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MECHANICAL PROPERTIES OF FIBER CONCRETE

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Abstract: The article describes and analyzes the results of systematic experimental studies of the strength of steel fiber concrete mixtures. Studies by domestic and foreign scientists show that steel fiber concrete has physical and mechanical characteristics that are significantly better than those of ordinary concrete. The bending and tensile strength increases, the shrinkage of the concrete mixture decreases, which prevents delamination, destruction of the cement-sand layer, the formation of cracks and chips. Impact resistance increases. There are quite a large number of publications in the world about steel fiber and its properties. These works touch on many aspects related to the production and use of steel fiber, including the choice of the composition of dispersed reinforced concrete. The characteristics of steel fiber concrete depend on a number of factors. However, different authors provide different quantitative estimates of their influence, so further research is needed.

In the process of work, the optimal characteristics of steel-fiber concrete mixtures were determined, and then the cubic and prismatic strength of fiber concrete under short-term and long-term loading was investigated. To solve these problems, 108 fiber concrete samples were tested: 54 with short-term loading (27 cubes 100x100x100 mm and 27 prisms 100x100x400 mm) and 54 with long-term loading (in the same proportion). At the same time, a batch of concrete samples of similar quantitative composition was tested. Compression tests of cubes from the same manufactured batch were carried out at the age of 28 days, and then at the age of 370 days. It was established that the development of deformations under long-term loading can be conditionally divided into three stages. At the first stage, accelerated deformation occurs. In the second stage, the deformation occurs at a conditionally constant rate, i.e. the growth of deformations is carried out almost according to a linear law. And in the third stage, the rate of growth of deformation almost approaches zero. Steel-fiber concrete prisms, which were subjected to long-term loading for 370 days, increased their bearing capacity, depending on the load level, by 30-50%.

Keywords: fiber reinforced concrete, long-term load, cubes, prisms, deformation

МЕХАНІЧНІ ВЛАСТИВОСТІ ФІБРОБЕТОНУ

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Анотація: У статті описано та проаналізовано результати системних експериментальних досліджень міцності сталеві фібробетонних сумішей.

Дослідження вітчизняних та зарубіжних вчених показують, що сталеві фібробетон має фізико-механічні характеристики, які значно кращі, ніж у звичайного бетону. Збільшується міцність на вигин та розтяг, зменшується усадка бетонної суміші, що запобігає розшаруванню, руйнуванню цементно-піщаного шару, утворенню тріщин та сколів. Підвищується ударостійкість. У світі існує досить велика кількість публікацій про сталеву фібру та її властивості. У цих роботах порушується багато аспектів, пов'язаних з виробництвом та використанням сталеві фібри, включаючи вибір складу дисперсно-армованого бетону. Характеристики сталеві фібробетону залежать від низки факторів. Однак різні автори надають різні кількісні оцінки їх впливу, тому необхідні подальші дослідження.

В процесі роботи було визначено оптимальні характеристики сталеві фібробетонних сумішей, а потім досліджено кубічну та призматичну міцність фібробетону при короткочасному та тривалому навантаженні. Для вирішення цих завдань було випробувано 108 зразків фібробетону: 54 – з короткочасним прикладанням навантаження (27 кубів 100x100x100



мм та 27 призм 100x100x400 мм) та 54 – з тривалим навантаженням (в тій самій пропорції). Одночасно було випробувано партію зразків бетону аналогічного кількісного складу. Випробування кубів на стиск з тієї ж виготовленої партії проводилися у віці 28 днів, а потім у віці 370 днів. Встановлено, що розвиток деформацій при тривалому навантаженні умовно можна розділити на три стадії. На першій стадії відбувається прискорена деформація. На другому етапі деформація відбувається з умовно постійною швидкістю, тобто зростання деформацій здійснюється майже за лінійним законом. А на третьому етапі швидкість зростання деформації майже наближається до нуля. Призми зі сталевібробетону, які піддавалися тривалому навантаженню протягом 370 днів, збільшили несучу здатність, залежно від рівня навантаження, на 30-50%.

Ключові слова: фібробетон, тривале навантаження, куби, призми, деформація.

1 INTRODUCTION

Research by domestic and foreign scientists shows that steel fiber concrete has physical and mechanical characteristics that are significantly better than those of conventional concrete [1–4]. the strength in bending and stretching increases, shrinkage of the concrete mixture decreases, preventing delamination, destruction of the cement-sand layer, formation of cracks and chips. impact resistance increases. fiber-concrete structures have been widely used abroad for over a hundred years, and there is a positive experience of their effective use in domestic construction [5]. the designs can be made with both fiber and combination reinforcement when there is fiber and rod or wire reinforcement. the range of applications is very wide: monolithic structures - roads, transfer of coverings, industrial floors, leveling floors, bridge decks, irrigation channels, explosion-proof structures, dams, fireproof plaster, capacities for water and other liquids, finishing of tunnels, spatial coverings and structures, repair of monolithic structures of floors, roads, etc; prefabricated elements and structures - railway sleepers, pipelines, beams, ladders, wall panels, roofing panels and tiles, floating dock modules, offshore structures, explosion-proof structures, slabs of airfield, road, pavement and channel fasteners, cornices, piles, heating elements, elements of spatial coverings and structures, street accessories.

2 ANALYSIS OF LITERARY DATA AND RESOLVING THE PROBLEM

Many works are devoted to the strengthening of reinforced concrete beams. all of them can be divided into experimental and theoretical, and the latter include analytical and numerical methods for calculating reinforcements. the theoretical methods of calculation of reinforcements are currently insufficiently developed. this is explained by the complexity of the mathematical model of amplification, regardless of the method used. this fully applies to beams reinforced with fiber concrete. in this regard, preference is given to numerical methods. first of all, the finite element method (fem), because it is the only universal method, the possibility of which is practically not limited. this explains the use of fem for numerical analysis in all modern engineering calculation programs. implementation of the fem algorithm is carried out using modern computer programs, such as ansys [1], abaqus [2], nastran [3], etc., designed for numerical modeling and analysis of complex structures, including beams with inclusions.

The article [4] discusses 3d modeling in ansys of the destruction of an element of a structural reinforced concrete beam. the authors [5] show the use of the finite element method for modeling damaged reinforced concrete beams. the corresponding numerical analysis was carried out in abaqus using the concrete plasticity model. the article [6] considers the critical parameters affecting the efficiency of fiber-reinforced polymer systems with an external lateral connection based on the finite-element model developed by the authors. an interesting work is presented by the authors of the article [7], where a multifactorial numerical experiment was conducted using computer modeling in the ansys program.

Articles [8-10] are devoted to a similar problem. in [8], experimental data from four-point bending of six reinforced concrete beams and the results of finite-element modeling obtained using ansys are considered. [9] suggests using discrete fiber reinforcement for tunnel finishing. the task is also modeled in ansys. the same authors in [10] investigate the ability of fibers to control cracks by summarizing the results of more than ninety tensile tests of reinforced concrete prisms, conducted with different sizes, reinforcement ratios, number of fibers, and concrete strength. recent finite element models for predicting crack spacing in fiber reinforced concrete composites are evaluated and critically discussed.

3 PURPOSE AND TASKS OF THE STUDY

The purpose of this work was to conduct systematic experimental studies of the strength of steel fiber concrete. The tasks of the work consisted in determining the optimal characteristics of the steel-fiber concrete mixture, followed by the study of the cubic and prismatic strength of the fiber concrete at short and long loads.

4 BASIC RESULTS

Since fiber concrete is a composite material, two approaches are commonly used in the study of its physical and mechanical properties, which are commonly used in the work of composites – phenomenological and structural. In the first case, the material is regarded as a certain isotropic system to which the methods of mechanics of a deformed solid are applicable. In this case, the material characteristics are determined on the basis of laboratory studies and tests using the methods of the theory of experiment planning and mathematical statistics [17]. In the second case, structural analysis is used, which implies the expression of the mechanical characteristics of the material through analogous indices of its components, the coefficient of fiber reinforcement, the type and geometric dimensions of the fiber, etc. [18].

In our country, the most widespread is structural approach to the study of the properties of fiber concrete by analogy with reinforced concrete, which allows you to determine the necessary strength and deformation characteristics based on the properties of the original components. This approach is complex, depends on many factors, but it is also convenient in solving the problems of optimal design of fibrous concrete structures.

The phenomenological approach has become widespread in Europe and America. World experience in designing concrete structures shows that the application of the phenomenological approach in determining the physical and mechanical properties of fiber concrete allows the most efficient use of the material and the design of rational concrete structures.

The experimental studies included two steps. The purpose of the first stage was to determine the optimal characteristics of the steel fiber concrete mix. For this purpose, the cubic strength of steel fiber concrete on samples of 100x100x100 mm was determined. The percentage of dispersed reinforcement varied, which was 0.5%, 1.0%, 1.5%, as well as the size of the fraction of large aggregate (crushed stone) – with the size of the fraction ≤ 10 mm in one series of tests and ≤ 20 mm – in the second. At the same time, the cubic strength of ordinary concrete at the same size of a large aggregate was determined. In total, 8 series of tests were carried out on 9 samples in each, the general characteristics of which are given in Table 1.

In the room where the samples were made and subsequently gained strength, the air temperature met the requirements and was 15 ... 20 ° C.

Before preparing the mixture, the right components were selected and the forms were prepared. For the production of samples used metal detachable molds. Before laying the concrete mixture in the form of their inner surfaces were greased with a thin layer of oil.

First, the required amount of each of the components was proportionally determined, and then the concrete mixture was prepared. For the first two series of experiments, a conventional concrete mixture was prepared and molded. Then they made another the same mixture, and it gradually "portions" was introduced fiber, continuing mixing in the concrete mixer until a uniform distribution of fiber in the mixture.

Table 1

Summary table of the first stage of tests

Series №	Material	Crushed stone dimension, [mm]	Percent of fibrous reinforcement
1	Concrete	≤ 10	–
2	Concrete	≤ 20	–
3	Fibrous concrete	≤ 10	0.5
4	Fibrous concrete	≤ 10	1.0
5	Fibrous concrete	≤ 10	1.5
6	Fibrous concrete	≤ 20	0.5
7	Fibrous concrete	≤ 20	1.0
8	Fibrous concrete	≤ 20	1.5

After the formation of specimens of ordinary concrete and steel fiber, they were left under normal conditions. After 5 days, the samples were removed from the forms, labeled, and stored for 28 days from the time of formation under normal conditions. After storage, the finished specimens were inspected (they should have the correct geometric shape and parallel faces), measured and prepared for testing.

The processing of the results of the first stage of the tests showed that the optimum characteristics of the steel-concrete mixture is a matrix with a large filler of 10 mm (the cubic strength was much higher than the size of the crushed stone 20 mm, in all series of experiments) at 1.0% fibrous reinforcement, since at a higher percentage of fiber reinforcement increased cubic strength was insignificant. This composition was accepted for the second stage of testing.

In all the experiments used cement grade 400 and washed river sand. The water-cement ratio is 0.449. For disperse reinforcement, bent-end fiber made from high-strength wire with a temporary resistance of 1335 MPa was used. The main characteristics of fiber are given in Table 2.

The fiber used is manufactured by Stalkanat-Silur Production Association (Ukraine) in accordance with European standard EN14889-1: 2006 [19]. It is the most common type of fiber, easy to handle, not prone to the formation of "hedgehogs", holds well in concrete.

The objectives of the experimental studies in the second stage were:

- determination of cubic and prism strength;
- study the nature of , change along time;
- elasticity modulus and deformation modulus determination.

To solve these problems, 108 specimens of fiber concrete were tested: 54 — with a short-term load application (27 cubes 100x100x100 mm and 27 prisms 100x100x400 mm) and 54 — with a long load (in the same proportion). A batch of concrete samples similar in quantitative composition was tested at the same time.

Table 2

Main fiber properties

Mark	Description	Length, [mm]	Diameter, [mm]	σ_u , [MPa]	E , [MPa]	μ
HE50	Wire chopped fiber	50	1.0	1335	200000	0.3

Cubes of concrete and fiber concrete were subjected to destruction by compression in a test facility with a loading rate, which provides an increase in the design stress in the sample before its complete destruction. The press was used as the test unit (figure 1). The cubes were set strictly in the center of the plate of the press. They turned on the equipment and gradually loaded the samples before their destruction. Tests of specimen cubes for compression from

the same manufactured batch were performed at the age of 28 days, and then — at the age of 370 days. In this case, the cubic strength of ordinary concrete during the observation increased by 3.5 MPa, which is 11.3%. Fiber concrete strength increased by 10.1 MPa over the same period, ie by 31%. And if, by the time of the set of branded concrete strength, the strength of fiber concrete was only 4.7% higher than the strength of ordinary concrete, then almost a year later this difference increased to 24%.



Fig. 1. Examples of tests

It should be noted that all without exception samples that have been under the influence of continuous load for a year have increased their load capacity. The higher the level of long load, the more compacted the concrete, and, of course, the higher its durability. Samples loaded to 0.8 (from cubic or prism strength respectively) for 370 days increase their load capacity by 40.5%. At the same time, in the sample loaded to 0.3 the long-term strength increased by 18.3%.

When testing concrete prisms with dimensions of $100 \times 100 \times 400$ mm, twin specimens were combined into groups and series. Samples of each group were made in one step. Prisms (like cubes) were concreted in metal cassette formwork. The concrete mixture was made in a free fall concrete mixer. The formulation was further mixed manually for greater uniformity prior to formworking. Prior to the experimental studies, the samples were stored at a temperature of 18-24°C. Before testing the side faces, the prisms were glued on to mount clock-type indicators.

The method of short-term and long-term testing of samples was made taking into account the recommendations of normative documents for testing concrete.

Determination of the modulus of elasticity and prism strength was preceded by centering the samples from the physical center by applying test loads that cause stresses up to 0.2 of the prism strength. The centering sought to ensure that the deformations along the four faces of the specimen were approximately the same and almost completely reversible. The workload was carried out in steps of 0.1 from prism strength. At each load stage, deformations were measured. The maximum force perceived by the sample prior to fracture was taken as the value of the destructive load. Continuous loading of the samples was carried out in power stands, consisting of 4 metal rods with a diameter of 46 mm, to which rigid load plates (4 pieces) were attached by means of threaded connections at certain levels. In order to maintain

the load during long-term tests at a given level, the transfer of forces from the hydraulic jack to the studied prisms was carried out through a power unit consisting of 4 springs and 2 load plates. The power of each spring is 100 kN.

All forces made by the power unit are balanced within the upper and lower load plates. From the installation to the foundation is transferred only its own weight and a possible dynamic impact during the fragile destruction of the prisms. Prior to loading, each spring cartridge is calibrated using a sample dynamometer (500 kN) mounted at the location of the experimental sample. The load during the experiment was maintained at the required level and controlled by deformation of the spring block and the pressure gauge of the pumping station.

On the height of the installation in one power line, that is, in 2 floors, there were 2 samples: one of ordinary concrete, and the other - of steel fiber. Thus, throughout the experiment (370 days), the mode and load level for both samples were exactly the same (figure 2).



Fig. 2. Long-time tests results

5 DISCUSSION OF THE RESULTS OF THE STUDY

To determine the bearing capacity, as well as to compare the results of short-term and long-term loading, in each group of samples 3 prisms were brought to destruction by short-term load on the hydraulic press. Five prisms of each concrete composition were loaded with a long load in the power stands and 4 prisms of each group were stored until the end of the experiment to determine the corresponding prism strength. As a result of short-term testing, it was found that the prism strength of ordinary concrete was 235 kN and that of steel fiber concrete was 252 kN.

To cover the entire operational spectrum of the stress state of real reinforced concrete elements, levels of 0.3 were assumed as continuous load levels; 0.4; 0.5; 0.67 and 0.8 from short-term destructive loading. In figure 2 presents the results of long tests for three levels - 0.3; 0.5 and 0.8. The solid lines show the deformation of the concrete, and the dashed lines show the steel concrete. The creep deformation of steel fiber is on average 20% lower than that of concrete.

6 CONCLUSIONS

The optimal characteristics of the steel fiber concrete mixture is a matrix with a large

filler of 10 mm at 1.0% fiber reinforcement, since at a higher percentage of fiber reinforcement the increase in cubic strength was insignificant.

Before the destruction of cubic specimens of steel fiber concrete, cracks along the axis of action of the short-term compressive load were observed. The destruction of specimens of steel fiber concrete with 0.5% of disperse reinforcement and ordinary concrete was fragile, while in the case of reinforcement of 1.0% and 1.5% brittle fracture was not observed.

The development of deformations under prolonged loading can be conditionally divided into 3 stages. In the first stage there is an accelerated deformation. The deformations that occurred during this period make up almost 75% of the total deformations during the whole observation period. In the second stage of deformation occurs at a relatively constant rate, ie, the deformation increase is carried out practically according to a linear law. At a load level of 0.3 R stable linear part begins after 35-40 days, for the level of 0.8 - after 65-70 days. The deformations appeared at this stage make up 20-23% of their total size. And finally, in the third stage, the growth rate of deformation is almost approaching zero. The deformation change graph is almost parallel to the horizontal axis.

Prisms made of steel fiber concrete, which have been in operation for 370 days under the influence of prolonged loading, have increased the load-bearing capacity, depending on the load level, by 30-50%. The higher the load level, the higher the durability. When reloading to the destruction of deformation of steel-fiber prisms changed according to linear law. This is explained by the fact that in the process of three-stage loading was elongated transient creep of concrete.

7 ETHICAL DECLARATIONS

The author has no relevant financial or non-financial interests to report.

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