The outlook for regulatory support for adoption of efficient concretes

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Abstract. The analysis of data obtained under studying scientific, technical and normative literature in the area of applying efficient concretes, in particular, fiber-reinforced concrete, in the world and national tunnel construction is presented herein. The European regulatory documents, standard metrologically certified methods and procedures for analyzing and testing, laboratory test equipment and measuring instruments are indicated. Steel fiber concrete studies was explored at the Scientific and Educational Center for Innovative Technologies of the Architectural and Construction Institute of the Ufa State Petroleum Technical University. Prism bending tests were made with different fiber content. In addition to laboratory tests, other tests were made in accordance with the Russian standards, where the prisms are tested without a notch. The correlation between the slope of the load-to-displacement curve of the crack mouth (CMOD - Crack Mouth Opening Displacement) and the length of the crack was used in the course of the study. The fiber content enabling to get an average residual bending strength of at least 1.5 MPa at 0.5 CMOD (equivalent to 0.47 mm center deviation) and an average residual bending strength of at least 1 MPa at 3.5 mm CMOD (equivalent to 3.02 mm o of center deviation) is found. Statistical distributions of the Grubbs tests are analyzed by methods of statistical modeling. The regulatory framework for fiber concrete is not currently well developed in the Russian Federation, thereby reducing greatly the application of new generation concretes meeting the current knowledge. The application of fiber concrete in tunnel construction will prove to be economically justified and the areas of applying effective materials are to be developed in future with the wide participation of scientific, design, production, construction and other specialized organizations, as well as educational and training centers.

1. Introduction
In tunnel construction, the fiber has been actively used for decades to replace traditional reinforcement all over the world. Such countries as the United Kingdom, Italy, the United States and Japan are actively engaged in the development of calculation methods, and make various tests. Currently, in the Russian Federation, various companies manufacture and are engaged in application of fiber in tunnel construction. The quality of fiber made by different manufacturers is noted to be differ greatly. Therefore, the only Russian standard for fiber concrete SP 52-104-2006 "Steel fiber concrete structures" until 2015 was specifying the application of certain types of fiber made by certain manufacturers. For this reason, the application of fiber in tunnel construction in Russia is relatively difficult. However, after issuance of STO NOSTROY 2.27.125-2013 "Constructions of transport tunnels from fiber-concrete", the fiber started to be considered for further application.
New requirements to durability of such a traditional type of construction material as concrete make searching for new types of reinforcing. Dispersed fiber reinforcement has recently been widely applied as a reinforcing material, with various materials like metal, basalt, polypropylene, glass being used for the manufacture thereof. The development of dispersed reinforcement as an alternative to the bar reinforcement was taking place gradually all over the world, initially being considered as an auxiliary to the traditional one [1]. The first patent issued in 1874 for a reinforcing additive to concrete was received by the Englishman A. Berard, in 1911 Porter discovered that the mechanical properties of concrete increased about 8 times by adding of wire and nails [2]. In our country, papers devoted to the production of fiber-reinforced mixed concrete and mortars with application of fibers are associated with the name of the Russian engineer V.P. Nekrasov [3]. He used small-diameter wire pieces as fiber reinforcement. But, at that time this material was not widely used in our country, since the technology of manufacturing fiber-reinforced concrete and the fiber itself at that time were not perfect [4].

2. Materials and methods

In the manufacture of steel fiber concrete (SFB) there was a problem of uniform distribution of fiber in the entire volume of the concrete mixture. For this purpose, manufacturers use special electromagnet-based equipment that somehow "stretches" the fiber throughout the entire volume of the mixture while making SFB. If concrete is reinforced with glass fibers, a method called pneumatic spraying is used. The method consists of simultaneous spraying of concrete mixture and glass fiber (finely chopped). The undoubted advantage of this technology is the possible manufacture of large-sized items.

Another serious disadvantage of traditional concrete is rather low bending and tensile strength thereof [5,6]. In fiber-reinforced concrete, this tension is taken over by the fiber, thereby increasing tensile strength up to 250%, and compression resistance up to 25%. Due to perfect hydration, the impact strength of fiber-reinforced concrete is 12 times higher than that of concrete. The fiber-reinforced concrete is also resistant to many chemicals and low temperatures. In Russia, there is not much experience in applying fiber-reinforced concrete while the volume of production thereof is small, but the world practical experience is likely to contribute to the development of this promising material in our country. [7,8].

Apart from the standard compression test for cubes, a prism-bending test is performed. In Europe, fiber concrete prisms are tested in accordance with the European Standards, EN 14651 "Test method for steel-fiber concrete to fix the residual bending strength", as well as the Italian Regulatory Document UNI 11039 "Steel-fiber concrete - definition, classification and purpose". It was UNI 11039 that was initially issued, and the European Document was already based on the Italian experience, but with some amendments adapted to the practice of most European countries. Both documents are based on the guidelines and requirements for concrete described in EN 206 "Concrete - Specification, Performance, Production and Conformity". In addition to European standards for testing steel fiber concrete, there are others, e.g., Japanese JSCE SF-4, American ASTM C-1018, and Belgian NBN B15-238. In Russia, bending tensile tests of any reinforced concrete prisms are made in accordance with GOST 10180 "Concrete. Methods for strength determination using reference specimens".

The basic difference between European regulatory documents and the Russian ones is that a beam with a notch is used for testing prisms for bending, and accordingly, the test concept differs from the Russian one (Figure 1).

According to Russian standards, steel-fiber concrete as well as reinforced concrete are tested according to the standard method, i.e. without making a notch. This difference makes it difficult to apply fiber-reinforced concrete in the underground construction in the Russian Federation. GOSTs and SNiPs contain no information on the fiber application, the test method is also not adapted to the Russian standards. Therefore, the application of fiber concrete is proceeding rather slowly, despite the fact that there are too many examples of foreign experience in applying this material in underground construction, in particular, in tunnel construction. Tests according to European standards seem to be made in the Russian Federation, while the results obtained thereunder are to be compared with the calculated data.
According to European tests, instead of considering the total energy balance of the entire specimen, the attention is paid to the top of a crack, the place of the highest stress concentration, where the released energy flows to the starting point of further destruction of the material.

The concrete is characterized by tear-off cracks, as well as by transverse shear cracks accompanying therewith.

In the materials proper, due to high stresses there appears a small crack tip plastic zone that is relieving infinite stresses [9, 10, 11].

Since the fiber is to remove the crack resistance, a prism with a notch, with the top thereof being the crack growth starting under loading, will be considered the optimum procedure for bending tests (Figure 2).

**Figure 1.** Steel fiber concrete prism to be tested for residual bending strength in accordance with EN 14651.

**Figure 2.** Residual bending strength test of steel fiber prism in accordance with EN 14651.
Therefore, the prism-bending test of steel fiber concrete should be made in accordance with EN 14651 "Test method for steel fiber concrete for determination of residual bending strength".

This European Standard describes a method for determining the effect of steel or polymer fibers on the residual bending strength of a reference concrete specimen.

The following reference documents are required for the application:
- prEN 14845-1, Test methods for fibers in concrete - Part 1: Reference concrete.
- EN 14889-1, Fibers in concrete - Part 1: Steel fibers - Definitions, specifications and conformity.
- EN 14889-2, Fibers in concrete - Part 2: Polymer fibers - Definitions, specifications and conformity.
- ISO 5725-2: 1994, Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for determining the repeatability and reproducibility of a standard measurement method.

Fiber is tested in one or more reference concrete (according to prEN 14845-1 standard) to determine the fiber content required to meet the specified residual bending strength at a specified deformation level.

The steel fiber concrete was tested at the Scientific and Educational Center for Innovative Technologies (SECIT) under the Federal State Budgetary Educational Institution of Higher Education Ufa State Petroleum Technological University [12,13]. SECIT is analyzing and testing a wide range of construction materials and products, such as: cement- and gypsum-based binders, aggregates, concretes, mortars, bricks, wall blocks, aerated concrete, rebars, under Certificate of assessment of laboratory measuring instruments No.TSM RB.OSL.ST.03022, issued by the Center for Standardization and Metrology of the Republic of Bashkortostan [14,15].

Twelve 550x150x150mm beams with a notch, made from reference concrete according to prEN14845-1 with fiber included, were tested 28 days after casting, with the load being applied to the center at 500 mm according to the test method for fiber concrete according to EN 14651.

Concrete is made with three fiber concentrations - 25, 30 and 35 kg in the bulk materials area of the testing laboratory of the FSBEI of Higher Education Ufa State Petroleum Technological University (figure 3).

Figure 3. Bulk materials (left) and testing area (right) of the SECIT under the FSBEI of Higher Education Ufa State Petroleum Technological University.

Most methods use a correlation between the slope of the load-to-displacement curve of the crack mouth opening (CMOD - Crack Mouth Opening Displacement) and the length of the crack. The fiber content that enables to get average residual bending strength of at least 1.5 MPa at 0.5 CMOD
(equivalent to 0.47 mm center deviation) and an average residual bending strength of at least 1 MPa at 3.5 mm CMOD (equivalent to 3.02 mm center deviation) needs to be defined [16,17].

When calculating the average performance of twelve beams, the effect of any intended (non-indicative) results should be excluded. Statistical distributions of the Grubbs tests are analyzed by methods of statistical modeling.

Wet sawing was used to make notches (cuts) on the test specimens. The specimens must be rotated 90° around the longitudinal axis and then a cut is made at mid-point. Notch width x is to be 5 mm or less, while hsp distance must be 125 mm ± 1 mm.

After uniform installation of all loading and support rollers over the surface, the test specimens were subjected to loading.

During the first two minutes of the test, the load values and the corresponding CMOD (Crack Opening Displacement) were recorded at a frequency of at least 5 Hz [18,19], thereafter the frequency was reduced to 1 Hz. When the CMOD value was 4 mm, the test was stopped. During the tests, the cracks outside the notch were ignored.

3. Results and discussions
The prism bending tests were made with different contents of the "Wirand FF3" prism. Testing equipment is Instron 8802 testing machine. The results of bending tests of steel fiber concrete prisms (at 25 kg/m³ of fiber) are given in Table 1 according to EN 14651:

Table 1. The results of bending tests of steel fiber concrete prisms (at 25 kg/m³ of fiber) according to EN 14651.

| Fiber content (kg/m³) | \( f_{c,l} \) (MPa) | \( f_{1,R} \) (MPa) | \( f_{3,R} \) (MPa) | \( f_{4,R} \) (MPa) | \( f_{4,R} \) (MPa) |
|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 2                    | 3                   | 4                   | 5                   | 6                   | 7                   |
| 25                   | 3.55                | 2.36                | 2.53                | 2.72                | 2.38                |
| 25                   | 4.22                | 2.65                | 2.78                | 2.78                | 2.97                |
| 25                   | 4.04                | 2.43                | 2.13                | 2.18                | 2.35                |
| 25                   | 4.14                | 2.89                | 2.88                | 2.92                | 2.74                |
| 25                   | 4.41                | 4.36                | 4.15                | 3.95                | 3.50                |
| 25                   | 4.22                | 2.92                | 2.94                | 3.15                | 3.17                |
| 25                   | 4.11                | 3.45                | 3.83                | 4.13                | 4.02                |
| 25                   | 3.98                | 2.75                | 2.71                | 2.76                | 2.88                |
| 25                   | 4.10                | 3.16                | 3.17                | 3.24                | 3.11                |
| 25                   | 4.02                | 3.00                | 3.25                | 3.32                | 3.43                |
| 25                   | 3.90                | 2.33                | 2.43                | 2.38                | 2.40                |
| 25                   | 4.46                | 2.90                | 2.69                | 2.52                | 2.52                |
The curve in Figure 4 above is going (a bit slightly but) up when a crack opens 0.7 mm. This phenomenon proves that the fiber concrete is possessing enhanced strength. The area below the curve shows the amount of energy released during loading, the larger the area under the curve, the greater the energy release meaning greater strength, and, consequently, the durability of the structure. Table 2 shows the results of bending tests of (at 30 kg/m$^3$ of fiber) according to EN 14651:

**Table 2.** Steel-fiber-concrete prism bending testing results (at 25 kg/m$^3$ of fiber) according to EN 14651.

| Fiber content (kg/m$^3$) | $f_{f1}$ (MPa) | $f_{1,R}$ (MPa) | $f_{2,R}$ (MPa) | $f_{3,R}$ (MPa) | $f_{4,R}$ (MPa) |
|--------------------------|----------------|----------------|----------------|----------------|----------------|
|                          |                |                |                |                |                |
| 2                        | 3              | 4              | 5              | 6              | 7              |
| 30                       | 0              | 0              | 0              | 0              | 0              |
| 30                       | 0              | 0              | 0              | 0              | 0              |
| 30                       | 0              | 0              | 0              | 0              | 0              |
| 30                       | 4.16           | 3.97           | 3.75           | 3.74           | 3.93           |
| 30                       | 3.96           | 3.77           | 3.64           | 3.48           | 3.51           |
| 30                       | 3.65           | 3.55           | 3.58           | 3.15           | 3.11           |
| 30                       | 3.55           | 2.89           | 2.87           | 2.73           | 2.58           |
| 30                       | 2.59           | 4.00           | 4.02           | 3.96           | 4.11           |
| 30                       | 3.92           | 3.89           | 4.59           | 4.93           | 5.71           |
| 30                       | 4.05           | 3.60           | 3.59           | 3.90           | 4.15           |
| 30                       | 3.41           | 3.52           | 3.88           | 4.14           | 4.32           |
| 30                       | 4.13           | 3.71           | 4.23           | 4.50           | 4.44           |

The results of laboratory prism bending tests are given in Tables 1, 2. In addition to laboratory tests the tests were made in accordance with the Russian standards, where prisms are tested without a notch.

The regulatory framework for fiber concrete is not currently well developed in the Russian Federation, thereby reducing greatly the application of new generation concretes [20]. The application of fiber concrete in tunnel construction will prove to be economically justified and the areas of applying effective materials are to be developed in future with the wide participation of scientific, design, production, construction and other specialized organizations, as well as educational and training centers.
4. Summary
An analysis of data in the study of scientific, technical and regulatory literature in the area of applying effective concretes, in particular, fiber concrete in the world and domestic tunnel construction, is presented. The European normative documents, standard metrologically certified methods and procedures for analyzing and testing, laboratory test equipment and measuring instruments are indicated.

A procedure for testing fiber concrete to be applied in the underground construction is proposed under the results thereof.

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