Experimental Study of the Connection of Reinforcement with Basaltfibrobetone

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**Abstract.** The performance of reinforced concrete structures largely depends on the bond strength developed at the interface between the reinforcement and the concrete. This dependency is directly influenced by the factors that ensure the integrity of the bond between the reinforcement and the concrete, the properties of the materials involved, and the ability of the reinforcement to act in unison with the concrete under load. The results of experiments on the bonding of reinforcement with basalt fiber-reinforced concrete and their analysis are presented. The studied parameter is variable, and its value depends on many factors. The law of coupling, or coupling theory, is the relationship between the longitudinal displacements of shear stresses occurring along the reinforcement surface relative to the concrete. This, in turn, is predicated on the dependence of bond strength on the properties of reinforcement and concrete. Basalt fibers in basalt fiber-reinforced concrete have a positive effect on its bonding with the reinforcement and lead to an increase in the strength of the contact zone. Predicated on the analysis of the obtained results, a model for calculating the bonding of reinforcement with basalt fiber-reinforced concrete is proposed.

**Keywords:** reinforcement, basalt fiber-reinforced concrete, bonding, strength, stress, character, displacement, result

# INTRODUCTION

According to the results of the conducted research, the addition of basalt fibers to concrete as dispersed reinforcement increases both its compressive and tensile strength compared to concrete without additives. In such concretes, the spatial formation of the micro-reinforced cement matrix effectively resists the compressive and tensile stresses induced by external forces in basalt fiber-reinforced concrete. Furthermore, the high physical, mechanical, and operational properties of basalt fibers play a crucial role in ensuring the properties of the concrete. According to the results of studies [1, 2], microstructural analysis of basalt fiber-reinforced concrete samples after destruction revealed that when the basalt fiber content exceeds 1%, local uneven accumulations appear as a result of unmixed volumes, which, in turn, results in a disruption of its structural uniformity, stress concentration, and the formation of microcracks. In reinforced concrete elements, the interaction between the reinforcement and the concrete ensures the anchorage strength of the reinforcement and the reliable composite action of both materials. Considerable attention is given to the study of the bond between reinforcement and concrete, as it plays a critical role in transferring support loads, in joints, at termination zones of reinforcement, and in the transmission of prestressing forces. Additionally, the bond between reinforcement and concrete is one of the key factors determining the stiffness and crack resistance of reinforced concrete flexural members. It should be noted that the bond between reinforcement and concrete is governed by physical phenomena, including the nature of contact at the interface, the physical and mechanical properties of the materials, and the boundary conditions. Predicated on the experimental results mentioned above, it can be concluded that the “reinforcement–concrete” interaction is highly complex. The resulting bond strength depends on multiple factors, and existing models often fail to fully account for the diverse effects occurring within the materials. Therefore, it is reasonable to conclude that further experimental and theoretical investigations in this area are necessary and well-justified.

# METHODS

In this experimental study, heavy concrete specimens were prepared using Portland cement of grade CEM II/A 32.5N produced by “Qizilqumcement” JSC, with a standard consistency of 27% and a compressive strength activity of 38.2 MPa.

As the coarse aggregate, granite crushed stone from the “Nerudnik” quarry with a fraction size of 5–20 mm was used, having the following properties:

* bulk density – 1380 kg/m³;
* intergranular void volume – 38%;
* water absorption: after 1 hour – 1.4%, after 48 hours – 1.8%.

Quartz sand from the same “Nerudnik” quarry was used as the fine aggregate, with the following characteristics:

* specific gravity – 2.62 t/m³;
* bulk density – 1470 kg/m³;
* fineness modulus – 2.8.

Tap water from the municipal water supply system was used.

Basalt fibers (manufactured by “MEGA INVEST INDUSTRIAL” LLC) were composed of segments of basalt threads of specific lengths. Their technical specifications are as follows:

* color – bronze;
* density – 2.8 g/cm³;
* fiber length – 20 mm;
* individual fiber diameter – 13–20 mk;
* melting point – 1450 °C;
* operating temperature – from 260 °C up to 700 °C;
* resistant to acids and alkalis.

The mechanical properties of the reinforcement bars used in the experiments were determined, and the corresponding values are presented in Table 1.

**TABLE 1.** Properties of the Reinforcement Used in the Experiments

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Reinforcement grade** | **Reinforcement diameter, mm** | **Yield strength, MPa (N/mm²)** | **Ultimate tensile strength, MPa (N/mm²)** | **Percentage elongation after fracture, %** |
| А 240 | 12 | 314 (235) | 468 (373) | 25.6 (25) |
| А 400 | 12 | 401 (390) | 620 (590) | 17.8 (14) |
| А 400 | 18 | 412 (390) | 658 (590) | 18.5 (14) |
| А 400 | 25 | 400 (390) | 625 (590) | 18.2 (14) |

Notes:

1. The presented values represent the arithmetic mean of the results obtained from three tests.
2. The values in parentheses are given in accordance with the requirements of O’zDSt 3025-2015.

Experimental studies were conducted on hydraulic presses (PGM-1000MG4) and tensioning hydraulic machines (RGM-500MG4). The shear deformations that occur during the removal of reinforcement from a concrete sample measuring 15x15x15 cm were taken from the dimensions of the machine itself and compared with each other using 0.01 mm indicators of clock-type sections.



**FIGURE 1.** Appearance of the test specimen installed on the RMG-500 hydraulic tensile testing machine

# RESULTS AND DISCUSSIONS

In addition to the factors ensuring the high strength of basalt fiber-reinforced concrete, its main cause is the compounds formed in the contact zones between the basalt fiber and the cement stone in the concrete. As a result of the chemical interaction of basalt fiber and cement hydration minerals, high adhesion of the fiber to the cement stone is formed. A similar situation can be expected with a high degree of cohesion between cement stone and coarse aggregates in concrete. This, in turn, determines the parameters of microcracking of basalt fiber-reinforced concrete and, accordingly, the strength of its bond with the reinforcement with a periodic cross-section. As proof of this, it is evident from the analysis of the results of a study of the bond strength of basalt fiber-reinforced concrete made of local raw materials with reinforcing bars of the A400 class with a sickle-shaped transverse rib with a periodic cross-section with diameters of 12.18 and 25 mm (**table 2**).

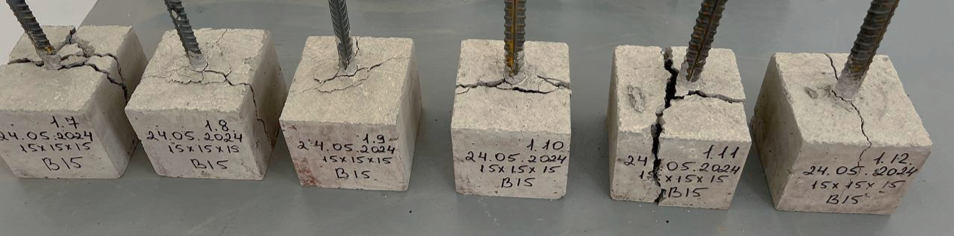
From the table 2, it is evident that the change in the bond strength of reinforcement bars with basalt fiber-reinforced concrete depends on the strength of the concrete. The main reason for this is the result of the technology used for the uniform distribution of basalt fibers in the concrete composition [3, 4].

**TABLE 2.** Bond strength of reinforcement with basalt fiber-reinforced concrete

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Basalt fiber-reinforced concrete class** | **Concrete strength, MPa** | **Reinforcement class** | **Reinforcement bond strength with concrete, MPa** | | |
| **Reinforcement diameter, mm** | | |
| **12** | **18** | **25** |
| **B15** | 21.6 | A240 | 1.52 | - | - |
| 21.5 | 1.59 | - | - |
| 20.4 | 1.5 | - | - |
| **Average value** | 21.2 |  | 1.54 |  |  |
| **B15** | 21.6 | A400 | 5.69 | 4.95 | 3.25 |
| 21.5 | 5.67 | 5.02 | 3.16 |
| 20.4 | 6.16 | 4.45 | 3.07 |
| **Average value** | 21.2 |  | 5.84 | 4.81 | 3.16 |
| **B20** | 28.41 | A240 | 2.12 | - | - |
| 27.83 | 2.22 | - | - |
| 24.2 | 1.90 | - | - |
| **Average value** | 26.8 |  | 2.08 |  |  |
| **B20** | 28.41 | A400 | 6.10 | 5.4 | 3.66 |
| 27.83 | 5.93 | 4.8 | 3.35 |
| 24.2 | 6.55 | 4.81 | 3.00 |
| **Average value** | 26.8 |  | 6.19 | 5.0 | 3.34 |
| **B22.5** | 29.28 | A240 | 2.32 | - | - |
| 30.24 | 2.28 | - | - |
| 30.82 | 2.12 | - | - |
| **Average value** | 30.1 |  | 2.24 |  |  |
| **B22.5** | 29.28 | A400 | 6.48 | 5.30 | 4.22 |
| 30.24 | 6.50 | 5.64 | 3.94 |
| 30.82 | 6.37 | 4.95 | 4.54 |
| **Average value** | 30.1 |  | 6.45 | 5.3 | 4.23 |

From the analysis of the results presented in the table 2, it can also be determined that the bond strength of reinforcement bars with a periodic cross-section in basalt fiber-reinforced concrete, under identical testing conditions, is significantly higher than that of reinforcement bars with a smooth surface (A240). According to the results of such comparisons, for reinforcement of concrete class B15, with a diameter of 12 mm, the increase in bond strength is 3.8 times; for concrete class B20, it is 3.0 times, and for concrete class B22.5, it is 2.88 times; on average, this value is equal to 3.22. The main reason for this is the interconnection of the reinforcement's transverse ribs with concrete. In this case, it is necessary to overcome the resistance of the reinforcement rod, applying a significant amount of force to pull it out (shift) along the concrete. The change in the bond strength of reinforcement bars with basalt fiber-reinforced concrete occurs according to the existing "bond theory" and proceeds according to a certain pattern [5].

When pulling out centrally located reinforcement bars from basalt fiber-reinforced concrete samples, it can be observed that the characteristics of failure are different (Figure 2.). At a certain load level, the intensive development of microcracks in the basalt fiber-reinforced concrete structure results in an increase in the sample volume.



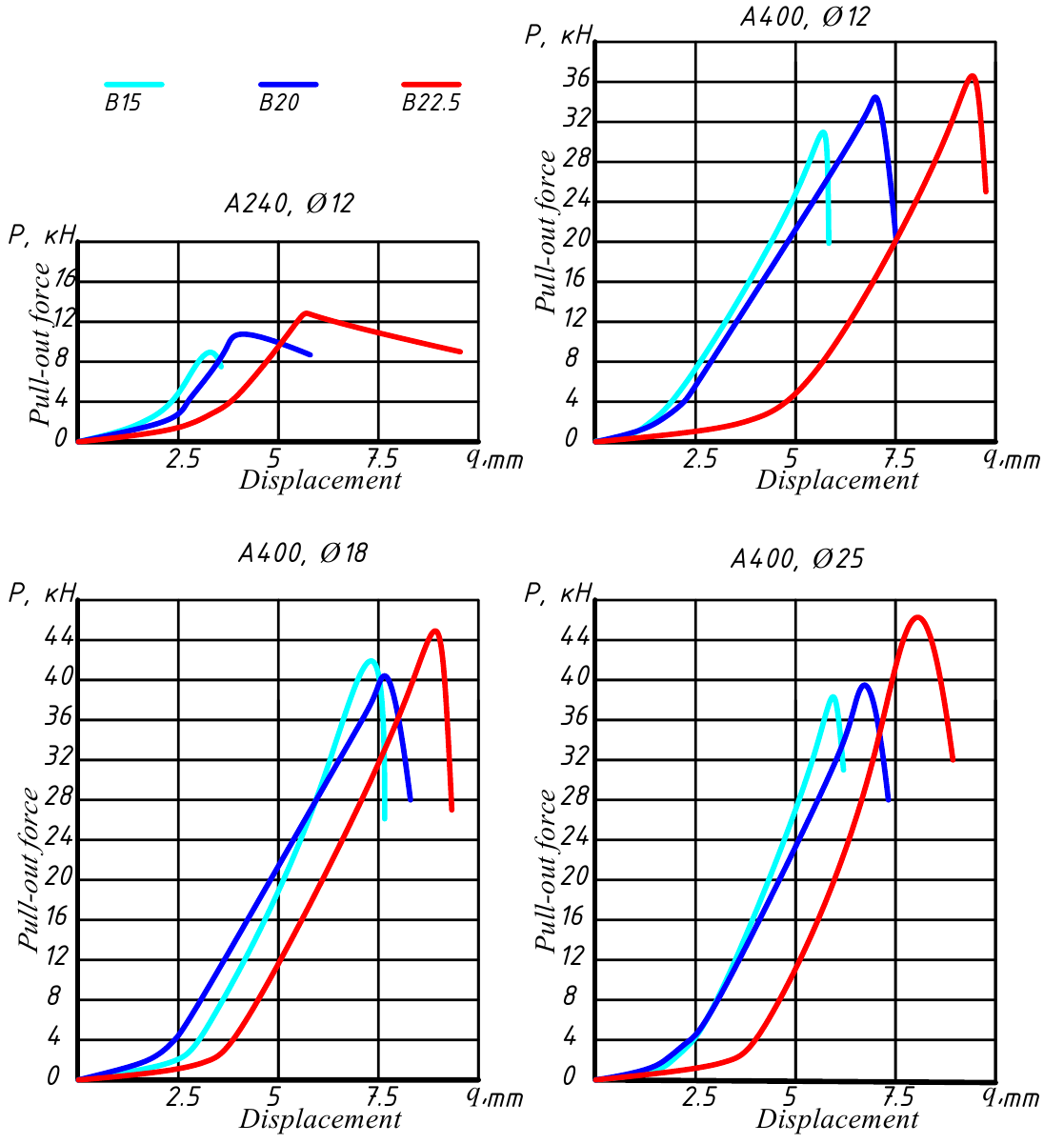
**FIGURE 2.** Characteristics of destruction of basalt fiber-reinforced concrete samples

The concrete sample, in which reinforcement with a smooth surface is placed, does not exhibit longitudinal cracking upon failure, as its bond strength is 2 to 3.5 times lower than that of reinforcement with a periodic cross-section embedded in basalt fiber-reinforced concrete. This is primarily as a result of the absence of transverse ribs on the reinforcement surface, which would otherwise resist tensile forces.

Predicated on experimental studies of the strength of the connection of reinforcement with concrete with a periodic cross-sectional area, the following can be noted:

* Reinforcement with a diameter of 12 mm split into two pieces when centrally placed concrete samples were destroyed. This is as a result of the height of the transverse ribs of the reinforcement (1.2 mm) and the high strength of the connection;
* Concrete samples with reinforcement diameters of 18 and 25 mm are mostly divided into three parts. This is as a result of the high transverse ribs of the reinforcement (1.5 and 1.7 mm) and low bond strength, i.e., it is possible to overcome high resistance and then pull out the reinforcement bars.

Graphical representations of the results obtained for individual samples in experimental studies for some samples are presented in Figure 3.



**FIGURE 3.** Graphs showing displacement changes during the pull-out of reinforcement

From the analysis of these graphs, it can be concluded that the stages of the stress-strain state of reinforcement during extraction from the concrete sample develop in connection with changes in the contact between them. In the longitudinal force characteristic, the joint operation of reinforcement with it in concrete depends on the coupling mechanism, causing mutual displacement.

Analysis of these graphs reveals that the stages of stress–strain behavior during the pull-out of reinforcement from concrete specimens are closely related to changes in the contact conditions between the materials. Under longitudinal tensile loading, the composite action of the reinforcement embedded in concrete is governed by the bond mechanism, which in turn induces relative slippage between the two. In the initial phase of the loading process, the bond strength arises primarily as a result of adhesion. During this phase, the observed slippage is minimal, and the bond strength typically does not exceed 0.5–1.0 MPa—approximately 50–60% of the total bond strength for smooth-surfaced reinforcement. This stage is characterized by elastic behavior in both the concrete and the reinforcement, with negligible transverse deformation in the concrete. The first cracks in the concrete surrounding the reinforcement may appear at the end of the elastic deformation stage, leading to a new stress–strain state as the applied tensile load increases. At this point, the bond strength becomes dependent on the tensile strength of the concrete, the ribbed profile of the reinforcement, and its geometric characteristics. The primary bonding mechanism in this stage is mechanical interlocking.

Stress distribution along the height of the specimen is non-uniform, with peak stresses typically observed in the central region. Cracking in this zone results from the breakdown of the bond interface and the development of tensile stresses exceeding the tensile capacity of the concrete. Additionally, plastic deformations give rise to slippage of unloaded reinforcement relative to the contact surfaces. This process contributes to localized damage at the transverse ribs, leading to bond deterioration. The redistribution of stress between the concrete and reinforcement can be observed, and relative displacement of the reinforcement with respect to the concrete begins. As the tensile load continues to increase, radial cracking initiates and propagates. From the graphs shown in Figure 3, it can also be observed that further increases in reinforcement stress lead to accelerated slippage. The ribs begin to shear through the concrete, eventually causing the specimen to split into two or three separate parts. This stage corresponds to complete failure of the contact zone between the reinforcement and the concrete. Moreover, the graphs indicate that in the initial stage of tensile loading, the resistance offered by the reinforcement is primarily as a result of frictional forces and adhesion. However, the adhesion component (i.e., molecular bonding between the concrete and reinforcement) is short-lived and contributes only about 7–15% to the total resistance. During this stage, significant slippage occurs and adhesive bonds begin to fail. In the subsequent stages of loading, mechanical interlock between the concrete and ribbed reinforcement becomes the dominant source of resistance, comprising the remaining portion of the total bond strength.

In general, the bond strength of reinforcement with basalt fiber-reinforced concrete is considered as a statistically distributed value, and its dependence on several factors is substantiated. The calculated values of these factors can be determined independently using a multiplicative model, i.e.:

(1)

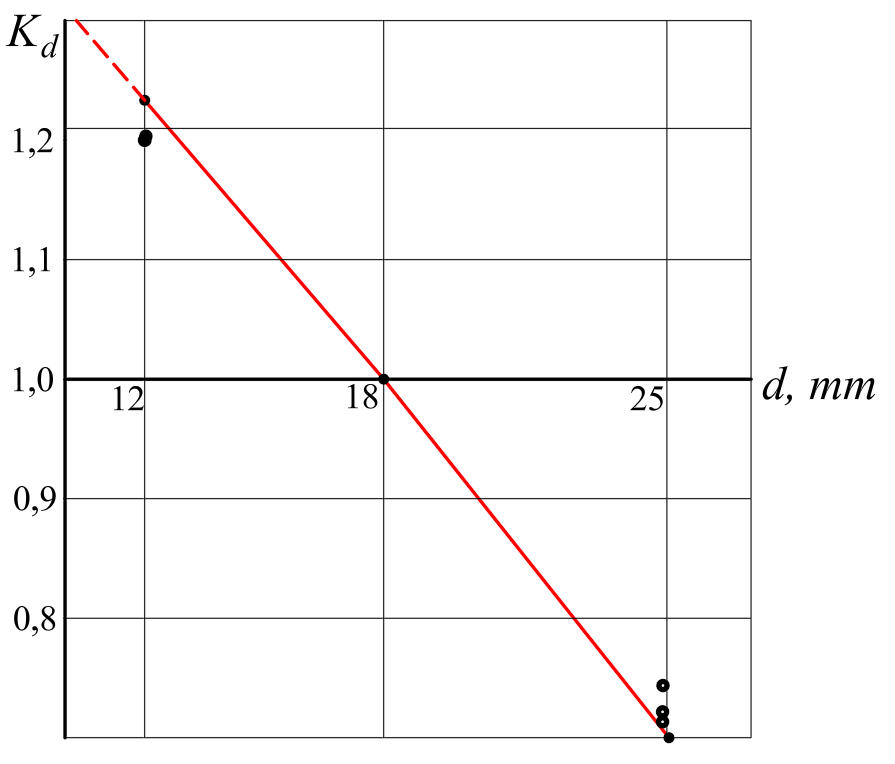
where: - conditionally accepted standard value of reinforcement bond strength with concrete   
(and concrete class B15). and - coefficients that take into account the influence of factors (function).

Using this method, an analysis of the obtained experimental results was carried out. Their graphical representations are presented in Figure 4. and Figure 5. respectively, in the form of dependencies, taking into account the influence of the reinforcement diameter and the concrete class. The following expressions were proposed for their calculation:

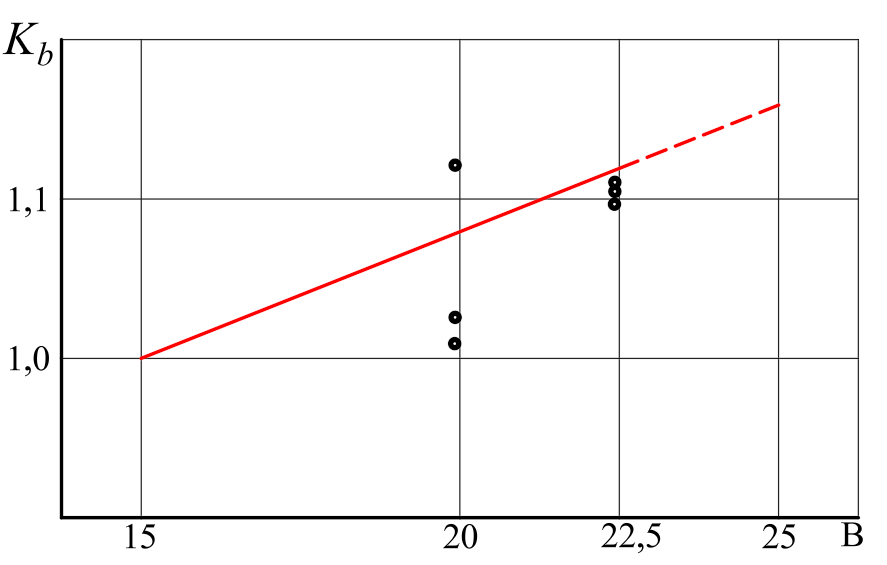
(2)

(3)

where - reinforcement diameter, mm; -compressive strength class of concrete.



**FIGURE 4.** Graph of coefficient change



**FIGURE 5.** Graph of coefficient change

# CONCLUSION

The following conclusions can be drawn:

- The strength of concrete affects the bonding strength of reinforcement with basalt fiber-reinforced concrete. In addition, the value of this parameter also depends on the diameter of the reinforcement;

- the bond strength with basalt fiber-reinforced concrete at a reinforcement diameter of 12 mm is higher than at reinforcement diameters of 18 and 25 mm; the established dependencies occur according to the established pattern for heavy concretes without additives and differ only in their values;

- The basalt fibers incorporated into the composition of basalt fiber-reinforced concrete have a positive effect on its bond with the reinforcement, contribute to the enhancement of the contact zone strength, and influence the magnitude of the slippages;

- A mathematical model was proposed for the calculation of the strength of the bond formed between reinforcement and basalt fiber-reinforced concrete.

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