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STRENGTHENING REINFORCED CONCRETE FLEXURAL ELEMENTS USING COMPOSITE POLYMER MATERIALS CONSIDERING SERVICE CONDITIONS

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This scientific article analyzes the issues of strengthening reinforced concrete flexural elements using modern composite polymer materials while considering service conditions. The long-term performance of building structures, the reduction of load-bearing capacity, and defects caused by aggressive environmental impacts are investigated. The mechanical and physical properties of composite materials, particularly composite polymer materials, as well as the efficiency of their interaction with reinforced concrete structures, are substantiated. In addition, strengthening methods, technologies, and the results of their practical application are scientifically discussed.

Keywords: reinforced concrete, flexural element, composite polymer material, strengthening, service conditions, load-bearing capacity, deformation.

Introduction

Currently, in the construction industry, the reconstruction of existing buildings and structures, extending their service life, and improving their technical condition are among the most pressing issues. In particular, various types of defects are widely observed in reinforced concrete structures that have been in use for many years, such as cracks, corrosion of reinforcement, and a decrease in the mechanical strength of concrete. Such problems are often directly related to the service conditions of the structures and occur as a result of increased loads, temperature and humidity variations, and the influence of chemically aggressive environments.

Flexural members, particularly beams and slabs, are among the main load-bearing components of buildings and structures, and they primarily operate under bending moments. The formation of cracks in the tensile zones of these elements negatively affects the overall structural stability. Therefore, it is important to strengthen them using efficient and economically appropriate methods. In addition to traditional strengthening methods (such as reinforcement with additional steel bars and concrete jacketing), the use of composite polymer materials has been widely increasing in recent years.

These materials have advantages such as high strength, low weight, corrosion resistance, and ease of installation. In particular, carbon- and basalt-fiber-reinforced composite polymer materials have shown effective results in strengthening flexural elements.

This article provides an in-depth analysis of the process of strengthening reinforced concrete flexural elements using composite polymer materials from the perspective of service conditions. In this regard, the effects of the external environment, types of loads, their direction and duration of action, as well as structural characteristics and specific features of strengthening technologies are taken into account.

Main body

Strengthening reinforced concrete flexural elements using composite polymer materials, particularly carbon- and basalt-fiber-reinforced composites, is currently one of the most effective and widely applied methods in practice. However, the high efficiency of this method depends not only on the strength of the material itself but also on its performance under real service conditions. In other words, environmental factors such as temperature, humidity, loading conditions, and other external influences during the service life of the structure directly determine the effectiveness of strengthening. First of all, the issue of temperature requires special attention. Composite materials are typically bonded to the concrete surface using epoxy-based adhesives. A characteristic feature of this adhesive layer is that it begins to lose its strength beyond a certain temperature limit.

A number of researchers have devoted their studies to the development of methods for calculating flexural reinforced concrete elements, including those strengthened with polymer composite materials and subjected to loading conditions. Among foreign researchers are D.O. Astafiev, M.V. Berlinov, S.A. Bokarev, V.M. Bondarenko, S.V. Bondarenko, A.B. Golyshev, A.S. Zalesov, A.I. Zvezdov, S.I. Ivanov, O.V. Kabantsev, V.A. Klevtsov, E.N. Kodish, V.I. Kolchunov, Vl.I. Kolchunov, E.A. Korol, S.M. Krylov, S.B. Krylov, and others. In our country, scientific research on strengthening reinforced concrete elements with composite polymer materials has not been sufficiently developed.

The normative methodology for calculating external reinforcement of flexural reinforced concrete elements was tested by D.V. Kuzevanov [1]. The ultimate strength of the test beams' normal sections was analyzed using both the limit equilibrium method and the nonlinear deformation model. Within the study, 397 flexural specimens were tested.

Based on the results of experimental beam tests presented by T.A. Mukhamediyev [2], it can be concluded that the proposed normative calculation methodology shows good agreement with experimental data. The average discrepancy between the results obtained using the ultimate stress method and the deformation model was approximately 2%. However, the authors did not specify whether a two-linear, three-linear, or nonlinear concrete deformation diagram was used in the calculations.

In the work of S.M. Yesipov [3], the authors address theoretical approaches to describing the stress-strain state (SSS) of flexural and compression-flexural reinforced concrete elements with internal and external polymer composite reinforcement. They compare calculation and design methodologies for such structures according to regulatory documents of different countries [4–7]. Analyzing similarities and differences in calculation formulas and limit state criteria, the authors conclude that determining an exact failure criterion for reinforced concrete structures strengthened with carbon and glass composite materials remains an open issue in modern design standards. Attention is also drawn to the volumetric system of material and load safety factors, which leads to a 40–60% reserve in load-bearing capacity. This reduction in design resistance is considered an important aspect of the economic and technological efficiency of using polymer composite materials for strengthening reinforced concrete structures.

Technical Fundamentals of Strengthening Flexural Elements with Polymers:

The load-bearing capacity of reinforced concrete elements primarily depends on the composite action of concrete and reinforcement.

The next important aspect is the compatibility of deformations and the process of crack formation. In flexural reinforced concrete elements, the lower zone is typically subjected to tension, and cracks primarily develop in this region. When composite polymer materials are applied to this zone, they restrict crack propagation, reduce flexural deformations, and increase the overall stiffness of the element. This is, of course, a positive effect. However, the high stiffness and tensile strength of composite polymer materials may, in some cases, also lead to undesirable consequences. In particular, there is an increased risk of sudden, brittle failure without prior warning. Such failure is often associated with debonding of the composite layer from the concrete surface. Therefore, in the design process, not only strength but also the deformation behavior of the structure must be studied in depth.

Environmental influences also have a significant impact on the long-term performance of strengthening systems using composite polymer materials. The adhesive layer that bonds them to concrete is not highly resistant to all conditions. For example, in outdoor environments exposed to direct sunlight, ultraviolet radiation gradually degrades the epoxy layer. Similarly, constant moisture or water exposure may also reduce bonding quality. For this reason, protective layers are commonly applied over composite materials in practice. These may include simple paint coatings, special plaster layers, or other protective materials. Such measures not only preserve the material but also extend the service life of the entire system.

Another critical aspect of strengthening systems is anchorage, i.e., the reliable fixing of the composite material. In many cases, composite strips or fabrics are bonded to the underside of the element, but if their ends are not properly anchored, they may detach under loading. This is especially common near support zones. As a result, the entire strengthening system may fail to perform its function. Therefore, proper selection of anchorage length and, if necessary, the use of additional mechanical fastening methods are essential.

In addition, the condition of the concrete must be carefully assessed before strengthening. No matter how strong the composite material is, it will not be effective if it is applied to poor-quality concrete. According to practical requirements, the compressive strength of concrete must be sufficient, and particularly the tensile surface strength should not fall below a certain limit. Otherwise, the composite layer may detach together with the surface layer of concrete. Therefore, surface preparation—cleaning, grinding, and removal of weak layers—is a crucial step before strengthening.

Another practical consideration is the level of loading during the strengthening process. If the structure is subjected to high loads, the bonded composite material may not perform effectively. Therefore, in most cases, the load is partially reduced during installation. This ensures proper curing of the adhesive layer and reliable composite action between the material and concrete.

In general, strengthening flexural reinforced concrete elements using composite polymer materials provides significant advantages. However, this method is not a simple “glue-and-apply” technique. Every factor—temperature, humidity, concrete quality, loading conditions, and even sunlight exposure—must be carefully considered. Only under such conditions can this technology fully justify its effectiveness and ensure reliable, long-term performance of the structure.

Conclusion

Strengthening flexural reinforced concrete elements using composite polymer materials is increasingly being applied in construction practice as an effective and modern solution. This method makes it possible to increase the load-bearing capacity of structures, reduce deformations, and extend the service life of existing buildings. Carbon- and basalt-fiber-reinforced polymer composites offer significant advantages over traditional methods due to their low weight, high strength, and corrosion resistance.

However, the effectiveness of strengthening is not limited only to material selection. Service conditions—such as temperature, humidity, aggressive environments, and load levels—directly affect the long-term performance of the composite system. Under high-temperature or fire conditions, the properties of the adhesive layer deteriorate, which reduces the effectiveness of strengthening. Therefore, the application of additional protective measures in such cases is essential.

The compatibility of deformations and the control of crack development are also important factors. Composite polymer materials limit crack propagation; however, improper design or deviation from technological requirements may lead to brittle failure, negatively affecting structural reliability. For this reason, accurate calculations and full compliance with technical requirements are necessary during the strengthening process. In addition, the quality of the concrete surface, bond strength, and anchorage reliability are key factors of the strengthening system. If the surface is not properly prepared, the composite material cannot fully perform its function. Therefore, preparation works, correct application of materials, and adherence to technological procedures are of special importance.

In conclusion, strengthening with composite polymer materials is one of the most effective approaches in the rehabilitation of structures. High reliability can be achieved through proper design, consideration of service conditions, and strict compliance with technological requirements. Future research and the development of new materials will further expand the potential of this technology.

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