Technical aspects of using composite materials for strengthening constructions

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Abstract. The construction industry has experienced the highest number of changes during all century’s history. Today in construction there is a huge set of scientific completions and innovative solutions that many times increase quality of works and process reliability of construction in general. This publication is devoted to an innovative element for strengthening building constructions and elements - to high-strength composite materials. Due to inevitable exhaustion of natural resources and increase in energy cost in the world the process of composite materials production in industrial is becoming more relevant, important and popular, such as fibreglass, basaltplastic, carbonoplastic. These composite materials possess sufficient characteristics on reliability, durability, profitability and that is the most important - environmental friendliness in comparison with the metal reinforcing elements. It is important that source replenishment of raw materials in modern production is possible due to processing of secondary raw materials and technogenic waste. Experience of using composite materials during strengthening building constructions, the comparative analysis from the point of ecology production and using materials, advantages of composite materials is reflected in this publication. The purpose of this publication is to show validity of using composite materials for strengthening building constructions from the point of view of reliability, profitability and also environmental friendliness in comparison with other reinforcing elements.

1. Introduction

Nowadays it is paid more attention to the problem of ensuring reliability of building elements in construction industry. The urgent need of carrying out high-quality construction works on exponentation of buildings and constructions, competent maintenance at all stages of construction and also carrying out timely repair and, if necessary, gain of constructions is the reason for that. First of all it is connected with the growing need to provide reliable maintenance of constructions because dismantling and changeover are much more expensive than repair or impossible at all. The purpose of this publication is to show validity of using composite materials for strengthening building constructions from the point of view of reliability, profitability and also environmental friendliness in comparison with other reinforcing elements. It should be noted that damages of reinforced concrete structures are, as a rule, connected with corrosion, an overload of separate elements, misuse, design errors and technology. Nowadays strengthening of building constructions with composite materials is the most reliable way of restoration and increasing in operational characteristics building constructions [1]. Considering the subject of strengthening it should be noted that throughout long time it is usually used steel reinforcement for concrete elements that has main shortcomings - corrosion of steel and conductivity. These facts have prompted researchers to improve quality of reinforcing so that nonmetallic composite reinforcement has been created. Researches show that metal reinforcement during design in hostile environment does not always satisfy to operational norms because of steel corrosion, and does not provide necessary anti-magnetic and dielectric properties for many materials and constructions and also cannot provide ease of constructions. So composite materials have been proposed. The most important factor for choosing composite materials in the construction industry is...
using low toxic materials in production of composite elements that meets the modern requirements of ecological safety [2].

The history of development polymeric reinforcement can be traced after the World War II. In the space industry advantages of high durability and ease of composite materials have been widely recognized, and during the Cold War of achievement in the space and defensive industry have led to wider using of composite materials. However, only in the 1960s, these materials began to be seriously considered by production of reinforcements for concrete elements. The interest to nonmetallic reinforcement has been arisen in connection with the number of circumstances. The reinforced concrete structures application operated in the highly aggressive environments where it was difficult to provide corrosion resistance of steel reinforcement [3]. It became necessary to ensure anti-magnetic and dielectric properties for medical room’s magnetic resonance tomography. Corrosion of reinforcement in bridges is caused by the action chloride - ions, also required the solution which, certainly, polymeric reinforcement were.

Researches in the field of composite reinforcement and its use at production of reinforced concrete structures are not new. Notice that the foundation of these researches in our country has been laid in the second half of the twentieth century when the Soviet Union was included into top three on a research, production and using composite materials. A big contribution to studying of composite materials, included fiberglass reinforcement, have been made by scientists, known in the field of theory and practice of reinforced concrete: N.I. Akhverdov, O.Y. Berg, A.A. Gvozdev, N.G. Litvinov, V.F. Nabokov, L.S. Friedman and others. Stepanova V.F. has considered introduction problems into the practice of construction nonmetallic composite reinforcement, considered disadvantages and advantages of composites in comparison with steel, gave proposals for the measures providing mass production of composite reinforcement [4,6]. It is discussed the problems of durability and strength of fiber-reinforced polymers used as reinforcement material, and the lack of normative literature on this technology for designers in Russia, discussed the prospects for the use of new modern composite materials in construction, its varieties, history of application, advantages and disadvantages in comparison with metal reinforcement, rational using in composite structures [5]. Ovchinnikov I.I., Ovchinnikov I.G., Garlic, Mikhaildykin E.S. in a number of the articles [7] and [8], [9] describe bases of designing and technology of strengthening reinforced concrete by modern composite materials on the basis of carbon, basalt- aramid and glass fibers. The authors gave the basic provisions on designing of strengthening bent reinforced concrete structures on the first and second groups of limit states, technology of strengthening reinforced concrete composite materials of the new generation, consider requirements for obligatory monitoring of the strengthened constructions. V.I. Rimshin analyzed the composite materials, gave examples of the introduction of innovative composite materials in modern construction, researched composite compression fixtures, and presented the results of his work on fiberglass plastic and basalt plastic reinforcement on compression in tests with different working zones. The results of the tests and mechanisms of sample destruction are analyzed [10-14].

2. Methods
Based on the data obtained from the results of physical-mechanical and corrosion tests of composite reinforcement in the Research, design institute of technology and reinforced concrete (Moscow), the following fact was established: building structures reinforced with composite reinforcement have a life of at least 100 years [15]. Durability of this kind is due to the high chemical resistance of composite reinforcement to aggressive environment, such as high concentrations of gas, sea water, various reagents, chloride salts, etc. Technical characteristics allow it to be used in industrial and civil construction and surface layers of concrete construction, for road construction with the reinforcement of bridges, fences in the structures working in conditions of accelerated corrosion of steel reinforcement and concrete. Also it is possible to use fiberglass reinforcement, that has the following properties: small weight; chemical resistance; low heat conductor; dielectric; non-flammable material; not corrosive material; high specific strength; a wide range of operating temperatures, resistance to ultraviolet radiation[16].
On the basis of researches, it is possible to single out the main characteristics of polymer reinforcement: corrosion resistance to alkaline condition of concrete; the first group of chemical stability to mineralized, marine, ammonia water; sulfuric, hydrochloric, hydrofluoric acid; linear-elastic nature of the "load-deformation" dependencies; low thermal conductivity; modulus of elasticity under tension and bending is not less than 40000 MPa; tensile and flexural strength not less than 1000 MPa; operating temperature -70 degrees C +100 degrees [17-19]. The using of non-metallic reinforcement in combination with special concretes (polymer, polymer silicate) increases the efficiency of its using[20]. Replacement of steel reinforcements with non-metallic ones excludes damages to reinforced structures due to corrosion of steel and destruction of the protective layer, and allows preserving the quality and appearance of structures during operation, and reducing operating costs due to the increase in overhaul period. Carbon plastic, carbon, carbon plastics - a polymeric composite of interlaced carbon fiber filaments located in a matrix of polymer (for example, epoxy) resins. The density is from 1450 kg / m$^3$. The materials are characterized by high strength, rigidity and light weight, often stronger than steel, but much easier (by specific characteristics superior to high-strength steel) and ecological compatibility. Note that this material is usually used as reinforcing additions to the basic material of the structure. The advantage of using CFRP is its strength characteristics and composition. The main constituent of carbon fiber is carbon filaments. Such yarns of about 0.005-0.010 mm in diameter retain good tensile strength, woven fabric from these yarns. They can have a different pattern of weaving (herringbone, matting, etc.). To give even greater strength, these fabrics of carbon fibers are laid in layers, each time changing the angle of the weaving direction, fixing the layers with epoxy resins [21].

The main features and advantages of composites in comparison with traditional construction materials are: non-adherence to corrosion and rot; resistance to the action of aggressive environments; lower density; strength at the level of high-quality structural steels; high fatigue strength; high electrical strength and dielectric properties; low heat capacity and thermal conductivity [22]. All these positive qualities provide the following advantages in application: large overhauls for structures, significantly lower costs for current maintenance and repair, reduction in product weight, increased operational reliability and durability of the structure or product, the ability to install and carry out routine maintenance and repair work without the use of special lifting equipment and machinery, lower costs for transporting structures and their components to the installation site.

3. Results
As a result of the researches, a comparative analysis was made on the main indicators of the examined materials, proving the validity of the purpose of this publication. Consider the comparative characteristics of metal and glass reinforced plastic in Table 1.

Table 1. The comparative characteristics of metal and glass reinforced plastic

| Characteristics       | Metal reinforcement A400C GOST 5781-82 | Non-metallic composite reinforcement (CRF) - fiberglass plastic TC 2296-001-12655746-2012 |
|-----------------------|--------------------------------------|-------------------------------------------------------------------------------------------------|
| Material              | Steel 35GS, 25G2S and others.        | CRF - glass fibers with a diameter of 13-16 microns polymer bound                                |
| Temporary tensile strength, MPa | 360                                   | 1200                                                                                            |
| Modulus of elasticity, MPa       | 14                                    | 2.2                                                                                             |
| Relative extension, %            | Curved line with yield point under load | Straight line with an elastinear dependence under load before failure                            |
| Property                                             | Value                                                                 |
|------------------------------------------------------|----------------------------------------------------------------------|
| The nature of the behavior under load (stress-strain relationship) | 13-15 9-12                                                          |
| Density, t / m³                                        | 7 1.9                                                               |
| Corrosion resistance to aggressive environment        | Corrodes with the release of rust products                         |
|                                                      | Stainless material of the first group of chemical resistance, including alkaline concrete |
| Thermal conductivity                                 | Thermal conductive                                                  |
|                                                      | Non-conductive                                                     |
| Electrical conductivity                              | Electrically conductive                                             |
|                                                      | Non-conductive-dielectric                                          |
| Produced profiles                                    | 6-80 4-20                                                           |
| Length                                               | 6-12 m Any length on request                                       |
| Ecological compatibility                            | Eco-friendly                                                       |
|                                                      | There is a sanitary-epidemiological conclusion, does not emit harmful and toxic substances |
| Durability                                           | According to construction norms                                    |
|                                                      | Forecasted durability at least 80 years                             |
| Replacement of reinforcement by physical and mechanical properties | 6 A400C, 10 A400C CRF-4, CRF-6 |
|                                                      | 12 A400C, 14 A400C CRF-8, CRF-10                                    |
|                                                      | 16 A400C, 18 A400C CRF-12, CRF-14                                   |
| Parameters of an evenly reinforced carcass at a load of 25 tons / mg | When using reinforcement 8A400, the cell size is 14x14 cm. Weight 5.5 kg / m² |
|                                                      | With the use of reinforcement the size of the cell is 23x23 cm. Weight 0.61 kg / m. Weight reduction 9 times |
| Economy                                              | At present, an increase in the cost of metal over the last 6 months has been observed on average by 67% |
|                                                      | The financial savings from the replacement of metal reinforcement by an equally strong composite reinforcement is 10-30%. The dynamic of price growth is 2-4% per year. |

The possibility of using fiberglass for reinforcing concrete structures is due to the specific properties of this material: glass fiber has a high time resistance; the coefficient of temperature deformation of glass slightly differs from the coefficient of temperature deformation of concrete. One of the methods of reinforcing concrete with fiberglass provides for its use in the structure of high-strength glass reinforced plastic reinforcement. Figure 1 shows the types of elements for composite reinforcement.
4. Discussion

On the basis of the obtained results, it is possible to single out the fundamental aspects of the advantages of using composite materials in strengthening structures and building elements. First of all, the use of composite reinforcement in the reinforcement of bent ferro-concrete elements contributes to the achievement of the following strategic and operational tasks: efficient distribution and rational use of available limited resources, preservation of chemical and corrosion resistance, which guarantees the durability of the structure, as well as the absence of possible cracking and destruction of reinforced structures due to internal stresses that may occur during corrosion and corrosion as in the case of steel reinforcement. Low thermal conductivity compared with metal reinforcement more than 10 times, which proves that composite construction reinforcement, unlike steel, is not a cold bridge in a reinforced concrete structure. The most important factor is the possibility of excluding gusts of reinforcement, as well as cracking in the concrete layer under the influence of temperature changes and the action of ultra-low temperatures [23]. The ecological safety of composite materials and the production without harming the natural complex is confirmed by multiple studies, which confirm the non-toxicity materials. Figure 2 shows a graph of an equally strong replacement of metal for composite reinforcement.
5. Conclusions
On the basis of a comprehensive study of composite materials and the load-carrying capacity of bent ferro-concrete elements, reliable characteristics of reinforcement materials were obtained. As recommendations for the use of composite materials in the reinforcement of structures, it is possible to designate: the effect on the load-bearing capacity of reinforced concrete elements reinforced with composite materials; the behavior of the structure under load with the total percentage of steel and composite reinforcement exceeding the boundary; the role and efficiency of the operation of anchor devices for re-reinforced cross sections when the type of composite material changes [24]. The production of the developed recommendations allows increasing the reliability and efficiency of reinforcement of bent ferro-concrete elements using the non-traditional method of amplification.

It can be concluded that improving the efficiency of repair and restoration work is currently impossible without improving the design solutions for reinforcing the structures that would ensure their reliability, durability, economy and environmental friendliness [25]. These indicators are equally dependent on the reduction in cost and labor intensity of technological processes during strengthening, economical use of material and energy resources, and the use of new materials. In this regard, it is the strengthening of building structures with the use of composite materials, which, thanks to such qualities as high tensile strength, low weight, manufacturability and immunity to aggressive environment, is increasingly used.

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