Influence Of Basalt Fibers On The Strength Of Heavyweight Concrete

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Abstract

The use of basalt fibers in concrete should be expected to increase its resistance to short-term loads. However, this assumption is not supported by the results of large-scale experimental and theoretical studies. We believe the answer to this question can be found by analyzing the fundamentals of basalt fiber-reinforced concrete strength. This article focuses on the impact of randomly distributed basalt fibers and concrete composition on its strength properties. Results on this issue were obtained by determining the optimal composition and studying its strength.

Keywords: Basalt fiber-reinforced concrete, strength, composition, dependence, result, analysis, indicator, parameter, crack.

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1. Introduction

One of the methods for increasing the strength of concrete is dispersed reinforcement using basalt fibers. Currently, this method is considered promising for application in precast and monolithic reinforced concrete structures, as the strength of dispersed reinforced concrete is 20–25% higher than that of concrete without additives. The reasons for this are currently confirmed by the results of scientific and experimental research. Concrete dispersed with basalt fibers is considered effective for use in structures subject to high crack resistance requirements, impact loads, and variable loads. The main reasons for this are the specific properties of basalt fibers, such as a tensile strength of 3500 MPa, an elastic modulus of 80 GPa, and an elongation of 2.0–4.5%. Based on the objectives of this study, the structural features of heavyweight concretes without additives and with dispersed reinforcement were analyzed. To determine their actual deformation under short-term compressive load, longitudinal and transverse deformations of the samples were recorded during testing. As a result, it was assumed that a damping process might occur.

2. Results

According to the general definition, damping is understood as the prevention of vibrations or absorption of deformations occurring in various systems, devices, and technical mechanisms. The main indicator in this case is the damping coefficient value. Based on this definition, an attempt was made to theoretically link these concepts to the analysis of basalt fiber-reinforced concrete's resistance to load impact. For composite and structural materials like concrete, the application of this indicator is possible by expressing it through strength characteristics, since the addition of various active additives or fibers as dispersed reinforcement has a positive effect on increasing strength. For example, experimental results have established that adding an optimal amount of basalt fibers to concrete can increase its cubic strength by 15–20%. However, experiments have also established that the prismatic strength of samples made from a basalt fiber-reinforced concrete mix of the same composition can exceed the prismatic strength of ordinary concrete samples by 25–50% (see table). The primary reason for this is considered to be the sample shape (cube or prism), but the main explanation lies in the positive influence of basalt fibers on the concrete matrix: the strength of the mixture of cement + sand + basalt fiber increases sharply. Under external load, such a system allows for the effective utilization of the coarse aggregate's strength due to the increase in the overall matrix strength. As noted above, in our opinion, damping processes occur, meaning basalt fibers act as "shock absorbers" and participate in bearing external loads (which can be considered an adaptation). It is logical to evaluate this positive phenomenon through the damping coefficient. For this purpose, it is advisable to determine the ratio of the prismatic strength of basalt fiber-reinforced concrete to the prismatic strength of concrete without fibers, as this indicator most objectively reflects the real effect.

During the testing of concrete samples, with increasing load, stress concentrations arise within them, where cracks form, followed by a process of their development [1]. These phenomena are related to the stress levels: $\sigma_b = R_b$; $R_b < \sigma_b < R_{max}$ ва $\sigma = R_{max}$. The values of these parameters, in turn, change depending on the strength and type of concrete, which is confirmed by experimental studies [1,2]. As evidence, one can cite the different nature of the "stress-strain" diagrams during concrete testing. For structural concretes, including basalt fiber-reinforced concrete, the total deformation consists of the elastic deformation from the initial section of the "σ–ε" diagram, the short-term creep deformation of the concrete, as well as plastic deformations associated with crack formation under high stress. Depending on the magnitude of these deformations, the nature of the "σ–ε" diagram changes. This is also observed in the results of the conducted research (see figure).

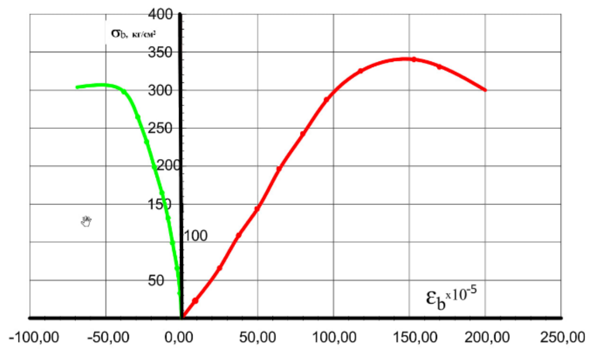

Figure. Stress-strain diagram of basalt fiber-reinforced concrete under compression.

The experimental deformation diagrams constructed from the test results confirm the stated points. According to them, for basalt fiber-reinforced concrete, the change in this diagram is linear up to 50–60% of its strength, whereas for concrete samples without additives, this level of linearity is significantly lower. This confirms that the elastic deformations of basalt fiber-reinforced concrete are higher compared to heavyweight concrete. Furthermore, the loading process shows that the microcrack initiation parameter(R^o_{crc}) is higher for basalt fiber-reinforced concrete. Accordingly, a higher value of the microcrack development parameter (R^{v}_{crc})) can be expected, meaning plastic deformations will also be higher.

To determine the strength effectiveness coefficient of basalt fiber-reinforced concrete, the cube strengths are first established, and then the obtained result is multiplied by the prismatic strength enhancement coefficient:

$$D_k = k \cdot \frac{R_b}{R_o}$$

where:

R_b —cube compressive strength of basalt fiber-reinforced concrete, MPa;

R_o —cube compressive strength of plain concrete, MPa;

k = 1.25 — proposed value of the additional coefficient introduced for determining the actual strength.

This additional coefficient, in our opinion, can be applied not only to basalt fiber-reinforced concrete but also to other types of fiber-reinforced concrete to assess their strength efficiency. To achieve this, it is necessary to conduct new experiments and analyze their results in a similar manner.

The proposed method can be used in cases where it is not possible to experimentally determine the prism strength of basalt fiber-reinforced concrete. In laboratories equipped with the necessary conditions, it can be determined directly.

Thus, it can be concluded that the damping coefficient characterizes the effectiveness of interaction between basalt fibers and the concrete matrix. This is confirmed by the experimental results presented in the table.

Results of comparison of prismatic strength of concretes.

Table.

Concrete type (C = 425 kg/m³)		Attitude R_{bf}/R_{bo}	Concrete type (C = 530 kg/m³)		Attitude R_{bf}/R_{bo}
Ordinary concrete	Basalt fiber concrete		Ordinary concrete	Basalt fiber concrete	
R_{bo}, MPa	R_{bf}, MPa		R_{bo}, MPa	R_{bf}, MPa	
27,7	34,3	1,24	32,6	46,7	1,43
28,0	33,1	1,18	34,1	48,2	1,41
26,4	32,6	1,24	31,7	50,1	1,58
26,7	33,7	1,26	31,0	42,5	1,37
28,1	34,0	1,19	33,2	47,8	1,44
25,9	32,1	1,24	27,6	43,6	1,58
Average price		1,23	Average price		1,47

Note. R_{bo} and R_{bf} are the prismatic strength of regular heavy concrete and basalt fiber-reinforced concrete, respectively.

Depending on the load level, it can be observed that the change in longitudinal strain of basalt fiber-reinforced concrete corresponds to the expression proposed in European standards [3]. Accordingly, the initial modulus of elasticity, the elastic limit coefficient, and the ultimate compressive strains of basalt fiber-reinforced concrete can be determined based on its prismatic strength. The values of these indicators are related to the strength and crack resistance of the concrete, since the microcrack initiation parameter for basalt fiber-reinforced concrete is high, which is confirmed by the results of conducted studies [2]. The obtained results show that the initial modulus of elasticity values for basalt fiber-reinforced concrete are 20–25% higher than those of ordinary concrete. Furthermore, its ultimate compressive strains are also higher. Based on this, it can be concluded that the use of basalt fiber-reinforced concrete in compressed reinforced concrete elements is advisable, as it ensures the full utilization of the compressive resistance of the reinforcement. Another reason is the sufficient bond strength between deformed reinforcement and basalt fiber-reinforced concrete [4]. Thus, it can be briefly concluded that, due to the specific strength and deformation properties of basalt fiber-reinforced concrete, it can be effectively used in load-bearing reinforced concrete elements. To this end, further research in this direction is necessary.

To obtain the actual strains of basalt fiber-reinforced concrete during testing, longitudinal and transverse strains of prismatic specimens under load were recorded simultaneously [5].

The compaction effect occurring when fibers are introduced into the concrete mix is based on the following assumptions: external loads are transferred to the fibers through interaction forces with the concrete matrix; if the elastic modulus of the fibers is high, they carry the main portion of the stresses. In the zones of mutual bond between coarse aggregate and fibers, due to the increase in their strength, an increase in the compressive and tensile strength of basalt fiber-reinforced concrete, as well as its other properties, can be observed. As a result of these positive changes, an increase in the resistance of basalt fiber-reinforced concrete elements to external loads can be assumed. This is confirmed by the results of several experiments [6,7]. According to them, adding basalt fibers to the concrete mix provides the following changes in the structural performance of flexural reinforced concrete elements made from it:

- the strength of normal and inclined sections increased by up to 15%;
- cracking moments increased by 1.5 times;
- crack widths decreased; a reduction in drying shrinkage of up to 40% was observed.

According to document [3], under short-term axial loading, the "σ–ε" (stress–strain) relationship is calculated using the following expression:

$$\frac{\sigma_b}{R_b} = \frac{k \cdot \eta \cdot \eta^2}{1 + (k-2) \cdot \eta}$$

where:

- $\eta = \frac{\varepsilon_b}{\varepsilon_{bR}}$ - coefficient of elastic deformation;
- ε_{bR} - relative deformation of concrete at the maximum value of stress;
- $k = 1{,}05 \cdot E_1 \cdot \frac{[\varepsilon_{bR}]}{R_b}$ - variable coefficient;
- $R_b = R + 8$; R - standard value of 28-day compressive strength of concrete;
- ε_b - relative deformation of concrete in compression;
- E_1 - modulus of elasticity of concrete;
- R_b - average strength of concrete.
- expression relative deformations of concrete $0 \leq [\varepsilon_b] < [\varepsilon_{bR}]$ is valid when it is between.

As stress increases and destruction approaches, the process of microcracks forming in the concrete composition begins. As a result, plastic deformations develop, microcracks form, and their increase is observed.

Under the influence of external load, the parameters of the basalt fiber-reinforced concrete stress-strain diagram (concrete's average compressive strength, initial elastic modulus, and deformation occurring at maximum stress) determine its state. To account for the influence of these parameters on the load-bearing capacity of the bent basalt fiber-reinforced concrete elements, their actual values must be used in the calculations. This, in turn, allows for the determination of the variability of factors influencing the reliability and durability of such structures.

3. Conclusions

Based on the results of the conducted experiments, the "σ-ε" diagrams of basalt fiber-reinforced concrete were constructed. It was established that these diagrams have the same dependence on the change in the prismatic strength of basalt fiber-reinforced concrete.

The strength bases of basalt fiber-reinforced concrete are determined by its real composition, the properties of the basalt fiber, and its consumption in the concrete mix. To determine the actual strength indicators of basalt fiber concrete, it is advisable to use its prismatic strength, as it reflects the actual strength. In order to clarify and improve the methods for calculating load-bearing elements made of basalt fiber-reinforced concrete, it is recommended to conduct new experiments taking into account the actual strength of such concretes. These issues are among the urgent tasks for expanding the areas of application of basalt fiber-reinforced concrete.

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