Experimental investigation of steel fiber dispersed reinforced concrete beams

Maksud ugli Bakhtiyorjon*, and *Sobirjon* Razzakov

Civil Engineering Department, Namangan Engineering-Construction Institute, Namangan, Uzbekistan

Abstract. The article presents the results of research on the deformation characteristics of concrete beams dispersed reinforced with steel fibers. One of the main disadvantages of conventional concrete is that its tensile strength is several times less than that of compressive strength, and the tensile behaviour of concrete in bending elements is not considered. This article takes into account the behaviour of concrete beams in the tensile zone by dispersing reinforcement of concrete beams with steel fibers, and the changes of strains in compressive and tensile concrete and tensile steel reinforcements depending on imposed load are highlighted. Also, by adding steel fibers to the concrete mix with lengths of 10, 20, 30, 40 and 50 mm and 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% by volume, their optimal amounts were determined by testing cubic and prismatic samples.

1 Introduction

In the world, many scientific research works aimed at increasing the strength of buildings and structures and ensuring seismic safety are being carried out. In particular, research aimed at increasing the strength and reliability of reinforced concrete structures, dispersive reinforcement of concrete using various composites and steel fibers is considered necessary. Also, determining the optimal length and amount of steel fibers for concrete, researching and modeling the physical and mechanical properties of fiber concrete, conducting research in the directions of increasing the strength, crack resistance and elasticity modulus of fiber reinforced concrete beams subjected to bending are considered urgent tasks [1-3].

In Uzbekistan, great attention is paid to the further development of the field of construction materials, the production of competitive construction materials, the production of new construction materials used to ensure the strength and seismic safety of buildings and structures. The roadmap for "Ensuring seismic safety and improving the system of increasing earthquake resistance of buildings and structures" to be implemented in 2024-2025 includes the tasks of testing new materials, studying their properties, and determining the field of application. In the implementation of these tasks, determining the composition of fiber concrete using steel fibers to increase the strength of concrete, researching the mechanical properties of fiber concrete reinforced with steel fibers, and studying the stress-deformation state, strength, crack resistance of fiber reinforced concrete beams, as well as creating new

* Corresponding author: maqsudoglibahtiyor@gmail.com

practical programs for calculating the mechanical properties of fiber reinforced concrete are important tasks. is considered

The analysis of the conducted scientific research and literature shows that in the conditions of Uzbekistan, scientific research works were conducted on the physical and mechanical properties of dispersed reinforced fiber concrete based on steel fibers. However, the physical and mechanical properties of fiber concrete based on steel fibers have not been sufficiently studied, taking into account the climatic conditions of Uzbekistan.

In the conditions of Uzbekistan, it is important and necessary to study the physical and mechanical properties of fiber concrete based on steel fibers, to determine the optimal amount of steel fibers for fiber concrete.

2 Tasks of research work

It is advisable to carry out research works to determine the strength, stress-strain state, crack resistance of concrete beams dispersed with steel fibers.

Based on the above, the tasks of this experimental research are as follows:

1. Study of strength and deformability properties of ordinary heavy concrete and steel fiber concrete.
2. Determination of compressive and tensile strains of the concrete in the normal section of the beams.
3. Determining stress and strains in main reinforcements of beam samples;
4. Study the deflection of concrete beams;
5. Determining the appearance of cracks in the normal section of beams under the influence of loads and the width of the opening of the cracks and their development;
6. Study of deformation characteristics of beams under static loads.

3 Preparation of samples for testing

For the experimental study of fiber-reinforced concrete beams based on steel fibers, sample beams were prepared in 10 series. The sample beams in the first series were made of ordinary concrete without steel fibers. Fibroreinforced concrete beam samples were prepared by adding 1%, 2% and 3% steel fibers to concrete in the second, third and fourth series of samples.

Fibroreinforced concrete beam samples were prepared by adding 20 mm long steel fibers to concrete in the amount of 1%, 2% and 3% in the fifth, sixth and seventh series of samples.

Fibre-reinforced concrete beam samples were prepared by adding 1 % steel fibers to concrete in the eighth series of samples. In the ninth series of samples, steel fibers with a length of 30 mm were added to concrete in the amount of 2 %, while samples were prepared by dispersing reinforcement, while in the tenth series of samples, fiber reinforced concrete samples were prepared by adding steel fibers with a length of 30 mm to concrete in the amount of 3 %.

Fibre-reinforced concrete and reinforced concrete sample beams had cross-sectional dimensions of 100x200x1200 mm and design length of 1050 mm. Reinforcements with a diameter of 12 mm and class A-III were used as working reinforcements for the tensile part of the sample beams. A-I class reinforcement with a diameter of 8 mm were used for the compressive zone of the beams. In the creation of the space frame, cross reinforcements class Bp-I and wire reinforcements with a diameter of 5 mm were used. [2]. The reinforcement cage is shown in Figure 1.

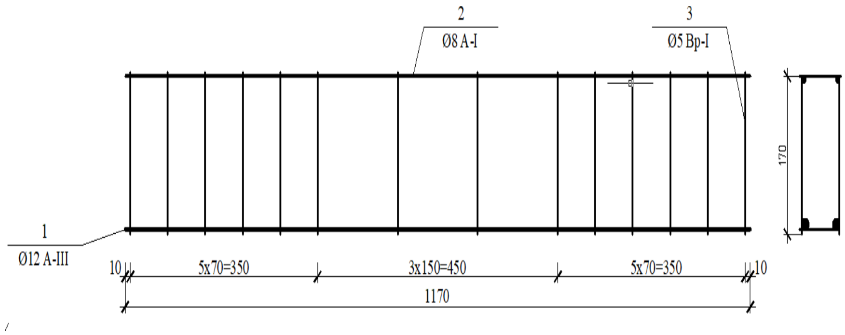

Fig. 1. Reinforcement cage of the beam.

For dispersive reinforcement of reinforced concrete beams with density 7850 kg/m^3, modulus of elasticity 200000 MPa and fiber diameter 0.3 mm and fiber lengths 10; 20; 30 mm steel fibers were used (Figure 2).

a) b) c)

Fig. 2. View of steel fibers: a – 10 mm; b – 20 mm; c – 30 mm.

4 Strength and deformation characteristics of materials

To determine the cubic strength of concrete and fiber concrete in compression, samples with cross-sectional dimensions of 10x10x10 cm were prepared based on the international standard DAST 24544-2020. The first series of samples was prepared without the addition of steel fibers, while the remaining samples were prepared by dispersing steel fibers of 10, 20, 30 mm length into concrete in amounts of 1.0, 2.0, 3.0%. The compaction of the mixture during molding of the samples was carried out based on standard requirements [3]. After 24 hours in the molds, the samples were removed from the molds and stored under normal conditions for 28 days. The general appearance of prepared cube samples is shown in Figure 3.

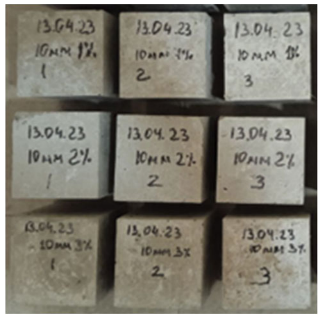

Fig. 3. Cube samples with the length of 10, 20 and 30 mm steel fibers in amount of 1.0, 2.0 and 3.0 %.

The compressive strength of the cube samples was determined in a PSU-125 hydraulic press with a load capacity of 125 tons. Loads were applied to concrete and fiber concrete samples at a speed of 0.4-0.6 MPa/s. Samples were tested until failure.

The failure of samples without steel fibers was in the form of two truncated pyramids. Cube-specimens with added steel fibers failed due to the steel fibers without the concrete separating from each other. The compressive strength of cube samples is shown in Figure 4.

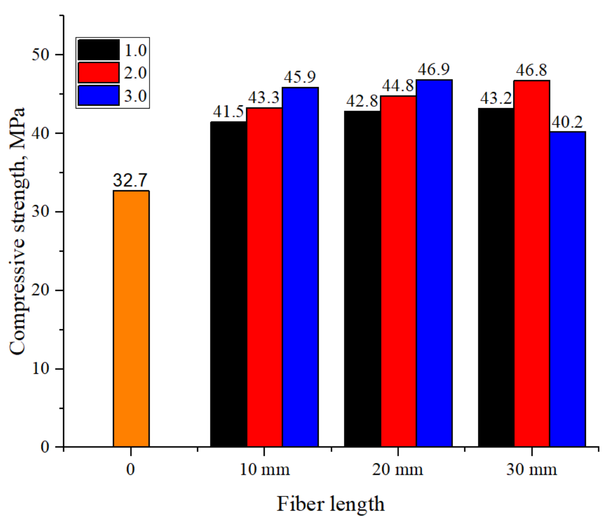

Fig. 4. Graph of 28 days cubic strength of concrete.

Based on the requirements of DAST 59535-2021, prism samples with cross-sectional dimensions of 150x150x600 mm were prepared to determine the residual tensile strength of fiber concrete dispersed with steel fibers. Dispersed reinforcement was made by adding 1.0, 2.0, 3.0% steel fibers to concrete with a length of 10, 20, 30 mm. The prepared samples were removed from the molds after being kept 24 hours. Samples were stored under normal conditions for 28 days. The scheme of applying loads to the samples is presented in Figure 5.

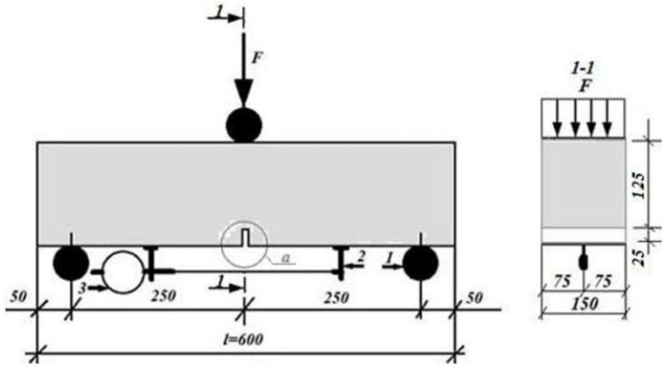

Fig. 5. Test scheme of the sample.

To determine the residual tensile strength of the prism samples, a clock-shaped indicator with a base of 20 cm was installed on the tensile part of the prism samples. The speed of applying loads to the samples was 0.05 mm/min until the width of the groove under the prism was 0.1 mm, and 0.2 mm/min after the width of the groove was 0.1 mm. The appearance of the prism sample during the test and after the test is shown in Figure 6 and 7.

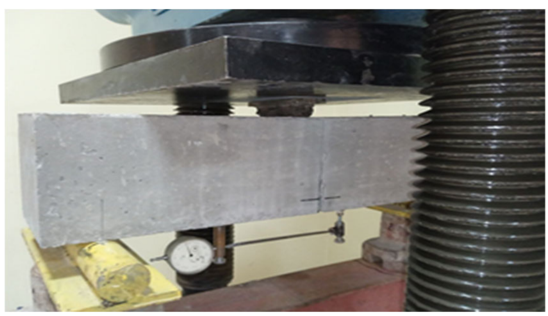

Fig. 6. Placement of the sample in the test device.

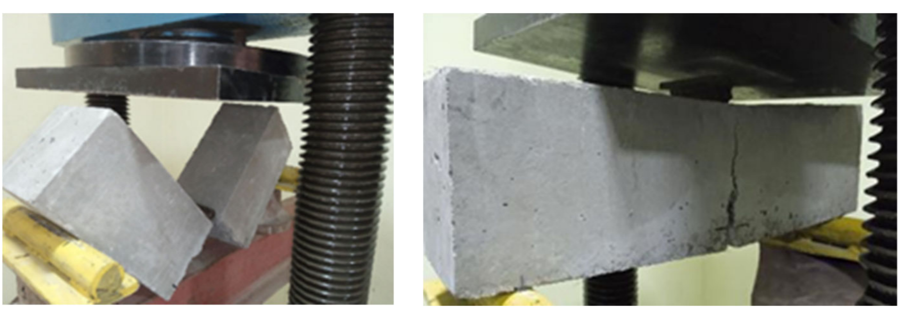

Fig. 7. General view of the sample after the test: ordinary concrete (a) and fiber concrete (b).

The residual standard tensile strength of fiber concrete dispersed with steel fibers is determined by the following formulas

$$R_{fbt2,n} = R_{F0.5,m}(1 - k_s \nu_{F0.5m}) \quad (1)$$

$$R_{fbt3,n} = R_{F2.5,m}(1 - k_s \nu_{F2.5m}) \quad (2)$$

where: $R_{F0.5,m} = 0.4$ and $R_{F0.5,m} = 0.4$are the average values of residual tensile strength of fiber concrete, kN/mm;

k_s -is a coefficient depending on the number of samples to be tested, based on GOST 59535-2021.

$\nu_{F0.5,m}$ and$\nu_{F2.5,m}$–coefficient of variation.

The results of the residual standard tensile strengths of fiber concrete dispersed with steel fibers are $R_{fbt3,n}$ shown in Figure 8. According to DAST 59535-2021, the values of the corresponding load when the width of the cut section (groove) is 2.5 mm were obtained as the residual standard tensile strengths of the prism samples.

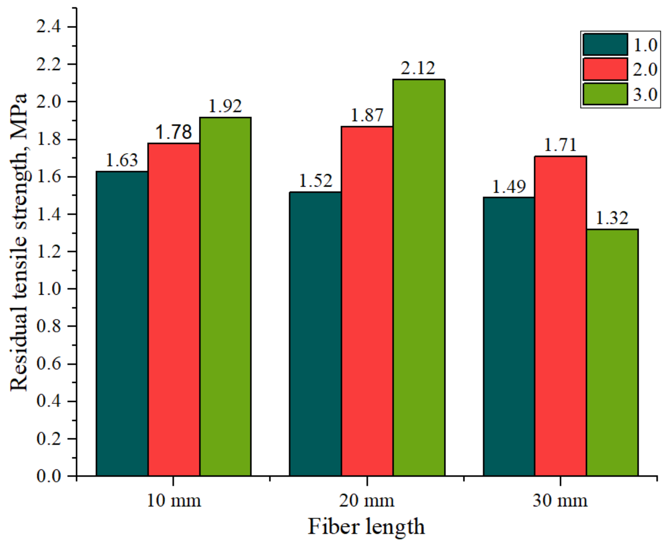

Fig. 8. Residual tensile strength of fiber concrete.

5 Methods of testing beams

Before testing, the geometric cross-sectional dimensions of the control samples were measured with a caliper with an accuracy of 1 mm. The characteristics of fiber-reinforced concrete beams dispersedly reinforced with reinforced concrete and steel fibers are presented in Table 1.

Table 1. Characteristics of experimental beams.

No	Beam notation	Dimensions of the beams, cm			Mechanical parametres of concrete, MPa				
		b	h	h_o	R	R_b	R_{btn}	R_{fbt3}	E_b
1	BO-1	121	19.5	17	32.7	23.1	2.1	-	30125
2	BO-2	120	20	17					
3	BP10-I-1	120	20	17	41.5	31.9	2.81	1.63	33321
4	BP10-I-2	120	20	17					
5	BP10-II-1	120	20	17	43.3	33.5	3.3	1.79	33876
6	BP10-II-2	120	20	17					
7	BP10-III-1	120	20	17	45.9	35.4	3.9	1.92	34630
8	BP10-III-2	120	20	17					
9	BP20-I-1	120	20	17	42.8	32.5	2.93	1.52	33725
10	BP20-I-2	120	20	17					
11	BP20-II-1	120	20	17	44.8	33.9	3.2	1.87	34318

12	BP20-II-2	120	20	17					
13	BP20-III-1	120	20	17	46.9	35.7	3.4	2.12	34905
14	BP20-III-2	120	20	17					
15	BP30-I-1	120	20	17	43.2	32.4	2.8	1.49	33846
16	BP30-I-2	120	20	17					
17	BP30-II-1	120	20	17	46.8	35.1	3.1	1.71	34878
18	BP30-II-2	120	20	17					
19	BP30-III-1	120	20	17	40.2	26.3	2.3	1.32	32902
20	BP30-III-2	120	20	17					

In order to clearly visualize and measure the width and development of the cracks formed in the beams, the beams were painted with lime and contour lines were drawn.

A deflection meter was installed to measure deflection in the middle part of the beams, and digital clock-type indicators were installed to detect deformations in the near support of the beams.

In order to determine the strain of the concrete in the control samples, digital watch-type indicators with a measurement accuracy of 0.01 mm and a portable gauge with a base of 30 cm were installed on the compressive and tensile parts of the control samples. To determine the strain in the reinforcements, a portable gauge with a base of 50 cm was installed. A microscope with a resolution of 0.05 mm was used to measure cracks in the samples. The measuring devices installed on reinforced concrete and fiber-reinforced concrete beams and the loading scheme of experimental work are shown in Figure 9.

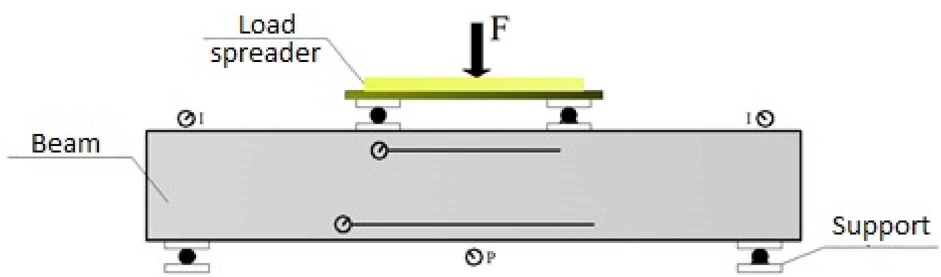

Fig. 9. Sample loading scheme.

Installation of measuring instruments: I-digital clock-type indicator, messur indicator with a base of 30 cm and 50 cm, P- deflection meter with a measurement accuracy of 0.001 mm.

When testing the samples, loads were given in two different orders. Based on theoretical calculations, 5% of the destructive force was given before crack formation, and 10% of the destructive force was given after crack formation. The interval between loading stages was 10 minutes. At each stage, the readings of the measuring instruments were recorded. That is, the values of the loads, the values of the coolness, the values of the deformations in the reinforcement and concrete, the opening of the cracks and their development were recorded at each stage. Cracks were measured under a microscope with an aperture width of 0.05 mm. When the breaking strength values reached 80-90%, the accessories were removed from the sample. Loads were applied until the reinforced concrete and fiber-reinforced concrete beams failed. The degradation process of the samples was monitored. After the experiment was completed, the sample beams were removed from the stand and placed in a specially designated place [4-6].

6 Analysis of the results of experimental study of samples working on flat bending

The following results were obtained by testing reinforced concrete and fiber-reinforced concrete sample beams:

1. Elastic strain and compressive zones of the concrete in the normal section of the beams.
2. Deformation and stresses in main reinforcement in sample beams.
3. Values of deflection in beams
4. Occurrence of cracks in the normal cross-section of beams under the influence of loads and the opening width of the cracks and their development.
5. Deformation characteristics of sample beams under the influence of loads.

The analysis of the experimental results shows that the deformations in the tensile and compressive parts of the concrete in the sample beams were linear in the initial stages of loading.

The I series specimen made of ordinary heavy concrete reached the values of compressive strains $\varepsilon_{fbt} = (25...32) \cdot 10^{-5}$ and tensile strains$\varepsilon_{fb} = (15...25) \cdot 10^{-5}$ of concrete in the normal cross-section of the specimen when the applied force in the reinforced concrete beams reached 20 kN. When the amount of destructive force reached 80-90 percent, the sample reached compressive strains $\varepsilon_{fb} = (170...185) \cdot 10^{-5}$and tensile strains $\varepsilon_{fbt} = (40...52) \cdot 10^{-5}$ of concrete in the beams (Figure 10).

When the amount of breaking force reached 20 kN in the beams of the II series reinforced by adding 1% of steel fibers with a length of 10 mm to the concrete, the compressive deformations$\varepsilon_{fb} = (6...10) \cdot 10^{-5}$ and the tensile strains of the normal section of the samples $\varepsilon_{fbt} = (8...15) \cdot 10^{-5}$ were equal to the amounts (Figure 11). As the loads increased, the compressive and tensile strains in the concrete also increased [7-9].

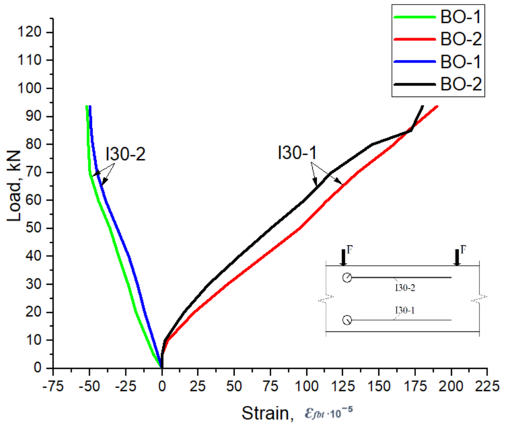

Fig. 10. Average strain of concrete in sample beams of series I.

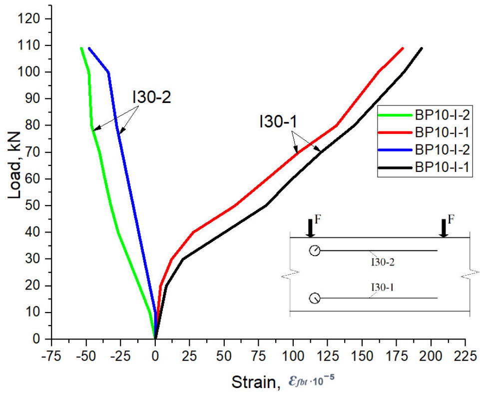

Fig. 11. Average strain of concrete in sample beams of the series II.

In the samples of the III series, when the amount of breaking force in fiber-reinforced concrete beams reinforced by adding 10 mm steel fibers to concrete in the amount of 2% reached 20-30%, the tensile strains $\varepsilon_{fbt} = (15\ldots25) \cdot 10^{-5}$ and compressive strains of concrete in the cormal section of the sample beams $\varepsilon_{fbt} = (7\ldots12) \cdot 10^{-5}$ became equal to the values. When the amount of load approached the failure of the samples, the tensile strains of concrete $\varepsilon_{fbt} = (160\ldots170) \cdot 10^{-5}$the compressive strains $\varepsilon_{fb} = (30\ldots40) \cdot 10^{-5}$ became equal to the values (Figure 12).

When the amount of breaking force reached 20-30 kN in the beams of the IV series reinforced by adding 3% of steel fibers with a length of 10 mm to the concrete, the compressive deformations $\varepsilon_{fb} = (12\ldots17) \cdot 10^{-5}$ and tensile strains of the concrete in the normal section of the samples $\varepsilon_{fbt} = (20\ldots25) \cdot 10^{-5}$ were equal to the amounts (Figure 13) [10-12].

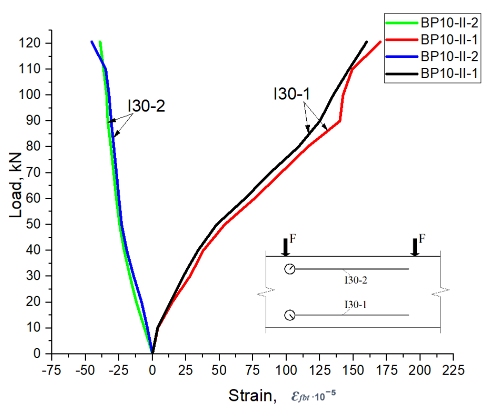

Fig. 12. Average relative compressive and tensile strains of concrete in fiber-reinforced concrete beams of the series III.

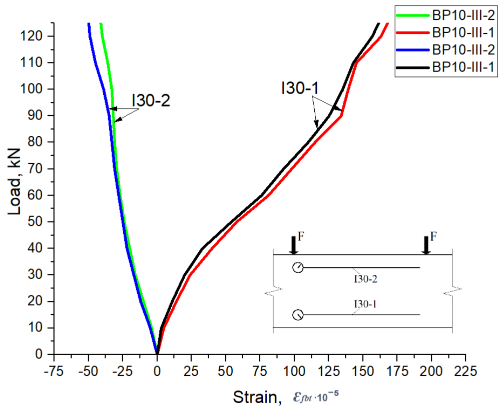

Fig. 13. Average relative compressive and tensile strains of concrete in fiber-reinforced concrete beams of the series IV.

In the samples of the V series, when the amount of breaking force in the fiber-reinforced concrete beams reinforced by adding 20 mm long steel fibers to the concrete in the amount of 1% reached 20-30%, the tensile strains $\varepsilon_{fbt} = (12...22)\cdot10^{-5}$, and compressive strains of the concrete in the cormal section of the sample beams $\varepsilon_{fb} = (5...15)\cdot10^{-5}$ were equal to the values. When the amount of load approached the failure of the samples, the tensile strains of concrete$\varepsilon_{fbt} = (140...160)\cdot10^{-5}$, compressive strains $\varepsilon_{fb} = (54...62)\cdot10^{-5}$ became equal to the values (Figure 14).

When steel fibers with a length of 20 mm were added to the concrete by adding 2.0% to the dispersion reinforcement, the compressive strain of the normal section of the fiber-reinforced concrete beams, the tensile strain at 20-30% of the breaking force $\varepsilon_{fbt} = (12...18)\cdot10^{-5}$, and the compressive strain $\varepsilon_{fb} = (6...12)\cdot10^{-5}$ were equal to the values (Figure 15).

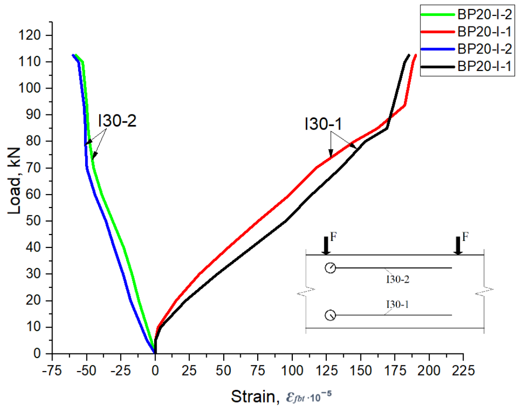

Fig. 14. Average relative compressive and tensile strains of concrete in fiber-reinforced concrete beams of the series V.

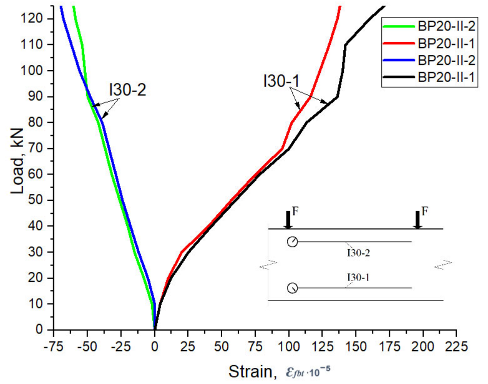

Fig 15. Average relative compressive and tensile strains of concrete in fiber-reinforced concrete beams of the series VI.

In samples of the VII series, in fiber-reinforced concrete beams reinforced with 3% addition of 20 mm long steel fibers, when the amount of breaking force reaches 20-30%, the tensile strains$\varepsilon_{fbt} = (20...25) \cdot 10^{-5}$, and compressive strains $\varepsilon_{fb} = (10...16) \cdot 10^{-5}$of concrete reached the values. When the amount of ultimate force in the beams reaches 80-90%, the tensile strains$\varepsilon_{fbt} = (132...162) \cdot 10^{-5}$and compressive strains $\varepsilon_{fb} = (73...85) \cdot 10^{-5}$ of concrete have reached the values (Figure 16) [13].

Tensile strains$\varepsilon_{fbt} = (10...23) \cdot 10^{-5}$, and compressive strains$\varepsilon_{fb} = (9...16) \cdot 10^{-5}$ of normal cross-section of concrete in fiber-reinforced concrete beams of the VIII series sample reached the values. When the amount of applied force in the beams reaches 80-90%, the tensile strains $\varepsilon_{fbt} = (130...146) \cdot 10^{-5}$ and compressive strains $\varepsilon_{fb} = (32...45) \cdot 10^{-5}$ of concrete reached the values (Figure 17).

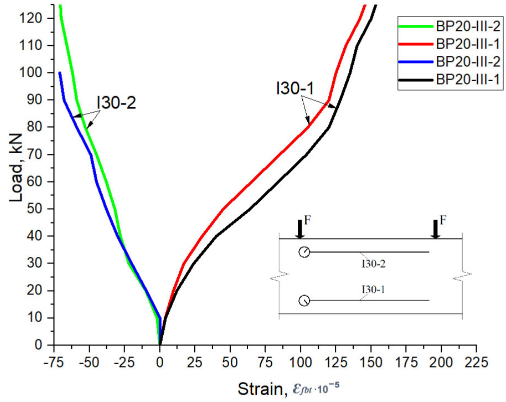

Fig. 16. Average relative compressive and tensile strains of concrete in fiber-reinforced concrete beams of the VII series.

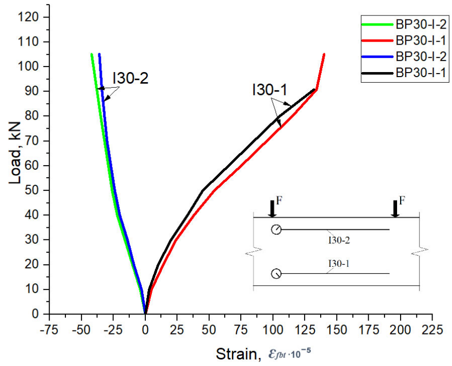

Fig. 17. Average strain of concrete in series VIII beams.

In fiber-reinforced concrete beams of series IX, the tensile strains of concrete reached 20-30% of the loads, $\varepsilon_{fbt} = (12\ldots20)\cdot10^{-5}$ and the compressive strains $\varepsilon_{fb} = (8\ldots13)\cdot10^{-5}$ reached values (Figure 18). As the loading stages approach the breaking force, tensile strains of concrete in the samples $\varepsilon_{fbt} = (145\ldots150)\cdot10^{-5}$, compressive strains $\varepsilon_{fb} = (42\ldots51)\cdot10^{-5}$ reached the values.

In the samples of series X, when the amount of destructive force in the fiber-reinforced concrete beams reinforced with the addition of 3% steel fibers to the concrete reaches 20-30%, the tensile strains and compressive strains of the concrete in the normal section of the sample beams $\varepsilon_{fbt} = (18\ldots26)\cdot10^{-5}$ are equal to the$\varepsilon_{fb} = (10\ldots13)\cdot10^{-5}$ values. When the amount of load approached the failure of the samples, the tensile strains of concrete $\varepsilon_{fbt} = (150\ldots160)\cdot10^{-5}$, the compressive strains $\varepsilon_{fb} = (40\ldots50)\cdot10^{-5}$became equal to the values (Figure 19) [14-15].

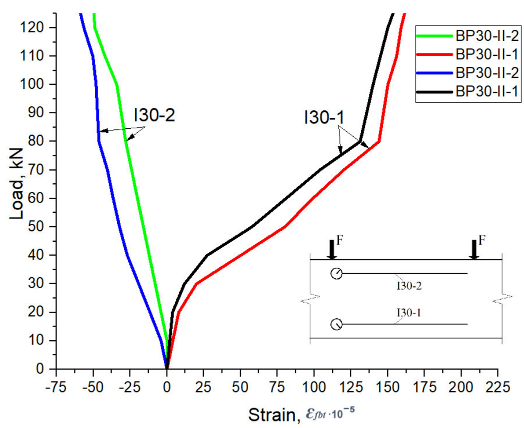

Fig. 18. Average strain of concrete in series IX.

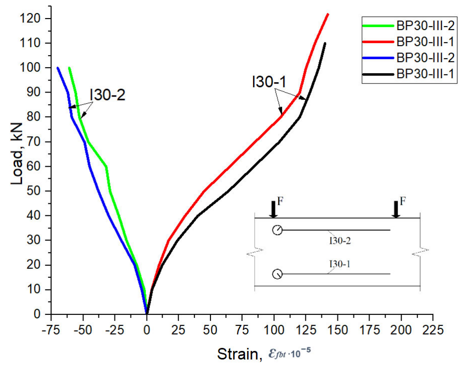

Fig. 19. Average strain of concrete in series X.

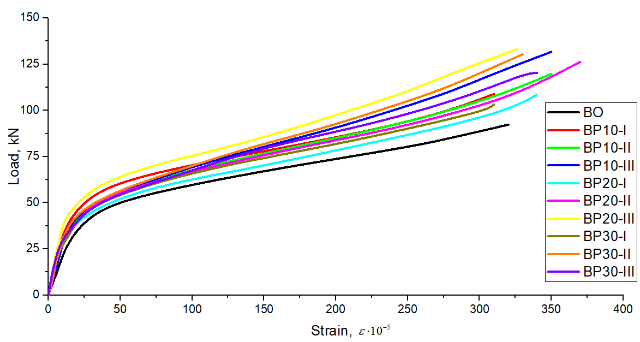

Fig. 20. Average strain of tensile main reinforcements.

The values of the strain in the working reinforcements in the tensile zone of fiber-reinforced concrete and reinforced concrete beams tested during the experimental tests were in the form of a straight line at the initial values of the loads (Figure 20). As the load increases, it was observed that the values of the strain increase dramatically after the reinforcement reaches the yield point [4].

The deflection results obtained on the basis of experimental tests of reinforced concrete beam samples made of ordinary reinforced concrete and dispersed reinforcement with steel fibers are presented in Figure 21.

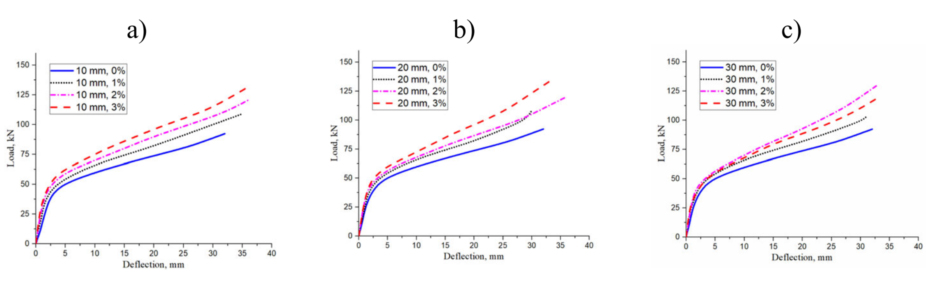

Fig. 21. Graph of deflection versus breaking force in sample beams with a) length of 10 mm, b) length of 20 mm and c) length of 30 mm with 1%, 2%, 3% of steel fiber added from the experimental test

7 Conclusion

It was determined that the values of the residual tensile strength of the dispersed reinforced concrete with the addition of steel fibers with the length of 10, 20, 30 mm in the amounts of 1.0, 2.0, 3.0% are in the range of 1.32÷2.12 MPa.

It was observed that the tensile strength of fiber concrete reinforced with steel fibers increased by 30-40% compared to ordinary concrete samples.

Compared to the average modulus of elasticity of prism samples made of ordinary concrete, the modulus of elasticity of fiber concrete samples dispersed with steel fibers increased by 10-15%.

According to the results of the experiment, it was found that the amount of load that creates normal cracks in fiber-reinforced concrete beams based on steel fibers increases by 2-3 times compared to the amount of load that creates normal cracks in ordinary reinforced concrete beams.

The scientific results obtained on the basis of experimental studies show that the load-carrying capacity of fiber-reinforced concrete beams is 20÷30% higher than that of ordinary beams.

According to the results of the experiment, it was found that the relative deformations of reinforcement and concrete in reinforced concrete and fiber-reinforced concrete beams are uniformly linear in the initial stages of loading. As the loads increased, it was observed that the relative deformation of the ordinary reinforced concrete beam was higher than the relative deformation of the fiber reinforced concrete beam.

It was observed that the stiffness obtained on the basis of experimental tests of reinforced concrete beam samples made of ordinary reinforced concrete and dispersed reinforcement with steel fibers increases homogeneously in the initial stages of loading.

As the amount of loads increased, it was observed that after passing the yield limit of the reinforcement, the values of deflection increased sharply. It was found that the stiffness of reinforced concrete beams is greater than the stiffness of fiber-reinforced concrete beams at homogeneous loads.

References

1. Odaa S. Aldeen, M.M. Hason, A.A. Sharba, Materials Today: Proceedings **42**, 2259-2267 (2021).
2. E.Anike, M. Saïdani, A. Olubanwo, A. Adegoke, A. Uchechukwu, Structures **39,** 1264-1278 (2022).
3. H. Hu, Z. Wang, F.P. Papastergiou, M. Guadagnini, K. Pilakoutas, Structural Concrete **20(2)**, 707-719 (2019).
4. S. Iqbal, I. Ali, S. Room, S.A. Khan, A. Ali, Materials and Structures **52(3)**, 56 (2019).
5. S.T. Kang, J. I. Choi, K. T. Koh, K.S. Lee, B. Y. Lee, Composite Structures **145**, 37-42 (2016).
6. N.B. Karki, *Flexural Behavior of Steel Fiber Reinforced Prestressed Concrete Beams and Double Punch Test for Fiber Reinforced Concrete* (USA, 2012).
7. J. Katzer, J. Domski, Construction and Building Materials **34**, 243-248 (2012).
8. A.B. Kizilkanat, Construction and Building Materials **100**, 218-224 (2015).
9. J. Krassowska, A. Lapko, Journal of Civil Engineering and Architecture **7(7)** 68 (2013).
10. C. Li, Case Studies in Construction Materials **14**, e00550 (2021).

11. Ch. Madhavi, International Journal of Emerging Technology and Advanced Engineering **4(4)** (2014).
12. Z. Marcalikova, P. Mateckovaa, M. Raceka, D. Bujdos, Procedia Structural Integrity **28**, 957-963 (2020).
13. M.N. Soutsos, T.T. Le, A.P. Lampropoulos, Construction and building materials **36**, 704-710 (2012).
14. D.S. Suman, G.P. Khare, M.P. Sahu, International Research Journal of Engineering and Technology **6(3),** 73-78 (2019).
15. P.R. Tadepalli, Y.L. Mo, T.T.C. Hsu, Magazine of Concrete Research **65(8)**, 462-474 (2013).