Regulatory support for the use of composite rod reinforcement in concrete structures

S Merkulov¹, V Rimshin², E Akimov³, V Kurbatov⁴ and S Roschina⁵

¹ Kursk State University, 305000, Radishcheva St., 33, Kursk, Russia
² Research Institute of Building Physics of the Russian Academy of Architecture and Building Sciences, 127238, 21, Locomotive passage, Moscow, Russia
³ Belgorod State Technological University named after V. G. Shukhov, 308012, 46 Kostyukova St., Belgorod, Russia
⁴ Belgorod State Technological University named after V.G. Shukhov, 357202, 24 Zheleznovodskaya St., Mineralnye Vody, Stavropol region, Russia
⁵ Vladimir State University named after Alexander and Nikolay Stoletovs, 600000, 87 Gorky St., Vladimir, Russia

E-mail: v.rimshin@niisf.ru

Abstract. Currently, regulatory documents for the design of reinforced concrete structures with composite rod reinforcement do not contain unambiguous provisions for the purpose of the design resistances of the reinforcement, there are no instructions for the design of structures to ensure fire resistance. The article presents an analysis of technical documentation and experimental studies to determine the mechanical characteristics of rod composite reinforcement. As a result of the research conducted by the authors, it was found that the tensile strength of rebar decreases in some cases by 35% when the diameter of rebar rods increases from 5 mm to 10 mm. When analyzing technical documentation and test results, the coupling of composite reinforcement rods with screw winding with concrete up to 14.0 MPa is provided. It is proposed to take a value of 50 °C below the glass transition temperature of the matrix polymer as the maximum permissible temperature for heating rebar rods in a concrete structure. The directions of further improvement of the regulatory framework for the design of reinforced concrete structures with composite rod reinforcement are outlined.

1. Introduction

The main task to be solved at all stages of the buildings and structures life cycle is to ensure reliability under specified conditions and operating modes, which is supported by the durability and reliability of both individual building structures and the structural building system as a whole. Corrosion damage not only reduces the bearing capacity of individual structures, but can also cause the collapse of the entire building [1-4]. Increasing the durability of reinforced concrete structures is solved by the use of non-metallic composite reinforcement. The non-metallic composite reinforcement use is effective both in the precast and monolithic reinforced concrete manufacture, as well as in the exploited reinforced concrete and stone structures reinforcement. Regulatory documents recommend the non-metallic composite reinforcement use in the reinforced concrete structures operation in aggressive conditions. Currently a certain range of non-metallic composite reinforcement production was mastered. Non-
metallic composite reinforcement has absolute resistance to aggressive environments (chloride, sulfate), high strength, composite reinforcement is fireproof, non-conductive and diamagnetic, has high rheological properties, does not lose high strength properties when exposed to extremely low temperatures. At the same time, the composite reinforcement use is constrained by the lack of experimentally sound regulatory framework for the design and manufacture of structures [5-7].

By structure, the polymer composite reinforcement is a highly oriented fibrous polymer, their high tensile strength is due to the strength parallel oriented fibers (glass, carbon, basalt, aramid) bonded by a polymer matrix. On the one hand, the polymer matrix provides the joint work of composite yarns under axial tension, on the other hand, it determines a number of properties the rod composite reinforcement, which are disadvantages: low elastic modulus, creep, low long-term strength. The matrix gives the product the necessary shape, combines multiple fibers into one and allows the composition to perceive various kinds of efforts [8-12]. The matrix creates the composite bearing capacity, providing the transfer of forces to the fibers, transfers forces from the destroyed to neighbouring undamaged fibers and reduces stress concentration near various defects. The matrix protects the fibers from mechanical damage and oxidation, and therefore must withstand greater deformations than fibers. Heat and moisture resistance, resistance to aggressive media, strength, dielectric and other properties of composite reinforcement depend on the polymer matrix. The polymer matrix for composites is selected based on the operating conditions. An increase in the amount of resin in the composite reinforcement rod reduces its strength. As the matrix used polyester and epoxy resins related to the so-called thermosetting resins [13-20].

It seems relevant to conduct experimental studies on the composite reinforcement design characteristics normalization, on the assessment of the bar reinforcement adhesion forces with concrete, on ensuring the specified fire resistance of concrete structures with composite bar reinforcement.

2. Methods
Modern codes and national standards do not contain experimentally justified guidelines for establishing the design composite reinforcement characteristics, which allow assigning appropriate values for designing concrete structures. The concrete structures with composite reinforcement design is possible only in relation to the specific enterprises products – composite polymer reinforcement manufacturers [21-32]. At the enterprises where composite materials are manufactured, technical specifications for various types of reinforcement have been developed. Composite polymer rod reinforcement is divided into the following types: glass composite reinforcement (GSR) with continuous reinforcing fiberglass; basalt-composite reinforcement (BCR) with continuous reinforcing basalt fiber; carbon composite reinforcement (CCR) with continuous reinforcing carbon fiber; aramid composite reinforcement (ACR) with continuous reinforcing aramid fiber. Various manufacturers set the tensile strength of GSR in the range of 800 - 1250 MPa, the strength of BCR in the range of 800 - 1450 MPa, GOST (State Standard) 31938-2012 sets the tensile strength of GSR and BCR at least 800 MPa. This leads to a situation, when designing structures for bar composite reinforcement, design characteristics specified in the specifications manufacturer of composite materials are assigned, or the recommended minimum characteristics are accepted GSR - 800MPa, BCR - 800 MPa, CCR - 1400.

3. Results and discussion
The authors conducted experimental studies of composite bar reinforcement, which made it possible to propose the composite reinforcement strength characteristics (table 1).

Experimental studies of the rod polymer-composite reinforcement adhesion to concrete were also carried out by pulling reinforcing bars from concrete cylinders, and rod composite reinforcement with screw winding was tested. The mechanism of reinforcing bars destruction is established, the displacement of the rod in concrete occurs with the coils peeling of winding. The average adhesion strength was 14.0 MPa.
Nowadays the properties of concrete structures with rod composite reinforcement under high temperatures remain poorly understood. Reinforced concrete structures are fire-resistant due to the protective layer of concrete for processing steel reinforcement. The regulatory documents on the reinforced concrete structures design contain requirements for the protective layer of concrete for bar steel reinforcement designation, according to which the concrete protective layer should ensure the joint operation of reinforcement with concrete, reinforcement anchoring, reinforcement protection from external influences and structure fire resistance. In this case, the main purpose of the protective layer is to ensure the joint work of steel reinforcement with the surrounding concrete and to ensure high-quality laying of the concrete mixture.

Fire resistance of building structures determines how building structures are able to maintain their operational functions during a fire for a certain time during a fire. The ultimate state of fire resistance is the loss of load-bearing capacity for load-bearing reinforced concrete structures. The fire resistance of reinforced concrete structures is determined by heating the steel working bar reinforcement in the structure to 300 - 350°C. The reinforcement properties are sharply reduced when steel bars are heated to 350°C and higher. The temperature is assigned for the operating temperature of the composite bar reinforcement, so when exceeded, it causes a sharp decrease in the physical and mechanical reinforcement characteristics due to the polymer composite matrix softening. When exposed to high temperature, the polymer matrix in the composite rod changes from a glassy to elastic state and the polymer matrix softens. The composite reinforcement strength and deformation properties are sharply reduced after reaching the glass transition matrix polymer temperature. The polymer matrix softening disrupts the adhesion of the composite rod to concrete, in addition, it is possible to break off the concrete protective layer in the structure due to the significant transverse expansion of the composite polymer rods during heating. The temperature limit for a composite material based on polyester resins is 150°C, on the basis of epoxy resins is 200°C, on the basis of phenol-formaldehyde resins is 250°C.

The composite bar reinforcement integrity is completely violated upon reaching extreme temperatures. Studies of the heating temperature influence on its mechanical properties determine approaches to the concrete protective layer designation in order to ensure the structures fire resistance [8]. It is necessary to establish requirements for the thickness design of the protective layer to prevent the rods from heating to the polymer matrix reinforcing bar softening temperature to ensure the concrete structures with composite reinforcement fire resistance.

The heating temperature of the working reinforcement, which determines the structure fire resistance, depends on the duration of the open flame on the structure and temperature exposure schemes. Temperature fire patterns were adopted in order to assess the reinforced concrete structures fire resistance: for ceilings, the impact from below was considered, for beams – from three sides, for the frame – from four sides. It was found that when one-way heating for 60 minutes, the concrete is heated to a temperature 100°C at a depth 75 mm, and for 90 minutes – at a depth 90 mm. in these conditions, composite core reinforcement use based on polyester resins is impractical. Under these conditions, composite rod reinforcement use based on polyester resins is not advisable. It is possible to use composite reinforcement based on phenol-formaldehyde resins, and the thickness of the concrete

### Table 1. Strength characteristics of composite reinforcement

| Reinforcement class           | Standard tensile strength (MPa) with the rods diameter | Reinforcement design resistance for the first limiting states (MPa) with the rods diameter |
|-------------------------------|------------------------------------------------------|-----------------------------------------------------------------------------------------|
|                               | 6 8 10 12 14-32                                      | 6 8 10 12 14-32                                                                          |
| Fiberglass reinforcement       | 1200 1050 950 900 800                               | 920 800 730 690 620                                                                     |
| Basalt-plastic reinforcement   | 1500 1400 1100 1000 900                              | 1150 1070 850 760 690                                                                   |

Nowadays the properties of concrete structures with rod composite reinforcement under high temperatures remain poorly understood. Reinforced concrete structures are fire-resistant due to the protective layer of concrete for processing steel reinforcement. The regulatory documents on the reinforced concrete structures design contain requirements for the protective layer of concrete for bar steel reinforcement designation, according to which the concrete protective layer should ensure the joint operation of reinforcement with concrete, reinforcement anchoring, reinforcement protection from external influences and structure fire resistance. In this case, the main purpose of the protective layer is to ensure the joint work of steel reinforcement with the surrounding concrete and to ensure high-quality laying of the concrete mixture.

Fire resistance of building structures determines how building structures are able to maintain their operational functions during a fire for a certain time during a fire. The ultimate state of fire resistance is the loss of load-bearing capacity for load-bearing reinforced concrete structures. The fire resistance of reinforced concrete structures is determined by heating the steel working bar reinforcement in the structure to 300 - 350°C. The reinforcement properties are sharply reduced when steel bars are heated to 350°C and higher. The temperature is assigned for the operating temperature of the composite bar reinforcement, so when exceeded, it causes a sharp decrease in the physical and mechanical reinforcement characteristics due to the polymer composite matrix softening. When exposed to high temperature, the polymer matrix in the composite rod changes from a glassy to elastic state and the polymer matrix softens. The composite reinforcement strength and deformation properties are sharply reduced after reaching the glass transition matrix polymer temperature. The polymer matrix softening disrupts the adhesion of the composite rod to concrete, in addition, it is possible to break off the concrete protective layer in the structure due to the significant transverse expansion of the composite polymer rods during heating. The temperature limit for a composite material based on polyester resins is 150°C, on the basis of epoxy resins is 200°C, on the basis of phenol-formaldehyde resins is 250°C.

The composite bar reinforcement integrity is completely violated upon reaching extreme temperatures. Studies of the heating temperature influence on its mechanical properties determine approaches to the concrete protective layer designation in order to ensure the structures fire resistance [8]. It is necessary to establish requirements for the thickness design of the protective layer to prevent the rods from heating to the polymer matrix reinforcing bar softening temperature to ensure the concrete structures with composite reinforcement fire resistance.

The heating temperature of the working reinforcement, which determines the structure fire resistance, depends on the duration of the open flame on the structure and temperature exposure schemes. Temperature fire patterns were adopted in order to assess the reinforced concrete structures fire resistance: for ceilings, the impact from below was considered, for beams – from three sides, for the frame – from four sides. It was found that when one-way heating for 60 minutes, the concrete is heated to a temperature 100°C at a depth 75 mm, and for 90 minutes – at a depth 90 mm. in these conditions, composite core reinforcement use based on polyester resins is impractical. Under these conditions, composite rod reinforcement use based on polyester resins is not advisable. It is possible to use composite reinforcement based on phenol-formaldehyde resins, and the thickness of the concrete
protective layer is doubled compared to similar structures with steel reinforcement. High temperatures affect on the physical and mechanical characteristics of rod composite reinforcement and impose certain restrictions on its use as concrete reinforcement designs. Rod composite reinforcement is limited by the glass transition temperature of the rods polymer matrix. It is proposed to take a value 50 °C lower than the glass transition temperature of the matrix polymer for designing concrete structures with rod composite reinforcement, as the maximum allowable temperature for heating reinforcing bars in the structure.

The analysis allows us to establish the structures nomenclature taking into account their fire resistance limit, in which the composite reinforcement use is possible. In building structures with the first degree of fire resistance, composite rod reinforcement is not allowed. In the frame supporting structures, the composite bar reinforcement use made using phenol-formaldehyde resin is allowed only for buildings with the second degree of fire resistance and lower, while the thickness of the concrete protective layer is doubled than for steel reinforcement. In the external walls and floors of buildings with the second degree of fire resistance and below, the use of composite bar reinforcement is allowed, the concrete protective layer thickness increases by 1.5 times. In prefabricated hollow and ribbed plates, the composite bar reinforcement use is not allowed.

4. Conclusions
1. The reinforcing bars has a significant effect on the composite reinforcement tensile strength, first the reinforcing bar sheath undergoes stretching to certain limits, and subsequently internal longitudinally spaced threads come into operation. It was found that the tensile strength of the reinforcement decreases in some cases by 35% with an increase in the diameter of reinforcing bars from 5 mm to 10 mm when analyzing the technical documentation and test results. Coupling of the composite reinforcement bars with screw winding with concrete is provided up to 14.0 MPa, it is necessary to provide anchor devices (loop anchors, spiral clips) to ensure the joint operation of bar reinforcement with concrete.

2. The concrete structures with composite polymer reinforcement design should be performed taking into account the requirements for the degree of fire resistance of the designed object. The heating temperature of the working reinforcement, which determines the structure fire resistance, depends on the duration of the open flame on the structure and temperature exposure schemes. The rod composite reinforcement use is limited by the glass transition temperature of the rods polymer matrix. It is proposed to take a value of 50 °C lower than the glass transition temperature of the matrix polymer as the maximum permissible temperature for heating reinforcing bars in the concrete structure.

References
[1] Merkulov S, Tatarenkov A, Lesovik R 2017 Assessment of progressive collapse of operated buildings and structures based on structural damage International Conference on Actual Issues of Mechanical Engineering (AIME) AER-Advances in Engineering Research V 133 pp 409-413
[2] Merkulov S, Lesovik R, Metrohin A, Kolashnikov N 2014 Development of Theory of Safety Structural for Buildings and Construction World Applied Sciences Journal 31 (4) 531-533
[3] Merkulov S, Lesovik R A 2013 Metrohin Strength and Deformability of Reinforced Concrete Structures in Service World Applied Sciences Journal 25 (12) 1747-1750
[4] Merkulov S, Rimshin V, Kuzina E 2019 Construction building systems protection under emergency exposure E3S Web of Conferences Volume 135 02014
[5] Karbhari V M, Chin J W, Dunston D 2003 Durability Gap Analysis for Fiber-Reinforced Polymer Composites in Civil Infrastructure Journal of Composites for Construction 7(3) 238-247
[6] Krishan A L, Narkevich M Yu, Sagadatov A I 2018 Experimental investigation of selection of warm mode for high-performance self-stressing self-compacting concrete 7th International Symposium on Actual Problems of Computational Simulation in Civil Engineering
[7] Varlamov A A Rimshin V I, Tverskoi S Y 2018 Security and destruction of technical systems
Varlamov A A, Rimshin V I, Tverskoi S Y 2018 Planning and management of urban environment using the models of degradation theory 3rd International Conference on Sustainable (ICSC)

Kuzina E, Cherkas A, Rimshin V 2018 Technical aspects of using composite materials for strengthening constructions XXI International scientific conference on advanced in civil engineering construction - the formation of living environment (FORM 2018), IOP Conference Series-Materials Science and Engineering V 365

Kuzina E, Rimshin V 2018 Deformation Monitoring of Road Transport Structures and Facilities Using Engineering and Geodetic Techniques International scientific conference energy management of municipal transportation facilities and transport, EMMFT 2017, Advances in Intelligent Systems and Computing V 692 pp 410-416

Cherkas A, Rimshin V 2017 Application of composite reinforcement for modernization of buildings and structures RSP 2017 - XXVI R-S-P SEMINAR 2017 Theoretical foundation of civil engineering MATEC Web of Conferences V 117

Erofeev V, Zavalishin E, Rimshin V 2016 Frame Composites Based On Soluble Glass Research journal of pharmaceutical biological and chemical sciences 7(3) 2506-2517

Krishan A, Troshkina E, Rimshin V 2016 Load-Bearing Capacity of Short Concrete-Filled Steel Tube Columns of Circular Cross Section Research journal of pharmaceutical biological and chemical sciences 7(3) 2518-2529

Krishan A, Rimshin V, Erofeev V 2015 The Energy Integrity Resistance to the Destruction of the Long-Term Strength Concrete International Scientific Conference Urban Civil Engineering and Municipal Facilities (SPbUCEMF), Saint-Petersburg, Russia, Mar 18-20, 2015

Kuzina E, Rimshin V, Kurbatov V 2018 The Reliability of Building Structures Against Power and Environmental Degradation Effects IOP Conference Series: Materials Science and Engineering 463(4) 042009

Krishan A L, Rimshin V I, Astafeva M A 2018 Deformability of a Volume-Compressed Concrete IOP Conference Series: Materials Science and Engineering 463(2) 022063

Krishan A L, Rimshin V I, Troshkina E A 2018 Strength of Short Concrete Filled Steel Tube columns of Annular Cross Section IOP Conference Series: Materials Science and Engineering 463(2) 022062

Varlamov A A, Rimshin V I, Tverskoi S Y 2018 The General theory of degradation IOP Conference Series: Materials Science and Engineering 463(2) 022028

Varlamov A A, Rimshin V I, Tverskoi S Y 2018 The modulus of elasticity in the theory of degradation IOP Conference Series: Materials Science and Engineering 463(2) 022029

Karpenko N I, Eryshev V A, Rimshin V I 2018 The Limiting Values of Moments and Deformations Ratio in Strength Calculations Using Specified Material Diagrams IOP Conference Series: Materials Science and Engineering 463(3) 032024

Telichenko V, Rimshin V, Kuzina E 2018 Methods for calculating the reinforcement of concrete slabs with carbon composite materials based on the finite element model IOP Conference Series: Materials Science and Engineering 463(3) 032024

Telichenko V, Rimshin V, Ereemeev V, Kurbatov V 2018 Mathematical modeling of groundwaters pressure distribution in the underground structures by cylindrical form zone MATEC Web of Conferences 196 02025

Rimshin V I, Labudin B V, Melekhov V I, Orlov A, Kurbatov V L 2018 Improvement of strength and stiffness of components of main struts with foundation in wooden frame buildings ARPN Journal of Engineering and Applied Sciences 13(11) 3851-3856

Rimshin V I, Varlamov A A 2018 Three-dimensional model of elastic behavior of the composite Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Tekhnologiya Tekstil'noi Promyshlennosti 2018-January(3) 63-68
[25] Rimshin V I, Pudova A A, Shubin L I 2018 Evaluation of efficiency of use of photoelectric systems at operation of a residential house Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil’noi Promyshlennosti 2018-January(3) 287-293

[26] Varlamov A A, Rimshin V I, Tverskoi S Y 2018 Durability of buildings in urban environment Materials Science Forum 931 MSF 340-345

[27] Telichenko V I, Rimshin V I, Karelskii A V, Labudin B V, Kurbatov V L 2017 Strengthening technology of timber trusses by patch plates with toothed-plate connectors Journal of Industrial Pollution Control

[28] Krishan A L, Rimshin V I, Rakhmanov V A, Troshkina E A, Kurbatov V L 2017 Bearing capacity of short concrete filled steel tube columns of circular cross-section Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil’noi Promyshlennosti 370(4) 220-225

[29] Shubin I L, Zaitsev Y V, Rimshin V I, Kurbatov V L, Sultygova P S 2017 Fracture of high performance materials under multiaxial compression and thermal effect Engineering Solid Mechanics 5(2) 139-144

[30] Krishan A L, Rimshin V I, Telichenko V I, Rakhmanov V A, Narkevich M Yu 2017 Practical implementation of the calculation of the bearing capacity trumpet-concrete column Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil’noi Promyshlennosti 2017-January(2) 227-232

[31] Kuzina E, Rimshin V 2019 Strengthening of Concrete Beams with the Use of Carbon Fiber Advances in Intelligent Systems and Computing 983 911-919

[32] Kuzina E, Rimshin V 2019 Experimental and calculated evaluation of carbon fiber reinforcing for increasing concrete columns carrying capacity E3S Web of Conferences 97 04007