Development of Technological Parameters for Introducing Fiber into the Concrete Mixture for a Ballast-Free Track

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**Abstract.** The development of technological factors related to the parameters of preparing a dispersed-reinforced concrete mixture for a ballast less track required laboratory studies related to the qualitative characteristics of fiber distribution in samples of various types and made it possible to establish the parameters of the effectiveness of applying fibers of different types, dependences related to the order of introduction, aggregate size, and calculation order. The adopted parameters of the methods for constructing a ballast-free track do not preclude the need to solve problems related to reducing the risk of technological cracks during the construction of a dispersed-reinforced ballast-free track in the dry and hot climate of the Republic of Uzbekistan. The criteria for choosing the method of erecting a span structure are determined by the peculiarities of the bridge structure, the remoteness of the object from engineering networks and production capacities, which necessitates the possibility of implementing the project under the given technological regime for the manufacture, transportation, and installation of a ballast less track.

**Keywords:** ballast less track, fiber, frost resistance, dispersed reinforced concrete, compression, fiber-reinforced concrete

# INTRODUCTION

The development of railways in the Republic of Uzbekistan, associated with the transition to high-speed traffic, necessitates scientific substantiation of requirements and the purpose of operational characteristics of ballast way, including span structures. Analysis of the practice of building bridges on high-speed railway lines in various countries of the world convincingly proves that the priority direction in the construction of bridge structures in conditions of high speeds of rolling stock is the use of reinforced concrete structures of span structures [1, 2, 3, 4, 5, 6, 7].

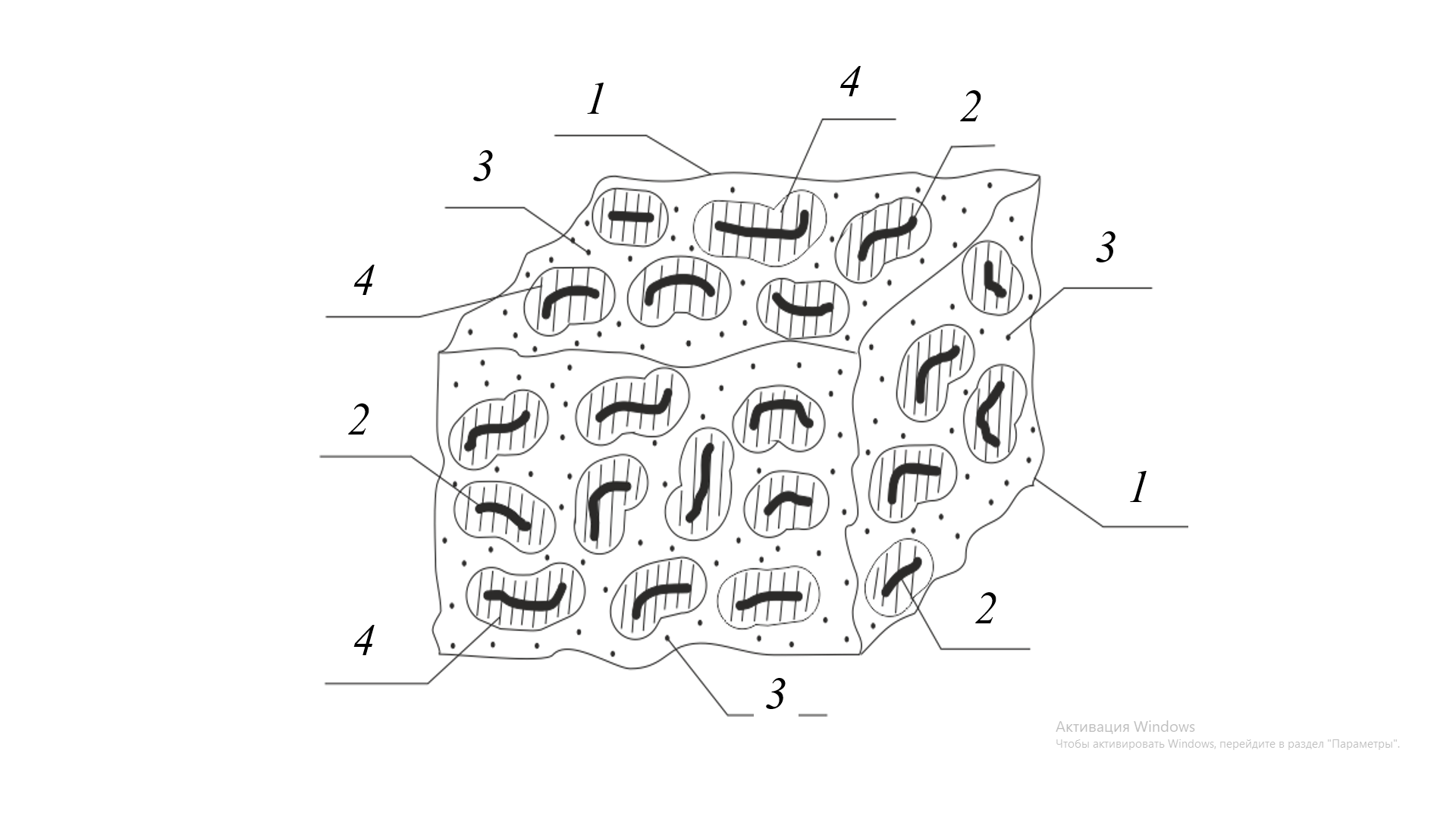
Analysis of technological risks associated with the manufacture of dispersed-reinforced structures of a ballastless track using fiber shows that the strength properties of the structure are largely determined by the nature of fiber distribution [8, 9, 10, 11, 12, 13, 14, 15].

When considering the structure of dispersed reinforced concrete, zones of interaction between the components of the concrete mixture are determined, determined by the conditional boundary of the macrostructural cell (*1*), fiber (*2*), the matrix structure of the concrete (*3*), and the zone of contact interaction of reinforcing fibers with concrete (*4*), which are presented in Figure 1.

As the results of research related to the application of different types of fibers in reinforced concrete structures of various purposes show, the final properties of dispersed reinforced concrete are influenced by the following factors characterizing the properties of fibers:

* strength properties of the fiber material (, );
* specific surface area of the reinforcing fibers ();
* Surface roughness characteristics of the fiber ().

At the same time, the properties of the concrete mixture and its components that determine the density of the mixture and its consistency, including the content (*%*) and maximum size of coarse aggregate (), water-cement ratio (*W/C*), cement-sand ratio (*C/S*), also affect the nature of the distribution of fiber throughout the volume of the structure [15, 16, 17, 18].



**FIGURE 1.** Structural diagram of a spatial cell of fiber-reinforced concrete

The technological parameters for the selected composition are as follows: *В*40, *W*12, *F*300, with cement consumption in *kg/m*³, fiber consumption *Q* = 57 *kg/m*³, *W/C*=0,41 and *C/S* = 0,74. This includes the sequence of fiber introduction into the mixture, both before and after the addition of coarse aggregates, as well as the mixing time (*t*) in seconds. These parameters were determined through the manufacturing and testing of 20 series of samples, based on design performance, at the “Laboratory for Testing Materials, Structures, and Quality Control” of JSC “Bridge Building Trust №6”.

# EXPERIMENTAL PART

The following types of fiber were adopted as the initial samples to be studied, which are shown in table 1:

* Steel, milled from slabs, fiber, taken into account in the calculation justification. Type *A*;
* Chopped wire fiber with ribbing. Type *B*;
* Chopped wire fiber with anchors at the ends. Type *V*;
* Fiber cut from sheet steel with anchors at the ends. Type *G*;
* Steel, finely milled, with protective coating, made in China. Type *D*.

**TABLE 1.** Steel fiber samples

|  |  |  |
| --- | --- | --- |
| **General view** | **Fiber type** | **Characteristic** |
|  | *А* | Density – 7,8 *g/sm*3;  Tensile strength – 0.8….3.15*GPa*;  Young's modulus – 200 *GPa*;  Elongation at break – 3…4*%*;  Fiber diameter: 0.3…1.6 *mm*;  Fiber length: 30…160 *mm*. |
|  | *В* | Density – 8.2 *g/sm*3;  Tensile strength – 0.7….2.55 *GPa*;  Young's modulus – 190 GPa;  Elongation at break – 5…7%;  Fiber diameter: 0.4…1.4 *mm*;  Fiber length: 60…160 *mm*. |
|  | *C* | Density – 8.0 *g/sm*3;  Tensile strength – 0.7….2.70 *GPa*;  Young's modulus – 190 *GPa*;  Elongation at break – 6…8*%*;  Fiber diameter: 0.3…1.6 *mm*;  Fiber length: 30…160 *mm*. |
|  | *D* | Density – 7,95 *g/sm*3;  Tensile strength – 0,6….3,05 *GPa*;  Young's modulus – 194 *GPa*;  Elongation at break – 4…5*%*;  Fiber diameter: - 0,4…1,8 *mm*;  Fiber length - 30…160 *mm*. |
| IMG_20160816_083245 | *E* | Density – 12,7 *g/sm*3;  Tensile strength – 0,9….3,35 *GPa*;  Young's modulus – 210 *GPa*;  Elongation at break – 5…7*%*;  Fiber diameter - 0,1…0,4 *mm*;  Fiber length – 0,5 …1,6 *mm*. |

Basic regulatory methods for determining the compressive strength, frost resistance, and water resistance indicators of the samples were adopted as testing procedures [18].

At the first stage of the tests, a study was conducted on the dependence of the accepted indicators on the technological order of introducing fiber into the mixture and the mixing time *t*, *sec*, with the fiber sample of type *A*, which was taken as the main option in the calculation justification.

In the second stage, the technological parameters of mixture preparation for alternative fiber samples compared to the main variant of type *A* were investigated by the comparison method, taking into account the mixing time *t*, *sec*, and the maximum size of the coarse aggregate used in the mixture .

The production of a series of samples with the adopted fiber types, introduced into the mixture, was carried out in a concrete mixer with an electric drive with a capacity of *V*=0,2 *m*3.

In the first stage, the procedure for introducing fiber was carried out in the following variants:

- in the first case, the fiber was introduced in a separate batch directly in front of the coarse aggregate;

- in the second case, fiber was introduced as part of the preliminary dry mixture of inert materials with cement;

- in the third case, the fiber was introduced in a separate batch after mixing the coarse aggregate.

In the second stage, preliminary dry mixing was used, as a variant that ensures the best fiber distribution in the mixture volume based on the results of the first stage.

The mixing time was taken based on the actual, working, and temporary modes of mixture preparation under production conditions, at mechanized concrete mixing units, with a mixture preparation time of *t* = 60, 120, 180, 240, 300, 360 *seconds*.

The test results confirm the dependence of the strength and macrostructural properties of dispersed reinforced concrete on the type and technology of mixture preparation (Figure 1). Thus, changing the mixing time *t*, *sec*, towards a gradual increase to *t* = 360 *sec* for the composition of concrete *B*40 increases the likelihood of increasing the degree of homogeneity of the mixture. This is confirmed by the convergence of the indicator values for different fiber types in the range of values from 46,5 to 52,5 *MPa*. At the same time, there is a tendency towards an increase in the average strength indicator of the dispersed-reinforced concrete samples in a series with longer mixing periods.

At the same time, the variance of values up to 10 *MPa* at a stirring time of up to *t* = 180 *sec* in the case of testing samples made from the mixture according to the third option determines the need to work out and clarify the technological regime associated with the order of fiber introduction. Such an order should be determined based on the actual properties of the concrete mixture, which affect the uniform distribution of the adopted fiber type in the case of its application [18].

# RESULTS AND DISCUSSION

When testing a series of samples for frost resistance F, it was established that the interdependence of the average strength loss indicator of the samples in the batch , characterizing the preservation of strength properties related to reinforcement efficiency, is also determined by the order of fiber introduction, which determines the homogeneity of the material. At the same time, the minimum strength loss , when using steel fiber from *A*-type slabs, taken into account in the calculation justification, is most likely due to the better adhesion of the cement matrix to the fiber metal surface, which has greater strength and adhesion area in the case of preliminary dry mixing.

*A* significant variation in the strength loss indicator in the series of samples up to 1.5*%* with a short stirring time *t* = 120 - 180 *sec* is due to the tendency of the fiber to form “hedges” due to the peculiarities associated with the properties of the fiber and the consistency of the mixture, which is explained by the uneven nature of the fiber distribution across the volume. Assessment of the influence of mixing time *t*, *sec*. on the water resistance indicator *W*, in the form of the resistance parameter of dispersed reinforced concrete to air penetration *m*c, *s/cm*3, which is a generalized macrostructural indicator, also, as in the case of assessing the strength properties and , determined the advantages of the preliminary dry mixing method when using *A* - type cut fiber. The distribution of the air penetration value of the dispersed-reinforced concrete indicator, *m*c, depending on the mixing time *t*, allows us to conclude about the normal distribution of fiber across the sample volume, ensuring homogeneity of properties and growth of the *W* indicator, in the case of preliminary dry mixing.

Analysis of the structure-forming factors associated with the technology of preparing dispersed reinforced concrete showed that the dependence of strength and homogeneity of the material is not exhausted by the technological parameters associated with the order of fiber introduction and mixing time. The nature of fiber distribution in the samples of the series subjected to destruction showed that it is related to the structural heterogeneity of the material, caused by the size and content of the coarse aggregate. This necessitated research on the dependence of the distribution of fibers of different types on the size of the coarse aggregate (Figure 2). As a parameter that generally characterizes the macrostructural properties of the samples, the resistance of dispersed concrete to air penetration *m*c, *s/cm*3, was adopted.

|  |  |
| --- | --- |
|  |  |
| – fiber is introduced with preliminary dry mixing of inert materials with cement;  – fiber is introduced in separate batches after mixing inert materials with cement; | – fiber is introduced in a separate batch before the large filler Δ*R* – loss of strength in percent;  t – travel time |

**FIGURE 2.** Dependence of the parameters on the series of samples characterizing the order of fiber introduction on the   
mixing time of the mixture

When analyzing the relationship between these values, it was established that the value of the parameter *m*c significantly decreases with an increase in the diameter of the coarse aggregate for fibers of types *A*, *B*, *C*, and *D*, having linear dimensions comparable to the size of the coarse aggregate. At the same time, samples with *D*-type fiber showed no dependence of the mc parameter distribution on the diameter of the coarse aggregate *D*. This circumstance is explained by the linear dimensions of *D* - type fiber samples comparable to the macrostructural parameters of the dispersed reinforced concrete cell, lying in the range of values from 0.5 to 3 *mm*. The results are of significant interest for further research regarding the use of *D* -type fiber, which significantly increases the effectiveness of material reinforcement and reduces the likelihood of macroscopic defects in the form of cracks (Figure 3).

At the same time, the area of rational use of fiber, adopted in the calculation justification, produced by the “Kurganstalmost” plant, is limited by the diameter of the coarse aggregate = 25 mm, according to the research results. Assessment of the nature of fiber distribution along the volume of the structure in the damaged samples shows its dependence on the following probabilistic parameters related to the arrangement of the fiber relative to the considered calculated plane: the intersection of the unit fiber with the calculated plane; the deviation of the force from the calculated plane; the probability of fiber anchoring in the cement stone matrix associated with the coarse aggregate; the uniformity of fiber distribution along the volume, determined by the number of fibers intersecting the calculated plane.

|  |  |
| --- | --- |
|  |  |
| - resistance of concrete to air penetration; *D* – diameter of coarse aggregate | - resistance of concrete to air penetration;  *t* – travel time |

**FIGURE 3.** Dependence of *W* series of samples of different types of fibers on the technological parameters of mixing and   
the size of the filler

The value of the deviation of the unit fiber from the calculated position was taken into account by the “flow adjustment method” of the fiber. For this purpose, methods for statistical evaluation of data series related to the studied parameters were used to obtain values of probability coefficients and their variation ranges for the adopted technology of ballast-free track construction. Consideration of the actual characteristics of the fibers of type *A* used in the justification was carried out taking into account laboratory test data.

Based on laboratory studies of the actual values of the technological parameters, the probabilistic range of changes in the values associated with the spatial location of the fiber was determined and the values of the probabilistic coefficients characterizing the reinforcement efficiency of a dispersed-reinforced spatial cell were clarified.

|  |  |
| --- | --- |
|  | () |

where – is the intersection of a single fiber of the design plane; – is the deviation of forces from the design plane; - is the possibility of anchoring the fiber; is the uniformity of fiber distribution over volume.

The values of the coefficients were selected in accordance with the condition of geometric similarity of the calculated cross sections and the maximum size of a large filler from the conditions:

|  |  |
| --- | --- |
| and | (2) |

where *B* and *h* are the cross–sectional dimensions of the element; is the length of the fiber.

|  |  |
| --- | --- |
|  | (3) |

where – is the maximum diameter of a large filler; is the length of the fiber.

The values of the calculated coefficients according to laboratory research data for practical use can be taken in accordance with Table 2.

**TABLE 2.** Values of the calculated coefficients

|  |  |  |  |
| --- | --- | --- | --- |
| **№** | **Meaning** | **Physical content of the probability coefficient** | **Range of values** |
| 1 |  | Intersection of the calculated plane by the fiber | 1,20 – 1,35 |
| 2 |  | Deviation from the calculated plane | 1,25 – 1,38 |
| 3 |  | Possibility of anchoring | 1,10 – 1,15 |
| 4 |  | Uniformity of distribution by volume | 1,40 – 1,54 |

# CONCLUSIONS

1. The development of technological parameters for introducing fiber into the concrete mixture for a ballastless track made it possible to solve a number of practical problems related to determining the order of introduction of fiber into the mixture, determining the boundary conditions for the fiber type adopted in the justification, the size of the coarse aggregate, and determining the values of the probability coefficients characterizing the arrangement of fiber in the macrostructural cell.

2. The obtained results can be used in the construction of a dispersed-reinforced ballastless track. The results allow for the determination and refinement of the technological modes of mixture preparation, depending on the adopted fiber types, which ensure a reduction in the probability of defects arising due to the construction technology. Further prospects for studying technological factors and related parameters of reinforcement efficiency include research related to the use of steel, finely-freshed fibers with a protective coating, which significantly increases the strength and improves the structural properties of dispersed reinforced concrete.

# FUTURE SCOPE

The present detection establishes a good basis upon which future research could be conducted on, to investigate on the use of alternative fiber material, like basalt, carbon or even the hybrid type of fibers in ballastless track technology. In the forthcoming research, the mechanical, thermal, and fatigue resistance properties of this type of composite materials can be tested under different climatic and working stress conditions.

One potential opportunity of growth is automation and optimization of fiber in the concrete matrix distribution. Deployment of AI-assisted sensors and real-time monitoring of the mixing and pouring process can assist in ensuring a more even distribution of fibers, reducing clumping and generally increasing the structural stability.

It is proposed that further work to corroborate the laboratory results is needed in the field on a long-term basis. A large-scale monitoring of the performance during the several years will assist in finding the degradation mechanism and the life-cycle behavior of the dispersed-reinforced concrete under the dynamic rail-loading.

The effects of fiber orientation and the volume fraction on the damping properties as well as ability to attenuate vibration of the track could be further examined. Such properties are critical when it comes to structural noise reduction and achieving a longer life out of both rolling stock and track components.

The potential of using this technology in the high-speed rail systems is considerable, with the greater rates of loading, and the tolerances driving to more challenging material performance. Such applications might benefit from design of the concrete mix and the design of the fibers used.

The environmental costs and economic costs of utilization of recycled or industrial waste based fibers (example, recycled steel wires or polymer-based fibers) should be researched in construction of ballastless tracks. This method might minimize the ecological impact of a construction project and present economically advantageous substitutes to conventional steel or artificial fibers.

The limit of numerical modeling and simulation studies might be broadened to compute the tendency of dispersed-reinforced concrete to react to different conditions of loading such as during extreme weather or earthquake. The Finite Element Modeling (FEM) may be used to help visualize stress and provide the optimal fiber positioning strategies.

In future, additional cross-disciplinary research with material scientists and structural engineers can take the system to the step of producing smart fibres with an embedded sensor that will enable real-time monitoring of structural health (SHM). Such fibers may deliver information about internal stress, 1st/2nd order temperature variations, or crack initiation (depending on the type of fiber).

The influence of curing methods and exposure to the natural environment (humidity, freeze-thaw cycles and salinity) on bonding between fibers and the matrix will also aid in improving the construction process and guaranteeing long-term stability in varying geographies.

Lastly, it is necessary to establish the standardization and the guidelines that can be used in applying fibre-reinforced concrete in railway infrastructure. Future developments must help in formulating national and international codes of practices to harmonise these in implementation and also guarantee safety, uniformity and dependability among projects.

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