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STUDY OF NON-METALLIC REINFORCEMENT INFLUENCE ON THE CHARACTERISTICS OF CEMENT CONCRETE BEAM SAMPLES PROPERTIES

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The article presents the results of a study of beams strength characteristics reinforced with non-metal rods. Concrete samples reinforced with composite and metal reinforcement of different diameters were tested. Based on the results of the study, the bending tensile strength and elasticity modulus of beams with composite reinforcement were determined. Graphs of the dependence of the beam deflections on the load based on the test results of concrete samples reinforced with metal and fiberglass reinforcement were constructed. A comparative analysis of metal and fiberglass reinforcement work in concrete was carried out on the example of a rod with a diameter of 8 mm, which indicated the higher strength characteristics of composite reinforcement.

The results of testing beam samples and analysis of the properties of non-metallic reinforcement allow us to prepare proposals for the use of reinforcement new type and engineering calculation of cement-concrete structures reinforced with fiberglass rods.

Key words: fiberglass reinforcement, cement concrete, reinforcement, modulus of elasticity.

Introduction. Today, the main volume of highways, airports and civil construction structures is carried out using metal reinforcement as the main component of the composite material - reinforced concrete. The development of the chemical and industrial sphere offers a number of other options for replacing the metal component, which are comparatively more reliable, stronger and more durable [1-5]. One of them is fiber reinforced polymer, which is considered in this study as an alternative material to the usual reinforcement. The main advantages of the fiberglass material are high resistance to environmental influences and significantly higher strength per unit area of reinforcement [2-4], increased service life [6-7]. However, it is necessary to carry out additional tests in laboratory conditions to establish the dependence on the crack resistance of concrete structures using different reinforcement coefficients [8-9], which determines the relevance of the chosen scientific direction.

The purpose of the research is to test samples to determine the physical properties of a new combination of concrete with fiberglass reinforcement, to establish dependences on the crack resistance of concrete samples using different reinforcement coefficients, to determine the strength and modulus of concrete beams elasticity, that work for bending.

Main part. Flexural strength and elasticity modulus are important components in the design concrete road and airfield pavements. Determination of these indicators was carried out on samples made using fiberglass and metal rods. Fiberglass rods meet the requirements of DSTU 9065:2021 [10]. The samples were tested according to the 4-point bending scheme with fixation of indicators in accordance with DSTU B V.2.7-217:2009 [11].

To determine the physical characteristics, time-type sensors are installed at 4 points, namely, in the central lower part (sensor D1, Fig. 1) and at the outlet of the armature (sensor D2, Fig. 1) on the lateral lower face of the sample (sensor D3, Fig. 1), and in the upper part of the press (sensor D4, Fig. 1).

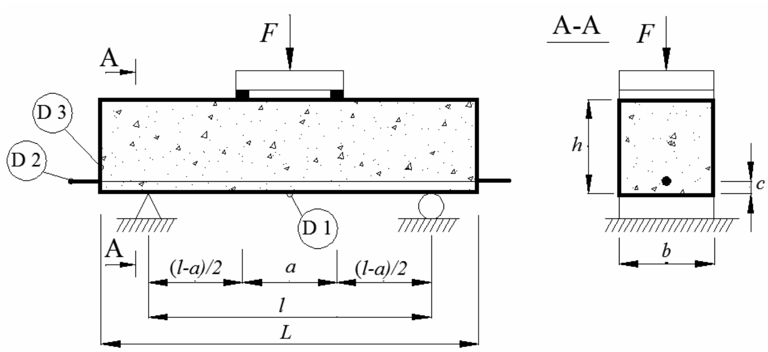

Fig. 1. Schematic of placement of sensors during tensile bending test
(*F* - load; *l* – calculated span length; *L* - total length of the sample; *a* -distance between load transfer points; *h* – cross-sectional height of the sample; *b* - width of the cross-section of the sample, *c* - width of the concrete protective layer)

For the test, concrete samples with dimensions of 150x150x600 mm were prepared, which were reinforced with one rebar in the central part of the sample at a distance of 20 mm (width of the concrete protective layer) from the lower edge.

In fig. 2 is shown the sample, which is placed in the press, and the location of sensors for measuring deformations at characteristic points.

The sample reinforced with metal reinforcement has characteristic signs of failure during loading, namely, a sharp increase in deflection in the central part after passing the load mark of 80 kN and displacement of 2.8 mm, respectively. A further load of 85 kN led to a significant increase in the deflection of the specimen to 9.5 mm and rupture of the reinforcement, which consequently caused the failure of the entire specimen with the formation of a characteristic narrowing in the form of a neck at the point of rupture.

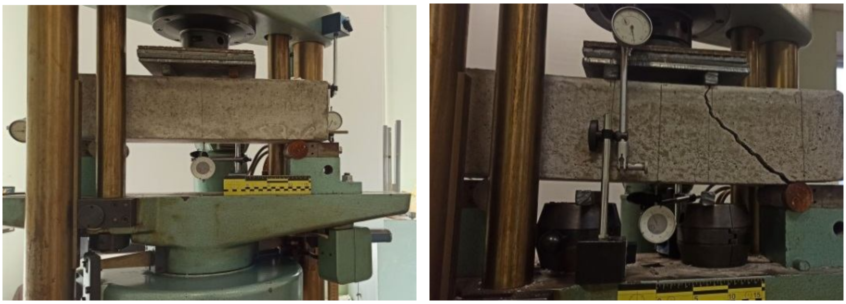

Fig. 2. Placing the concrete sample in the press during the test

In fig. 3 are shown samples after complete destruction that were reinforced with fiberglass and metal rods with a diameter of 8 mm.

Fig. 3. Appearance of broken reinforcement d=8 mm in the samples after the test

Samples with fiberglass reinforcement during the test have a more predictable nature of destruction, in particular, the increase in load leads to a uniform deflection of the sample. The deflection in the central part at 80 kN was 4.5 mm and increased uniformly to 5 mm at a load of 85 kN, which was destructive for samples with metal reinforcement with the formation of one main crack in the center of the sample and a characteristic narrowing. The destruction of the fiberglass sample occurred under a load of 117 kN and a corresponding deflection in the central part of 10 mm with the formation of three main cracks, which indicates the inclusion in the work of the entire volume of the material of the sample.

Rupture of fiberglass reinforcement with a diameter of 10, 14, 15 mm did not occur when testing samples under the same conditions. However, it should be noted that in these samples, sliding of the reinforcement on the concrete at the point of grafting was observed, which indicates insufficient effective grafting area of the reinforcement with concrete and insufficiently effective transfer of shear forces at the boundary of covering fiberglass reinforcement with concrete matrix.

The samples after testing are shown on fig. 4.

Fig. 4. Samples after testing

The nature of the concrete destruction and the formation of the first crack has a regularity in its location. The formation of cracks occurs at an angle of 45 degrees.

In the process of testing, under appropriate loads, beam deflections were recorded according to the readings of sensor D1. The processing of the received data made it possible to plot graphs of the dependence of the beam deflections on the load at different diameters of the reinforcement in the samples (Fig. 5).

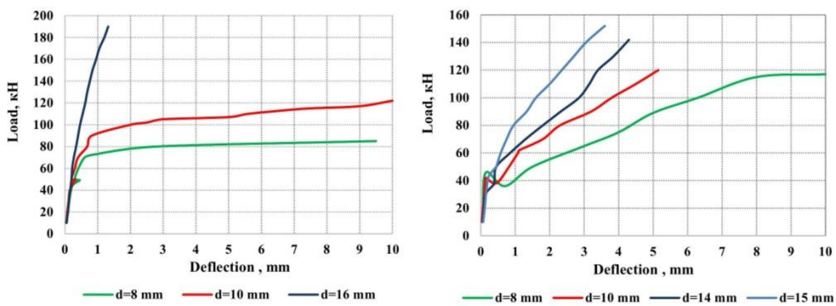

Fig. 5. Graphs of the dependence of the beam deflections on the load according to the test results of concrete samples reinforced with metal and fiberglass rods

The maximum moment in the samples during failure is determined by the formula [12]:

$$M = \frac{F\left(l-a\right)}{4}, \tag{1}$$

where F – load (N); l – calculated span (m).

The modulus of elasticity was determined during bending of concrete samples according to the formula [13]:

$$E = k_w \cdot \frac{F \cdot a \cdot (3l^2 - 4a^2)}{24 \cdot f \cdot J}, \tag{2}$$

where F – the amount of load transferred to the test sample (N); k_w – deflection refinement factor (k_w = 1,33 [13]); l – calculated beam span (m); J – moment of inertia (m^4); f - calculated deflection of the concrete sample (m); a – sample cross-section width (m).

To obtain the specified deflection to the actual trace of the coefficient from § D.2.2.6 DBN B.2.2-24:2009 [14].

The bending tensile strength is determined by the formula [11]:

$$f_c = (F \cdot l) / (b \cdot h^2), \quad (3)$$

where F – destructive load (N); l – the distance between the supports during tensile testing of samples during bending (m); b – cross-sectional height of the sample (m).

Using formulas (1) – (3) based on the test results, the main characteristics of concrete samples were determined (Table 1).

Table 1

Characteristics of the tested reinforced samples

Characteristic	Without reinforcement	Diameter of rods in samples, mm						
		8		10		14	15	16
		Metal	Fiberglass	Metal	Fiberglass	Fiberglass	Fiberglass	Metal
Modulus of elasticity, MPa		22659	34839	29133	31374	22659	20349	25491
Destructive load, kN	37	85	117	122	128	142	152	195
Maximum deflection, mm	1,3	9,5	10	10	5,15	4,3	3,6	1,32
Bending tensile strength, MPa	4,93	11,33	15,60	16,27	17,07	18,93	20,27	26,00
Maximum moment, kNm	2,775	6,375	8,775	9,15	9,6	10,65	11,4	14,625
Deflection arrow according to the table, mm	2,42	5,56	7,65	7,97	8,37	9,28	9,93	12,75
Reinforcement coefficient, %	0	0,266	0,266	0,419	0,419	0,834	0,961	1,098

During the test, it was established that the elasticity modulus of the concrete structure is higher in samples reinforced with fiberglass, despite the fact that the tensile modulus of fiberglass reinforcement is 60 GPa, and that of metal reinforcement is 200 GPa. The elasticity modulus of samples reinforced with fiberglass rods with a diameter of 8 mm and 10 mm, respectively, is 34.9% and 16.4% higher than that of samples reinforced with metal reinforcement (Fig. 6).

In order to compare the obtained results of experimental tests, the work of samples reinforced with composite and metal rods with a diameter of 8 mm was simulated for tension during bending in the software complex Lira-SAPR

2021 R2.2 (Ukraine) (Fig. 7-9) and a comparative analysis was performed (Table 2). The beam was broken down into plates for modeling the concrete matrix, the rod reinforcement was modeled with end elements КЕ10 for metal and К1 for fiberglass rods.

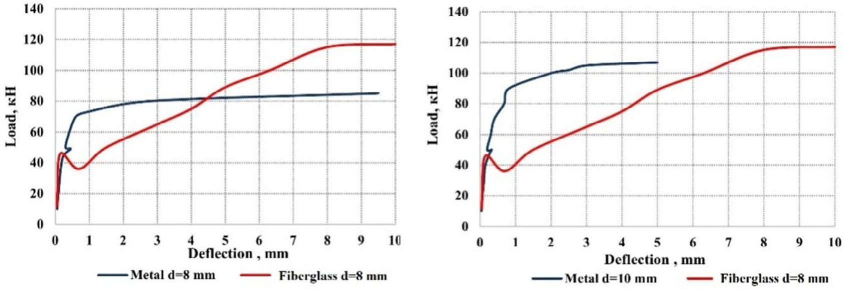

Fig. 6. Comparison of deflections of samples with different reinforcement

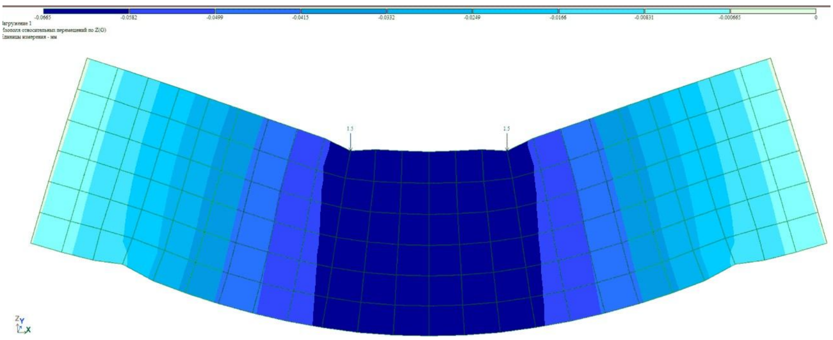

Fig. 7. Deformed scheme of the sample with composite reinforcement
in the Lira-SAPR software complex

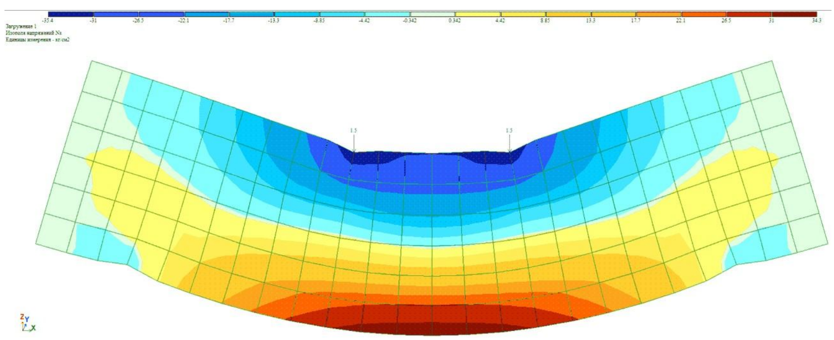

Fig. 8. Normal stresses of the sample with composite reinforcement

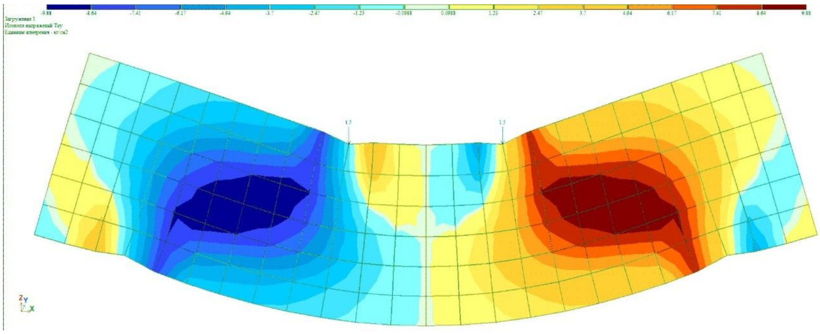

Fig. 9. Tangential stresses of the sample with composite reinforcement

Table 2

Comparative analysis of sample deflections

Load, kN	Deflection in the middle of the beam, mm			Variance, %
	Experiment	Calculation Lira-SAPR	Obtain with [13]	
Metal *d*=8мм				
30	0,13	0,039	0,117	11,1
40	0,19	0,058	0,174	9,2
Fiberglass *d*=8мм				
30	0,09	0,038	0,114	-21,1
40	0,12	0,052	0,156	-23,1
80	4,35	0,105	0,315	1281,0

A comparison of the obtained data based on the results of the experiment and modeling in the Lira-SAPR software complex shows that with an increase in the load on samples with composite reinforcement, the error in determining the deformations increases. The obtained deflection of beams reinforced with composite rods under a load of 30 kN, 40 kN has a deviation of - 22% on average, which indicates the need to refine the modeling in Lira-SAPR, or introduce additional coefficients. In turn, the obtained deflection data for samples with metal reinforcement coincide with those obtained experimentally within the limits of work in the elastic zone and have variances in average 10%.

The ratio between the reinforcement coefficient and bending tensile strength is shown on fig. 10.

From fig. 10 follows that the problem of the interaction of non-metal reinforcement with the concrete matrix with diameters of reinforcement greater than 14 mm requires a separate solution.

Conclusions. As a result of the testing of samples reinforced with fiberglass reinforcement, an increase in elasticity modulus and tensile strength during bending was found to be higher than that of similar samples with metal rods. The strength characteristics of structures reinforced with fiberglass rods with a diameter of 8 mm exceed similar indicators of samples with metal reinforcement by 36%. This makes it possible to use composite reinforcement with a smaller diameter during construction.

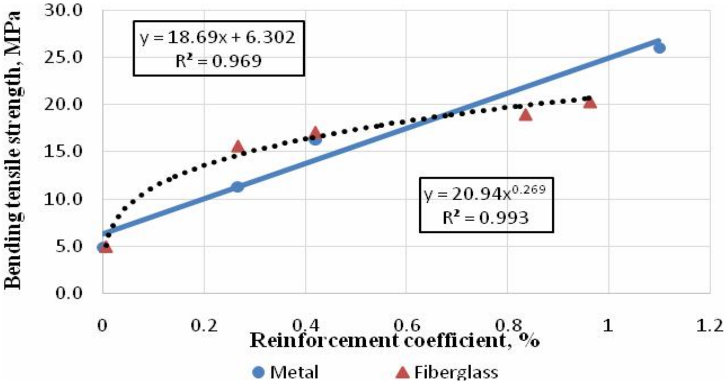

Fig. 10. The ratio between the reinforcement coefficient and bending tensile strength

The test results showed that the nature of the destruction when using fiberglass reinforcement is more predictable. One of the advantages of using such reinforcement, as was found out during the experiment, is the effect of closing cracks when the load is removed.

Comparative analysis of the deformations obtained experimentally and calculated showed that there is a significant discrepancy between the indicators. Thus, it is necessary to carry out further research on the comparison of experimental and calculated data in order to clarify the mathematical methodology for calculating concrete structures using composite materials. In turn, it is necessary to finalize modern software complexes for the design of building structures, namely to provide an additional module with the actual representation of rods.

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ДОСЛІДЖЕННЯ ВПЛИВУ НЕМЕТАЛЕВОЇ АРМАТУРИ НА ХАРАКТЕРИСТИКИ ВЛАСТИВОСТЕЙ ЦЕМЕНТОБЕТОННИХ ЗРАЗКІВ БАЛОК

В статті наведенні результати дослідження міцнісних характеристик балок, армованих немателевими стержнями. Було виконано випробування зразків бетону, армованого композитною та металевою арматурою різного діаметру. За результатами дослідження визначено міцність на розтяг при згинанні та модуль пружності балок з композитною арматурою. Побудовано графіки залежності прогинів балки від навантаження за результатами випробування бетонних зразків армованих металевою та полімерною арматурою. Виконано порівняльний аналіз роботи металевої та полімерної арматури в бетоні на прикладі стержня діаметром 8 мм, який вказав на вищі міцнісні характеристики композитного армування. В свою чергу, міцність на розтяг при згинанні зразків з композитним та сталевим армуванням відповідно діаметром 8 мм та 10 мм має збіжні значення. Це дає можливість на практиці використовувати композитну арматуру меншим поперечним перерізом.

Відповідну роботу армованих бетонних зразків було змодельовано в програмному комплексі Ліра-САПР. Результати моделювання показали, що приведений прогин балок армованих композитними стержнями при навантаженні 30 кН, 40 кН має відхилення в середньому -22 %. При цьому приведений прогин зразків армованих металевими стержнями має вищу збіжність з експериментальним значеннями та похибку в межах 10%. Таким чином моделювання роботи балок з композитним армувнням в програмних комплексах потребує уточнення, або введення додаткових коефіцієнтів при розрахунках.

Результати випробовування зразків балок та аналіз властивостей неметалевої арматури дозволяють підготувати пропозиції щодо використання нового виду армування та інженерного розрахунку цементобетонних конструкцій армованих склопластиковими стержнями.

Ключові слова: полімерна арматура, цементобетон, армування, модуль пружності.

Gameliak I.P., Kulak V.V., Tsybulskyi V.N., Kharchenko A.N.

STUDY OF NON-METALLIC REINFORCEMENT INFLUENCE ON THE CHARACTERISTICS OF CEMENT CONCRETE BEAM SAMPLES PROPERTIES

The article presents the results of a study of the strength characteristics of beams reinforced with non-matel rods. Tests were performed on concrete samples reinforced with composite and metal reinforcement of different diameters. Based on the results of the study, the tensile strength in bending and the modulus of elasticity of beams with composite reinforcement were determined. Graphs of the dependence of the beam deflections on the load are constructed based on the results of testing concrete samples reinforced with metal and polymer reinforcement. A comparative analysis of the work of metal and polymer reinforcement in concrete was carried out using the example of a rod with a diameter of 8 mm, which indicated higher strength characteristics of composite reinforcement. In turn, the tensile strength in bending of samples with composite and steel reinforcement, respectively, with a diameter of 8 mm and 10 mm has adjacent values. This allows in practice to use composite reinforcement with a smaller cross section.

The corresponding work of reinforced concrete samples was modeled in the Lira-SAPR software package. The simulation results showed that the reduced deflection of beams reinforced with composite rods at a load of 30 kN, 40 kN has an average deviation of -22%. At the same time, the reduced deflection of samples reinforced with metal rods has a higher convergence with the experimental values and a discrepancy within 10%. Thus, the modeling of the operation of beams with composite reinforcement in software systems requires clarification, or the introduction of additional coefficients in the calculations.

The results of testing samples of beams and analysis of the properties of non-metallic reinforcement make it possible to prepare proposals for the use of a new type of reinforcement and engineering calculation of cement concrete structures reinforced with fiberglass rods.

Key words: fiberglass reinforcement, cement concrete, reinforcement, modulus of elasticity.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ НЕМЕТАЛЛИЧЕСКОЙ АРМАТУРЫ НА ХАРАКТЕРИСТИКИ СВОЙСТВ ЦЕМЕНТОБЕТОННЫХ ОБРАЗЦОВ БАЛОК

В статье приведены результаты исследования прочностных характеристик балок, армированных немателевыми стержнями. Были выполнены испытания образцов бетона, армированного композитной и металлической арматурой разного диаметра. По результатам исследования определена прочность на растяжение при изгибе и модуль упругости балок с композитной арматурой. Построены графики зависимости прогибов балки от нагрузки по результатам испытания бетонных образцов армированных металлической и полимерной арматурой. Проведен сравнительный анализ работы металлической и полимерной арматуры в бетоне на примере стержня диаметром 8 мм, который указал на более высокие прочностные характеристики композитного армирования. В свою очередь, прочность на растяжение при изгибе образцов с композитным и стальным армированием соответственно диаметром 8 мм и 10 мм имеет смежные значения. Это позволяет на практике использовать композитную арматуру меньшим поперечным сечением.

Соответствующая работа армированных бетонных образцов была смоделирована в программном комплексе Лира-САПР. Результаты моделирования показали, что приведенный прогиб балок армированных композитными стержнями при нагрузке 30 кН,

40 кН имеет отклонение в среднем -22 %. При этом приведенный прогиб образцов армированных металлическими стержнями имеет более высокую сходимость с экспериментальными значениями и расхождение в пределах 10%. Таким образом, моделирование работы балок с композитным армированием в программных комплексах требует уточнения, или ввода дополнительных коэффициентов при расчетах.

Результаты испытания образцов балок и анализ свойств неметаллической арматуры позволяют подготовить предложения по использованию нового вида армирования и инженерного расчета цементобетонных конструкций, армированных стеклопластиковыми стержнями.

Ключевые слова: полимерная арматура, цементобетон, армирование, модуль упругости.

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У статті наводяться результати випробування зразків бетону, армованого композитною та металевою арматурою різного діаметру, а також здійснено порівняння характеристик металевої та полімерної арматури.
Іл. 10. Табл. 2. Бібліогр. 14 назв.

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Gameliak I.P., Kulak V.V., Tsybulskyi V.N., Kharchenko A.N. **Study of non-metallic reinforcement influence on the characteristics of cement concrete beam samples properties** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA. 2022. – Issue 109. – P. 152-163.
The article presents the results of testing concrete samples reinforced with composite and metal reinforcement of different diameters, as well as a comparison of the characteristics of metal and fiberglass reinforcement.
Fig. 10. Tab. 2. Ref. 14.

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Гамеляк И.П., Кулак В.В., Цыбульский В.Н., Харченко А.Н. **Исследование влияния неметаллической арматуры на характеристики свойств цементобетонных образцов балок** // Сопротивление материалов и теория сооружений. – К.: КНУБА, 2022. – Вып. 109. – С. 152-163.
В статье приводятся результаты испытания образцов бетона, армированного композитной и металлической арматурой разного диаметра, а также сравнение характеристик металлической и полимерной арматуры.
Ил. 10. Табл. 2. Библиогр. 14 назв.

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