Features of deformation and destruction of fine-grained fiber concrete

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Abstract. The article analyzes the conditions of buildings construction in town Shakhty after the closure of coal mining enterprises. The appearance of deformation processes after old mine workings were flooded, is usually accompanied by uneven surface deformations and cracks formation in load-bearing structures is noted in the article. The positive effect of polypropylene microfiber additives on the deformation properties of Portland cement masonry solutions was studied, as it significantly reduces the probability of cracks in building structures. The results of experimental studies of mechanical properties of compositions with optimal dosage of polypropylene microfiber are presented. An increase in flexural and compressive strength of microfiber-modified samples was noted in comparison with the control ones. The dependence of ultimate deformations on normal stresses is established, which allows predicting the permissible ultimate deformations of masonry. The module of the total solution strain was evaluated.

1. Introduction

Despite many years of experience and a huge volume of concrete used in the construction industry, the improvement and optimization of its composition has not lost relevance to date. The first studies of fiber-reinforced concrete in our country date back to the beginning of the last century, but the volume of its application is still small [1].

The question of the quality and new features of fiber-reinforced concrete stimulates numerous studies [2–7] and increase its further application in various fields of construction.

Due to the obtained results the unique operational properties of steel fiber reinforced concrete were confirmed, which allowed increasing the number of structures made of it and use it in the construction of various objects [8-12].

The most important advantages of fiber-reinforced concrete are as follows: high physical and mechanical properties; high frost resistance, moisture resistance, crack resistance, resistance to shock loadings, adhesion and abrasion resistance [13–14]. These indicators determine high performance reliability and durability of the concrete.

Such physical and mechanical characteristics of fiber-reinforced concrete meet the requirements necessary for construction in areas with high seismic activity, as evidenced by the foreign experience of extensive and widespread use as the main building material in earthquake-prone areas, for construction: tunnels, roads, bridges, industrial structures, etc. [15–16].
2. Purpose of the study

As part of restructuring the coal industry in Russia almost all enterprises of the East Donbass were closed at the end of the 90s of the last century. This led to the cessation of pumping water from the mine workings, and, accordingly, to the flooding of the developed spaces.

However, the negative consequences of mines closure provoked not only flooding. The dampening of the destroyed mountain massifs is accompanied by significant changes in the physical and mechanical properties of rocks, since a large number of clay layers are present in the stratigraphic structure of the region. This is accompanied by surface deformations and accordingly uneven deposition of the building foundations.

In the central part of the town on exploited buildings, which were guarded by pillars of coal, new cracks appear (Figure 1) and the development of previously formed ones takes place (Figure 2). Moreover, measures to strengthen structures in the undermined areas do not fully prevent crack formation due to significant soil deformations.

![Figure 1. Cracks in the building of the Drama Theater.](image1)

The design scheme of the vast majority of newly built town buildings with load-bearing walls made of ceramic or silicate bricks. This circumstance contributes to the appearance of defects at newly constructed facilities (Figure 3), since additional loads on the soil will be accompanied by uneven soil deposition.

![Figure 2. Opening cracks after sealing](image2)
Figure 3. Crack formation in new buildings

In this case, the use of special measures to prevent cracking is required, which is accompanied by a significant increase in the cost of construction. However, despite the construction of special structures on a number of objects, crack formation and their development are still observed. The level of modern research in the field of regulation of the properties of Portland cement mortars and concretes makes it possible to substantially change the characteristics of mixtures and solids. Therefore, a very promising direction for reducing crack formation is to increase the deformation characteristics of masonry.

Since it is impossible to change the properties of bricks, it is possible to reduce the probability of cracking in masonry, using masonry mortar with high deformation capacity.

3. Methods and materials
Improving the performance of concrete and mortar is achieved by introducing microfiber into their formulation [1–3]. Therefore, to assess the impact of microfiber on the characteristics of sand-cement mortar at the Department of Construction and Technosphere Safety at the Institute of Service and business (branch) of Don State Technical University in Shakhty, studies were conducted to establish the optimal dosage of polypropylene and steel microfiber in solutions.

For research, Portland cement of the Sebryakovskiy plant CEM I 42.5 and fine-grained sand of Yagodinsky quarry with Mk = 1.92 were used, the content of the fraction 0.63 did not exceed 2 %. At the ratio of cement and aggregate 1:3 adopted for the control additive-free composition, the water-cement ratio corresponding to the normal consistency of the standard cone on the shaking table in accordance with the GOST 310.4-81 method was 0.44.

In the preparation of modified solutions, polypropylene fiber 12 mm long, 20 μm in diameter and steel 15 mm in length and 0.4 mm in diameter was used as an additive. The amount of mixing water was determined from the condition of equal mobility with a control composition, that is, with a cone spread of 108–112 mm. To determine the optimal amount of polypropylene microfiber, compositions were prepared with the addition of 1–3.5 % fiber from the mass of cement, and steel 3–9 %. From
each composition, 6 beam samples were made for testing under bending and compression after 28 days after mixing.

4. Results
The results of bending and compression tests of solutions with polypropylene fiber are shown in Figures 4–5, and with steel in Figures 6–7.

The analysis of the results of the performed studies shows that when testing the bending strength the introduction of 1 to 3.5 % of polypropylene fiber from the weight of cement, there is an increase in strength. At the same time, the compression test is characterized by a decrease in the effect on the strength indices with an increase in the microfiber content of more than 2 % of the mass of cement (see Figure 5). It can also be noted that the introduction of polypropylene microfiber is accompanied by an increase in bending strength by 47.4 %, and compression by 15.3 %.

![Figure 4. The graph of the dependence of the strength of the samples on bending on the microfiber content](image1)

![Figure 5. The graph of the compression strength of the samples on the microfiber content](image2)

![Figure 6. The graph of the dependence of bending strength of the samples on the microfiber content](image3)
The effectiveness of the addition of steel fiber is characterized by a stable increase in bending and compressive strength to an additive content of 7 % by weight of cement. However, with an increase in the amount of fiber, the strength growth sharply slows down. The most appropriate introduction of fiber is in an amount of 8 % by weight of the binder. In this case, the bending strength of the samples exceeds the control ones by 28.3 %, and the compression by 43.7 %.

![Graph of the dependence of the compressive strength of the samples on the microfiber content](image)

**Figure 7.** The graph of the dependence of the compressive strength of the samples on the microfiber content

Visual inspection of the samples shows that most of the fibers do not collapse, forming a crack during bending, but are pulled out of the sand-cement stone. This explains the decrease in the growth of bending strength of samples with steel fiber. At the same time, steel fiber better resists shear deformations on the cut inclined planes during compression.

It was also established that the strains at the ultimate stresses of solutions modified with polypropylene microfiber are several times higher than the deformations of the control and almost three times greater than for samples with steel fiber. This circumstance required a more detailed study. Therefore, in the future, when determining the bending strength and compression to control the magnitude of deformation of samples on the press E160 the indicator of clock type ICH-50 (Figure 8) is installed, which allowed fixing deformation, and applied stress at a constant rate of loading with the help of video shooting at certain points in time.

![Study of deformation characteristics of samples](image)

**Figure 8.** Study of deformation characteristics of samples
According to the results of studies, the destruction of the beams halves without additives occurs when deformation on average is 0.22 mm, and modified is 1.37–1.96 mm. The results of the study of the deformation characteristics of the halves of beams with a dosage of polypropylene microfiber of 1.5, 2 and 2.5 % of the mass of cement are presented in the 9–11 figures.

**Figure 9.** The dependence of the deformation of the samples on stresses with fiber content of 1.5 %

**Figure 10.** Sample deformation dependence on strains with 2 % of fiber content

**Figure 11.** Dependence of deformation of samples on stresses at 2,5% fiber content

The analysis of tests of 34 samples shows that compositions keep linear dependence (elastic) of deformations on stresses approximately to 70 % from a compressive strength limit. After excluding strain values outside the linear dependence from the sample, a graph was constructed that, with a high degree of certainty, $R^2 = 0.9443$, is approximated by a linear function (Figure 12).
The equation (1) obtained by the results of approximation will allow to determine the permissible additional deformations of masonry from uneven sedimentation of the foundation base when using a modified polypropylene microfiber solution.

\[ \varepsilon = 0.0027\sigma + 0.0009, \]  \hspace{1cm} (1)

where \( \varepsilon \) is relative deformations of samples; \( \sigma \) is normal compressive stresses, MPa.

Figure 12. The graph of the dependence of the relative deformation of samples modified with polypropylene microfiber on stresses.

Figures 13–14 show the results of the destruction of the beams halves on compression.

Figure 13. The nature of the halves destruction of the control samples

The analysis shows that despite the significant deformations in compression (the samples contain dents from load plates up to 2 mm) there was no clear exfoliation on almost all 34 samples.

The nature of the destruction of concrete samples (Figure 15) modified polypropylene microfiber was investigated on samples of cubes with a rib size of 100×100×100 mm. As a result, it can be noted that the destruction of concrete without additives is accompanied by exfoliation of the destroyed zones of the side faces of the cubes with the formation of an “hourglass” (Figure 15a).

Figure 14. Samples of polypropylene microfiber modified solution after compression test

The loading of modified concrete samples is accompanied by significant vertical deformations without exfoliation of the faces of the cubes (Figure 15b). The load schedule of tests (Figure 16) is
characterized by a prolonged decline in tensions after extremes. That is, the risk of avalanche-like destruction is reduced.

The tests also found that, unlike gravitational, forced mixing ensures even distribution of fibers by composition and, accordingly, a maximum increase in strength on bending and compression.

![Figure 15. Destruction of concrete: a – without additives; b – modified polypropylene microfiber](image)

![Figure 16. Loading characteristic of concrete modified polypropylene microfiber](image)

5. Conclusion
According to the results of studies of sand-cement mortar, it was found:

- when testing the compression of the halves of control samples, the ultimate deformation (at the time of destruction) is averaged 0.22 mm;
- ultimate strains of samples of solutions modified with polypropylene microfiber were 1.37–1.96 mm;
- when a load is applied not exceeding 50 % of the limit, the deformation of the modified samples is on average 0.8 mm, the decrease in compressive strength is 11 %, which is within the range of variation of the compressive strength of samples of the same composition.

Thus, it is established that the limit deformations of samples of modified composition are 5–7 times more than the control ones, which can provide more uniform stress distribution in masonry, thereby reducing the probability of cracking. Preliminary calculations show that masonry with a height of 1 m can allow vertical deformations of up to 2.5 mm without breaking the continuity.

Since the mechanical characteristics of concrete are mainly determined by the properties of the sand-cement mortar, the use of concrete modified with polypropylene microfiber for deformable structures and the fastening of underground structures will ensure their higher reliability.
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