Technologies for creating directional orientation of fiber reinforcement in concrete

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Abstract. Information on the analysis of methods for creating directional orientation of steel fiber rodding of reinforced concrete structures is presented. The design of a mobile experimental setup for the manufacture of fiber-concrete and fiber-reinforced concrete linear elements with a directional orientation of steel fibers by mechanical means has been developed. The test results of the pilot plant are presented. The required dimensions of the bunker for the fiber-reinforced concrete mixture, the type of the leveling element and the method of increasing the fiber-reinforced concrete mobility during casing using a pilot unit have been determined. The creation of a directed orientation of fiber threads in fiber-reinforced concrete makes it possible to make the most of this material’s advantages. Despite a sufficient number of theoretically possible ways to create a directional orientation of fibers in a concrete mixture, not all of them can be applied in real construction conditions. Also, a number of methods introduce additional difficulties into the concreting process, which can adversely affect the construction processes duration. The use of a mechanical method for creating a directional orientation of steel fiber reinforcement in concrete made it possible to obtain the desired result on a mixture already containing fiber threads, without the need for their separate laying. The optimal design of the mechanical element leveling and the features of the process of leveling steel fibers in concrete have been established.

Introduction

Obtaining a fiber-reinforced concrete mixture with the specified parameters is possible only with the correct selection of a combination of raw materials and their manufacturing technology.

At the moment, the steel fiber reinforced concrete compositions selection issues, depending on its purpose, have been well studied.

The main problem that restrains the massive use of steel fiber reinforced concrete in construction is a more complex technology for its production and laying in molds compared to ordinary concrete, which leads to an uneven distribution of fiber in the concrete body, the appearance of fibers’ fisheye, so-called “balls”, which, as a result, do not allow to get the specified design parameters.

As stated in previously published works of the authors [1], even the usual distribution of fibers in concrete leads to a significant increase in its compressive and tensile strength characteristics (more than 25 and 50%, respectively).

Even more (up to 40 and 100%, respectively) the compressive and tensile strengths of concrete grow with the aggregated distribution of fibers [2], which makes it possible to get rid of fisheye and achieve a more uniform distribution of fibers over the concrete volume.

The next jump in the strength properties of concrete, both in compression and tension, occurs with the directional orientation of the fibers, in which the fibers are directed along the tensile stresses acting
in the structure. At the same time, the creation of an oriented structure of the fibers’ arrangement in concrete in practice is a complex and difficult technical task.

At the moment, we can conditionally distinguish two main directions in the steel fiber reinforced concrete manufacturing technologies:

- separate packing technology;
- technology of joint mixing of concrete and fibers.

The technology of separate packing consists of preliminary layer-by-layer fiber reinforcement placing into the formwork with the formation of a fiber cage, followed by the introduction of a concrete mixture into it and vibration shaping. The same technology includes the method of spraying fibers into the mixture at high speed and the vibro-extrusion method.

This technology can significantly reduce the labor intensity of work, but practically excludes the use of coarse aggregate and requires special equipment - a technological line with a vibro-extruder, which provides an oriented arrangement of fibers in a cement-sand matrix.

The technology of joint mixing of a concrete mixture with fiber at the preparation stage is easier to use, does not require any additional equipment or a special technological line, allows to obtain structures of any shape, to use a large aggregate, but leads to a chaotic arrangement of fibers in concrete, as a result of which some of the fibers are simple not included in work.

Most of the earlier studies [3-6] were aimed at improving the fibers’ uniform distribution technology in a concrete matrix and, only recently, experimental work to create a method for the oriented arrangement of fibers after they are mixed with concrete in a concrete mixer and fed into the formwork has started.

Currently, the following methods for creating an oriented structure of the fibers’ arrangement in the concrete body using the joint mixing technology are known:

- constraint of fibers by formwork;
- roller pressing;
- mechanical orientation of fibers, achieved by passing the mixture through special meshes;
- intense vibration of the mixture, in which the fibers occupy a horizontal position in one plane;
- various kinds of electromagnetic influences at the stage of molding products.

The above-mentioned methods, tested in laboratory conditions, turn out to be rather complicated, difficult to implement in practice and, as a rule, only partially provide directional orientation of fibers in full-scale structures.

At the same time, the methods of constraining fibers by formwork, roller molding of products, intense vibration of the mixture, passing fibers through the meshes do not initially focus on the fibers’ orientation along the stresses acting in the finished product and do not allow achieving the maximum effect from the use of reinforcing steel fibers [7].

The most promising in this direction is the method of electromagnetic alignment of fibers at the stage of forming products, which is aimed at a clear unidirectional orientation of fibers in a concrete matrix. At the same time, this technology is still at the scientific development stage and is not applied in practice, it provides for the use of a concrete mixture of increased mobility without the use of a large aggregate and requires specific equipment to create magnetic fields. The application of this method involves the use of formwork made of non-magnetic materials, the need to create constant or variable electromagnetic fields of certain parameters, taking into account their interaction with linear steel reinforcement and the possible effect of “interference” from steel working reinforcement on the fibers’ orientation [8-11].

The method of the fibers’ directional orientation aggregated creation in concrete with separate placement of components in the formwork, at the moment, is also at the stage of theoretical development and has not been introduced into construction production practice, since there are still no mobile installations that allow using this method on a construction site.

Moreover, the use of the above-mentioned technologies does not allow obtaining directional orientation of fibers in two or more directions for use, for example, in slab elements.
Materials and methods
An additional factor preventing the implementation of previously developed methods of fibers orientation in a concrete body in a given direction into construction practice is that the proposed methods initially exclude the use of large aggregate in the form of crushed stone.

In connection with the above-mentioned, in order to obtain steel-fiber concretes with an oriented arrangement of fibers with increased characteristics, it is necessary to create a technology that allows solving the following problems:
- to ensure uniform distribution of fibers in the concrete body, completely eliminating the appearance of fisheye from it in the “balls” form;
- to ensure the use of this technology not only in fine-grained heavy concrete, but also in concretes containing a large aggregate in the form of crushed stone;
- to include a larger number of fibers in the work, due to their orientation along the tensile stresses acting in the structure;
- to ensure the simplicity and manufacturability of the applied method of orientation of fibers, which makes it possible to use it not only in laboratory conditions, but also in construction practice;
- to ensure the mobility of the used installation, allowing it to be used directly on the construction site.

Taking into account the tasks set in this work, a significantly simpler, mechanical, technology for producing fiber-concrete and fiber-reinforced concrete elements with a directional orientation of fibers is proposed, which is much easier to implement both in the factory and on the construction site.

The proposed technology is based on the following basic principles:
- assembly and mobility of the installation, allowing it to be used for concreting linear elements of any length, width and height;
- preliminary orientation of the fibers when feeding the fiber-concrete mixture into the formwork from the conical hopper, which is carried out due to the combination of vibration action and the use of the fibers restraining method with a cone at the place where the mixture exits the formwork;
- concreting placing, allowing to obtain uniform distribution of a given thickness fibers in each layer;
- the use of a manifold-shaped working body, operating in a vibration-translational mode and allowing to create a given orientation of fibers in each layer and in the element as a whole.

These principles are the distinctive features of the proposed technology, to which its basing not on an electromagnetic, but on a mechanical basis is added.

A schematic structural diagram of the proposed installation for creating fiber-concrete and fiber-reinforced concrete elements with directional orientation of fibers according to the proposed mechanical technology is shown in Figure 1.

![Diagram of a mobile installation for concreting linear elements with directional fiber orientation.](image)

**Figure 1.** Diagram of a mobile installation for concreting linear elements with directional fiber orientation.

1 – steel frame installation; 2 – spring chassis; 3 – a concrete element formwork; 4 – reinforcement cage of a concrete element; 5 – fiber-concrete mix feed bunker; 6 – vibrating element; 7 – manifold with teeth rows; 8 – first layer of fiber-reinforced concrete mix.
Steel frame 1 on a spring chassis 2 continuously and evenly moves at a given speed along form 3 with a reinforcing cage 4 installed in it (or without it), into which a movable steel-fiber-concrete mixture is fed from a bunker 5 to a given thickness of the first (lower) layer 8.

An electric motor with an eccentric 6 is installed on the frame, which sets the vibrational vertical reciprocating movements to the working body of the installation in the form of a manifold with teeth 7, which can move in height in the range of 25-50 mm - depending on the aggregate size and the concrete layer thickness.

The preliminary orientation of the fibers is achieved when the fiber-concrete mixture is fed from the conical bunker. At the same time, the bunker walls converge on a cone with a rectangular finish, oriented along the formwork and, at the place where the mixture exits, narrow to a size that allows the large aggregate to pass freely, but forces the fibers to unfold when vibrated in the longitudinal direction of the installation movement.

The final orientation of the fibers takes place directly in the formwork at the contact of the fiber-reinforced concrete mixture with longitudinally arranged elements (knives). At the same time, the distance between the leveling elements of the manifold is greater than the size of the coarse aggregate, but much less than the fibers length. This allows the coarse aggregate to pass freely between the manifold knives, but forces the fibers, upon contact with them, to align along the movement of the machine.

After the first heading, vibration compaction and creation of a directed orientation of the mixture first layer fibers, the mold is filled with the second layer of the fiber-concrete mixture and the cycle is repeated again. This happens until the form is completely filled, the proposed mobile installation is completed and the element is concreted.

The proposed mechanical technology for creating directional orientation of fibers can be successfully applied to linear fiber-reinforced concrete and fiber-reinforced concrete elements. However, the application area of the proposed technology is far from being exhausted by the linear elements.

If we provide a mutually perpendicular direction in the orientation of the fibers in different layers of the structure, this will allow the proposed technology to be used for the manufacture of not only linear, but also plate elements with different support conditions and working in two directions.

To create the first layer of a slab element with a longitudinal arrangement of fibers, the first installation is made. The formwork of the slab is filled from the installation bunker to a given layer thickness with preliminary orientation of the fibers in a given direction. The layer thickness is regulated by the movement speed of the bunker and the mobility of the fiber-reinforced concrete mixture. After that, the final orientation of the fiber to the width of the manifold is carried out with simultaneous vibration and the formation of the first layer.

To create a second layer with a transverse arrangement of fibers, the installation is turned at an angle of 90° and the form is filled with a second layer of concrete mixture, in which the fibers are located strictly perpendicular to the first layer.

This happens until the form is filled in layers and in different directions to the entire height of its section with a vibrated fiber-reinforced concrete mixture.

The use of this technology makes it possible to set any layer-by-layer orientation of the fibers in the structure for the tensile stresses perception and get the maximum effect from the fiber-reinforced concrete use.

The difference in the mobile installation design for concreting slab elements with a directed orientation of fibers from the installation for linear elements lies only in the design of the feed bunker and a wider manifold.

**Discussions and results**

To work out the optimal parameters of the proposed technology for creating a directed orientation of fibers, a prototype of a mobile installation for concreting linear elements, shown in Fig. 2, has been performed, the composition of fiber-reinforced concrete has been selected, which was subsequently used for the manufacture of prototypes.
During the experimental studies, heavy concrete of design class B30 and anchor fiber made of high-carbon steel wire from spring steel 70-85 with a tensile strength of 2200 MPa, with a brass coating, nominal diameter 1.0 mm, length 50 mm were used (FSR-A-0,7/50), produced by JSC “Tanis” TC RB 400518274.004-2009.

The used fiber has curved anchors at the ends, preventing it from being pulled in the concrete composition, and the ratio of length to diameter is 50 (l/d = 50). The brass coating of the fiber increases its resistance to corrosion and, at the same time, improves adhesion to the cement stone at a microscopic level.

For the manufacture of prototypes, the following was used: Portland cement of the OJSC “Novoroscement” brand PC 500-D20 according to GOST10178-85; crushed stone from the Beslan quarry, fraction 10 mm, strength 140 MPa, with a content of silt and clay particles - 0,3…0,8%; quartz river sand with a size modulus was used as a fine aggregate (Mк) within 1.6 ... 1.8, bulk density 1510 kg/m³.

In order to increase the concrete mixture mobility and improve the concrete adhesion with fiber reinforcement elements, the plasticizing additive “Optimist superplasticizer С 409” was used.

The composition of heavy concrete of B30 class was selected by the calculation and experimental method, concrete and fiber-reinforced concrete mixtures were made with the same amount of all main components.

**Table 1.** Composition of B30 class heavy concrete with natural hardening without fiber reinforcement

| Concrete class | Material consumption for 1m³ concrete, kg |
|----------------|------------------------------------------|
|                | C  | S  | CS | W  | Plasticizer |
| B30            | 459| 456|1267|177|     8.5     |

**Table 2.** Composition of B30 class heavy concrete with natural hardening with fiber reinforcement

| Concrete class | Material consumption for 1m³ concrete, kg |
|----------------|------------------------------------------|
|                | C  | S  | CS | W  | Plasticizer | Fiber |
| B30            | 459| 456|1267|177|     8.5     | 152.7 |

**Figure 2.** General view of a prototype of an experimental mobile installation for concreting linear elements with directional orientation of fibers.

Based on the previous studies, when designing a mobile unit, a choice was made in favor of a platform vibrator, with a vibration frequency of the working body 90 Hz, and the design of the feeding bunker is based on the fibers restraint principle in combination with intense vibration.

When designing a bunker for feeding a fiber-concrete mixture into the form, we used a conical cross-sectional shape, which, under vibration action, allows the mixture to move without “hanging” on the walls and, at the point of its exit into the formwork, using the constraint method, force the fiber to turn
in the direction we need. At the same time, the rotation of the fibers, located initially across the walls of the bunker, occurs under the gravity action in combination with vibration action, and the specified layer thickness is controlled by the installation speed.

The greatest effect on the preliminary orientation of the fibers is achieved with the maximum possible narrowing of the walls of the bunker finish feeding opening. At the same time, its width depends on the length of the fiber used and should not lead to sticking of the fiber-reinforced concrete mixture at the exit to the formwork.

Taking into account the use of steel fiber with a diameter of 1 mm, a length of 50 mm and a combination of compositions of different plasticity with a maximum size of a coarse aggregate of 10 mm in our study, we tested various options for the bunker design with a change in the walls inclination angle and the feeding opening width as well as several types of manifolds that differ from each other by the arrangement of the alignment elements.

During experimental concreting, the optimal movement speed of the installation along the mold was selected, regardless of the type of manifold, which was about 2 m / min, which ensured the orientation of the fibers, the orientation of the layer and its high-quality vibration. In this case, the thickness of the formed layer at a given movement speed was 30 .... 35mm.

A general view of a fiber-concrete mixture with a chaotic arrangement of fibers is shown in Figure 3 (a), and the view of the mixture with the oriented fiber arrangement is shown in Figure 3 (b).

![Figure 3](image)

**Figure 3.** General view of the chaotic (a) and directional (b) arrangement of fibers in concrete when using the proposed mechanical technology.

### Summary

Analyzing the above-said, we can draw the following conclusions:

1. The mechanical method of steel fibers orientation in concrete is the most promising for use in real construction conditions, since it provides the required result with minimal complication of the steel fiber reinforced concrete placing process;

2. The optimal inclination of the feeding bunker walls from the vertical axis for the steel fiber concrete mixture is in the range from 35° till 45°, and the optimal finish width is in the area 20÷25mm (0,4÷0,5l/f), which allows the coarse aggregate to pass freely under vibration and, at the same time, ensures the fiber rotation in the installation movement direction;

3. The final orientation manifold must have a distance between the knives greater than 0,3÷0,5 the length of the fibers, while the manifold knives should be of the sufficient width, close to the length of the fibers used, allowing them to act on the fiber for a time sufficient to flatten it;

4. The optimal speed of the experimental setup for mechanical orientation of steel fibers in concrete mixture was 2 m / min, which provided the necessary orientation of fibers and high-quality concrete vibration.

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