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Mechanical properties of concrete reinforced with basalt fibers

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Abstract. In the article, the compressive strength, tensile strength, and residual tensile strength of fiber-reinforced concrete reinforced with basalt fibers were studied based on the experiment. Basalt fibers 10 mm and 30 mm in length and 0.017 mm thick were added at 0.0%, 0.1%, 0.2%, and 0.3%. The samples were stored at room temperature and relative humidity above 75%, and the samples were tested on days 7 and 28. The addition of fibers increased the compressive strength, tensile strength, and residual tensile strength of concrete and changed its brittle behavior to a more ductile one. When 10 mm length basalt fibers were added to concrete in amounts of 0.1, 0.2, and 0.3%, the tensile strength was 2.35 MPa, 2.38 MPa, and 2.40 MPa, respectively. When 30 mm length basalt fibers were added to concrete in amounts of 0.1, 0.2, and 0.3%, the tensile strength was 2.22 MPa, 2.32 MPa, and 2.36 MPa, respectively. The compressive strength of prism samples reinforced with basalt fibers increased by 10-20% compared to ordinary concrete.

1 Introduction

According to their technical and economic indicators, concrete and reinforced concrete still occupy a leading role among structural building materials around the world. Due to its unique properties, reinforced concrete replaced expensive metal and was named the material of the 20th century [1]. The large-scale use of concrete and reinforced concrete has made it possible to make revolutionary changes in construction technology, creating an opportunity to restore huge structures that are durable for a long time. Research shows that reinforced concrete will retain its leading role in the 21st century [2].

The work of concrete together with other materials does not cause serious problems. The first example of this is the armature. As a result of research conducted in many developed countries, metal fittings are being improved, and new types of them are being researched, but the problem of protecting them from corrosion has not been fully resolved [3]. In recent years, European countries have been conducting research on mirror fittings. Although plastic glass and plastic basalt are used as such fittings, further improvement is required [2-6].

It should be noted that concrete and reinforced concrete remain promising materials among the materials used in the construction of buildings and structures. It can be used in various conditions; it can be used together with other materials, it meets high aesthetic

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requirements and it is reliable, especially the fact that concrete is a local material in many countries further expanding its application possibilities [7]. In addition, reinforced concrete is characterized by energy efficiency and environmental safety. Nevertheless, concrete and reinforced concrete has a number of disadvantages, so it is difficult to say that the current state of reinforced concrete will fully satisfy builders. One of them is the tensile strength of concrete, which is 10-15 times lower than the compressive strength [8-12]. Therefore, it is one of the urgent tasks to carry out scientific research on increasing the tensile strength, crack resistance, and long-term durability of concrete with the help of dispersed reinforcement with basalt fibers and reducing the deformations [13].

Basalt fiber is obtained from different rocks, such as basalt, basanites, amphibolites, or their mixtures, which are close to each other in terms of chemical composition [14-18]. The production of basalt fibers is based on the extraction of basalt solution (mixture) in melting furnaces and its free flow through special devices. The melting temperature is 1450ºC. The advantages of basalt fiber for dispersed reinforcement are that it has high strength, does not stretch under the influence of stresses, is resistant to chemical, corrosion, and thermal effects of the external environment, changes in temperature and direction of stresses, and is also inexpensive [19].

Currently, basalt fiber is widely used in the production of concrete for reinforcement of foundations and floors of buildings, concrete structures, gas and foam concrete, and concrete, and asphalt concrete pavements of highways.

Basalt is added before adding water to the dry mix in any concrete mixer. For better mixing, fibers are added to the mixture in batches while it is being mixed. The fibers are mixed in a compound mixing machine at 90-110 rpm or higher. 15% more time should be spent on the mixing process with the addition of fiber because the effectiveness of the fiber is directly related to its good distribution in the mixture [20-21].

2 Method

Cement, fine aggregate, coarse aggregate, water, and basalt fibers were used in the experimental work. Cement is one of the important components of concrete. It directly affects the strength of concrete. PS400D20 cement was used in the research work. The specific surface of cement is 3000-3500 cm^2/g. The main indicators of cement are presented in (table 1).

Table 1. Physical and mechanical properties of cement

Basic properties	Test value
True density, g/m^3	3.1
Bulk density, g/cm^3	1.3
Initial setting time, min	2-30
Final setting time, min	4-40
Degree of granularity, %	8.2

River sand with a density of 2700 kg/m^3, dimensions of 0-5 mm, moisture content of 3.0% was used as a fine aggregate. Coarse aggregates used were crushed granite having 5-20 mm maximum size.

Basalt fibers of 10 and 30 mm in length and 0.017 mm in diameter were used in fiber concrete mixes. An overview of the basalt fiber used in the study is shown in Fig. 1

Fig.1. View of basalt fibers.

This paper is based on the study of the compressive, tensile, and tensile residual resistances and elastic moduli of fiber-reinforced concrete dispersed with basalt fibers. The samples were stored at room temperature and relative humidity above 75%, and the samples were tested on days 7 and 28.

Samples of prisms with dimensions of 100x100x400 mm were prepared to determine the prismatic strength of concrete. Prism samples were prepared in 7 series. A portable measuring device with a base of 250 mm and dial gauge with an accuracy of 0.01 mm was installed to determine the deformations of the prism samples. The samples were placed in the center of the lower plate of the press. In each step, the amount of load increased continuously and the rate was 0.6 ± 0.2 MPa/s. Each stage was 4-5 minutes. The readings on the dial gauge have been recorded. The devices were removed from the samples when the prism-breaking load reached 0.8R. Further loading was carried out continuously until the specimen failed. An overview of the samples is shown in Fig. 2.

Fig.2. Overview of concrete prism testing

Prism samples with cross-sectional dimensions of 150x150x550 mm were prepared to determine the residual tensile strength of fiber concrete, based on the requirements of SP 297.1325800.2017. The results of the residual tensile strength of fiber concrete obtained in

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laboratory conditions were used to theoretically calculate the strength of fiber-reinforced concrete beams.

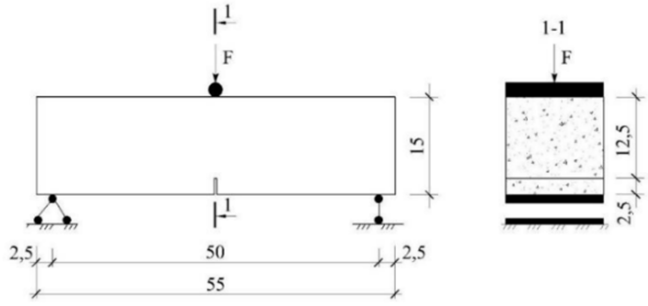

Fig. 3. The test scheme of sample

The procedure for filling the mold with fiber concrete mixture was carried out according to Figure 3. When the mixture was placing in the mold, the volume of the mixture filled in the central part of the mold (section 1 in Fig. 4) was equal to the total volume of filling the edge parts of the mold (section 2 in Fig. 4). Initially, the height of the test sample was filled to about 90% and compacted on a vibrating platform.

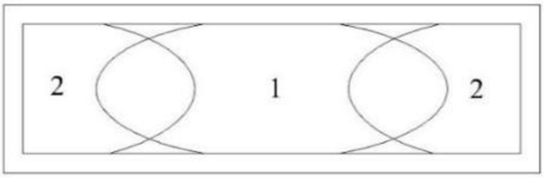

Fig. 4. Form filling procedure. 1, 2 mold filling steps

Fig. 5. Overview of prepared samples

According to the requirements of the standard, the width of the groove does not exceed 5 mm, the depth is (25±1) mm, and the distance between the top of the groove and the upper edge of the sample is (125±1) mm. An overview of the prepared samples is shown in Fig. 5 and Fig.6.

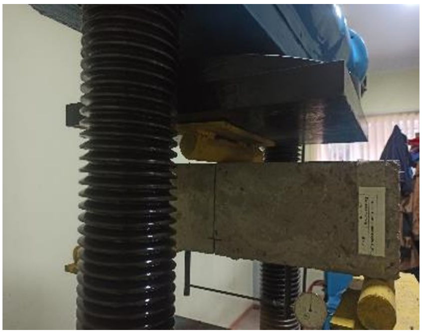

Fig. 6. Placement of sample in test device

A portable gauge with a base of 200 mm, equipped with a dial gauge with an accuracy of 0.01 mm was installed to measure the elongation of the samples. The loading speed was 0.2 mm/min. The readings on the dial gauge have been recorded. An overview of the sample is shown in Fig. 7.

With an accuracy of 0.1 N/mm^2 for each sample, taking into account the inelastic properties of fiber concrete, the strength values $R_{F0.5}$ and $R_{F2.5}$ are determined according to the following formulas:

$$R_{F0.5} = \frac{3 \cdot F_{0.5} \cdot l}{2 \cdot b \cdot h_{sp}^2} \cdot k_{F0.5} \quad (1)$$

$$R_{F2.5} = \frac{3 \cdot F_{2.5} \cdot l}{2 \cdot b \cdot h_{sp}^2} \cdot k_{F2.5} \quad (2)$$

where $F_{0.5}$ is the value of the load corresponding to the outer edges of the trimmed section a_F=0.5 mm; $F_{2.5}$ is the value of the load corresponding to the outer edges of the trimmed section a_F=2.5 mm; *l* islength, mm; *b* issample cross-sectional dimensions, mm; distance from the upper part of the h_{sp} cut place (groove) to the upper surface of the sample, mm; h_{sp} is the distance from the upper part of the cut place (notch) to the upper surface of the sample, mm; $k_{F0,5}$=0,4 and $k_{F2,5}$=0,34 are coefficients for taking into account inelastic deformations of the stretched zone of the sample in fiber concrete.

The residual normative values of fiber concrete in elongation are determined by the following formulas.

$$R_{fbt2,n} = R_{F0.5,m} \cdot (1 - k_s \cdot \nu_{F0.5,m}) \quad (3)$$

$$R_{fbt3,n} = R_{F2.5,m} \cdot (1 - k_s \cdot \nu_{F2.5,m}) \quad (4)$$

where $R_{F0.5,m}$=0.4 and $R_{F2.5,m}$=0.34-average values of residual tensile strength of fiber concrete, N/mm; $\nu_{F05,m}$ and $\nu_{F25,m}$ is the coefficient of variation and is determined by the following formulas:

$$\nu_{F0.5,m} = \frac{S_{F0.5,m}}{R_{F05,m}} \quad (5)$$

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$$\nu_{F2.5,m} = \frac{S_{F2.5,m}}{R_{F2.5,m}} \tag{6}$$

$$S_{F0.5,m} = \sqrt{\frac{\sum_{i=1}^{n}(R_{F0.5,i} - R_{F0.5,m})^2}{(n-1)}} \tag{7}$$

$$S_{F2.5,m} = \sqrt{\frac{\sum_{i=1}^{n}(R_{F2.5,i} - R_{F2.5,m})^2}{(n-1)}} \tag{8}$$

n is the number of test samples.

The value of the coefficient of variation for samples should not exceed 0.15

$$R_{fbt2} = \frac{R_{fbt2,n}}{\gamma_{ft}} \tag{9}$$

$$R_{fbt3} = \frac{R_{fbt3,n}}{\gamma_{ft}} \tag{10}$$

The value of the reliability coefficient for fiber concrete under tension is assumed to be equal to γ_{ft}=1.3.

Cube samples of 100x100x100 mm were prepared to determine the tensile strength of fiber concrete. Cube samples were prepared based on standard requirements. Particular attention was paid to the processes of standard preparation requirements and compaction of the concrete mixture in the formwork. The prepared samples were removed from the molds after standing in the room for 1 day, the samples were marked and stored for 28 days.

The samples were installed in the center of the lower plate of the press (Fig. 7). The loading rate in the test was 0.6±0.4 MPa/s. Tensile strength of concrete is calculated using the following formula.

$$R_t = \gamma \frac{2 \cdot F}{\pi A} \tag{11}$$

where F is the breaking force, kg; A is the cross-sectional surface of the sample, cm^2; γ is the transition coefficient.

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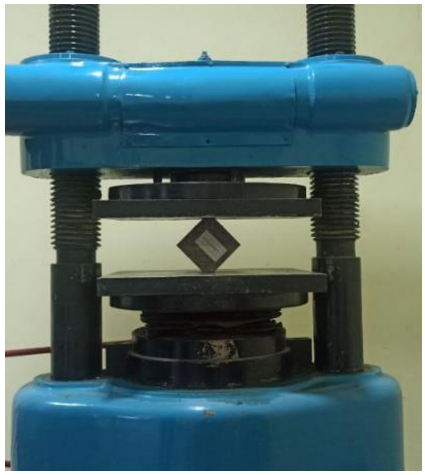

Fig. 7. Testing cubes for tensile strength in cracking

3 Results and Discussion

Samples reinforced with basalt fibers were tested in laboratory conditions and a number of scientific results were obtained. The results of the compressive, tensile, and tensile residual strengths of the fiber concrete samples are presented below.

The failure of prism specimens made of concrete with basalt fiber and concrete without basalt fiber was significantly different from that of cubes. Concrete prisms without basalt fiber were broken brittlely. As soon as the main crack appeared, the sample immediately split into pieces. In the prism-samples made of basalt fiber concrete, the failure occurred in a unique state. After the prism samples were tested, the parts of the sample remained connected by many deformed fibers of the concrete matrix. An overview of the prism specimens after testing is shown in Fig. 8 and Fig. 9.

Fig. 8. General view of prism-sample without basalt fiber addition after test

Fig. 9. General view of prism-sample with basalt fiber addition after test

Samples were kept in natural conditions for 7 and 28 days and tested. The compressive strength of prism samples obtained as a result of testing is shown in Fig. 10.

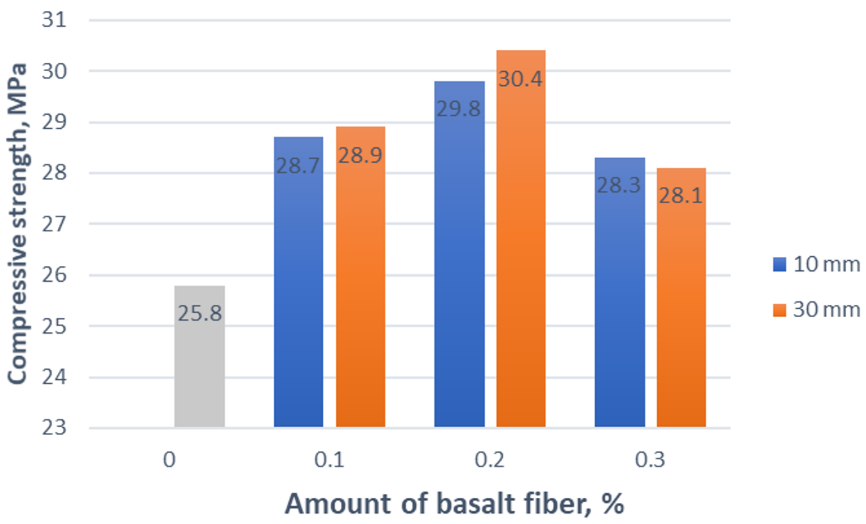

Fig. 10. Prismatic strength of concrete

The residual tensile strength of fiber concrete was determined by adding basalt fibers of different lengths and amounts to concrete. The results obtained by testing the residual tensile strength of fiber concrete are presented in Fig. 9. When 10 mm and 30 mm length basalt fibers were added to the concrete in the amount of 0.2 %, the strength was 2.4 MPa and 2.41 MPa, respectively.

After the test, "F - a_F" graphs were drawn for each sample (Fig. 11-13).

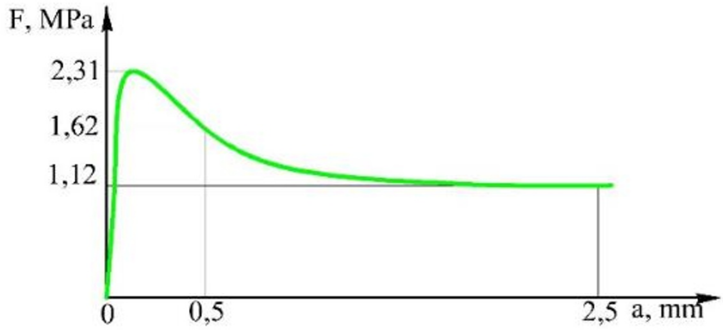

Fig.11. Graph of "displacement of outer edges of grooves under influence of load" of sample prepared with addition of 0.1% basalt fiber 10 mm length

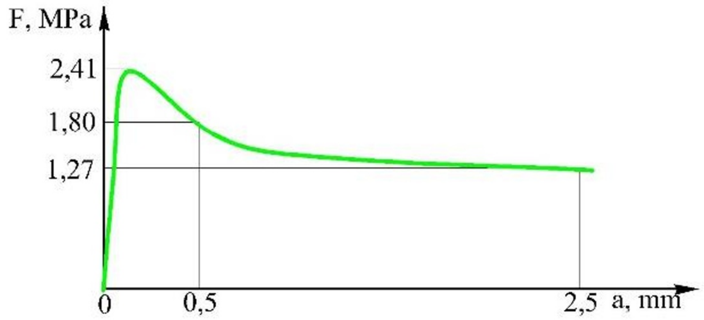

Fig.12. Graph of "displacement of outer edges of grooves under influence of load" of sample prepared with addition of 0.2% basalt fiber 10 mm length

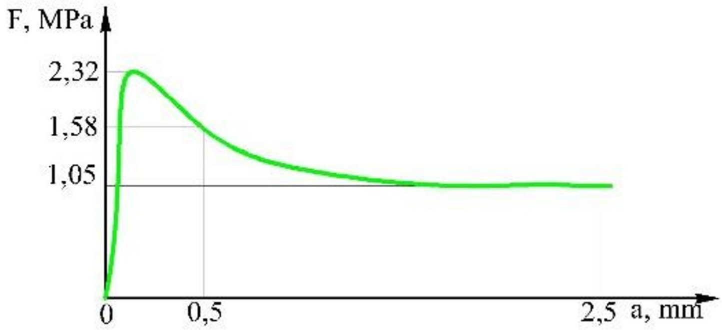

Fig.13. Graph of "displacement of outer edges of grooves under influence of load" of sample prepared with addition of 0.3% basalt fiber 10 mm length

When 10 mm length basalt fibers were added to concrete in amounts of 0.1, 0.2, and 0.3%, the tensile strength was 2.35 MPa, 2.38 MPa, and 2.40 MPa, respectively. When 30 mm length basalt fibers were added to concrete in amounts of 0.1, 0.2, and 0.3%, the tensile strength was 2.22 MPa, 2.32 MPa, and 2.36 MPa, respectively. The tensile strength of the samples obtained as a result of the test is shown in Fig. 14.

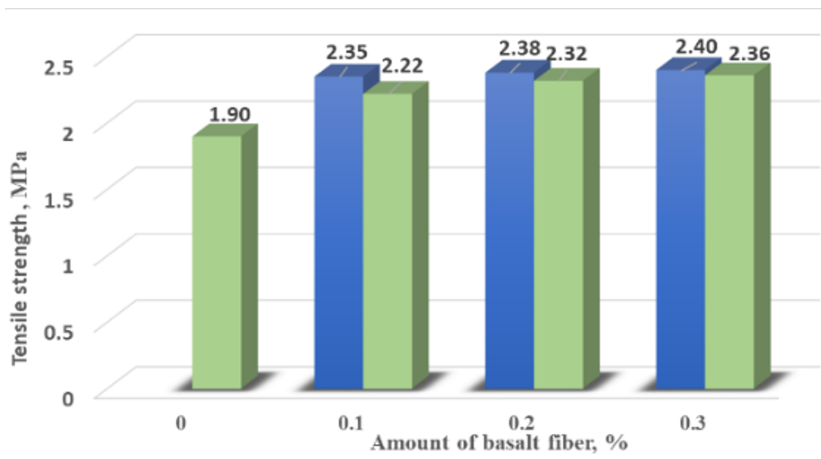

Fig. 14. Graph of tensile strength of samples

4 Conclusions

Experimental studies were conducted to study the mechanical properties of fiber concrete dispersed with basalt fibers and the following conclusions were obtained:

The compressive strength of prism samples reinforced with basalt fibers increased by 10-20% compared to ordinary concrete.

By adding basalt fibers to concrete in amounts of 0.1-0.3%, the modulus of elasticity of concrete increased significantly.

It was determined that the tensile strength of reinforced concrete with basalt fibers increases by 15-25% compared to ordinary concrete samples.

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