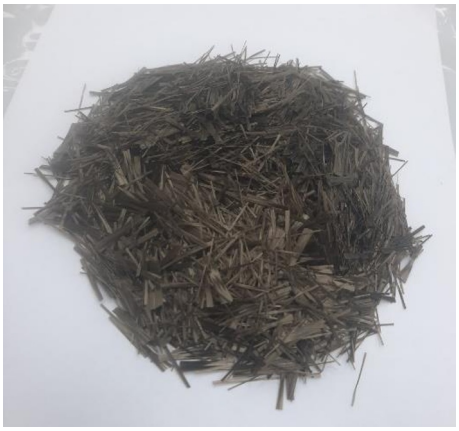

Fig. 1. Basalt fibers used in the experiments.

in an already practically prepared concrete mix, there are no conditions for its splitting into individual units because the fibers in their initial form will start to adhere to the cement-sand mixture and form clumps. Therefore, to split bundles of basalt fibers, mechanical or other external forces are necessary. In this process, bundles of basalt fibers should split at least by 70-80% without compromising the properties of the fibers. It can be expected that the surface and shape of the fibers will not be significantly deformed by mechanical actions, which will contribute to their uniform dispersion and bonding with the cement paste. After analyzing existing technologies for preparing basalt fiber-reinforced concrete mix, some conclusions can be drawn: it is recommended to mix basalt fiber only during the preparation of concrete mix in forced-action mixers, as there is no way to control the splitting and dispersion of fiber bundles that will initially be present together with all concrete components as a separate constituent. As evident from the analysis above, it is most likely necessary to change the composition of the basalt fiber-reinforced concrete itself by adjusting the proportion of coarse

aggregates in the aggregate mixture, reducing their consumption, and consequently increasing the share of sand. The composition calculation is performed as for ordinary heavy concrete with some adjustments, introducing a reducing coefficient of 0.85 for the consumption of coarse aggregates and compensating for their volume by increasing the consumption with an enhancing coefficient of 1.2 for the calculated values of these parameters. Unlike traditional concrete, the structure of basalt fiber-reinforced concrete allows for the most complete utilization of the intergranular void volume of the coarse aggregates to achieve uniform distribution of basalt fibers throughout the volume of the cement-sand mortar in concrete. In this process, the efficiency of basalt fiber-reinforced concrete compositions will be determined by the selection of the optimal grain composition of the aggregates, ensuring minimal voids due to the dense arrangement of fibers in the cement-sand mortar.

4 Results of the Study

When selecting the concrete composition, two main assumptions were based on the characteristics of heavy concrete based on Portland cement. First, it aims to maximize the strength of the cement-sand mortar while minimizing the consumption of coarse aggregates. This is based on the expectation that after introducing basalt fiber, the strength of the mortar will increase significantly, ensuring good adhesion (bonding) with coarse aggregates and the required reinforcement effect without compromising the technology of basalt fiber-reinforced concrete. The second condition is to provide the necessary workability of the basalt fiber-reinforced concrete mix at different commonly used binder consumptions (350-550 kg/m3) and water-cement ratios, with an optimal consumption of aggregates. This condition is determined by both technology and the expected strength of the concrete. Furthermore, the recommended technology for preparing basalt fiber-reinforced concrete mix should be based on the use of existing mixing equipment for mixing a five-component concrete composition. For this purpose, a gravity mixer was used. Gravity mixers are periodic-action drum-type machines for batch mixing of concrete components in a rotating drum with fixed blades inside. Mixing of the concrete mix in such mixers is achieved through the action of gravity forces. The blades, during rotation, pick up, lift, and then drop the mix streams downwards. The rotation frequency is 20 rpm. The preparation of basalt fiber-reinforced concrete mix was carried out in a laboratory mixer of a similar type. In this process, two variants of the sequence for loading concrete components were considered, different from other technologies of such concretes.

After testing the existing and proposed technology for preparing basalt fiber-reinforced concrete mix, it was concluded that the best method involves the pre-separate loading of 50% of the aggregate with fiber, introduced in 3-4 portions. Another method is initially loading 50% of the aggregate plus 50% of the sand and introducing basalt fiber.

The first method involves loading the necessary amount of basalt fiber into the mixer drum after loading 50% of the aggregate, and mixing them together for 3-5 minutes. Then, the remaining part of the aggregate, sand, water, and cement are added to the mixer. Mixing continues until the desired consistency is achieved (approximately 5-7 minutes).

The second method involves loading the necessary amount of basalt fiber into the mixer drum after loading 50% of the aggregate and 50% of the sand, and mixing them together for at least 5 minutes. Then, the remaining portions of the aggregate, sand, water, and cement are added to the mixer. Mixing continues until the desired consistency is achieved (approximately 5-7 minutes). This process involves a two-stage modification of basalt fibers. The state and appearance of basalt fiber-reinforced concrete mixes prepared using the above-described technology are shown in Figure 2.

Fig. 2. View of basalt-fiber concrete mix after discharge from the mixer. (a) - using the first method; (b) - the same, using the second method.

From these mixes, concrete cubes with a side length of 10 cm were prepared, which were tested for compression in the MIG-1000 hydraulic press [8]. The composition of the concrete was as follows: cement - 425 kg/m³; granite gravel, fraction 5-20 mm - 950 kg/m³; quartz sand - 815 kg/m³; water - 210 liters/m³; basalt fiber 1% by mass of cement. Negative phenomena were not observed during the preparation of cube specimens. The test results are presented in the table 1.

Table. Changes in strength under all comparable test conditions.

Preparation Method	The age of concrete at the time of testing, days	Concrete strength without additives, MPa	Strength of basalt-fiber-reinforced concrete, MPa	Increase in strength, %
According to Option I	7	22,6	25,8	14
	14	26,1	30,2	15,8
	28	30,2	34,8	15,2
According to Option II	7	22,6	26,4	16,8
	14	26,1	31,0	18,7
	28	30,2	34,2	13,2

As can be seen from the data in the table, under all comparable test conditions, there is an increase in the strength of basalt-fiber concrete (on average by 15%) compared to the strength of concrete of similar compositions without basalt fibers. The increase in strength is directly related to the introduction of basalt fibers into the composition of the concrete, which leads to an improvement in its structure during the hydration of cement and the setting of concrete. Technological recommendations have been developed that allow for further improvement of the compositions of other concretes and the development of the production of basalt-fiber concrete based on local materials. Currently, work is underway to confirm the results of laboratory studies in industrial conditions.

5 Conclusions

- one of the ways to improve the strength and durability characteristics of concrete is the introduction of basalt fibers into its composition. Currently, such concretes based on cement binders have limited areas of application in load-bearing structures, despite their technical advantages;
- compositions and technology for obtaining basalt-fiber concrete mixtures have been developed, which improve the properties of such concretes due to a more uniform distribution of fibers throughout the volume of the concrete;

- the selection of compositions of basalt-fiber concrete with commonly used cement consumption should be based on the selection of concrete compositions calculated by the calculation-experimental method based on absolute volumes, with a reduction in the consumption of coarse aggregate and the adjustment of sand consumption. At the same time, its consumption should not exceed the consumption of coarse aggregate;
- an effective technology for basalt-fiber concrete should be based on the splitting of basalt fibers at the initial stage of mixture preparation by mixing with half of the coarse aggregate (the first method) or with half of the coarse aggregate and half of the sand taken together (the second method). With this technology, it will be possible to achieve the maximum splitting of basalt fibers and their uniform distribution;
- the strength of basalt-fiber concrete specimens under compression, manufactured according to the recommended technology with a content of basalt fiber of 1%, results in an increase in the corresponding characteristic by 15% compared to the composition without the additive;
- the technical and technological advantages inherent in basalt-fiber concrete provide a basis to continue research with the aim of using basalt fiber for reinforcement in load-bearing concrete and reinforced concrete structures.

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