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Article

Experimental study on physical-mechanical characteristics of steel fiber reinforced concrete with worn rope fibers

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Abstract. This study examined the physical-mechanical properties of steel fiber reinforced concrete with different fiber orientations and vibration times. The concrete mixtures contained crushed stone, sand, Portland cement, Rheobuild 181A plasticizer, and 5 cm steel fibers with 2% reinforcement. Using steel fibers from worn ropes from Innotech LLP (Almaty, Kazakhstan) increased the average strength of concrete and improved its ductility, allowing for plastic failure instead of brittle failure. Joint mixing of steel fiber-reinforced concrete with randomly oriented fibers made from used cables increased the mean value of flexural strength. The concrete mixtures with a vibration time of 9 seconds showed the highest flexural strength, which was 2.1 times higher than that of concrete samples without fiber. These findings demonstrate the potential of steel fiber reinforcement to improve the mechanical properties of concrete, especially in applications requiring flexural strength.
Keywords: steel fiber, concretes, flexural strength, worn rope, joint mixing.

1. Introduction

Steel fiber reinforced concrete (SFRC) is a type of reinforced concrete that incorporates steel fibers into a specially designed concrete matrix [1], reducing the need for traditional reinforcement and providing technical and economic benefits in various construction applications [2]. The traditional SFRC production process involves preparing a concrete mix in a mixer, adding a specified amount of dispersed steel reinforcement, and mixing both components until the reinforcement is evenly distributed throughout the mixture. The SFRC mixture is then placed in forms or molds and subjected to vibration compaction. The components of traditional SFRC vary in composition, with a cement-to-sand ratio of 1:1.9 to 2.0, a water-to-cement ratio of 0.4 to 0.5, and the addition of plasticizing agents in amounts of 0.6 to 1.0% of the cement's weight. The parameters of the steel fiber reinforcement of the concrete mixture are characterized by values such as a fiber volume content of 2%, a geometric factor (ratio of fiber length to diameter) of 30 to 45, and a fiber diameter of 1.6 mm. Steel fiber-reinforced concrete (SFRC) has drawbacks like fiber clumping during mixing, limiting fiber length and reducing mixture homogeneity. The strength of SFRC is proportional to inter-fiber spacing which can be increased from 6-10 mm to 3-5 mm resulting in material strengthening up to 2.5 times. Traditional SFRC structures fail due to insufficient fiber anchoring with fibers over 80-100 geometric factor. Increasing fiber volume content by more than 3% causes fiber clumping, complicating compaction and reducing material strength [3]. Research is underway to solve these issues.

This study aims to investigate the influence of the manufacturing process of steel fiber-reinforced concrete (SFRC) using wire fiber obtained from discarded ropes on the strength of the structure under bending. The main objective is to determine the optimal manufacturing process that maximizes the material's strength characteristics. To achieve this goal, bending tests were conducted, during which the strength parameters of the SFRC structure were measured. Discarded ropes were used as a source of wire fiber, which improved the material's characteristics. The research results may help optimize the SFRC production process and create stronger and more durable structures for use in construction.

The research tasks include:

– Investigating the strength of SFRC manufactured using the combined mixing method under bending.

– Conducting comparative analyses on the influence of fiber technological parameters on the main physical and mechanical characteristics of SFRC structures.

– Analyzing the results and comparing them with the findings of previous studies.

2. Methods

The concrete samples used in the study were composed of a combination of various components. The primary components used in the samples included 5-10 mm crushed stone, sand with a fineness modulus of 2.5, Portland cement with an activity of grade M450, Rheobuild 181A plasticizer, as well as tap water. Additionally, for the experiments, we used a fiber made from recycled cables from Innotech, LLP (Almaty, Kazakhstan) [4] to manufacture the SFRC samples. The fiber reinforcement percentage was 2%, with a fiber length of 5 cm.

The experimental program included [5-6]:

– Bending test of concrete samples under bending;
– The flexural strength estimation;
– Comparative analysis of the influence of fiber technological parameters.

Tests were conducted to determine the effect of vibration time of the samples, as well as its technical characteristics, on the flexural strength of SFRC.

To perform the bending test, reference samples were manufactured in the form of square prisms with dimensions of 100×100×400 mm according to [5]. Each series included three samples, with different vibration times: 3 and 9 seconds. The series manufacturing modes are depicted in Table 1 below.

Table 1 – Manufacturing modes

No. of series	Method	Fiber length, см	Features of samples manufacturing
1	Volumetric-arbitrary orientation	5	With optimal compaction time on the vibrating table
2	Volumetric-arbitrary orientation	5	With a compaction time on the vibrating table 3 times longer than optimal

To accelerate the strength gain of concrete samples, we employed a technique known as thermal-moisture treatment. This method involved utilizing a steam curing chamber, specifically the KUP-1 (as depicted in Figure 1), and following a specific treatment cycle. The cycle consisted of a holding period of 2-3 hours, with a gradual temperature increase at a rate of 25-30 °C per hour. This was followed by isothermal heating at 80-90 °C for 6-8 hours, and then a temperature decrease at a rate of 30-40 °C per hour. After this meticulous process, the concrete achieved a strength level ranging from 70-100% of its ultimate strength at 28 days. Prior to testing, a thorough visual inspection was conducted to identify any potential defects in the concrete samples. Additionally, linear measurements were taken using a caliper with a high level of accuracy, with an error margin of no more than 1%. This ensured precise and reliable results for evaluating the strength gain of the concrete samples after the thermal-moisture treatment.

Figure 1 – Universal steaming chamber KUP-1

Samples, at a vibration time of 3 and 9 seconds, made to determine the flexural strength are shown in Figure 2.

Figure 2 – SFRC samples with vibration times of 3 (left) and 9 (right) seconds

The measurement results were recorded in the testing journal. A hydraulic press (2PG-10) was used to determine the flexural strength. Each sample was placed on two supports and loaded until it fractured at a constant rate of stress increase (0.05 ± 0.01) MPa per second, with the load applied at the mid-span and evenly distributed over the sample width. The setup configuration is illustrated in Figure 3.

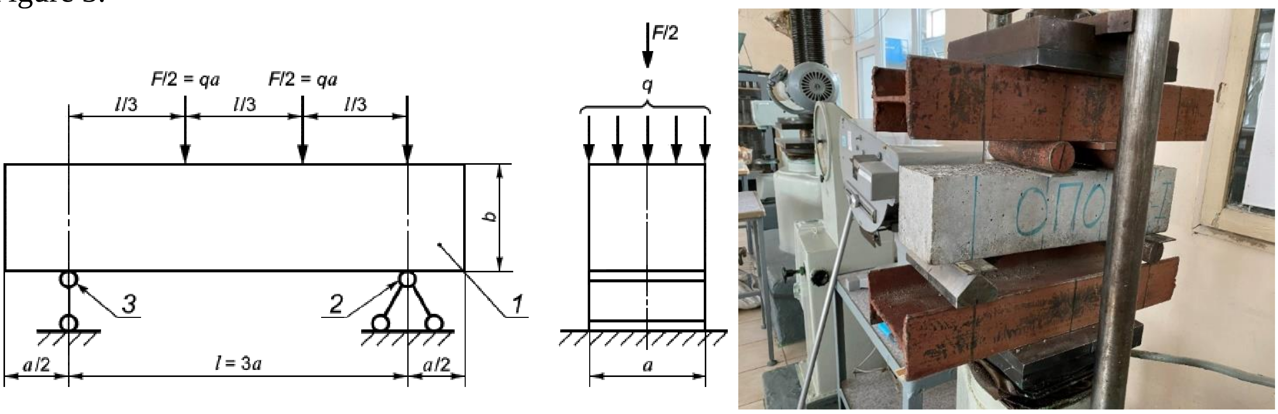

Figure 3 – Test setup: 1 – sample; 2 – hinged and fixed bearing; 3 – pivot bearing; a – width and height of sample; F – load; q – evenly distributed load; l – distance between supports.

The flexural strength (R_{tb}, MPa) was determined according to the following equation [5]:

$$R_{tb} = \delta \frac{Fl}{ab^2} \quad (1)$$

Where: F – Destructive load, N;

a, b, l – width and height of sample prism, and distance between supports, respectively, mm;

δ – scaling factor for converting the strength of concrete to the strength of concrete in samples of basic size and shape.

The strength in a series of samples was determined as the arithmetic mean value of the strength of the tested samples in the series for the three samples with the highest strength.

3. Results and Discussion

After conducting the experiment and analyzing the obtained data, a comparative analysis of the influence of the technological parameters of the method of joint mixing of steel fiber-reinforced concrete mixture under volumetric-arbitrary fiber orientation was carried out. The experiments revealed that the nature of the samples' failure with 3 and 9 seconds of vibration during the strength test in bending was predominantly plastic, as opposed to the brittle failure exhibited by samples without fibers. A graph depicting the comparison of the impact of the technological parameters of the joint mixing method of steel fiber-reinforced concrete mixture under volumetric-arbitrary fiber orientation on the flexural strength of the samples is presented in Figure 4.

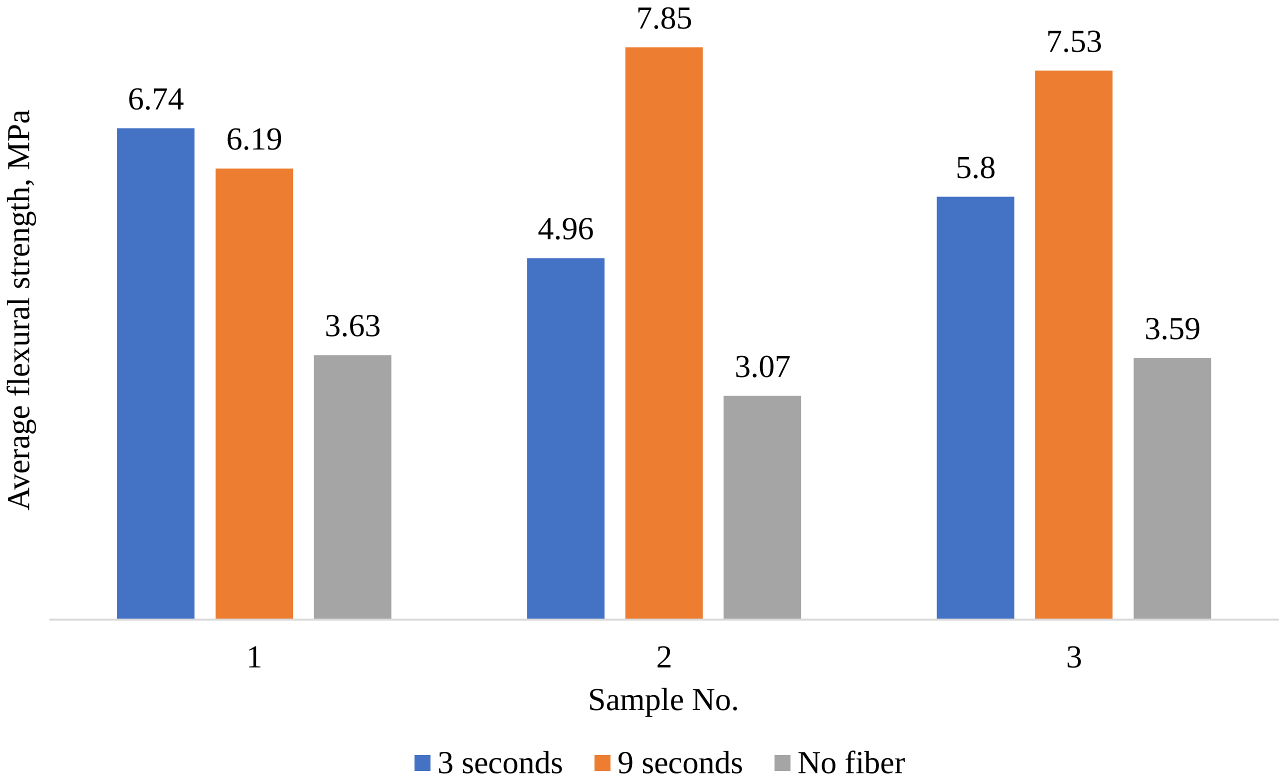

Figure 4 – Effect of the manufacturing technology of steel fiber concrete on its flexural strength

The graph indicates that the flexural strength of samples subjected to 3 seconds of vibration increased on average by 1.7 times (i.e., 70%), while those subjected to 9 seconds of vibration increased by 2.1 times (i.e., 210%). Analyzing the obtained results, it can be concluded that the bending strength of the samples is comparable to that obtained in similar studies [7].

4. Conclusions

The results of the study indicate that the incorporation of steel fibers into the concrete mixture can enhance the material's ductility, leading to a plastic failure mode instead of brittle failure. This observation underscores the potential of steel fiber reinforcement to improve the mechanical properties of concrete, particularly in applications where flexural strength is critical, such as in structural elements subjected to bending loads.

The analysis of the test results confirmed that the method of joint mixing of steel fiber-reinforced concrete with randomly oriented fibers made from used cables increases its mean value of flexural strength. At the same time, the highest flexural strength is exhibited by the concrete mixtures with a vibration time of 9 seconds. The strength of samples made from this type of mixture was found to be 2.1 times higher than that of plain concrete samples based on the test results.

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