Fiber type influence on the reinforced concrete under axial tension

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Abstract. The results of experimental studies of properties of steel fiber-reinforced concrete of different types under axial tension are presented. A stand with a flexible design of the grip element connection has been developed, which provides axial load application and minimizes the effect of stress concentration at the ends of the specimen. The design is based on the ideas of the well-known Michaelis device. The design of the stand is such that the distance between the axis of load application and the central joint is 108 cm and between this joint and the axis of the test specimen is 21 cm, resulting in the load applied to the specimen being 5.143 times the applied load. The limits of fiber concrete axial tensile strength have been determined - 1.28 MPa when reinforced with wave or spun fiber and 1.37 MPa when reinforced with anchor fiber or a combination of the three types of fiber, which is 4.1 % and 4.4 % of compressive strength, respectively. It was also found that the concrete reinforced with anchor fiber or with the combined dispersed fiber reinforcement has higher deformation properties than the concrete reinforced with wave or spun fiber. The analysis of strength and deformation properties of fiber concrete when reinforced with different types of fibers allows to recommend anchored fibers for practical application.

Introduction
Concrete is known to perform poorly in tension. Its tensile strength is only 7-10% of its compressive strength, which is a significant disadvantage of concrete. There are several types of tensile strength of concrete: flexural tensile strength, axial tensile strength, splitting tensile strength.

In practical terms, the tensile strength of concrete shows the ability to withstand various deformation loads while maintaining the geometry of the structure unchanged. In addition, the tensile strength of concrete shows the resistance of the material to temperature variations and is also taken into account when calculating the load-bearing capacity of structures, especially those working in flexure.

The axial tensile strength is the most difficult to determine. One of the options is the tension of dog-bone specimens. The bending tensile strength is determined on 100x100x400 mm prisms; 150x150x600 mm, etc. Samples are tested under the action of two forces applied in 1/3 of the span. The destruction of concrete occurs from the tensile stresses, reaching the greatest values in the lower layer of the tensile zone. Due to the complexity of determining the pure tensile and flexural strength of concrete, the determination of the tensile strength of concrete in splitting (sometimes this method proposed by F. Carneiro is called the Brazilian test) is widely used. The standard cubes used are split on presses with steel or plywood liners. Splitting strength is slightly higher than pure tensile strength, on average 30%.

For conventional concretes, even in bendable structures, the tensile strength of concrete is not regulated. Tensile stresses in them are taken up by the reinforcement. In the concrete of the tensile zone due to its low extensibility cracks are allowed and formed. But the width of their opening is limited (in the limit -
up to 0.3 mm). At the same time, cracks are inadmissible in a number of structures - road surfaces, tanks, hydraulic structures. For them, the tensile strength becomes essential and may be the main standardized characteristic.

One way to increase the tensile strength and cracking resistance of concrete is its dispersed steel fiber reinforcement.

1. Materials and methods
Determination of physical, physical-mechanical and construction-technical properties of concrete and mixtures with dispersion reinforcement has been carried out in accordance with the current regulatory documents and generally accepted methods. Mathematical methods of experiment planning and analysis of the obtained experimental results by methods of mathematical statistics have been used.

2. Analysis of publications
The tensile strength of concrete and fiber concrete has been the subject of study by many researchers. Wu et al. [1] conducted experimental studies on the tensile strength of concrete at low strain rates using three different test methods: axial stretching, splitting stretching and flexural stretching. In the latter case, the ultimate tensile strength was the greatest. The effect of specimen end grips on the ultimate tensile strength of concrete was investigated by Wille et al. [2], Li Z. et al. [3] and Zijl et al. [4]. A number of works [5-7] investigated the axial tensile strength of lightweight concrete samples with different aggregate sizes. The authors found that the tensile strength increased with decreasing specific weight of the concrete.

It has been noted that the end conditions affect crack formation and strain distribution in the cross section of the tested specimens [8]. I.K. Mohammad investigated the axial tensile strength and compared the results with the bending tensile strength. They were comparable [9]. V. Sarfarazi and colleagues conducted a Brazilian test to compare the results of the same two methods. The test results showed that the axial tensile strength was much lower than in the Brazilian test - the difference was about 33% [10]. However, all of these methods have some kind of disadvantages - inhomogeneous fracture plane, stress concentration and slippage at the end of specimens, and bending loads due to imprecise specimen alignment during testing.

3. Problem formulation
Thus, the tensile strength of concrete and fiber concrete is significantly affected by a number of factors - the test method, the design of the test bench, the nature of the load application, the composition of the mixture, etc., so the problem of determining the tensile strength of fiber concrete continues to be relevant.

4. Aim of Paper
The purpose of this work is to experimentally investigate the properties of steel fiber concrete reinforced with steel fibers of different types under axial tension, in order to further ensure the specified performance characteristics of steel fiber concrete structures.

5. Research results
In order to make samples in the process of kneading the concrete mixture, fibers were evenly added, the total volume of which was 1% of the product itself. This volume was determined as optimal in previous studies [11]. The tests were conducted on prisms and cubes with dimensions of 100x100x400 mm and 100x100x100 mm, respectively, cured for 28 days. The prisms and cubes were made in accordance with regulatory documents [12]. Four groups of prisms and cubes were made. One of each - from ordinary concrete (with coarse aggregate dimensions up to 10 mm) class C20/25, and three more - with different types of fibers (anchored, spun and corrugated, figure 1). Each group consisted of six samples.
The fiber used for the research was provided by Stalkanat-Silur and made in accordance with the requirements of EN 14889-1:2006 [13]. In all experiments, cement grade 400 and washed river sand were used. The water-cement ratio was 0.449.

At the second stage, 32 dog-bone specimens with 1.0% dispersed reinforcement were made (8 specimens each of concrete reinforced with anchor, spun and wave fibers, and another 8 of concrete reinforced with a mixture of three types of fibers in equal amounts). All specimens had the same dimensions, a cross-section of 110 x 110 mm at the ends and a cross-section of 50 x 70 mm in the middle (figure 2).

For the tests a specially designed test stand with a flexible design of the connection of the gripping elements, which provides axial application of the load and minimizes the effect of stress concentration at the ends of the specimen (figure 3). The design is based on the ideas of the well-known Michaelis instrument, which is usually used to determine the bending strength of binders in the form of standard beam specimens.

The design of the bench is such that the distance between the axis of load application and the central joint is 108 cm, and between this joint and the axis of the test specimen is 21 cm. It follows that the load applied to the specimen is 5.143 times the applied load.

The division value of the dynamometer when fixing the load transferred to the sample is 1 division = 0.3 kg. The base of the indicators attached to the dog-bone specimen (figure 3) was 24 mm. The load was applied in steps, with an endurance at each step of loading.

After processing the test results of each series by the methods of mathematical statistics [14, 15], the average values of the controlled values were obtained.

Table 1 shows the average values of relative strains at each test step.
Table 1. Relative deformations at the four reinforcement options

| Fiber type | Anchor | Crimped | Wave | Mix |
|------------|--------|---------|------|-----|
| Load, Kg   | Strain, ε·10^4 | Load, Kg | Strain, ε·10^4 | Load, Kg | Strain, ε·10^4 | Load, Kg | Strain, ε·10^4 |
| 0.00       | 0.0000  | 0.00     | 0.000 | 0.00 | 0.0000  | 0.00     | 0.0000  |
| 108.00     | 0.083   | 123.43   | 0.042 | 123.43 | 0.042 | 108.00   | 0.167   |
| 154.29     | 0.167   | 169.71   | 0.083 | 169.71 | 0.083 | 154.29   | 0.208   |
| 200.57     | 0.208   | 216.00   | 0.167 | 216.00 | 0.125 | 200.57   | 0.250   |
| 200.57     | 0.208   | 216.00   | 0.167 | 216.00 | 0.125 | 200.57   | 0.250   |
| 246.86     | 0.292   | 262.29   | 0.208 | 262.29 | 0.167 | 246.86   | 0.333   |
| 246.86     | 0.333   | 262.29   | 0.208 | 262.29 | 0.167 | 246.86   | 0.333   |
| 293.14     | 0.375   | 308.57   | 0.292 | 308.57 | 0.250 | 293.14   | 0.438   |
| 293.14     | 0.375   | 308.57   | 0.292 | 308.57 | 0.250 | 293.14   | 0.438   |
| 339.43     | 0.500   | 354.86   | 0.333 | 354.86 | 0.333 | 339.43   | 0.542   |
| 339.43     | 0.500   | 354.86   | 0.333 | 354.86 | 0.333 | 339.43   | 0.542   |
| 385.71     | 0.625   | 401.14   | 0.375 | 401.14 | 0.458 | 385.71   | 0.646   |
| 385.71     | 0.625   | 401.14   | 0.375 | 401.14 | 0.458 | 385.71   | 0.646   |
| 432.00     | 0.833   | 447.43   | 0.417 | 447.43 | 0.542 | 432.00   | 0.708   |
| 432.00     | 0.833   | 447.43   | 0.458 | 447.43 | 0.583 | 432.00   | 0.708   |
| 478.29     | 1.042   | -        | -     | -     | -      | 478.29   | 0.750   |
| 478.29     | 1.083   | -        | -     | -     | -      | 478.29   | 0.777   |

The load-strain diagrams for the four reinforcement options are shown in figure 5, 6.
Figure 6. Load-strain diagrams Wave, Mix fibers.

At the rupture, the average number of fibers caught in the section of the dog-bone specimen was 16 units, the anchor fiber - 22 units, the spun fiber - 10 units. And at the rupture of the dog-bone specimen with combined reinforcement the number of fibers was: anchor fiber - 0 units, spun fiber - 19 units, wave fiber - 2 units.

6. Conclusions

Thus, the design of the test stand for tensile testing of concrete and fiber concrete dog-bone specimens, which provides an axial load application and minimizes the effect of stress concentration at the ends of the specimen, was developed. The design is based on the ideas of the Michaelis instrument, which is usually used to determine the flexural strength of binders in the form of standard beam specimens.

At the first stage of tests it was found that the optimal characteristics of the fiber concrete mixture is a matrix with coarse aggregate ≤ 10 mm with 1.0% fiber reinforcement.

At the second stage, the limits of fiber concrete axial tensile strength were determined - 1.28 MPa when reinforced with wave or spun fiber and 1.37 MPa when reinforced with anchor fiber or a combination of the three types of fiber, which was 4.1% and 4.4% of the compressive strength, respectively.

It is also established that concrete reinforced with anchor fiber or with combined dispersed reinforcement has higher deformation properties than concrete reinforced with wave or spun fiber. The analysis of strength and deformation properties of fiber concrete when reinforced with different types of fibers allows to recommend anchored fibers for practical application.

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