An Investigation of Shear Strength of Fiber-Reinforced Concrete Beams Experimentally

Abdurasul Martazaev1, a), Sobirjon Razzakov1, b), Ravshanbek Mavlonov1, c) and Bakhtiyor Juraev1

1*Namangan State Technical University, 12 Islam Karimov Street, Namangan 160103, Uzbekistan*

*a) Corresponding author:* [*abdurasul.mas@gmail.com*](mailto:abdurasul.mas@gmail.com) *b)* [*sobirjonrsj@gmail.com*](mailto:sobirjonrsj@gmail.com2) *c)* [*ravshanbek.mavlonov@gmail.com*](mailto:ravshanbek.mavlonov@gmail.com)

**Abstract.** This is the research paper on a laboratory study of the investigation of concrete beams containing dispersed fibers. The experimental analysis of these buildings is concentrated in the study. Fiber-reinforced concrete beams were prepared in three versions of fibers: glass, steel and basalt. Basalt, steel and glass fibers, the length of which is 30 mm. The mixtures in the beam incorporation of the basalt and glass fibers were 0.1, 0.2 and 0.3 percent concentrations. Tile investigation proved that the integration of fibers into reinforced beams of concrete led to a number of positive effects. These were the hindrance of the diagonal cracks propagation in the test specimens, improvement in crack formation and reduction in crack spacing. At the point when the level of the ruining load was 50-60%, the cracks distance in the regular reinforced concrete beams was 0.37 mm. In the specimens that contained glass and basalt fibers, the value came out to be 0.2 mm whereas in the specimens containing steel fibers the value was 0.15 mm. The research found out that the implementation of the fibers in the beams lead to an increase in the shear strength of the beams as opposed to non-fiber reinforcement beams.

**Keywords:** Fiber, sample, reinforced concrete, strength, beam, shear strength, material, compressive strength, tensile strength, flexural strength

# INTRODUCTION

With the world population continuing to grow today, the need of buildings and infrastructure also keeps increasing. Thus, the construction industry, which is based on concrete technology, is experiencing continuous improvements [1, 2, 3]. New concrete is very pliable and this gives it the ability to be easily shaped in any shape. It also possesses great compressive strength, outstanding durability and its labor costs of construction and repair are relatively small in comparison with many other materials. The tensile strength of concrete is however much weaker- about 10- 15 times weaker than its compression strength. To tackle this issue, reinforcements in reinforced concrete buildings are provided through reinforcement to increase tensile strength. In addition, addition of different sizes of steel and composite fibers has been found helpful in enhancing the tensile characteristics of concrete. Scientific researches are encouraging the use of diverse varieties of materials and procedures to enhance the force of concrete [4, 5, 6].

It is not easy to predict strength nature of reinforced concrete beams along inclined planes. This comes about as a result of many factors, which have an influence on it; this is due to geometry of the element, strength of the reinforcement in the beam as well as the reinforcement configuration [7, 8]. In addition, other complications like diagonal cracking, the bond breakdown between the bar and the concrete as well as the failure of the bar that is in line with the slope would incur so that it is not easy to directly determine the ultimate hauling capacity as well as failure processes of such beams [7]. Saribiyik, A., et al. [8] have experimentally and theoretically examined shear strength of basalt-fabric reinforced beams of several different reinforcement classes. According to the results of their experiment, it was discovered that the tested conventional reinforced concrete samples have a shear strength of 58.7 kN whereas beams reinforced with basalt fiber-based fabrics represented substantially high shear strength between 83.9 and 117.6 kN. Aref A. Abadel tested samples of self-compacting concrete and reinforced the same with the help of various techniques. In the study, it was revealed that the range of strength of the control specimens was 164.1 to 196.9 kN, whereas the self-compacting concrete specimens achieved a higher shear strength that ranged between 233.8 to 256.4 kN. A study by Y.O. Ozkilic, et al. [9] discussed the composition of beams that utilised aluminum wire scraps as reinforcements in the shear strength of the beam.

Nevertheless, in spite of these profound researches, there is one of the challenges that is still persistent when applying steel and composite fibers in reinforced concrete the issue is lack of understanding behavior of these fibers to be used in reinforced concrete in beams. The problem is even higher in the environment of Uzbekistan where in fiber-reinforced concrete no experimental or theoretical studies have been made in respect to material available locally. That is why, it is scientifically and practically important to conduct accordingly extensive studies on mechanical characteristics and structural properties of fiber-reinforced concrete created in the conditions particularly peculiar to Uzbekistan [11, 12]. The project is meant to cover that gap by being devoted to the assessment of physical and mechanical characteristics of the fiber-based concrete that is already manufactured in the country at the moment. The study provides experimental tests on beams of different fiber types and dosage to create an effective scope of design recommendations and performance expectations of shear-dominated concrete structures. The results obtained are critical to establishing how the advanced composite materials can be applied in more work in the construction sector of Uzbekistan, thus achieving innovation and strength in civil constructions.

# METHODS

Cement is a very vital part of concrete that has a lot to do with the strength of the concrete. The PS400D20 Portland cement of the plant named the LLC plant was used in this test called the Namangan cement. The actual cement density was at 3.1 g/cm3, the bulk density at 1.3 g/cm3, the standard viscosity at 26%, the granularity at 8.2% and the 28 day strength capacity at 43.0 MPa on compression, 7.1 MPa on flexion since the reference surface area was 3000-3500 cm 2/g. A fine aggregate, sand of a density 26.70 kN/m3 and 0-5 mm dimensions and moisture content 3.1 percent was applied in the samples whereas, a coarse aggregate granite pebbles of a density 26.65 kN/m3 and 5-20 mm dimensions was used. Figure 2.1 indicates an overview of the fine and coarse aggregates sampled as part of the cube.

During these tests, Sunlight CO LTD joint venture located in the town of Boston in the Andijan region was used on fibers made of glass. The glass fibers were 3000 MPa tensile strength, density 2490 kg/m3, diameter 0.015 mm and length 30 mm. The overall look of the glass fibers is indicated in Figure 1 and the physical characteristics in Table 1.



**FIGURE 1.** Overview of glass fibers

The concrete reinforcement was dispersed using steel fibre that has a length of 30 mm and diameter of 0.3 mm. It had 200000 MPa as modulus of elasticity, 250 MPa as tensile strength and the density of the fiber was 78.50 kN/m3 [8]. In figure 2, the overview of the steel fibers is shown.



**FIGURE 2.** Overview of steel fibers

The research work employed basalt fibers manufactured by the Mega Invest Industrial joint venture in the region of Jizzakh in the Uzbekistan country (Figure 3 below). Basalt fibers density was 2650 kg/m3, its tensile strength was 3500 MPa, elasticity modulus was 110 GPa, fiber diameter was 0.017 mm and the length was 30 mm [8]. The summary of overviews basalt fibers are reflected in Figure 3, and its parameters of physical characteristics are reflected in Table 1.



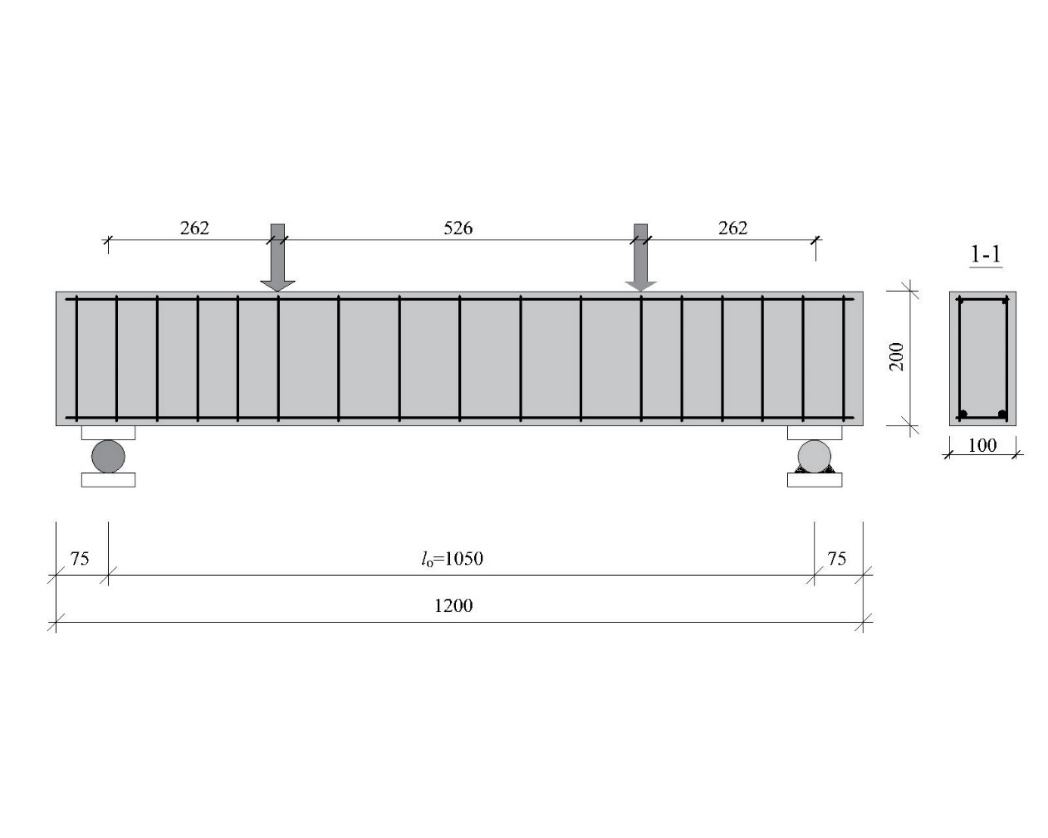
**FIGURE 3.** Overview of basalt fibers

**TABLE 1.** Main indicators of fibers

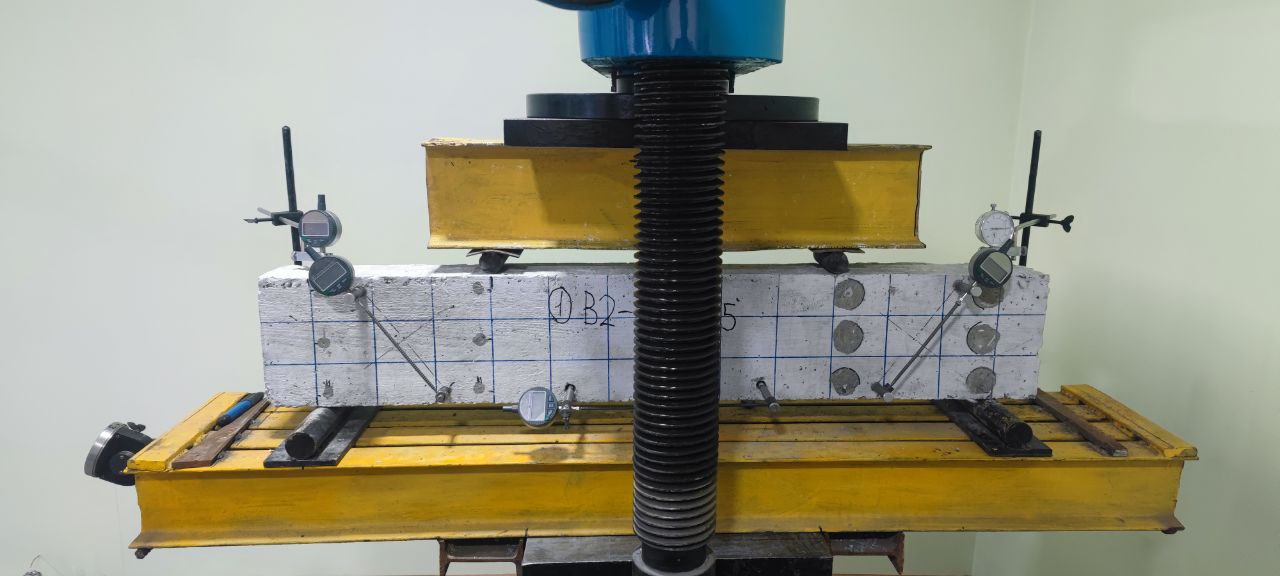
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fiber type | Density, kg/m3 | Tensile strength,  MPa | Elastic modulus, GPa | Fiber diameter, µm | Fiber length, mm |
| Basalt | 2650 | 3500 | 110 | 17 | 30 |
| Glass | 2490 | 3000 | 69 | 15-19 | 30 |
| Steel | 7850 | 250 | 200 | 300 | 30 |

Under interstate standard DAST 24544-2020 specific samples of cubical shape with the dimensions 10x10x10 cm, cylindrical with the diameter of 10 and 20 cm, respectively, and other samples with the cross-section 15x15 cm and length of 60 cm were specially made to be used to determine the compressive strength of the concrete, tensile strength, and the bending strength, respectively. The samples were taken out of the molds after 24 hours of storage and the sample stored in normal conditions in the period of 28 days.

Steel, basalt and glass fibers reinforced concrete beams were made with dimensions of 10x20x120 cm. Figure 4, 5 illustrate the procedure of sample preparation and testing. The longitudinal reinforcement was done with two rebars of A-III classes with a diameter of 12mm. The beams reinforcement was 1.33%. In the present case, the wires of the following grade A-I, the same diameter of 5 mm are installed in front of the beam support (pitch of 70 mm) and in the center of the beam (pitch of 150 mm) as transverse reinforcement. The reinforcement is characterized by mechanical properties based on the demands of GOST 5781-82 (2006).



**FIGURE 4.** Beam reinforcement scheme



**FIGURE 5.** The process of testing the strength of reinforced concrete beams on an inclined section

Before testing, geometric dimension of the beams had been measured and control specimen had been tested in order to assess the most important characteristics of concrete and reinforcement. For visual inspection of crack initiation and development, the sides of the beams were covered with lime and the outlines of the reinforcement cages were drawn on them. The beams were tested under uniform loads. Before the formation of cracks, they were tested with a load not exceeding 5% of the calculated breaking force, and after the formation of cracks, with a load not exceeding 10%. The interval between the stages was 10-15 minutes.

In the process, the readings of all measuring instruments were taken as well as the observation of new cracks and crack-growth process development, and crack width measurements. At the same time, a monitoring of the applied load was carried out. The gauges were taken off when the load was about 85÷90% of the breaking load and then the specimen was further loaded until it failed observing the failure behavior carefully.

# RESULTS AND DISCUSSION

The compressive resistance, tensile resistance and flexural resistance of the fiber reinforced concrete pieces which were dispersed with the fiber increased remarkably. Addition of 0.1 percent and 30 mm long glass and basalt fibers to concrete improved the compressive strength of concrete by 12.4 and 17.6 percent respectively when compared to that of an ordinary concrete. Adding 1 percent of steel fibers into the concrete raised the strength of concrete by 32.7 percent in compressive strength. It was found that the flexural strengths were two to three times more in the samples containing steel, basalt and glass fibers as compared to the normal concrete. The strength of the concrete in terms of compression, tension and flexural test has been the best evidence of the sample with fiber-reinforced concrete backed up with steel fibers.

With dispersion of reinforcement in reinforced concrete beams and no additional fiber there was a failure along the slope. The diagonal cracks propagated at approximately 45 degrees angle in the front sections of the support of control samples and gradually the strength of beam overcame its maximum and the samples failed in brittle form without warning signs. Figure 6-15 shows the reinforcement of concrete beam that occurs in the formation of the cracks as well as the crack failure. The fibers supplementation of the reinforced concrete beams proved to be effective in the resistance to the spread of the diagonal cracks on the samples, it enhanced the number of cracks and filled in the gap between the cracks. When the amount of the destructive load reached 50-60%, the width of the cracks in ordinary reinforced concrete beams was 0.37 mm. This indicator was 0.15 mm in samples that had steel fibers added, and 0.2 mm in those that had glass and basalt fibers added. According to an analysis of the data, the specimens' ability to support loads has been considerably increased by the inclusion of fibers. The experimental results of the samples are shown in Table 2.



**FIGURE 6.** BO - sample failure

The normal shear failure mode of control beam (BO) was obtained with diagonal cracks being developed at near 45 level in the support locations adjacent to loading points. The propagation of the cracks was quite fast and specimen failed in brittle mode, showing no indication of ductility. The length of the crack as measured at 50 percent of the ultimate load was 0.37 mm which means that there was minimal control of the crack when no fiber reinforcement was effected. This mode of failure proves the natural weakness of traditional reinforced concrete beam susceptible to failed diagonally confident under shear Figure 6.



**FIGURE 7.** BB30-0.1 - sample failure

The beam which had 0.1 percent of 30 mm basalt fibers exhibited better shear than the one with control. The diagonal cracks was further spread and finer compared with a reduced crack width of about 0.2 mm at 50 percent of peak load. Even though the specimen fractured on the shear plane, cracks were bridged due to existence of fibers, which postponed its catastrophic fracture. Such behavior points to the crack-restraining ability of low volume basalt fiber reinforced concrete Figure 7.



**FIGURE 8.** BB30-0.2 - sample failure

This beam, with 0.2 per cent of basalt fibers, exhibited an increased load carrying bending and crack control. The cracks were thin and more narrow and closely positioned, and the crack width at middle load was about 0.18 mm. The fibers were efficient in the delay of crack propagation resulting into a ductile and gradual failure. This specimen showed a good combination of fiber dispersion and fiber volume that leads to enhanced shear resistance of reinforced concrete Figure 8.



**FIGURE 9.** BB30-0.3 - sample failure

Being strengthened with 0.3 % basalt fibers, this beam showed slightly worse performance than that one with strengthening of 0.2 percent. Failure was on a diagonal shear plane and the crack width went up to 0.25 mm. Presence of too much fibers could be a cause of slight balling or less bonding within the concrete matrix which can be considered as the slight reduction in performance. However, both the strength and ductility of the beam were higher in comparison to that of the control Figure 9.

****

**FIGURE 10.** BP30-0.1 - sample failure

There was moderate improvement on crack distribution in the 0.1% volume of 30 mm glass fibers specimen. It indicated a similar behavior to control, except that diagonal cracks exhibited smaller width of about 0.2 mm on average. Unlike in basalt or steel fibers, glass fibers also provided some post-cracking resistance, though its impact was not as high. The beam broke at shear, however with a more controlled fracture surface **Figure 10**.



**FIGURE 11.** BP30-0.2 - sample failure

The specimen of glass fiber-reinforced beams showed the most satisfactory outcomes. When the crack width was narrowed to 0.15 mm, the process of crack control was considerably enhanced through the fiber addition, which is 0.2% of volume fraction. The specimen had an upsurge in energy absorption capability and slower failure association. These findings imply that a fiber content of 0.2 percent is a good range of performing better in shear using glass fibers Figure 11.



**FIGURE 12.** BP30-0.2 - sample failure

Similar results but with slightly inferior performance compared to BP30-0.2 was observed with the BSH30-0.3 beam. Cracks were limited to about 0.2 mm and broken after a slow increase in width of shear cracks. The slight decreases in strength and stiffness can possibly be explained by the clustering or saturation of the fibres. Nevertheless, the behavior had much improved compared to the non-fiber control beam Figure 12.



**FIGURE 13.** BS30-1.0 - sample failure

The beam with 1.0 percent 30 mm steel fibers showed great enhancement in shear capacity and post-cracking responses. The maximum load that the specimen could withstand was 192.3 kN and the width of crack at 50 percent of maximum load was 0.15 mm. Obtained ductility and the ability to control the propagation of cracks by the presence of steel fibers was effective as well, the failure progressed slower than in the brittle material whose sample was used as the control Figure 13.



**FIGURE 14.** BS30-2.0 - sample failure

BS30-2.0 had the best performance in all specimens. At half-load conditions, the width of cracks was minimum (0.10 mm) and the beam opposed the maximum load 210.8 kN. The presence of steel fibers has formed a great internal bridging mechanism and this has increased its strength as well as energy absorption by a considerable amount. Failure was flexible and circumscribed, demonstrating the best reinforcing potential of an optimum amount of steel fibers Figure 14.



**FIGURE 15.** BS30-2.0 - sample failure

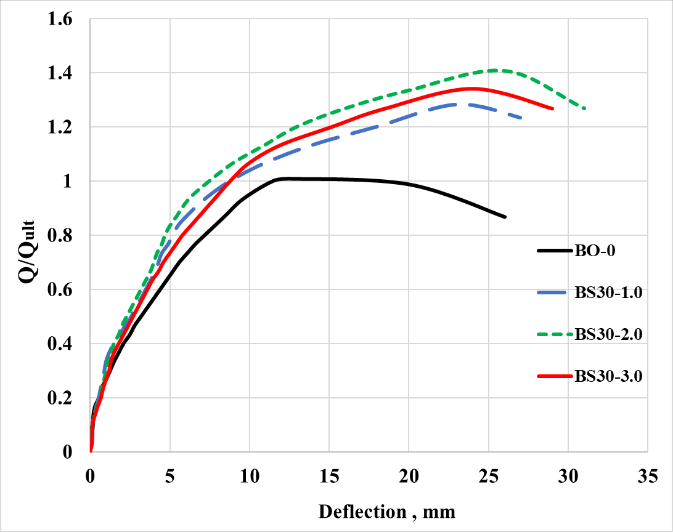
Compared to the control beam, the BS30-3.0 specimen showed somewhat lower performance as compared to BP30-2.0 despite registering better results. Maximum load went down to 201.3 kN and crack width was 0.12 mm. Such a small reduction can be explained by the presence of too much fiber, thereby resulting in problems with workability or uneven distribution. Nevertheless, the sample maintained high crack resistance and ductile damage, which means that the positive effect of steel fibers was established even in terms of increased dosageFigure 15.

**TABLE 2.** Experimental results of samples

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Series** | **ID** | **Qmax, (kN)** | **Crack width 50% Qmax,(mm)** | **Deflection, (mm)** |
| 1 | BO | 151.1 | 0.37 | 12.0 |
| 2 | BB30-0.1 | 178.3 | 0.2 | 20.0 |
| BB30-0.2 | 183.6 | 0.18 | 22.0 |
| BB30-0.3 | 169.3 | 0.25 | 17.0 |
| 3 | BP30-0.1 | 210.1 | 0.2 | 19.0 |
| BP30-0.2 | 208.2 | 0.15 | 16.2 |
| BP30-0.3 | 201.4 | 0.2 | 15.4 |
| 4 | BS30-1.0 | 192.3 | 0.15 | 28.0 |
| BS30-2.0 | 210.8 | 0.10 | 32.0 |
| BS30-3.0 | 201.3 | 0.12 | 27.0 |

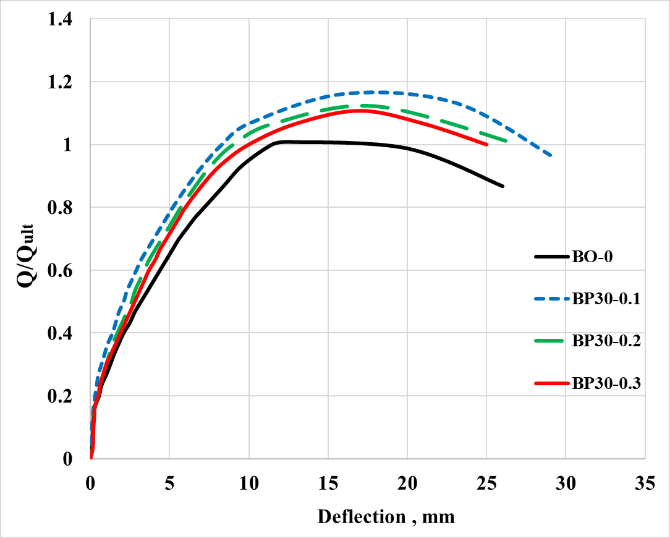
In the first series of samples, i.e., the control samples designated as BO, the crack width in the beam when the amount of the destructive force reached 50% was 0.37 mm. In the second series of samples, i.e., BB30-0.1, BB30-0.2 and BB30-0.3, this indicator was in the range of 0.2-0.25 mm. In the samples with ID BP30-0.1, BP30-0.2 and BP30-0.3, the crack width in the beam when the amount of the destructive force reached 50% was 0.15-0.2 mm. In the last series of samples with the addition of steel fibers, namely samples with ID BS30-1.0, BS30-2.0 and BS30-3.0, it was observed that the crack width in the beam was 0.10-0.15 mm when the breaking force reached half. It was found that the crack opening width at 50% of the breaking force in the samples with the addition of steel fibers was smaller than in the samples in the rest of the series.

The shear strength of the control sample was 151.1 kN. This indicator was 169.3-183.6 kN for samples dispersed reinforced with basalt fibers, 166.1-174.2 kN for samples dispersed reinforced with glass fibers, and 192.3-210.8 kN for samples dispersed reinforced with steel fibers.



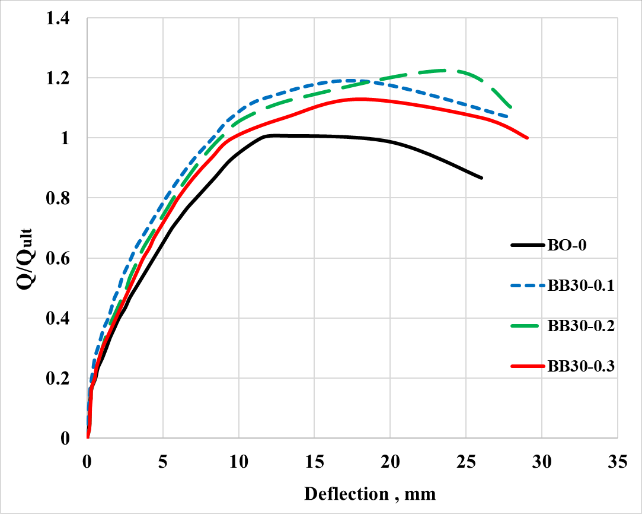
**FIGURE 16**. Deflection in samples BO, BS30-1.0, BS30-2.0, BS30-3.0

In the BS30-1.0, BS30-2.0, BS30-3.0 series samples, the deflections were 28.0, 32.0 and 27.0 mm at the forces Qmax=192.3 kN, Qmax=210.8 kN and Qmax=201.3 kN, respectively. It was found that the load-bearing capacity of the beams was significantly higher due to the addition of steel fibers with a length of 30 mm, and the deflections in these samples were smaller at the same force.



**FIGURE 17**. Deflection in samples BO, BP30-0.1, BP30-0.2, BP30-0.3

In the BSH30-0.1, BSH30-0.2, BSH30-0.3 series samples, the deflections were 19.0, 16.2 and 15.4 mm when the force was Qmax=174.2 kN, Qmax=168.4 kN and Qmax=168.4 kN, respectively. In the control sample, the deflection was 12 mm when the load reached 175 kN, while in the BP30-0.1 series sample this indicator was 8.2 mm, in the BP30-0.2 series sample the deflection was 7.6 mm, in the BP30-0.3 series sample the deflection was 6.8 mm.



**FIGURE 18**. Deflection in samples BO, BB30-0.1, BB30-0.2, BB30-0.3

In the BO series, the deflection was 12 mm when the maximum breaking force Qmax=175.1 kN. In the BB30-0.1, BB30-0.2 and BB30-0.3 series, the deflections were 20.0, 22.0 and 17.0 mm when the force was Qmax=178.3 kN, Qmax=183.6 kN and Qmax=169.3 kN, respectively. It was observed that at the same force, the deflection was higher in the plain beam, and the deflection was smaller in the samples with added fibers.

Figures 16-18 illustrate the relationship between the maximum load-bearing capacity and the deflection for the control samples and fiber-reinforced concrete beams with dispersed reinforcement. In the control samples and in the samples with the addition of fibers, the deflection was observed to be linear at the initial stages of the loads. It was found that after the maximum load-bearing capacity of the control samples reached the maximum, the deflection in the beams increased sharply. In the fiber-reinforced concrete beams with dispersed reinforcement based on fibers, it occurred gradually. This may be due to the function of the fiber bridge, which limits the subsequent opening of cracks and prevents them from spreading while being loaded.

# CONCLUSIONS

Compressive failure strength, tensile failure strength and flexural strength of the fiber reinforced concretes whose fibers were spread went up conspicuously. There are two percentages of admixing: 0.1% glass and basalt fibers of 30 mm in size, which raised up the compressive strength of the concrete by 12.4 and 17.6 percentages, respectively, against that of ordinary concrete. Adding 1 percent steel fibers to the concrete yielded a 32.7 percent enhance in compression strength. Moreover, flexural strength of the steel, basalt and glass fiber reinforced samples have been found to be 2-3 times higher, as compared to common concrete.

The supplementation of steel, basalt, and glass fibers to ordinary reinforced concrete beams was found to effectively resist the spread of diagonal cracks, increase their occurrence, and reduce the interval between them.

When the amount of destructive load reached 50-60%, the width of cracks in ordinary reinforced concrete beams was 0.37 mm. This indicator was 0.2 mm in samples with glass and basalt fibers, and 0.15 mm in samples with steel fibers.

Shear strength was significantly improved: the control beam showed 151.1 kN, while fiber-reinforced beams exhibited increases across all types—ranging from 168.4 to 210.8 kN, depending on the fiber type and dosage. Among all, the series with 1–2% steel fibers (BP30) showed the highest performance, with strength increases of 27.3–39.5% over the control sample. Beams reinforced with basalt and glass fibers also showed notable strength gains of 15–24%.

Samples from the BS30-1.0, BS30-2.0, BS30-3.0 series show the best results compared to samples from other series. The analysis revealed that samples BS30-1.0, BS30-2.0, and BS30-3.0 exhibited strength levels 30-40% greater than the BO sample. For the samples BP30-0.1, BP30-0.2, and BP30-0.3, this measurement was 10-15% greater. It is illustrated that the strength of samples BB30-0.1, BB30-0.2, BB30-0.3 is 12-20% higher than that of BO.

# FUTURE SCOPE

The encouraging findings reported in this paper provide the potential of carrying out a vast research work on fiber-reinforced concrete beams, especially in a condition of complex loading and change of environmental factors. Although the present study was carried out in environmental conditions during which the shear performance was kept constant, in future it might be possible to work not only in cyclic loading but also under impact loading conditions and apply it to the real world to understand the effect of seismic or dynamic loading on the structural members that are strengthened by dispersed fibers. Besides, finite element analysis (FEA) as a numerical modeling approach may be used to create predictive models, incorporating fiber orientation, volume fraction and behaviour of interfaces. The models can be used to optimize fiber choice and dosages in order to bespoke structural performance to certain engineering requirements. Meanwhile, long-term durability tests such as freeze-thaw resiliency, chloride permeability, and exposure to extreme temperatures must be conducted in order to determine feasibility of such composite materials used in infrastructural works. Since this research has regional focus in Uzbekistan, one may also investigate the locally available fiber materials, as well as alternatives that resort to usage of industrial wastes to increase cost-worthiness and sustainability of concrete mixes. This would facilitate in the creation of construction materials, which are custom suited to the local climatic and economic factors of the Central Asia region. Also, could be integrated smart sensing, e.g., embedded fiber-optic sensors in fiber-reinforced concrete beams, providing the real-time crack propagation and strain distribution monitoring, and long-term structural conditions. The given interdisciplinary approach would play a great role in making the breakthrough into intelligent infrastructure systems. In general, the results of the current study establish a stable ground to further focus on the study of high-performance, long-lasting, and adjustable concrete systems through hybrid fiber reinforcement approaches, with a significant likelihood to be used in run-of-the-mill or leading-edge structural engineering fields.

It is also an avenue of re-stating design standards and codes in the field. Presently, it can be said that most of the structural design codes do not entirely apply the contribution of fibers in their calculations, especially that of shear strength and toughness. Design-oriented formulation wherein well-tested data and simulated results are used to enable structural engineers to substitute or minimize regular steel reinforcement with fibers, particularly, in second-as well as non-critical components can be formulated. Alternate fiber-reinforced concretes on a large scale also have social and economic implication. Carrying out cost benefit calculations, where not only the material cost, but also savings in maintenance, repair, and long-life span are taken into account, would convince the stakeholders and the policymaker to invest into such advanced materials. It is possible to highlight the practical advantage of the technology through pilot projects in infrastructure (fiber-reinforced road pavements, sidewalks, airport runways, and precast elements).

Specific focus shall be provided to the regional studies. As an example, in the Uzbekistan- and Central Asian- context, the special environmental conditions of arid climate, the high temperatures and the low availability of high-quality aggregates require the creation of local concrete mix designs. Experimental work with locally derived materials (e.g. natural pozzolans, basalt in central Asia), mineral additives (e.g. volcanic ash, or slag) could develop cost effective, durable and ecologically responsive concrete mixes. Furthermore, training programs, knowledge transfer, and industry, academia and government teamwork is required to speed up the translation of the FRC research to the field. These goals could be achieved by creating interdisciplinary research centers and establishing regional testing laboratories which may also enable certification of new methods and materials of construction.

# REFERENCES

1. Y. M. Abbas, A. Tuken, and N. A. Siddiqui, *Improving the structural behavior of shear-deficient RC deep beams using steel fibers: Experimental, numerical and probabilistic approach*, Journal of Building Engineering **46**, 103711 (2022). doi:10.1016/j.jobe.2021.103711.
2. C. Zhao, Z. Wang, Z. Zhu, Q. Guo, X. Wu, and R. Zhao, *Research on different types of fiber reinforced concrete in recent years: An overview*, Construction and Building Materials **365**, 130075 (2023). doi:10.1016/j.conbuildmat.2022.130075.
3. A. Martazaev and S. Khakimov, *Dispersed reinforcement with basalt fibers and strength of fiber-reinforced concrete beams*, AIP Conference Proceedings **3256**, 030011 (2025). doi:10.1063/5.0266797.
4. M. Anas, M. Khan, H. Bilal, S. Jadoon, and M. N. Khan, *Fiber reinforced concrete: a review*, Engineering Proceedings **22**, 3 (2022). doi:10.3390/engproc2022022003.
5. G. Plizzari and S. Mindess, *Fiber-reinforced concrete*, in *Developments in the Formulation and Reinforcement of Concrete*, 2nd ed., edited by S. Mindess (Woodhead Publishing, Cambridge, 2019), pp. 257–287. doi:10.1016/B978-0-08-102616-8.00011-3.
6. R. Mavlonov and S. Razzakov, *Numerical modeling of combined reinforcement concrete beam*, E3S Web of Conferences **401**, 03007 (2023). doi:10.1051/e3sconf/202340103007.
7. S. Razzakov and A. Martazaev, *Mechanical properties of concrete reinforced with basalt fibers*, E3S Web of Conferences **401**, 05003 (2023). doi:10.1051/e3sconf/202340105003.
8. A. Saribiyik, B. Abodan, and M. T. Balci, *Experimental study on shear strengthening of RC beams with basalt FRP strips using different wrapping methods*, Engineering Science and Technology, an International Journal **24**, 192–204 (2021). doi:10.1016/j.jestch.2020.06.003.
9. Y. O. Özkılıç, M. Karalar, C. Aksoylu, A. N. Beskopylny, S. A. Stel'makh, E. M. Shcherban, et al., *Shear performance of reinforced expansive concrete beams utilizing aluminium waste*, Journal of Materials Research and Technology **24**, 5433–5448 (2023). doi:10.1016/j.jmrt.2023.04.120.
10. A. Ashteyat, W. Almahadin, and S. Almuaythir, *Shear repairing of reinforced concrete beams exposed to high temperature using basalt fiber reinforcing bars and CFRP ropes and strips*, Composites Part C: Open Access **12**, 100517 (2024). doi:10.1016/j.jcomc.2024.100517.
11. A. Martazaev, M. Orzimatova, and M. Xamdamova, *Determination of optimum quantity of silica fume for high-performance concrete*, AIP Conference Proceedings **3256**, 030012 (2025). doi:10.1063/5.0266799.
12. R. Mavlonov, S. Razzakov, and S. Numanova, *Stress-strain state of combined steel-FRP reinforced concrete beams*, E3S Web of Conferences **452**, 06022 (2023). doi:10.1051/e3sconf/202345206022.