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# INVESTIGATION OF FIBER-REINFORCED CONCRETE BEHAVIOR UNDER SHORT-TERM COMPRESSION

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**Abstract**. During the design and subsequent construction of structures, both abroad and in domestic projects, concrete reinforced with various types and forms of fibers—fiber-reinforced concrete—is being used increasingly often. Compared to ordinary concrete, it exhibits enhanced strength characteristics and numerous other properties that indicate improvements in its physical and mechanical performance.

The use of fiber-containing concretes in the production of various structures and their individual elements continues to grow. The combination of the properties of the individual components that make up fiber-reinforced concrete results in a material with improved operational characteristics. As a composite material, fiber-reinforced concrete largely depends on the type and variety of fibers incorporated into its structure, since these determine the key characteristics of the final composite.

Among the different types of fibers, steel fiber is considered one of the most efficient and widespread options, both from an economic standpoint and in terms of its availability across various regions of our country. Different types of fibers are used in manufacturing fiber-reinforced concrete elements and structures to enhance their performance.

The percentage of fiber reinforcement significantly influences the properties of the manufactured specimen or structure as a whole. The characteristics of steel fiber-reinforced concrete also depend heavily on the selected reinforcement percentage, which is determined before production begins.

Compared to ordinary concrete, steel fiber-reinforced concrete exhibits improved strength and deformation characteristics [5,7,9]. This has a positive effect on the economic aspects of production and further operation, as such structures require less maintenance and fewer potential repairs during their service life.

To conduct a deeper analysis of the influence of the quantity, type, and characteristics of steel fibers on axial compression, experimental studies were carried out, the results of which are presented below.

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**Keywords**. deformation; fiber concrete; prismatic strength; fiber.

## INTRODUCTION

In the production of fiber-reinforced concrete elements, various types of fibers-including metallic fibers - are used to increase their strength characteristics compared to ordinary concrete. As noted by various researchers [3, 4, 15, 17], their addition significantly improves the strength and deformation properties of the material and the structure as a whole.

The type of fibers used, their length, and their percentage content in the mixture must be selected according to the requirements for the product or structure while strictly adhering to the manufacturing technology.

Deviations from the optimal values of these parameters, whether upward or downward, reduce the effectiveness of dispersed reinforcement and lead to the formation of fiber clumps (“hedgehogs”) that are not evenly distributed throughout the volume. Conversely, the absence of fiber reinforcement reduces the overall strength characteristics of the element.

## RESEARCH PURPOSE

Experimental studies of fiber-reinforced concrete prisms in axial compression using metal fibers of various types.

## RESEARCH OBJECTIVES

When performing these studies, the following research tasks were solved:

1. Selection of elements included in the composition of concrete.
2. Search and use of fibers produced by Ukrainian factories.
3. Casting experimental samples.
4. Testing samples.
5. Processing the results and drawing up appropriate conclusions based on the results of the studies.

## MAIN PART

To achieve the set goal and implement the specified tasks, samples were manufactured and tested, and experimental studies of the operation of prisms reinforced with different types of fibers were conducted (Table 2), with subsequent comparison with concrete samples without reinforcement. This made it possible to determine their strength and deformation characteristics.

The formed experimental samples [5] are presented in Fig. 1.

**Fig.1.** Forming samples for an experiment. Photo by Oleg Skoruk

**Рис.1.** Формування зразків для проведення експерименту. Автор фото Олег Скорук

The types of samples of each type are given in Table 1.

**Table 1** Types of test specimens

**Табл. 1** Види дослідних зразків

| № series | Type of samples | Sample size, mm | Quantity, pcs | Notes |
|---|---|---|---|---|
| 1 | prisms | 100×100×600 | 6 | concrete matrix on fine aggregate |
| 2 | prisms | | | fiber concrete matrix made of wavy fibers |
| 3 | prisms | | | fiber-reinforced concrete element made of fiber having anchor ends |
| 4 | prisms | | | reinforced concrete matrix |
| 5 | prisms | | | fiber concrete matrix - fiber mix |

The prisms were tested after storage in accordance with the requirements of DSTU for 28 days.

In total, 30 prisms of different matrix composition and with and without reinforcement were manufactured.

Before testing, clock-type indicators with a division value of 0.001 mm were attached to the surface of the prisms, see Fig. 2.

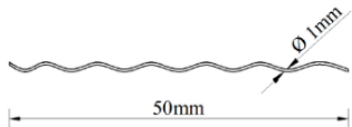
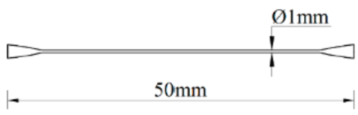
**Fig.2.** Installing sensors on fiber-reinforced concrete prisms. Photo by Oleg Skoruk
**Рис.2.** Влаштування датчиків на фібробетонних призмах. Автор фото Олег Скорук

The compression testing of the prisms was performed on a hydraulic press, using the appropriate methodology. The process of testing the test specimens on the equipment, see Fig. 3.


**Fig.3.** The process of testing prototypes on equipment. Photo by Oleg Skoruk
**Рис.3.** Процес випробування дослідних зразків на устаткуванні. Автор фото Олег Скорук

The loading on the samples was performed in steps, the value was taken to be about 10% of the expected destructive force. At each step, there was a delay of 10 minutes to stabilize internal stresses and deformations, as well as to take readings from the sensors.The indicators on the samples were placed using special mounts and fixed to them with screws.

**Table 2.** Types of fibers used
**Табл. 2** Types of fibers used

| Name | General view(sketch) |
|---|---|
| Wave-shaped wire fiber |   |
| Wire fiber having anchor ends |   |

Before the start of the tests on the press, the samples were centered relative to the actual axis. For this, the samples were loaded with a test load, which is 5% of the expected destructive force. This load corresponded to σc=1.5 MPa. After that, the difference in the indicators was recorded.

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SAMPLE – 1 SERIES

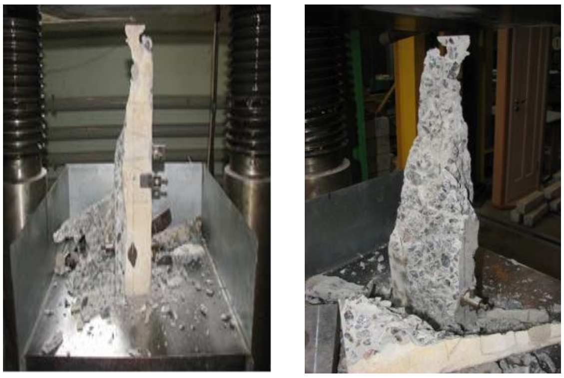

**Fig.4.** Test results and nature of destruction. Photo by Oleg Skoruk
**Рис.4.** Результати випробування та характер руйнування. Автор фото Олег Скорук

If significant discrepancies in the indicators on four sides were detected, i.e. more than 10%, the test sample was moved along the support plate several times until uniform values were achieved for all arranged indicators. Accordingly, the sample was placed in the desired position in two to four attempts. Then, each sample was tested to determine longitudinal deformations. The general appearance of the fracture of the samples is shown in Fig. 5-8. During the study of experimental research elements, the applied load and the deformation changes that developed were recorded. The applied load and the resulting deformations for sample №1-5 are given in the Tables 3-7.

**Table 3.** Change in deformations of test specimen №1.
**Табл. 3** Зміна деформацій дослідного зразка №1.

| Sample № | Load, % | $f_{c,prism}$, MPA |
|---|---|---|
| 1 | 15 | 19,7 |
| | 30 | 20,3 |
| | 45 | 20,4 |
| | 60 | 19,9 |
| | 75 | 19,5 |
| | 85 | 20,2 |

SAMPLE – 2 SERIES

Side surface
**Fig.5.** Test results and nature of destruction. Photo by Oleg Skoruk
**Рис.5.** Результати випробування та характер руйнування. Автор фото Олег Скорук

**Table 4.** Change in deformations of test specimen №2.
**Табл. 4.** Зміна деформацій дослідного зразка №2.

| Sample № | Load, % | $f_{c,prism}$, MPA | $\rho_{fv}$ |
|---|---|---|---|
| 2 | 15 | 32,8 | 1,5 |
| | 30 | 33,5 | 1,5 |
| | 45 | 33,4 | 1,5 |
| | 60 | 33,0 | 1,5 |
| | 75 | 32,9 | 1,5 |
| | 85 | 33,1 | 1,5 |

SAMPLE – 3 SERIES

Side surface
**Fig.6.** Test results and nature of destruction. Photo by Oleg Skoruk
**Рис.6.** Результати випробування та характер руйнування. Автор фото Олег Скорук

**Table 5.** Change in deformations of test specimen №3.
**Табл. 5.** Зміна деформацій дослідного зразка №3.

| Sample № | Load, % | $f_{c,prism}$, MPA | $\rho_{fv}$ |
|---|---|---|---|
| 3 | 15 | 34,2 | 1,5 |
| | 30 | 34,6 | 1,5 |
| | 45 | 34,0 | 1,5 |
| | 60 | 33,8 | 1,5 |
| | 75 | 34,1 | 1,5 |
| | 85 | 33,9 | 1,5 |

SAMPLE – 4 SERIES

Side surface

**Fig.7.** Test results and nature of destruction. Photo by Oleg Skoruk
**Рис.7.** Результати випробування та характер руйнування. Автор фото Олег Скорук

**Table 6.** Change in deformations of test specimen №4.
**Табл. 6.** Зміна деформацій дослідного зразка №4.

| Sample № | Load, % | $f_{c,prism}$, MPA |
|---|---|---|
| 1 | 2 | *3* |
| 4 | 15 | 27,9 |
| | 30 | 28,1 |
| | 45 | 28,3 |
| | 60 | 27,8 |
| | 75 | 28,0 |
| | 85 | 28,2 |

SAMPLE – 5 SERIES

Side surface
**Fig. 8.** Test results and nature of destruction. Photo by Oleg Skoruk
**Рис.8.** Результати випробування та характер руйнування. Автор фото Олег Скорук

**Table 7.** Change in deformations of test specimen №5.
**Табл. 7.** Зміна деформацій дослідного зразка №5.

| Sample № | Load, % | $f_{c,prism}$, MPA | $\rho_{fv}$ |
|---|---|---|---|
| 5 | 15 | 38,2 | 0,75+0,75 – fiber mix |
| | 30 | 37,8 | 0,75+0,75 – fiber mix |
| | 45 | 38,6 | 0,75+0,75 – fiber mix |
| | 60 | 39,4 | 0,75+0,75 – fiber mix |
| | 75 | 38,7 | 0,75+0,75 – fiber mix |
| | 85 | 39,1 | 0,75+0,75 – fiber mix |

After testing various series of samples, the corresponding parameters were determined, which are listed in Table 8.

**Table 8.** Results of testing of experimental samples.
**Табл. 8.** Результати випровування дослідних зразків.

| Sample series | $\rho_{fv}$ | $f_{cf,prism}$/ $f_{c,prism}$ | $f_{cf,prism,m}$/ $f_{c,prism,m}$ | $E_{cf}\times 10^{-3}$ | $E_{cf,m}\times 10^{-3}$ | $\nu$ | $\nu_m$ | $\varepsilon_{cf1}$ | $\varepsilon_{cf1,m}\times 10^{-3}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 0 | 19,7 | 19,8 | 17,2 | 17,3 | 0,18 | 0,18 | 0,2 | 0,2 |
| 1.2 | 0 | 20,3 | | 17,3 | | 0,19 | | 0,2 | |
| 1.3 | 0 | 20,4 | | 17,2 | | 0,18 | | 0,2 | |
| 1.4 | 0 | 19,9 | | 17,4 | | 0,18 | | 0,2 | |
| 1.5 | 0 | 19,5 | | 17,3 | | 0,19 | | 0,2 | |
| 1.6 | 0 | 20,2 | | 17,2 | | 0,19 | | 0,2 | |
| 2.1 | 1,5 | 32,8 | 33,2 | 34,4 | 34,4 | 0,23 | 0,23 | 0,24 | 0,25 |
| 2.2 | 1,5 | 33,5 | | 34,3 | | 0,24 | | 0,25 | |
| 2.3 | 1,5 | 33,4 | | 34,5 | | 0,23 | | 0,25 | |
| 2.4 | 1,5 | 33,0 | | 34,4 | | 0,24 | | 0,24 | |
| 2.5 | 1,5 | 32,9 | | 34,5 | | 0,23 | | 0,25 | |
| 2.6 | 1,5 | 33,1 | | 34,4 | | 0,23 | | 0,25 | |
| 3.1 | 1,5 | 34,2 | 34,1 | 35,6 | 35,6 | 0,23 | 0,24 | 0,25 | 0,25 |
| 3.2 | 1,5 | 34,6 | | 35,7 | | 0,24 | | 0,25 | |
| 3.3 | 1,5 | 34,0 | | 35,6 | | 0,24 | | 0,25 | |
| 3.4 | 1,5 | 33,8 | | 35,5 | | 0,25 | | 0,24 | |
| 3.5 | 1,5 | 34,1 | | 35,6 | | 0,25 | | 0,24 | |
| 3.6 | 1,5 | 33,9 | | 35,6 | | 0,24 | | 0,25 | |
| 4.1 | 0 | 27,9 | 28,1 | 25,4 | 25,3 | 0,2 | 0,25 | 0,21 | 0,21 |
| 4.2 | 0 | 28,1 | | 25,4 | | 0,21 | | 0,21 | |
| 4.3 | 0 | 28,3 | | 25,3 | | 0,21 | | 0,2 | |
| 4.4 | 0 | 27,8 | | 25,2 | | 0,2 | | 0,2 | |
| 4.5 | 0 | 28,0 | | 25,3 | | 0,21 | | 0,2 | |
| 4.6 | 0 | 28,2 | | 25,3 | | 0,2 | | 0,2 | |
| 5.1 | 1,5 | 38,2 | 38,3 | 39,1 | 39,3 | 0,26 | 0,25 | 0,27 | 0,26 |
| 5.2 | 1,5 | 37,8 | | 39,2 | | 0,25 | | 0,26 | |
| 5.3 | 1,5 | 38,6 | | 39,3 | | 0,26 | | 0,26 | |
| 5.4 | 1,5 | 39,4 | | 39,2 | | 0,26 | | 0,27 | |
| 5.5 | 1,5 | 38,7 | | 39,3 | | 0,26 | | 0,26 | |
| 5.6 | 1,5 | 39,1 | | 39,2 | | 0,25 | | 0,26 | |

For series of samples where there was no fiber in the composition, the prismatic strength was denoted by - $f_{c,prism}$.

The prismatic strength was determined using the formulas [1]:

$$f_{cf,prism} = f_{c,prism} + (k^2_n \varphi_f \rho_{fv} f_f)$$

in this formula

$$\varphi_f = (5+L)/(1+4,5L),$$

$$L = (k2\rho fvf_f)/(f_{cf,prism}),$$

where

$f_f$ – tensile strength of individual fibers;
$k_n$ – coefficient that takes into account the work of fibers in a cross section perpendicular to the direction of the external compressive force;
$\varphi_f$ – коефіцієнт ефективності непрямого армування фібрами;
$\rho_{fv}$ – коефіцієнт фібрового армування $E_{cf}$.

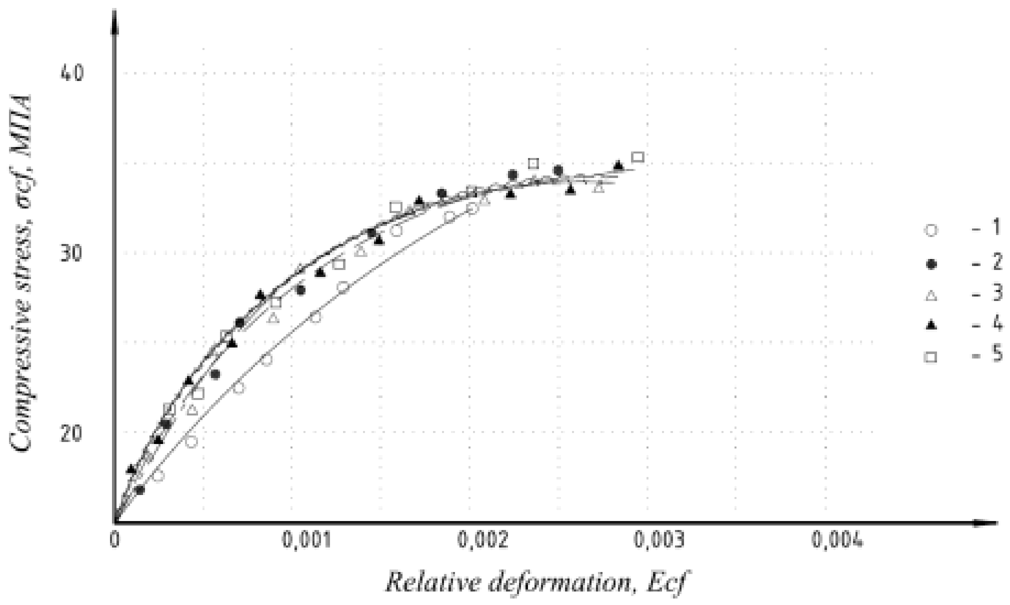


**Fig.9** Diffraction diagram of sample deformation
**Рис. 9** Дифракційна діаграма деформування зразка

## CONCLUSIONS

1. The data obtained from the results of the experiment showed that samples with the addition of any type of fiber demonstrate significantly higher strength indicators in axial compression compared to conventional concrete and reinforced concrete samples.
2. The type of fiber used has an impact on the load-bearing capacity of the element under axial compression, which is evident from the nature of the destruction of the samples and the obtained indicators.
3. Using a mix of different fibers does not significantly improve the load-bearing capacity of the element under axial compression, but remains within the average values.
4. According to the results of the study, the influence of fiber reinforcement on the strength and deformability of elements using fiber was analyzed.
5. The obtained data make it possible to recommend the use of fiber reinforcement in the structures of the country's defense fortifications that perceive static dynamic impacts.

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# ДОСЛІДЖЕННЯ РОБОТИ ФІБРОБЕТОНУ ПРИ КОРОТКОТРИВАЛОМУ СТИСКУ

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**Анотація.** При проектуванні та подальшому будівництві як за кордоном так і у вітчизняних проектах все частіше застосовують бетон армований різними типами і видами волокон - фібробетон, який має у порівнянні зі звичайним бетоном підвищені характеристики міцності та багато інших властивостей, що вказують на покращення його фізико-механічних характеристик.

Застосування бетонів з вмістом фібри під час виготовлення різноманітних конструкцій і окремих їх елементів постійно зростає. Поєднання властивостей окремих компонентів, що входять до складу

фібробетону, створює і форм матеріал з покращеними експлуатаційними якостями. Як композиційний матеріал, фібробетон значною мірою залежить від типу та різновиду фібри, що вводиться до його структури, адже саме вона визначає основні характеристики готового композиту.

Серед різних видів волокон сталева фібра вважається однією з найбільш ефективних та поширених з економічної точки зору так із точки зору доступності у різних куточках нашої держави.

Різні види фібр використовують при виготовлені елементів і конструкцій з фібробетону для підвищення характеристик виробу.

Відсоток армування фібрами елементів з фібробетону значною мірою впливає на властивості виготовленого зразка чи конструкції в цілому.

Властивості сталефібробетону також багато в чому залежать від обраного відсотка армування, який розраховується перед початком виготовлення конструкції.

Сталефібробетон, в порівнянні зі звичайним бетоном, має підвищену міцнісні і деформативні характеристики [5,7,9]. Це сприє. Це впливає на економічну складову вартості конструкції при виготовленні і подальшій експлуатації, так як вимагає у подальшому меншого догляду та можливих поточних ремонтів при експлуатації.

З метою глибшого аналізу впливу кількості, типу та характеристик металевих волокон на осьовий тиск було виконано експериментальні дослідження, результати яких наведено нижче.

**Ключові слова.** Деформація, фібробетон; призмова міцність; фібра.

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