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STRENGTHENING OF REINFORCED CONCRETE STRUCTURES BY COMPOSITE MATERIALS ON THE BASIS OF CARBON FIBRE

Abstract. This article presents a study on strengthening of reinforced concrete structures. Various strengthening composite materials and their analysis associated with the determination of efficiency of methods are reviewed. Physical and mechanical properties of the most common fibers of composite materials were examined and identified the most efficient brands by analyzing their calculation characteristics. The experimental results showed that the strengthened structures by composite materials had higher failure load, less deflections and better cracking patterns than without strengthening.
Keywords: reinforced concrete(r/c), strengthening, plate, fiber, composite material.

Introduction. Strengthening of reinforced concrete element is an important task in the field of structural maintenance. In the operation of buildings and structures constructive elements damaged as a result of corrosion of reinforcement and concrete fracture, resulting to decreasing of carrying capacity and appearing of an emergency. The aim is to increase the capacity of an existing element.

One of the main reasons of building structures strengthening becomes changing of the functionality of a building and the increasing of loadings. Very often in practice there appears the necessity of strengthening of r/c bending elements, like monolithic overlapping, roof slabs, and beams.

Different types of strengthening materials are available in the market. Examples of these are ferrocement, sprayed concrete, steel plate and fibre reinforced polymer (FRP) laminate. Generally the use of steel plate and FRP are preferred in this field due to their advantages such as easy construction work, minimum change in the overall size of the structure after plate bonding and less disruption to traffic while strengthening is being carried out.

In order to ensure widespread use of composite materials in Ukraine, we have to conduct their ample experimental and theoretical study and creation on the basis of existing regulations optimum method of calculation, which will enable efficient use of composite materials to enhance the flexural reinforced concrete structures.

Today much attention is paid to a question which deals with the strengthening of building structures. Causes and ways of strengthening the r/c beams are analyzed in works of many authors as A.IA. Barashikova, S.V. Bondarenko, A.B. Golyshev, E.V. Klymenko, P.I. Kryvosheev, D.N. Lazovskii, A.I. Malganov, N.M. Onufriev, V.L. Chernyavskii, J.G. Khayutin, E.Z. Axelrod, V.A. Klevtsov, N.V. Fatkullin and others.

Strengthening materials and methods. For the purpose of repair and strengthening of r/c. elements, several materials and methods are available such as sprayed concrete, ferrocement, steel plate and fibre reinforced polymer (FRP).

The use of this composite material in Europe as a material for strengthening can be for both normal and oblique sections for bending of reinforced concrete structures. Widespread use of composite materials in Ukraine is constrained because of lack of existing regulations optimum method of calculation adapted to DBN of Ukraine, sufficient experience in the application and production of composite materials. Today there is no single theory calculation that would be consistent with the experimental data of all authors and there are not investigated efficient use of composite materials.

It is necessary to separate out three most important factors that influence on choice of method of reinforcement:

1. Minimum turnaround time for strengthening and, accordingly, the minimum delay of the construction of structure.
2. Minimum workforce in the manufacture and installation of reinforcing structures.
3. Reliability and durability of strengthened structures.

However, among all of the strengthening materials, Fibre reinforced polymer laminate is the most common and effective materials due to its advantages which will be described further.

Fibre reinforced polymer (FRP) for civil engineering structures are being increasingly studied in recent years. These materials are being used in the aerospace, automotive and shipbuilding industries for almost two decades.

In general, FRP offer excellent resistance to corrosion, good fatigue resistance (with the possible exception of some glass-based FRP), low density, high stiffness and strength, and a very low coefficient of thermal expansion in the fibre orientation.

Strengthening of reinforced concrete elements is performed by reinforcing the carbon-filled plastic by bonding it to stretched parts design on places with parallel fiber tensile maximum efforts.

Analyzing of physical and mechanical characteristics of composite materials. Fibre reinforced polymer – is a highly, linearly elastic material which could be used as a basis for external reinforcement of concrete and considered as an alternative to steel reinforcements. For the repairing of reinforced concrete structures are commonly used elements in the form of tapes and canvases. However, in recent years, in addition to the canvases and strips of composite materials are also made smooth and grooved fittings, wire ropes, strands, skeletons and shells. These types of composite materials are mainly used for new construction.

Physical and mechanical properties of the composites are determined by the type and amount of fibers used, their distribution and orientation of the cross-sectional bands, and the volume ratio of the fibers and curing the polymer in the composite. The mechanical characteristics of fibers used in construction of composite materials are shown in Table 1.

Table 1.

Physical and mechanical characteristics of some types fibers

Type of fiber	**Tensile strength, MPa**	**Modulus of elasticity, GPa**	**Deformation of elongation, %**	**Density, t/m3**
High strength carbon fiber	3400 - 3900	200 - 250	1,5-2,5	1,75-1,95
High modulus carbon fiber	2900 - 4000	300 - 700	0,45-1,2	1,75-1,95
High strength aramid fiber	3500	75	4,6	1,4
High modulus aramid fiber	2900	110	1,5-2,4	1,4
Glass (type A), alkali resistant	21 -74	3000-3500	2,0-4,3	2700

Glass (type C), high strength	75-88	4300 - 4900	4,2-5,4	2500
Glass (type E), universal	21 -74	3400 - 3700	3,3-4,8	2600

The coefficient of linear thermal tension (c.l.t.t.) composite materials also depends on the type of fiber, resin and fiber volume content. C.l.t.t. for composite strengthening agent in the longitudinal and transverse directions is presented in Table 2.

Table 2.

Coefficients of thermal expansion (c.l.t.t.) composite materials

Direction/ Strengthening agent	**Fiberglass, c.l.t.t. 10^{-6} / ºC**	**Carbon fiber, c.l.t.t. 10^{-6} / ºC**	**Aramid fiber, c.l.t.t. 10^{-6} / ºC**
Longitudinal, a_L	6-10	от -1 до 0	от -6 до -2
Transverse, a_T	19-23	22-50	60-80

All types of fibers in the table have linear diagram «stress-strain» until fracture without any plastic zone (Fig. 1).

Carbon fibers – type of reinforcing fibers which has been created to overcome shortcomings of glass fibers such as a low modulus of elasticity and high density. As a raw material for producing carbon fibers typically used polymer polyacrylonitrile or rayon fibers.

Carbon fibers are continuously improved, increasing their strength and stiffness, increased range. One of the most promising ways to reduce the prices of such fibers is the use of oil and other pitches (heavy polyaromatic compounds) as feedstock. Carbon fibers and composites of them have deep blacks and conduct electricity well, that defines and limits their application.

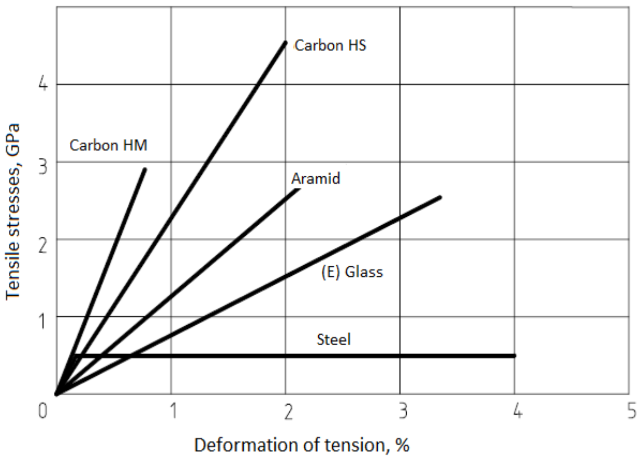

Figure 1. Diagram of tension

Selection the most efficient type of carbon fiber. Dimensions and thickness of carbon fiber required to ensure the desired strength, determined by calculation. When designing the strengthening of reinforced concrete structures using external reinforcement analysis is used ultimate limit state.

Materials from different manufacturers have different strength and deformation characteristics.

Key provisions that must be taken during the calculation:

- When designing the strengthening of reinforced concrete structures using the method of calculating the ultimate limit state.
- The system is designed to strengthen the perception of the tensile stress on the joint deformations of the outer reinforcement and concrete structures.
- When designing structures gain taken into account that the design bearing capacity is sufficient for the perception of

constant load and limited time in the event of damage to the system gain for any reason.

Special feature of carbon fiber are the following obligatory requirements:

- System of strengthening can be used if the actual compressive strength of concrete structures is not less than 15 MPa;
- Maximum operating temperature of work may not exceed the glass transition temperature of the polymer matrix and adhesive;
- technology must be strictly observed, repair layer should be a reliable basis for reinforcing pads stickers and work with them together;
- It is necessary to limit the maximum permissible forces resulting from the fixture by a factor k_m, which ensures no delamination of CFRP at rated load, as stiffness increases with increasing probability of detachment.

Equation (1) gives an estimate of the coefficient of working conditions fiber reinforcing plastic k_m , which depends on the element stiffness gain:

$$k_m = \begin{cases} \frac{1}{60\varepsilon_{ft}}\left(1 - \frac{nE_{ft}t_f}{360000}\right) \leq 0.9 \\ \frac{1}{60\varepsilon_{ft}}\left(\frac{90000}{nE_{ft}t_f}\right) \leq 0.9 \end{cases} \qquad (1)$$

Calculation of strength sections bent elements, reinforced carbon composite material produced from the general condition: $M<M_{ult}$.

The calculation results of several embodiments of composite carbon materials used as reinforcement for the structure are shown in Table 3.

Table 3.
Design characteristics of different carbon composite materials

BRAND of manufacturing firms	**Thick-nes, mm**	**Width, mm**	**E, GPa**	**R_k, MPa**	**M, kN**	**Under-stress, %**
Carbon fiber – tapes						
SIKA® CARBODUR® S	1,2	660	>155	2400	301	15
SIKA® CARBODUR® M	1,4	840	>210	2000	306	27
SIKA® CARBODUR® H	1,4	1000	>300	1400	279	44
MAPEI® CARBOPLATE E 170	1,4	750	170	>3100	303	19
Carbon fiber – canvases						
MAPEWRAP.® C UNI-AX 600/10	0,335	300	230	4800	210	10
MAPEWRAP.® C UNI-AX 300/20	0,167	200	230	4800	131	19
S&P.® C SHEET 640	0,19	450	640	2650	285	5
S&P.® C SHEET 240 - 200	0,117	300	240	3800	111	5

The best result shows material S & P ® C Sheet 240-200, because it not only provides the necessary strength of the section, but also the strength of the external reinforcement is used almost entirely.

Results and discussion. The advantages of fibre reinforced polymers are the high tensile strength and modulus, low weigh, manufacturability, resistance to aggressive external factors, the ability to repeat almost any form design, endurance, and other factors.

The use of this composite material in Europe as material for strengthening can be for both normal and oblique sections for bending of reinforced concrete structures. Widespread use of composite materials in Ukraine is constrained because of lack of existing regulations optimum method of calculation adapted to DBN of Ukraine, sufficient experience in the application and production of composite materials. Today there is no single theory calculation that would consistent with the experimental data of all authors and there are not investigated efficient use of composite materials.

Thus, using of composite materials can be the beginning of a new direction for reconstruction of reinforced concrete structures. The advantages of composite materials are: high strength and deformation modulus, light weight, adaptability, resistance to aggressive external factors, the ability to copy shape of constructive elements, shortening delays, reducing costs and labor costs, reliability and durability of strengthened structures.

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Аннотация. Данная статья представляет собой материалы исследования укрепления железобетонных конструкций. Рассмотрены методы и результаты укрепления различными композиционными материалами и проведен анализ эффективности методов. Были обследованы физические и механические свойства наиболее распространенных в использовании волокон композитных материалов и с помощью анализа их расчетных характеристик определены наиболее эффективные бренды. Результаты эксперимента показали, что усиление композиционными материалами железобетонные конструкций позволяет выдержать большую нагрузку и получить меньшие прогибы и лучшие образцы по растрескиванию, чем без усиления.

Ключевые слова: железобетон ж/б, укрепления, плиты, волокно, композитный материал.

Анотація. Дана стаття являє собою матеріали дослідження зміцнення залізобетонних конструкцій. Переглянуті методи і результати зміцнення різними композиційними матеріалами та проведено аналіз ефективності методів. Були обстежені фізичні і механічні властивості найбільш розповсюджених у використанні волокон композитних матеріалів і визначені за допомогою аналізу їх розрахункових характеристик найбільш ефективні бренди. Результати експерименту показали, що підсилення композиційними матеріалами залізобетонних конструкцій дає змогу витримати більше навантаження та отримати менші прогини і кращі зразки по розтріскуванню, ніж без підсилення.

Ключові слова: залізобетон, зміцнення, плити, волокно, композитний матеріал.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ КОНСТРУКЦІЙ ПОКРИТТЯ ІЗ СТАЛЕЗАЛІЗОБЕТОНУ

Анотація. Наведені результати експериментальних досліджень сталезалізобетонних балок з приклеєним до сталі бетоном. Зроблений