Research Results of Pre-stressed Concrete Elements Using Stress Cements and Basalt-reinforced Plastic Reinforcement

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Abstract. Basalt fibres created from rocks of magmatic origin, in contrast to artificial glass, carbon, mineral fibres, are the only fibres that are produced from natural raw materials of magmatic origin. Basalt plastic reinforcement (BPR) classified as a modern composite material with good chemical and physical properties. Basalt fibbers and special organic binders, which ensure their joint efficient operation, are the basis for the production of BPR. The advantages and disadvantages of composite reinforcement are discussed in comparison with steel reinforcement. Proposals are stated needed for actions to improve and successful application mass of composite elements for the reinforcement of concrete structures.

Introduction

Research carried out to identify the possibility of creating prestressed concrete structural elements with basalt plastic reinforcement (BPR) based on the use of continuous basalt fiber (BCF). Basalt fibers created from rocks of magmatic origin, in contrast to artificial glass, carbon, mineral fibers, are the only fibers that are produced from natural raw materials of magmatic origin.

When using BPR in structures for reinforced concrete elements, it is possible to avoid problems associated with corrosion of steel reinforcement, which ultimately translates into the durability of structures. In addition, BPR has a low density, which can somewhat reduce the weight of reinforced concrete and reduce the pressure from its own weight. In the performed theoretical and experimental studies, new results were obtained on the design of concrete elements reinforced based on the use of BPR and stress concretes based on NTs-20 stress cements. Such structures have higher mechanical strength, corrosion resistance, heat-shielding and dielectric properties, non-magnetic and radio-transparent.

Basalt fiber for building reinforcement and other composite materials

The positive results obtained in the USSR in melting basalt in bath furnaces during the production of superfine basalt fibers (SBF) with the use of spinnerets formed the basis for research and development of a technology for the production of basalt continuous fibers (BCF) in a one-stage method [1, 2].

On the basis of crushed basalt processing the high basalt fiber (roving, filaments, basalt fiber etc.) can be obtained those having the following physical and mechanical characteristics:

1. Tensile strength 18000-19000 kgf /cm2,
2. 2650 - 6000C in the temperature range does not alter the physical and mechanical characteristics,
3. Corrosion resistance than iron and steel products 15 - 20 times higher,
4. Compared to materials based on iron and steel, structural weight obtained on the basis of basalt fiber is 3.5-3.6 times lighter,
5. Modulus of elasticity of basalt fiber is within a range of 650000-700000 kgf/cm2.

BPR has a number of advantages over steel reinforcement. The main advantages are:

Lightness - a significant advantage for all kinds of construction works. Low weight BPR not only facilitates its delivery (transport costs), unloading and installation, also due to the law weight of the structure the cost of the construction works and the total weight of the whole building or structure is also reduced, on the basis of which the costs of the foundation and other bearing structures are reduced.

Reliability – BPR reinforcement has more strength than steel reinforcement. This reinforcement has high ultimate (rapture) strength. It is capable of withstanding action of 1000 - 1200MPa. This indicator allows using the reinforcement in the construction of buildings and structures of various sizes and for various purposes.

Non-conductor of electricity (dielectric) - it allows boosting the quality of safety factor against fire, as well as eliminates the occurring of vagabond currents and accumulation of static voltage.

The high rate of resistance to corrosion processes - BPR is resistant to corrosion and virtually cannot be destroyed by corrosion.

Low thermal conductivity - the use of BPR allows reducing heat consumption, and energy through thermal bridges, respectively, which occur when a steel reinforcement is used. This quality is very important and should be taken into account in the construction of efficient structures in terms of heat energy consumption.

The strength characteristics of BNF exceed those of E-glass fiber, are close to special and carbon fibers, while having a low production cost. In terms of its strength characteristics, BNF occupies an intermediate position between glass fiber and carbon fibers. Taking into account the whole complex of characteristics, BCF has a number of advantages over glass, carbon and chemical fibers, as well as a better ratio of performance and cost.

Basalt plastic reinforcement (BPR) can be classified as a modern composite material with good chemical and physical properties. Basalt fibers and special organic binders, which ensure their joint efficient operation, are the basis for the production of BPR. A specific feature of the BP reinforcement is its anti-corrosion performance, antimagnetic and dielectric properties of the armature, and other features. BPR has high tensile, bending and tensile strength characteristics, which is especially important in those places where increased stress of structures or exposure to aggressive chemical media, including acids and alkalis, is expected [3-7]. It is more expedient to use BPR in the temperature range: from -70 to + 100 ° C (for special cases up to -160 ° C).

Numerous studies carried out have confirmed that the adhesion of concrete to BPR is less than the adhesion of concrete to steel reinforcement [3-7, 10-23]. Therefore, the factor in the adhesion of BP reinforcement to concrete should be given a greater role and attention than when adhesion to concrete of steel reinforcement. In this regard, numerous studies have been carried out in order to create the most acceptable corrugated surface of the BPR (Fig. 1, 2).

We found that the presence of a braiding thread and dents on the surface of the BPA greatly increases the adhesion of basalt plastic reinforcement to concrete, and later it was found that the increase occurs 3-4 times.

Fig. 1. Different options for creating a corrugated surface for BPR based on the use of a braid thread to create increased adhesion to concrete

The diagram "stress-strain" BPR, obtained with this method of production, is almost straightforward up to rupture.

By varying between the materials of the binder and filler, basalt fiber-based products can be obtained with the properties most suitable for a particular application. Due to the fact that for the reinforcement of concrete [8,9] and with the use of BPR, high strength of reinforcing rods is required, with a large number of tension-compression cycles, as well as alternating transverse forces, taking into account the dynamics, the selection of such materials in combination with concrete was given special meaning.

When analyzing the test results, we found that the highest adhesion rates of BPA and concretes made using NTs-20 were obtained by BPR samples with a winding with threads located at an angle of 45 degrees in the axis of the reinforcement.

Elastic modulus Ea. unidirectional basalt-plastic reinforcing bar (energized) can be calculated using the formula:

$$\text{Ep. bp} = \text{Eab Fst} + \text{Ec Fc}, \tag{1}$$

where: Ea and Ec - respectively, the modulus of elasticity for stretching the fiber and the binder;
Fst and Fc - volumetric content of basalt plastic and binder in the composite.

The section stress of the reinforcement itself must be determined by the following formula:

$$\sigma = \text{V1 E1 } \varepsilon 1 + \text{V2 E2 } \varepsilon 2, \tag{2}$$

where: V1 - respectively the volume of elasticity for stretching the basalt fiber and the binder;
Ea is the modulus of elasticity for stretching the fiber and the binder, respectively;
Ɛ1 - accordingly, Fst and Fc are the volumetric content of basalt plastic and binder in the composite.

Concrete elements manufactured using NTs-20 [8,9] can be reinforced with BPA of periodic profile. The design strength for the calculation of structures for a long-term load, taking into account the short-term strength of the BPA, is taken equal to:

$$\text{R} = 18000\text{XK} = 13950 \text{ kg/cm}^2, \tag{3}$$

where the coefficient κ = 0,65-0,7 takes into account the drop-in strength over time.

Considering that the industrial production of basalt plastic reinforcement is only getting better and standards for its characteristics have not yet been developed, the value of the coefficient 0,65-0,7 should be considered justified.

BPR modulus of elasticity E_a = 650000-750000kg / cm2; duration factor –0.65; deformation time coefficient –0.85-0.9.

Estimated characteristics of stressing concrete: Rdl = 320 kg / cm2; Unit = 25E4 kg / cm2.

The diameter of the reinforcement significantly affects the value of the ultimate strength of the basalt plastic reinforcement. The thinner the reinforcement, the higher its strength. Strength of reinforcement with a diameter of 3 mm reaches 1900MPa, and with a diameter of 10 mm - only 1200-1300 MPa. Therefore, with an increase in the BPR diameter, its increased content in structures is required, which leads to a rise in the cost of structures.

The tensile strength of such a composite material was determined by the formula:

$$\sigma_k = \sigma_m \nu_m + (1 - \nu_m)\sigma_n = \sigma_m \nu_m + \sigma_n \nu_n, \tag{4}$$

where: tensile strength of composite material, metal and coating, respectively, MPa;
volume fraction of metal and coating, respectively, %.

Formula (1) is valid only for ideal adhesive contact with concrete, assuming that:

a) the connection between BPR and concrete is perfect,

b) the interaction of BPR and concrete does not lead to the appearance of transverse deformations,
c) there are no residual stresses in the structures before loading,
d) all phases at all stress levels are in conditions of equal deformation,
e) the fibers in the BPR are located parallel to the loading axis.

Hence = 375MPa. The actual strength (control) of the composite samples was determined on a tensile testing machine at the institutes KivZNIIEP and TbilZNIIEP.

Data for the based on the studies of test samples of with BPR periodic (ribbed) profile made by tightening methods in the experimental setup.

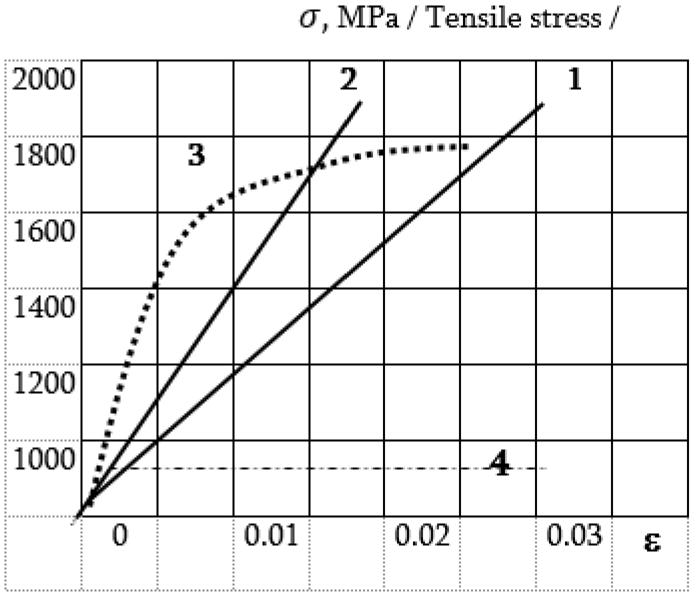

Fig. 2. The dependence of the relative elongation ε of the stressed σ for:
1. BPR, 2. cold-drawn steel, 3. high-strength cable, 4. steel with high yield stress

BPR "Stress-strain" diagram obtained with this method of production is substantially rectilinear to failure (Fig. 2). However, the data are experimental and subject to further refinement, taking into consideration the content of the fiber. The essential fact is that the diameter affects the temporary resistance value of the BPR, thinner reinforcement, the greater its strength.

Due to the fact that elements made of a composite material can be in conditions of sharp temperature changes, there is a concern that due to the difference in the coefficients of linear expansion and in connection with a decrease in adhesion strength, the strength indicators of BPR will decrease.

One of the most time-consuming technological operations in the production of prestressed concrete products is the laying and tension of reinforcing bars. Therefore, it makes sense to pay more attention to the development of various self-stressed concrete structures, reinforced based on the use of BPR. In such structures, it is more expedient to use high-strength BPR for tensioning, based on the use of tensile concrete, in comparison with mechanical or electromechanical tension of reinforcing bars.

The use of BPR for reinforcing prestressed concrete elements will reduce the estimated cost as a result of reducing the consumption of materials (in particular, high-strength steels and concrete) and, therefore, will reduce the material and energy consumption of production and will allow the introduction of new progressive solutions.

Conclusions and recommendations

The carried out theoretical and experimental studies give grounds to draw the following conclusions:

1. Thanks to scientists from Kiev, a new branch of production of continuous fiber from basalt stone was born, which had no analogues at that time in the world,
2. The use of BPR and stressing concretes makes it possible to obtain materials not only without metal, but also having qualitatively new higher characteristics, allowing to increase the service life of structures used in an aggressive environment, reduce the metal consumption of structures, their weight, cost and, accordingly, the labor intensity of construction. Such structures have higher mechanical strength, corrosion resistance, heat-shielding and dielectric properties, are non-magnetic and radio-transparent,
3. The strength of the BPR is quite sufficient to ensure the required bearing capacity of concrete elements, in which BPR is supposed to be used as prestressed reinforcement,
4. The results of comparing the obtained values according to the proposed methodology, according to the SNiP 11-21-85 methodology and on computer modeling to determine the stress-strain state of structures differ on average by 15-20%,
5. The use of low expansion energy stress cement to create prestressed structures should be considered ineffective because the destruction of beams occurs before reaching the limit values in the basalt plastic reinforcement. The most expedient can be the use of stressing cements NTs-40 or higher in combination with basalt-fiber-reinforced concrete.

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