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# RESPONSE OF FINE-GRAINED FIBER-REINFORCED CONCRETES UNDER DYNAMIC COMPRESSION

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**Abstract.** The article presents the results of tests of different types of fiber-reinforced concrete in comparison with concrete-matrix. The dynamic experiments were carried out using the split Hopkinson bar technique on samples of fine-grained concrete-matrix, as well as with the addition of steel and polypropylene fiber. The static tests of these materials were carried out using the Z100 Zwick-Roell testing machine. Diagrams of deformation and dependences of maximum stresses versus the stress rate are constructed. The obtained data were used to determine the values of the incubation failure time of the studied materials. The influence of the stress rate on the strength of the materials and the applicability of the structural-temporal approach for the prediction of this effect is shown.
**Keywords:** fiber-reinforced concrete, split Hopkinson pressure bar, stress rate, incubation time criterion

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## 1. Introduction

Currently, fiber-reinforced concretes are being actively introduced in the building structures industry. Metal and non-metal fibers which have adhesion along their surface to the concrete are used for fiber-reinforced concrete. Fiber-reinforced concrete is recommended to be used for high-responsibility constructions. In such structures, the following technical advantages of fiber-reinforced concrete can be effectively used in comparison with traditional concrete: increased crack resistance, impact strength, fracture toughness, wear resistance, frost resistance, and cavitation resistance, as well as reduced shrinkage and creep. Cases of emergencies that are accompanied by intense impacts and explosions have become more frequent in recent years. Such situations occur as a result of natural disasters, terrorist attacks, and technological disasters. Therefore, it is necessary to take into account these dynamic effects when designing responsible buildings and structures. Dynamic effects are characterized by continuous changes of parameters and high intensity. It is necessary to know the mechanical properties of building materials at high strain rates for rational and reliable design of dynamically loaded structures. In this regard, the study of the behavior of modern

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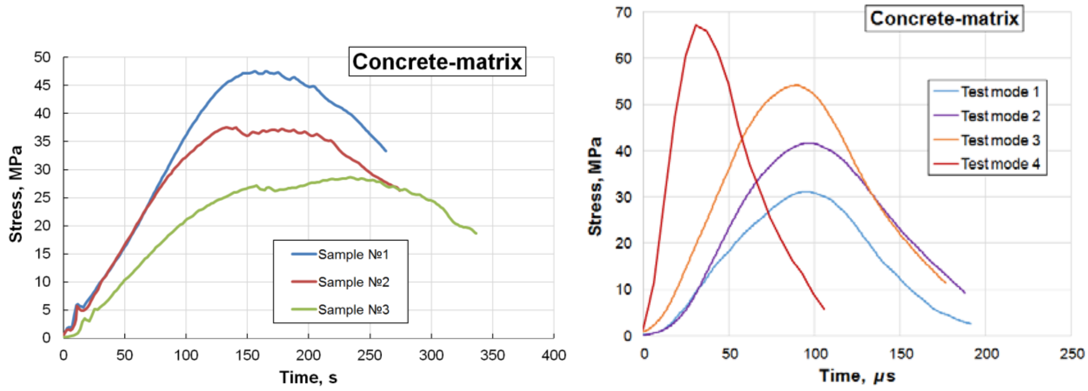
structural building materials under high rate loading is a relevant problem and the efforts of many researchers are aimed at its solution [1-5, etc.].

**2. Obtaining experimental data**

The tests were carried out on fine-grained concrete-matrix, concretes with the addition of steel and polypropylene fibers (the volume fraction was 1.5%). The fiber of wave profile and the grade ФСВ-В-0,30/15 according to ТУ 14-1-5564-2008 was used from high-carbon steel wire 0.3 millimeters in diameter and 15 millimeters in length for steel fiber reinforced concrete. The "PoliArm" fiber which consisted of separate rigid sinusoidal-wavy fibers 25 millimeters in length was used for polypropylene fiber reinforced concrete. Samples were made in the form of cylinders 20 millimeters in diameter and 10 millimeters in length for dynamic tests. The diameter and length of the samples were 20 millimeters for static tests. Three to seven samples of each material were taken for static tests, as well as for each dynamic test mode.

Static tests on uniaxial compression until fracture of samples at a constant strain rate $30 \cdot 10^{-6}$ $s^{-1}$ in accordance with [6] were carried out using a Z100 Zwick-Roell testing machine. Dynamic tests on uniaxial compression were carried out using the Kolsky method with the split Hopkinson pressure bar [7]. The experimental setup [8,9] consisted of a gas gun of 20 millimeters caliber, incident and transmitter bars with a diameter of 20 millimeters, and a test sample between its. A striker 20 millimeters in diameter and 250 millimeters in length as well as measuring bars were made of an aluminum alloy. The registration of strain pulses of measuring bars was carried out using strain gauges glued to its lateral surface. The signals from strain gauges were transferred to a digital oscilloscope for further processing. The speed of the striker was varied and ranged from 10m/s to 35 m/s for obtaining different stress rate modes in the experiments.

The static and dynamic diagrams of deformation of concrete-matrix in stress-time axes were obtained which are shown in Fig. 1. The results of dynamic tests are presented in the form of averaged deformation diagrams obtained under different test modes by the speed of the striker. The strength of the material was 35.4 MPa (average) at a static stress rate of 331 kPa/s. The values of dynamic strength were 41.7 MPa, 54.13 MPa and 67.1 MPa (average) at stress rates 726 GPa/s, 857 GPa/s and 2492 GPa/s respectively. Stress rate was determined as the slope of the linearly ascending branch of the time history of compressive stress. Test modes in dynamic were chosen in such a way as to smoothly approach the fracture of the sample. Therefore, when determining the strength, test modes with low-stress rates were not taken into account at which no increase of strains occurred on the deformation diagram of materials with a decrease of stresses after its reached maximum. The strength corresponded to the test modes under which the fracture of the sample and those preceding it occurred that were visible on the stress-strain diagram of the material. The static and dynamic diagrams of deformation of polypropylene fiber reinforced concrete in stress-time axes were obtained which are shown in Fig. 2. The strength of the material was 44.31 MPa (average) at a static stress rate of 497 kPa/s. The values of dynamic strength were 51.36 MPa, 56.26 MPa and 73.46 MPa (average) at stress rates 864 GPa/s, 1196 GPa/s and 3768 GPa/s respectively. The static and dynamic diagrams of deformation of steel fiber reinforced concrete in stress-time axes were obtained which are shown in Fig. 3. The strength of the material was 58.8 MPa (average) at a static stress rate of 608 kPa/s. The values of dynamic strength were 84.51 MPa and 96.9 MPa (average) at stress rates 1442 GPa/s and 5835 GPa/s respectively. It can be noted that the deformation diagrams of all investigated concretes have a similar form. But the values of strength which increase with an increase of the stress rate are different for various concrete. The most increase of strength occurs when steel fibers are added to the concrete mix.




a b

**Fig. 1.** Static (a) and dynamic (b) diagrams of deformation of concrete-matrix

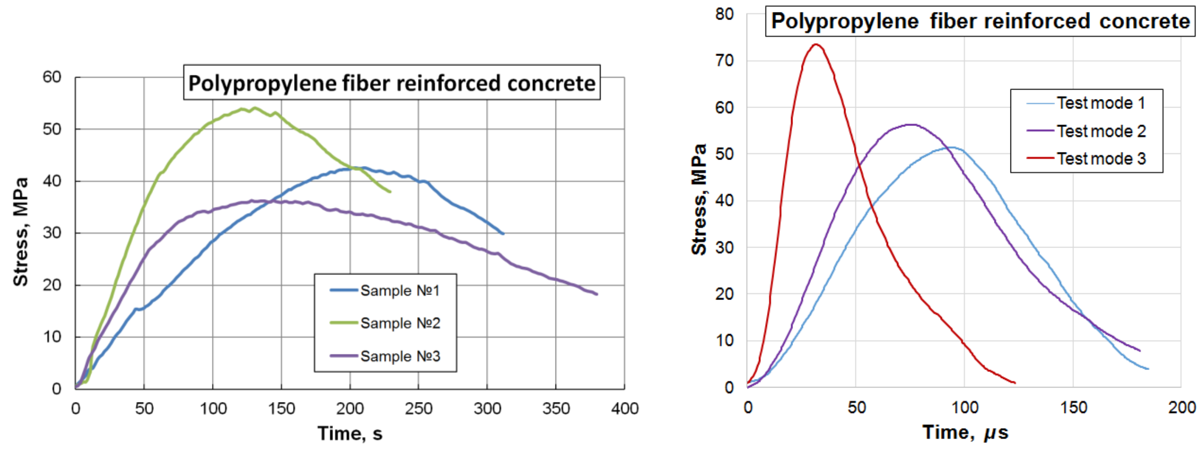



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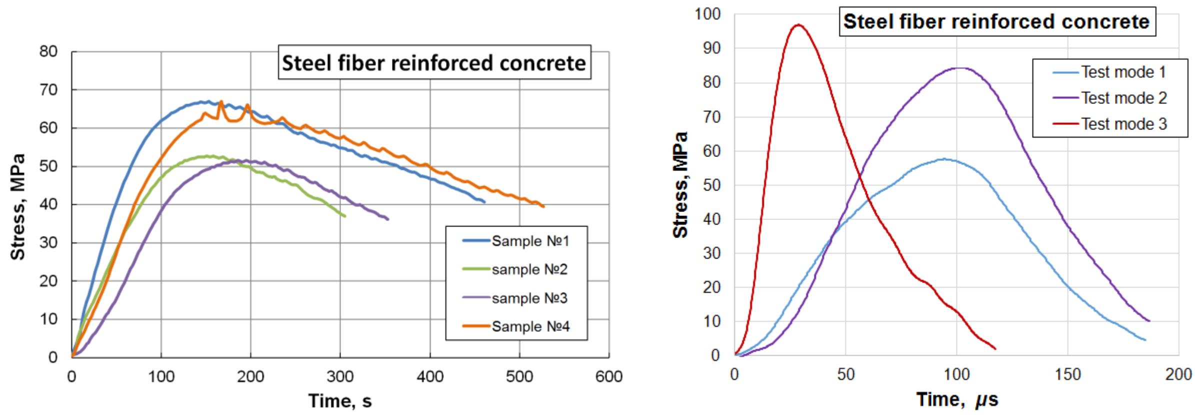
**Fig. 2.** Static (a) and dynamic (b) diagrams of deformation of polypropylene fiber reinforced concrete




a b

**Fig. 3.** Static (a) and dynamic (b) diagrams of deformation of steel fiber reinforced concrete

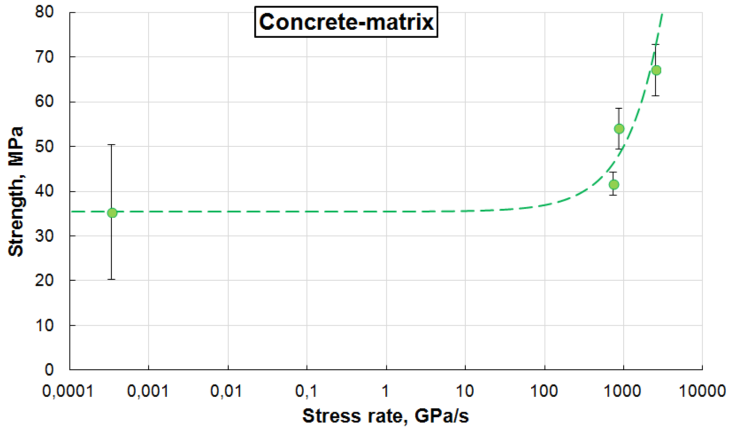
## 3. Experimental data processing

The obtained experimental data were used to determine the parameters of the Morozov-Petrov strength criterion based on the concept of incubation time [5,8-10]. The fracture of the material occurs when:

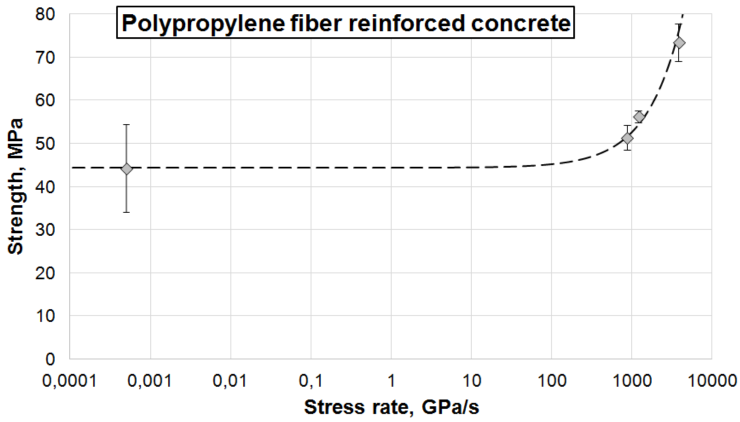
$$\frac{1}{\tau}\int_{t-\tau}^{t} \sigma(t') \, dt' \le \sigma_c^{compr}, \tag{1}$$

where σ(t′) – time history of stress in material point, $\sigma_c^{compr}$ and τ – material constants: static strength and incubation failure time respectively. The growth of compressive stresses was assumed to be linear until the moment of fracture to determine the incubation time.

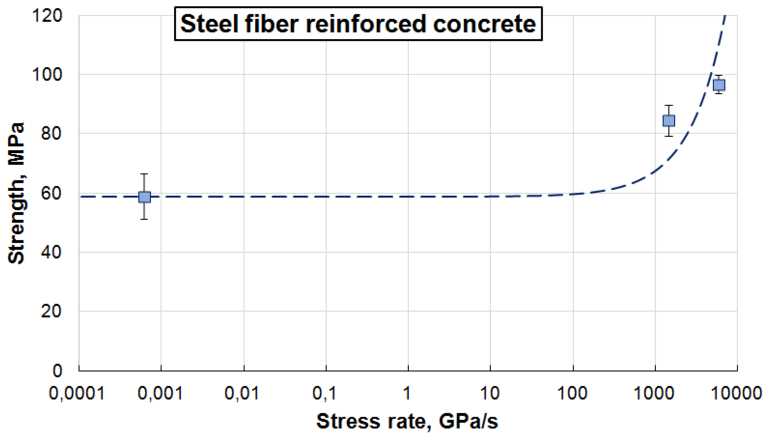
The observed dynamic increase in of strength of the tested materials was calculated using the incubation time criterion. The rate dependences of strength plotted on the basis of the structural-time approach are in good agreement with the experimental data for all tested materials (Fig. 4). The values of incubation failure time determined for studied concretes are summarized in Table 1.




a




b




c

**Fig. 4.** Dependences of the strength of concrete-matrix (a), polypropylene fiber reinforced concrete (b), and steel fiber reinforced concrete (c) versus the stress rate: points – experiment, line – calculation by criterion

Table 1. Values of incubation failure time for the studied concretes

| Fiber type | τ, μs |
|---|---|
| without fiber | 29 |
| steel fiber | 18 |
| polypropylene fiber | 17 |

## 4. Conclusions

Uniaxial static and dynamic compression tests were carried out for samples of different types of fiber-reinforced concrete and concrete-matrix. The obtained experimental results are characterized by a temperate scatter and show the influence of the stress rate on the mechanical properties of the tested materials. The maximum stresses increased with increasing stress rate for materials. The parameters of the incubation fracture time criterion were determined for investigated materials on the basis of the experimental data. It is shown that the time dependence of the strength of investigated concretes in compression can be predicted by the incubation time criterion. The rate dependences of the strengths of the materials predicted on the basis of the structural-temporal approach are in good agreement with the experiment.

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