

Creating Conditions for the Industrial Application of Basalt-Plastic Reinforcement in Manufacturing Precast Concrete Structures

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Abstract. *The search for alternative methods of replacing steel reinforcement in load-bearing reinforced concrete structures with composite polymer reinforcement is an urgent scientific and practical task. Composite reinforcement (basalt-plastic, fiberglass) is an economically viable alternative to steel reinforcement; it possesses high tensile strength and chemical resistance, light weight (more than 4 times lighter than the steel ones), low thermal conductivity, radio transparency, dielectric properties. Such properties make it possible to use this type of reinforcement of concrete structures in civil, industrial, and road construction. Only in recent years, the specialists in Uzbekistan have paid special attention to the need for composite polymer reinforcement in construction. This type of reinforcement makes it possible to increase the service life of concrete structures and the building as a whole and to reduce the country's dependence on imports of steel reinforcement. At present the production of basalt-plastic reinforcement is localized in the country – its fiber is made from local basalt. For the possibility of industrial application of composite polymer reinforcement in construction, it is necessary to establish a relationship between a customer, a designer, and a manufacturer. For a customer, the project must be economically profitable, a designer must understand the physical and mechanical properties of the reinforcement and know the regulatory base, and a manufacturer must be interested in producing quality units and assemblies in accordance with the interstate standards, and be sure that the reinforcement produced by him will be in demand. The high deformability of structures caused by the low modulus of elasticity of composite reinforcement does not allow the manufacture of structures that work as bending and eccentrically compressed elements, embedded in reinforced concrete; however, it is noted that such reinforcement can be used in structures for which the requirements for the second group of limiting states are not determinant. The national standards acting in the CIS countries and other states limit the scope of application of composite polymer reinforcement in concrete structures in industrial objects of the economic complex.*

An analysis of the actual operation of prefabricated road panels, taking into account the low deformation characteristics of basalt-plastic reinforcement, showed the possibility of replacing steel reinforcement with a composite polymer one according to the criterion of uniform strength in terms of design tensile strengths while maintaining the number of working reinforcement bars and their location in reinforcing units.

The results of testing the pilot panels of the road surface (prefabricated ones) reinforced with basalt-plastic reinforcement were considered to determine their crack resistance and bearing capacity. The test results of experimental road panels show that the bearing capacity not only decreased but substantially increased. The high corrosion resistance of basalt-plastic reinforcement, when used in road panels, contributes to an increase in the service life of such panels, since the values of crack opening under operational loads are set lower than the permissible limit values. The results of this study show that it is possible to expand the scope of industrial application of basalt-plastic reinforcement in the production of precast concrete structures, for example, for road construction. To do this, it is necessary to create a regulatory framework based on the results of relevant research work.

Keywords: *Composite polymer reinforcement; Problems of industrial application; Basalt-plastic reinforcement; Road panels; Tests.*

I. INTRODUCTION

Ensuring reliability under specified conditions and operating modes is a fundamental task that must be solved at all stages of the life cycle of buildings and structures. Reliability should be supported by the durability and safety margin of separate building elements and the structural system of the building as a whole [1]. The durability of reinforced concrete structures is maintained largely by the durability of steel reinforcement, which in turn depends on the corrosion resulting from the force and environmental influences. Due to the corrosion of steel reinforcement, and, to some extent, of the concrete itself, there occurs a loss of bearing capacity of reinforced concrete structures.

Considering that the safety of reinforcement is one of the key parameters that ensure the durability of reinforced concrete structures, the replacement of steel reinforcement with composite reinforcement is of great importance [2].

To date, the improvement of the properties of steel reinforcement has reached a level above which the development is impractical due to the fact that there is no need for this, or it is theoretically impossible [3].

Revised Manuscript Received on October 20, 2020.

Manuscript Received On October 06, 2020

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The search for alternative ways to replace steel reinforcement in the bearing elements with a composite one (no corrosion and high bearing capacity) is an important scientific and practical task for the present [4]. Composite reinforcement has high corrosion resistance to chemical environments; this solves the problem of reinforcement corrosion in structures.

Today, in the CIS countries and in many other countries, due to economic features, fiberglass and basalt-plastic composite reinforcement has become widespread in construction.

Studies on the creation of basalt-plastic reinforcement and organization of its industrial production are conducted so far only in Russia and are promising for the following reasons [5, 6]:

- raw material to obtain continuous basalt fiber is cheap;
- the technology for producing basalt fiber does not differ from the technology for manufacturing glass fibers; there is no need to manufacture a multi-component feed stock, to transform it into a smelt and to form glass "balls"; all these can significantly reduce the fiber cost;
- for basalt-plastic reinforcement, in contrast to fiberglass one, it is possible to use less scarce and economical coupling agents and binders.

Composite basalt-plastic reinforcement is not only an economically feasible alternative to steel reinforcement, but it also represents an innovative building material that allows achieving positive results that are impossible to obtain with traditional steel reinforcement: to solve the problem of reinforcement corrosion, to reduce the mass of the structure, to increase the service life and reliability, especially when the structure operates in aggressive environments, and to increase significantly the overhaul period, which will significantly reduce the costs of further service [7].

There is no ferrous metallurgy in Uzbekistan; therefore, the use of composite reinforcement based on basalt in an industrial volume makes it possible to reduce the dependence of our country on imports of steel reinforcement. In this regard, a joint venture "MEGA INVEST INDUSTRIAL" is founded in Jizzakh region, where continuous basalt fiber is produced from local basalt stone, and composite basalt-plastic reinforcement of a diameter from 4 to 24 mm is made. The reserves of raw materials for the production of continuous basalt fiber could last for several hundred years, they are sufficient not only for the production of composite reinforcement for construction but also for other composite materials planned for future production.

Composite reinforcement has high tensile strength (normative tensile strength of basalt and fiberglass reinforcement is $R_{fn} = 800$ MPa), and, at the same time, low modulus of elasticity ($E_f = 50,000$ MPa), linear stress-strain relationship, small values of residual deformations at the time of tensile break (no more than 2.4%).

The low modulus of elasticity of composite reinforcement does not allow manufacturing most of the serial elements that are traditionally embedded in reinforced concrete. Due to the small values of residual deformations at the time of tensile break of the composite reinforcement, the issue of reinforcing

structures intended for operation in seismic regions has not been determined.

Specialists of the Tashkent Institute of Architecture and Construction have developed state standards for the design of concrete structures reinforced with composite polymer reinforcement (SHNK 2.03.14-18), launched by the Ministry of Construction of the Republic of Uzbekistan on April 1, 2019. This normative document regulates the methods of calculation and design of concrete elements reinforced with composite reinforcement. These norms are based on the principal methods for calculating reinforced concrete structures in Uzbekistan (national standards of Uzbekistan KMK 2.03.01-96 "Concrete and reinforced concrete structures") and Russia (SP 63.13330.2018 Code specifications "Concrete and reinforced concrete structures. Fundamentals"), which do not always reflect the actual operation of composite polymer reinforcement in concrete elements. The norms ShNK 2.03.14-18 (section 1 "Application field") restrict the use of composite polymer reinforcement in the construction of a number of facilities in the country's economic complex. For example, the recommendations of these standards do not concern to building elements that perceive vertical and horizontal seismic loads (columns and crossbars of the frame, floors, vertical bearing elements of large-plate and monolithic buildings, diaphragms and stiffening cores). Further, when using composite polymer reinforcement in structures that are not provided for by the recommendations of these norms and regulations, it is necessary, in the project stage, to provide for a computational-experimental assessment of the strength, crack resistance and deformability of these structures, taking into account the coefficient of the conditions of work stated in the national standards KMK 2.01.03- 96 "Construction in seismic areas". Thus, further studies of the stress-strain state of concrete structures with composite polymer reinforcement is a relevant task.

The abovementioned norms and standards SHNK 2.03.14-18 restrict the use of composite polymer reinforcement in structures built for various purposes, but they contribute to the creation of a regulatory base for its widespread use in construction on our country, being an innovative building material. The regulatory base is planned to be created by developing departmental building codes that take into account the specifics of the country's economic sectors and establish requirements for the design, production of structures and units, construction, (with the development of design documentation and technical specifications for the production of structures for various purposes using composite polymer reinforcement (basalt-plastic and fiberglass) - defining the range of products and testing experimental structures. Currently, due to the lack of relevant regulatory documents for the design of concrete structures with composite polymer reinforcement, the areas of its application in our country are the reinforcement of masonry of load-bearing walls to increase their bearing capacity and operational reliability, the strengthening of the canal and river banks, drainage trays, paving plates, industrial floor slabs, lightly loaded strip foundations and foundation slabs.

Composite polymer reinforcement is practically not used in structures manufactured at precast concrete factories.

The lack of the necessary design regulatory framework limits the use of composite reinforcement in structures for various purposes; however, the main problem of using such reinforcement is predetermined, as noted above, by a low modulus of elasticity, which means high deformability of structures reinforced with composite reinforcement [8, 9, 10].

Therefore, it can be assumed that composite polymer reinforcement can be used in those structures for which the requirements for the second group of limiting states are not determinant. For example, road plates calculated as structures on an elastic foundation - under appropriate soil conditions, when the plate does not function as a cantilever structure. The aim is to analyze the prospects and problems of using concrete structures with composite polymer reinforcement, to consider their implementation in industrial construction having as an example the use of basalt-plastic reinforcement in prefabricated concrete road plates.

II. METHODOLOGY

II.1. Design methodology according to the criterion of uniform strength of structure materials

Analysis of the actual operation of prefabricated panels of road surfaces and the reinforcement schemes given in [11, 12, 13, 14] showed the possibility of alternative reinforcing by replacing steel reinforcement with composite polymer reinforcement according to the criterion of uniform strength in terms of design tensile strengths while maintaining the number of working reinforcement bars and their location in reinforcing units. As advised by the Manufacturer (JV "BINOKOR TEMIR BETON SERVIS") production drawings were plotted to study the road plates, similar to the plates of brands 1P18.18-10 and 1P18.18-30, designed for permanent urban roads surface under a car load of N-10 and H30, based on (GOST 21924-84 "Interstate standards. Reinforced concrete plates with non-tensioned reinforcement for urban roads surface"). Plates of the above brands are supplied in a massive scale to the Consumer; as they are the most widely used plates in road construction in the country. These panels have a section height of 160 mm and are reinforced with hot-rolled rebar. The design tensile strength of steel reinforcement (R_s) of the A400 brand is 355 MPa, and the design tensile resistance of basalt-plastic reinforcement is $R_f = 490$ MPa according to the above-mentioned state standards of Uzbekistan KMK 2.03.01-96 and ShNK 2.03.14-18, respectively. The results of replacing steel reinforcement with basalt-plastic reinforcement for the considered brands of road panels are given in Table 1.

Table 1. Results of uniform strength replacement of steel reinforcement with composite basalt-plastic reinforcement for the considered brands of road plates

Road plate brand	Diameters of working reinforcement bars of plates, mm	
	steel	basalt-plastic
1P 18.18-10	Ø10A400	Ø8BPR
1P 18.18-30	Ø12A400	Ø10BPR

Physical and mechanical characteristics of the basalt-plastic reinforcement produced by the joint venture "MEGA INVEST INDUSTRIAL" and used in the road plates

under consideration are given in Table 2. The tests were performed in accordance with the requirements of interstate standards GOST 31938-2012 "Composite polymer reinforcement for reinforcing concrete structures" and GOST 32492-2015 "Composite polymer reinforcement for reinforcing concrete structures. Methods for determining physical and mechanical characteristics."

Table 2. Indices of physical and mechanical characteristics of basalt-plastic reinforcement

Controlled indicator	Standard value of the indicator according to GOST 31938-2012	Measured indicator (average value)	
		Ø8BPR	Ø10BPR
Tensile strength, MPa	800	984	949
Tensile modulus, MPa	50000	53400	51600
Bond strength to concrete, MPa	No less than 12	12.6	13.8
Decrease in tensile strength after holding in an alkaline medium,%	No less than 25	6.5	5.8

The meshes and frames for the road plates under consideration were constructed by tying the rods from basalt-plastic reinforcement using low-carbon steel wire (a "knitting" wire). The number of rods and their spacing in meshes and frames, as well as their design position, and the grade of concrete were taken in accordance with the requirements of the above-mentioned GOST 21924-84 for brands of road plates reinforced with steel reinforcement.

III. TEST PROCEDURE

The road plates, reinforced with composite basalt-plastic reinforcement, implemented in the JV "BINOKOR TEMIR BETON SERVIS", were tested according to the design scheme (Fig.) given in GOST 21924.0-84 "Reinforced concrete plates for urban road surfaces. Specifications", considering the relevant requirements of the Interstate standards GOST 8829-94 "Concrete and reinforced concrete prefabricated building products. Loading test methods. Rules for assessing strength, stiffness and crack resistance".

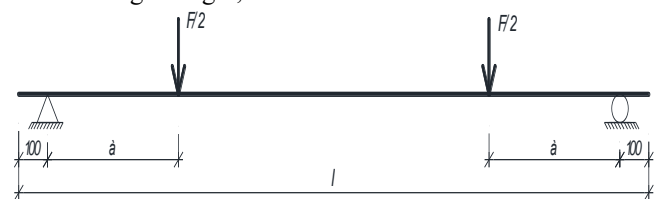


Figure. Road plate testing scheme according to GOST 21924.0-84, drawing 9 (here: $a = 400$ mm, $l = 1800$ mm, depending on the standard size of plates)

The plate is considered to pass the test when the following conditions are met:

- when the control load for crack resistance is reached, the maximum crack opening width should not exceed the maximum permissible value of 0.2 mm;
- the plate destruction does not occur (the fracturing or slippage of the tensioned reinforcement, concrete crushing or shearing in the compressed zone) when the control load strength is reached.

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The plates were loaded with concrete blocks in steps of 0.05 of the reference strength load. The crane balance of the OCS-SP-1 type was used. The cracking was measured with an MPB-2 microscope with 0.05 mm graduation.

The concrete strength of the tested road plates was determined by a Silver Schmidt sclerometer of the RSN type (a shock-impulse method) and an ONIX-OS device with an electronic unit (to determine the strength and brand of concrete by the method of the shear test) and was 26.7 MPa, which is higher than the specified delivery strength of concrete in road plates of brand B30 according to the Interstate standards GOST 13015-2012 "Concrete and reinforced concrete products for construction. General technical requirements. Rules for acceptance, labeling, transportation, and storage".

IV. TEST RESULTS AND THEIR DISCUSSION

Data on control loads and test results of road plate s reinforced with basalt-plastic reinforcement are given in Table 3 (excluding the plate's own weight). The own weight of the plates is 1P18.18-10 - 1070 kg; 1 P 18.18-30 - 1075 kg.

Table 3. Test loads and experiment results of road plates

Road plate brand	Test load for crack resistance, kN	Width of crack opening at test load for crack resistance, mm	Test load for strength, P_{cont} , kN	Breaking load P_u for plate, kN	P_u/P_{cont}
1P18.18-10	71.5	0.20	129.4	144.7	1.12
1P18.18-30	100.9	0.25	184.2	192.4	1.04

The destruction of the test road plate, reinforced with basalt-plastic reinforcement, occurred as a result of concrete crushing in the compressed zone. The plate were not damaged under control strength load.

According to the International Standards GOST 21924-84, under control loads for crack resistance, the maximum crack opening width when testing road plates reinforced with steel reinforcement should not exceed 0.2 mm. The increased crack opening in the test plates is related to the low modulus of elasticity of the composite polymer (basalt-plastic) reinforcement. However, the corrosion resistance of the composite reinforcement compensates for this factor; and the crack formation in concrete does not lead to corrosive failure, as is the case with the structures reinforced with steel reinforcement [6, 15]. In addition, in the aforementioned state standards of Uzbekistan for the design of concrete structures with composite polymer reinforcement ShNK 2.03.14-18 and Russia SP 295.1325800.2017 "Code specifications. Concrete structures reinforced with polymer reinforcement. Rules for design" the maximum permissible crack opening width ($a_{crc,ult}$) is 0.5 mm at long-continued crack opening (regardless of the operating conditions of the structures).

The tests results established the following:

when replacing steel reinforcement of plates covering permanent urban roads under road loads of H-10 and H-30 (GOST 21924-84) with composite (basalt-plastic) reinforcement according to the criterion of their uniform

strength in terms of design tensile strength, the bearing capacity of the plates does not decrease;

a slight increase in the crack opening in the test plates does not lead to their corrosive failure due to the high corrosion resistance of the basalt-plastic reinforcement to the effect of aggressive media (acids, alkalis, salts, ammonia water, etc.).

V. CONCLUSION

1. Experimental studies indicate the fundamental possibility of using basalt-plastic reinforcement to reinforce prefabricated road plates. At that, the economic effect is achieved by lower costs for the manufacture of meshes and frames from basalt-plastic reinforcement (due to a 5 times weight reduction as compared to similar reinforcement units); and the high corrosion resistance of basalt-plastic reinforcement contributes to an increase in the service life of road plates.
2. To expand the scope of application of composite polymer reinforcement (including basalt-plastic one) in construction of the country, it is necessary to create a regulatory base (to develop departmental building codes), taking into account the specifics of the industry, regulating the design rules for the structures with the reinforcement of this type in seismic regions, establishing requirements for control parameters in limiting states.

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Dr. Mirzaev Pulat, Professor of the Department of Building Structures of the Tashkent Institute of Architecture and Construction; he has graduated from the Tashkent Polytechnic Institute with a degree in Industrial and Civil Engineering. He graduated from the postgraduate course of the Kiev Civil Engineering Institute and defended the thesis on the deformability study of prestressed ceramsite concrete bent elements under long-term loading. He is the author of 41 articles published in journals in Uzbekistan and other countries (including 4 articles in journals from the SCOPUS database); has 5 patents for utility models. He is a scientific supervisor of 4 state grant projects and 14 innovation projects commissioned by departments and individual enterprises. Areas of scientific and innovative activity are safety and reliability of buildings (structures) elements in seismic regions; introduction of new generation of reinforced concrete and composite-concrete structures in the construction in seismic areas; technical condition assessment and anti-seismic strengthening of buildings and structures. He is supervising the development of normative documents of the republican rank - urban planning norms and rules SHNK 2.03.14-18 "Concrete structures with composite polymer reinforcement". He is the winner of the Republican competition "The best teacher of a higher educational institution of Uzbekistan" in the nomination of "The best teacher-researcher" (2015).



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