Research of stress-strain state of basalt fiber polymer rods at adhesive anchoring in concrete

O Kichaeva¹, S Zolotov², P Firsov²,³ and Zafari Togian²

¹ Soil Mechanics, Foundations and Engineering Geology Department, O.M. Beketov National University of Urban Economy, Marshala Bazhanova str. 17, 61002, Kharkiv, Ukraine
² Building Structures Department, O.M. Beketov National University of Urban Economy, Marshala Bazhanova str. 17, 61002, Kharkiv, Ukraine
³ Email: pavelfirsov1991@gmail.com

Abstract. The results of experiments to determine the strength and deformability of adhesive anchoring, depending on the depth of embedding basalt fiber polymer rods in the concrete array, are given. The technique of basalt fiber polymer reinforcement preparation for conducting experiments to determine basic longitudinal deformations is fully described. Numerical characteristics of basalt fiber polymer reinforcement for tensile and compression test, to determine bearing capacity in concrete, were obtained. Test methods of adhesive basalt fiber polymer joints are described in detail, as well as research to determine the influence of technological factors on the strength of adhesive bonding, using acrylic modified compositions. Experimental research on the effect of concrete class, adhesive layer thickness and adhesive joint distance from the face of a concrete specimen, on a joint strength, has been performed. The obtained results of experimental research data can be used for attachment joints projecting and industrial technological lines development, as well as for further polymeric adhesive materials, widely applied in industrial and civil engineering, improvement.

1. Introduction
The main problem of metal fittings and anchors in the chemical and metallurgical industries is the influence of the aggressive environment. As a result, corrosion of the metal rods and, to a certain extent, of the concrete itself occurs, with the loss of bearing capacity of the structures. Reinforcement corrosion is caused by excessive crack opening, insufficient thickness of the protective layer and occurs independently of the concrete corrosion. This problem is especially relevant for anchoring metal products (rods, anchors, bolts etc.) for fastening various technological equipment, roofs reinforcing, mine fasteners (to ensure reliable rocks position). The negative role of reinforcement corrosion acceleration processes is played by the degree of stress condition, both for concrete and reinforced concrete [1]. Therefore, the use of composite materials is completely advisable.

Composite materials are made to minimize corrosion and other environmental impacts. Composite reinforcement is a material which is consisting of a base in the form of basalt or glass roving (thin fibers of 14-16 microns in diameter) and thermosetting synthetic resin (plastic) as a binder [2]. Composite (basalt fiber polymer) fittings are made by the method of pultrusion - a stretch of impregnated reinforcing basalt fibers through the heated molding die connector, or by the method of nidltrusion - by twisting individual fibers into one unit with simultaneous impregnation. In this case, the periodic profile of the cross-section is formed by pressing the winding harness into the carrier rod, or by spiral winding.
of the bearing rod ledges with the winding harness [3]. Time resistance of composite reinforcement, depending on the type of roving, is 750-1200 MPa (basalt roving) and 600-800 MPa (glass roving), modulus of elasticity – 40-43 GPa, density – 2.03 t/m³ [4].

The most common types of technological equipment and production lines fastenings are welded, bolted and anchor joints. The main material in the anchor glued fastenings are epoxy and acrylic compounds, because their chemical properties are corresponding to all the necessary requirements for adhesives [5, 6] to create reliable, high-strength steel-concrete joints [7, 8]. But for today, there are virtually no data on the mass use of basalt fiber polymer reinforcement in the construction industry and specific data on the bearing capacity of concrete structures with basalt fiber polymer anchors. There is no complete information on the amount of adhesion to concrete and the dependence on the concrete composition and the method of its sealing, on the treatment of the basalt fiber polymer reinforcement outer surface in different ways to increase its adhesion, the destruction nature of such joints from the influence of external loads.

2. Determination of basalt fiber polymer reinforcement characteristics under basic longitudinal deformations (tensile and compression)

Initially, it is necessary to obtain numerical characteristics of a basalt fiber polymer reinforcement under tensile/compression and to determine its bearing capacity in concrete.

To obtain the results, basalt fiber polymer reinforcement type 10BP-P (basalt fiber polymer reinforcement of periodical profile 10 mm in diameter) and 12BP-P (12 mm in diameter) were tested for tensile stress on the MR-100 press in the laboratory of the Building Structures Department of O.M. Beketov National University of Urban Economy (Figure 1).

![Figure 1. Tensile test of the basalt fiber polymer rods.](image)

The length of the experimental rods was 40 cm. First attempts to stretch (break) the reinforcing rods were unsuccessful because of the poor grip with the press gripping device (rods were slipping or slamming). Next, after studying this issue, a decision was made to conduct windings from the rod ends with annealed wire with a diameter of 1 mm for 8 cm extension, but it also did not give a costly result. After 75 seconds of experiment, the rods slipped again on the top end, on the press scale it was 2300 kg. After that, there was an attempt to apply epoxy and then acrylic glues on the rod ends, but it also failed to produce the desired effect – the epoxy and acrylic glued layers were destroyed during the tensile force. In order to continue the study, special clamps of metal tubes of 7 cm in length were manufactured, and basalt fiber polymer fittings were installed there (Figure 2).
Figure 2. Experimental rod sample prepared for tensile test: 1 – basalt fiber polymer fitting, 2 – special metal tube, 3 – acrylic modified adhesive layer.

The distance between the fittings and the clamp was initially filled with epoxy glue, which for 83 seconds as a result of the tensile test was forged on a press scale of 2800 kg. Then the distance between the rod and the clamp was filled with acrylic modified adhesive. Basalt fiber polymer fittings were forged for 114 seconds on the press scale of 3500 kg. Were tested 3 basalt fiber polymer rod samples with a diameter of 10 cm and 12 cm (Table 1).

Table 1. The initial data of the basalt fiber polymer rods tensile test.

| Samples number | Samples mark | Tensile load, kg | $\sigma$, MPa | Forged time, sec | Metal fittings of similar diameter, class A400, MPa |
|----------------|--------------|------------------|---------------|-----------------|-----------------------------------------------|
| 1              | 10BP-P       | 3500             | 1062          | 114             | 590                                           |
| 2              | 10BP-P       | 3360             | 1020          | 113             | 590                                           |
| 3              | 10BP-P       | 3580             | 1087          | 117             | 591                                           |
| 4              | 12BP-P       | 4200             | 1275          | 117             | 592                                           |
| 5              | 12BP-P       | 4200             | 1275          | 118             | 589                                           |
| 6              | 12BP-P       | 4500             | 1266          | 121             | 590                                           |

In some foreign standards [9], it is not recommended to use composite reinforcement as compressed either in columns or in compressed structural elements, or even as compressed in bending elements. Nevertheless, the compressive strength of basalt fiber polymer reinforcement should not be neglected. For the following compression experiment under the press (flattening), as samples, were taken rods with a diameter of 10 mm and 12 mm, 10 cm in length. The data of the compression experiment, on changing the rods diameter from the applied load, are shown in Table 2.

Table 2. The initial data of the basalt fiber polymer rods compression test.

| Compression load, kg | Time, sec | 1.10BP-P, mm | 2.10BP-P, mm | 3.10BP-P, mm | 4.12BP-P, mm | 5.12BP-P, mm | 6.12BP-P, mm |
|----------------------|-----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 100                  | 5         | 9.5           | 9.6           | 9.6           | 11.6          | 11.4          | 11.4          |
| 250                  | 15        | 8.5           | 8.7           | 8.7           | 10.7          | 10.6          | 10.7          |
| 400                  | 25        | 7.0           | 7.5           | 7.4           | 9.0           | 8.9           | 9.1           |
| 650                  | 40        | 4.7           | 6.3           | 6.1           | 8.5           | 7.0           | 7.0           |
| 800                  | 55        | 2.8           | 4.9           | 4.5           | 4.9           | 5.0           | 4.9           |
| 1000                 | 65        | complete destr-n | 2.1         | 1.8          | 3.1           | 3.0           | 3.0           |
| 1100                 | 75        | complete destr-n | complete destr-n | complete destr-n | complete destr-n | complete destr-n | complete destr-n |
3. Determination of strength and deformability of adhesive anchoring in concrete using basalt fiber polymer reinforcement of periodical profile

The main purpose of the experimental research was to establish the strength and deformability of the adhesive anchoring, depending on the depth of basalt fiber polymer rods embedding in the concrete array (of different class) and the distance from the edge of the concrete samples.

The following test was carried out in the certified laboratory on concrete block samples of 200×200×200 mm. These blocks were pre-fabricated in factory conditions in steaming chambers. Technological holes for anchoring basalt fiber polymer rods were formed by drilling wells in concrete blocks in predetermined places using a manual pneumatic hammer drill with chisel-type crowns. The diameter of the crowns was taken depending on the diameter of the installed reinforcement and the thickness of the adhesive layer.

In order to determine the optimum depth of laying, it varied from 10 to 20 diameters of the basalt fiber polymer rod. The distance from the face of the concrete specimen to the geometric center of the basalt fiber polymer rod was taken from 5 to 15 of its diameter ($d_{bfp}$). The minimum value of 5$d_{bfp}$ was taken based on the technological conditions of well formation [10]. The thickness of the adhesive layer was taken 8 mm. Acrylic modified adhesive with improved adhesion properties was used to provide high strength adhesion of basalt fiber polymer bars with concrete [11]. As anchor samples were accepted basalt fiber polymer rods of periodical profile 10 mm in diameter with the following characteristics: modulus of elasticity ≈ 55000 MPa, tensile strength - 1250 MPa, density - 2.0 g/cm³, elongation factor - 2.5 %.

Before basalt fiber polymer bars embedding, the wells surfaces in concrete samples were cleaned of dust using compressed air, and the reinforcement was degreased with acetone. A total of seventeen series of samples were prepared for testing. There were six samples in each series.

The preparation of acrylic modified glue and its curing took place in vivo at an ambient temperature of 22-24 °C. The moisture content of concrete samples was not controlled.

The main characteristics of adhesive anchor joints samples are presented in Table 3.

| Series number | Concrete class | Basalt fiber polymer rod mark, $d_a$ | Bore diameter, $d_b$, mm | Embedment depth, $l_{emb}$, mm | Adhesive layer thickness, mm | Removal of the anchor axis from the face of the concrete sample, mm |
|---------------|----------------|-------------------------------------|--------------------------|-------------------------------|-----------------------------|-------------------------------------------------|
| 1             | C8/10          | 10BP-P                              | 22                       | 50                            | 8                           | 100                                             |
| 2             | C8/10          | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 3             | C8/10          | 10BP-P                              | 22                       | 150                           | 8                           | 100                                             |
| 4             | C12/15         | 10BP-P                              | 22                       | 50                            | 8                           | 100                                             |
| 5             | C12/15         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 6             | C12/15         | 10BP-P                              | 22                       | 150                           | 8                           | 100                                             |
| 7             | C16/20         | 10BP-P                              | 22                       | 50                            | 8                           | 100                                             |
| 8             | C16/20         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 9             | C16/20         | 10BP-P                              | 22                       | 150                           | 8                           | 100                                             |
| 10            | C8/10          | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 11            | C12/15         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 12            | C16/20         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 13            | C16/20         | 10BP-P                              | 22                       | 150                           | 8                           | 100                                             |
| 14            | C16/20         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 15            | C16/20         | 10BP-P                              | 22                       | 150                           | 8                           | 100                                             |
| 16            | C16/20         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
| 17            | C16/20         | 10BP-P                              | 22                       | 100                           | 8                           | 100                                             |
A general view of the experimental samples of adhesive anchoring before testing, to determine the joint strength and deformability, is presented in Figure 3.

![Figure 3. Experimental samples of adhesive basalt fiber polymer anchoring in concrete before testing.](image)

Strength tests of glued anchor joints were carried out after 6 days of curing the adhesive in natural conditions. To pull out the anchor from concrete samples massive, the MR-100 laboratory tensile testing machine was used as a power device. During the test, it was planned to remove the support installation nodes from the axis of the embedded rod, so that the concrete had the possibility of forming a puncture cone or other destruction with a small anchor embedment depth. The fixing of the anchor joint samples in the grips of the tensile testing machine was carried out using a special metal mold, which ensured that the position of the concrete specimen was unchanged during the joint destruction (Figure 4).

![Figure 4. Strength and deformability test of adhesive anchoring: 1 – concrete sample, 2 – basalt fiber polymer rod, 3 – metal mold, 4 – tensile testing machine.](image)

The deformability of the embedment was determined by measuring the displacements of the loaded end of the basalt fiber polymer rod with two deflection meters with an accuracy of 0.01 mm. In this case download speed was not controlled. The results of the strength and deformability testing of adhesive anchor joints samples are presented in Table 4.
Table 4. The value of deformability and bearing capacity of tested adhesive anchor joints.

| Series number | Concrete class | Adhesive layer thickness, mm | Removal of the anchor axis from the face of the concrete sample, mm | The average value of the bearing capacity joint, MPa | The destruction character of the adhesive joint |
|---------------|----------------|-----------------------------|------------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------|
| 1             | C8/10          | 8                           | 100                                                              | 1066                                             | cracks in concrete with a puncture cone puncture cone on adhesive-concrete contact |
| 2             | C8/10          | 8                           | 100                                                              | 1133                                             | puncture cone on adhesive-concrete contact   |
| 3             | C8/10          | 8                           | 100                                                              | 1147                                             | puncture cone on adhesive-concrete contact   |
| 4             | C12/15         | 8                           | 100                                                              | 1141                                             | puncture cone on adhesive-concrete contact   |
| 5             | C12/15         | 8                           | 100                                                              | 1239                                             | BFP rod destruction                         |
| 6             | C12/15         | 8                           | 100                                                              | 1243                                             | BFP rod destruction                         |
| 7             | C16/20         | 8                           | 100                                                              | 1185                                             | BFP rod destruction                         |
| 8             | C16/20         | 8                           | 100                                                              | 1241                                             | BFP rod destruction                         |
| 9             | C16/20         | 8                           | 100                                                              | 1246                                             | BFP rod destruction                         |
| 10            | C8/10          | 8                           | 80                                                               | 1121                                             | puncture cone on adhesive-concrete contact   |
| 11            | C12/15         | 8                           | 80                                                               | 1233                                             | BFP rod destruction                         |
| 12            | C16/20         | 8                           | 80                                                               | 1234                                             | BFP rod destruction                         |
| 13            | C8/10          | 8                           | 80                                                               | 1123                                             | puncture cone on adhesive-concrete contact   |
| 14            | C12/15         | 8                           | 80                                                               | 1230                                             | BFP rod destruction                         |
| 15            | C16/20         | 8                           | 80                                                               | 1231                                             | BFP rod destruction                         |
| 16            | C16/20         | 8                           | 100                                                              | 1235                                             | BFP rod destruction                         |
| 17            | C16/20         | 8                           | 100                                                              | 1228                                             | BFP rod destruction                         |

The results of the tests demonstrate that the destruction character and the direct strength of the adhesive joint of the basalt fiber polymer reinforcement with concrete significantly depend on the concrete class and the depth of BFP rods laying. Therefore, in the case of adhesive rods anchoring in concrete C12/15 to a depth of $5d_{bfp}$, the joint bearing capacity value was 1066 MPa (experimental series 1), which is almost 85% of the tensile strength of the basalt fiber polymer reinforcement. Destruction of the investigated joint type occurred on a concrete layer with the formation of cracks and/or puncture cone. In this case, the puncture cone was formed almost along the entire depth of the laying. This character of destruction is explained by the low strength of concrete.

With an increase in the depth of anchor embedment to 10 and 15 of its diameter, the value of the joint bearing capacity increased accordingly to 1133 MPa and 1147 MPa, respectively, which amounted to 90.6% and 91.7% of the tensile basalt polymer fiber rod strength. The destruction of the joint occurred with the formation of a concrete puncture cone at the adhesive-concrete contact. The height of the concrete puncture cone was 5 diameters of the depth of the BFP rod. When the anchor embedment depth is 15 diameters, in two cases, the joint failure occurred as a result of the rod destruction. An
increase in concrete strength from C8/10 to C16/20 entailed a general increase in joint strength and a change in the destruction character of the adhesive anchor joint.

With an increase in embedment depth to $l_{emb} = 10d_{bfp}$ and $l_{emb} = 15d_{bfp}$, the value of the bearing capacity of the joint increased almost to the limit of tensile strength of the basalt fiber polymer rod (series 5, 6, 7, 8, 16, 17). The destruction of the joint in all cases occurred as a result of the destruction of the rods. The research of the effect of removing the anchor from the concrete sample edge on the strength of the adhesive anchor joint showed the following information.

When the anchor approaches the edge of the concrete sample to $L = 5d_{bfp}$, embedding in a concrete C8/10 to a depth of $l_{emb} = 10d_{bfp}$ and $l_{emb} = 15d_{bfp}$, the bearing capacity of the adhesive anchor joint slightly decreases. The value of the joint bearing capacity decreased respectively to 1121 MPa and 1123 MPa (series 10 and 13), which amounted to 89.5% of the tensile strength of the BFP reinforcement. The destruction character of the joint is similar to the case of anchor embedment in the concrete block geometric center. In the case of rods embedment in concrete C12/15 and C16/20, the destruction of the joints occurred as a result of the anchors destruction, when the tensile strength of basalt fiber polymer rods was almost completely reached (series 11, 12, 14, 15).

On the basis of experimental results statistical processing, using correlation methods, graphs of the joints test specimens strength and deformability were developed, depending on the rods embedding depth at a distance of 100 mm from the concrete sample edge (Figure 5).

![Figure 5. The deformation diagrams of the adhesive joint of BFP rods with concrete, depending on the laying depth and the distance from the concrete sample edge.](image)

Obtained diagrams shows that the beginning of the displacement of the loaded end of the anchor was observed reaching 52.0 MPa in the case of $l_{emb} = 5d_{bfp}$, 75.0 MPa in the case of $l_{emb} = 10d_{bfp}$ and 95.0 MPa in the case of $l_{emb} = 15d_{bfp}$. During the experiment, a linear deformation character of the adhesive anchor was observed until the stress at its free end was equal to $\approx 650$ MPa. In this case, the displacement of the loaded anchor end at $l_{emb} = 5d_{bfp}$ amounted to 0.091 mm, at $l_{emb} = 10d_{bfp}$ amounted to 0.048 mm and at $l_{emb} = 15d_{bfp}$ amounted to 0.032 mm.
It should be noted that, when the anchor approaches the sample edge to $5d_a$, the displacements of the loaded anchor end, respectively, amounted to $l_{emb} = 10d_{bfp} - 0.042$ mm, at $l_{emb} = 15d_{bfp} - 0.029$ mm. However, at the moment of anchor joint destruction, its deformability is higher than in the first case.

4. Conclusions
1. Analyzing the experiments, we come to the conclusion that the declared technical conditions of the basalt fiber polymer reinforcement coincide with reality. This means that the composite reinforcement withstands a tensile load almost twice as much as a metal one, and the compression is about inferior to it by 30 MPa. Basalt fiber polymer reinforcement is entirely applicable in the chemical and metallurgical industries for various technological equipment fastening, under the influence of the external aggressive environment.

2. Acrylic modified adhesive provides reliable adhesion of basalt fiber polymer reinforcement to concrete in case of chemical anchoring. In its turn, the strength of the acrylic glued composition depends on the amount of filler, monomer and the quartz sand grain size.

3. As a result of research, it was determined that the optimal embedment depth of periodic basalt fiber polymer rods in the concrete mass drilled wells, using acrylic modified adhesives, is 10 diameters for C12/15 concrete and above, 15 diameters for C8/10 concrete and less.

5. References
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