Testing steelfibroconcrete centrifuged specimens of pipes used in drainage and water disposal systems at places of automobile and railway transport heavy traffic

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Abstract: Ferroconcrete pipes, used in drainage and water disposal systems of roads, works in conditions, in which the direction of the main tensile stresses is either unknown, or can change during exploitation. One of the ways of solving this problem is using of steel fibrous concrete, i.e. concrete on hydraulic tenacious substances with addition of reinforcing elements in the form of short lengths (fibers). Using of steel fibrous concrete allows to get the construction of low pressure centrifuged pipe for drainage and water disposal systems at places of automobile and railway transport heavy traffic with higher tensile and bending strength, crack resistance for the work under conditions when the direction of the main tensile stresses is unknown.

1. Introduction
Low tensile strength and as a result of it bad crack resistance are known to be characteristic features of reinforced concrete constructions.

Traditional strengthening concrete by the directional reinforcing is effective only in those cases when the direction of the main tensile stresses in constructions is known.

However, there are a number of structural elements working at perception of shock, dynamic and temperature actions, in which the direction of the main tensile stresses is either unknown, or can change during exploitation. Examples of such constructions are ferroconcrete pipes, used in drainage and water disposal systems at places of automobile and railway transport heavy traffic.

Not exact knowledge of stressed and deformed state of these constructions during their operation results in overconsumption of concrete and reinforcement, what finally makes manufacture of these constructions more difficult and costly [3].

2. Theoretical stresses in fibroconcrete
One of the ways of solving this problem is using of steel fibrous concrete, i.e. concrete on hydraulic tenacious substances with addition of reinforcing elements in the form of short lengths (fibers) [1].
Fiber adhesion with concrete occurs due to friction, adhesion and mechanical interlocking of the contact surfaces. The effect of each of these processes on the strength of fiber anchoring can be different depending on the type of fiber.

For example, for smooth fibers, adhesion and friction will play a large role, and the mechanical interlocking of fiber protrusions with the protrusions of concrete for shaped fibers. Fiber profiling enables increased load they can take depending on the profile parameters.

The length of the fiber affects the average tensile stress \( \sigma' \) which is produced in it, which determines the overall strength of the composite material.

At fracture of the composite material the fibers which happen to be in the area of the fracture, are oriented in different directions towards the fracture surface of the composite material. With some fibers, the fracture surface runs in the middle of the length, with most others it does between the middle and one of the ends. In the latter case, the tension in the fiber at the moment of fracture will depend on the distance between the surface of the composite material fracture and the end of the fiber closest to it. The equation of the composite materials mix with the tailored solid reinforcement is shown below:

\[
\sigma_k = \sigma_u (1 - V_a) + \sigma_a V_a
\]

where \( \sigma_k, \sigma_u, \sigma_a \) – stresses in the composite material, reinforcement and the matrix correspondingly; \( V_a \) – the amount of reinforcement materials in the composite material.

In [2], it is proposed to reduce the fiber reinforcement to an equivalent unidirectional reinforcement by using a complex coefficient \( \lambda_{red} \), equal to the multiplication of three coefficients that take into account: the chaotic nature of fiber orientation \( \lambda_p \), the deviation of the force from the direction of the fibers \( \lambda_{or} \), the anchoring of the fibers \( \lambda_{an} \). Thus, the mix equation looks like below:

\[
\sigma_k = \sigma_u (1 - V_a) + \lambda_{red} \sigma_a V_a
\]

After the fracture initiation, the strength of the composite material relies only on the strength of the fibers and the bonding strength of the fibers with the matrix and cannot exceed \( \sigma_a V_a \). The ultimate strength of the composite material in this case will be equal to:

\[
\sigma_k = \lambda_{red} \sigma_a V_a
\]

The theory of composites treats the composite material as a combination material (matrix and fiber), with individual components working elastically, and the non-slip interaction of these components with each other.

3. Problems of the theoretical approach

Based on these assumptions, the above analytical dependencies are derived. However, despite the apparent self-consistency of the equations which describe the properties of composite materials, the theory of composites, generally, works both ways.

First, although the computational theory of a composite material takes into account various coefficients which affect the accuracy of the calculation results, it nevertheless does not consider such a critical parameter as the steel fiber concrete mixing, placement and curing process. The experience of using steel fiber concrete shows that its properties can vary in a wide range and depend on the technology adopted by the manufacturer.

Second, the above theory does not take into account the geometric properties of the fiber, which determine the number of fibers per unit volume of concrete and the quantity of the fiber side face which is engaged with the matrix.

Third, it does not consider the cracking moment.
Therefore, the principle of the fiber performance at the stage of destruction is mis-addressed. In fact, if the fiber cuts across the crack, then the tangential stresses along the fiber are distributed differently from those in the intact concrete (Fig. 1).

In this case, the stress in the fiber $\sigma_{II}^f$ directly within the crack is about 10 times that in the intact fiber ($\sigma_{II}^i$) [4]. Thus, the theory of composites is quite good at describing the behavior of the material at the elastic stage of work. However, due to the incorrect description of the mechanism of destruction, it is impossible to accurately predict neither strength nor deformation during fracture.

Along with the above concept of calculating a composite material, there is the so-called “gap concept”, which states that the strength and crack resistance of dispersed-reinforced concrete depend on the calculated distance between the centers of the fibers in the fibrous reinforcement.

This concept is based on the hypothesis that the geometric properties of the reinforcing elements (their diameter and the degree of dispersal) should be commensurable with "congenital lesions".

The "congenital lesions" here are both voids in the matrix and cracks initiated in the concrete body as it hardens, triggered by internal stresses, mainly in the “cement-aggregate” interface area.

This problem has been the subject of research by numerous authors. The authors have developed the techniques and proposed various analytical dependencies for calculating the distance between the fibers. We believe the calculation formula below [3] is suitable for practical purposes:

$$S = 12.5d_f \sqrt{\frac{d_f}{\mu}},$$

where $S$ is the calculated distance between the fibers, mm; $d_f, l_f$ respectively the diameter and the length of the fiber, mm; $\mu$ reinforcement percent by volume, %.

Assuming that the fracture of the steel fiber reinforced concrete is induced by shearing of concrete between the fibers, the member’s axial tension formula with due account for the fiber orientation is given in [3]:

$$R_{bt}^f = 0.375R_{bt}l_f \sqrt{\mu \frac{k_0}{d_f}},$$

![Figure 1. Distribution of normal and tangential stresses along the fiber length in the cracked and intact members.](image)
where $k_0$ is the coefficient of the fiber orientation.

The calculation, based on the gap concept, describes the physical processes of crack propagation and inhibition during the fracture of concrete. However, this technique does not take into account the work of the fibers after the formation of cracks. As shown by numerous tests [1, 4], the steel-fiber-concrete member won’t run out of the carrying capacity after it has suffered from cracking. Steel fiber reinforced concrete member can sustain a significant extra load after the concrete has become ruptured all the way through. Therefore, the gap concept should be considered as a crack resistance criterion rather than that of the strength of steel fiber reinforced concrete.

4. Experiment results

Investigations revealed that the most characteristic features of steel fibrous concrete are strength, toughness and work of destruction at axis extension and bending. As for the last feature is concerned steel fibrous concrete may be 10-15 times better than usual concrete [2]. Besides, steel fibrous concrete pipes, used in drainage and water disposal systems at places of automobile and railway transport heavy traffic differ from the traditional ones in the following things: they have higher shock strength, crack and frost resistance, water tightness, cavity resistance, fatigue and high-temperature strength and failure toughness [2].

Comparing strength characteristics of steel fibrous concrete and reinforced concrete was held at testing pipe rings, made by centrifuging (Figure 1). Two series of ring pipes, containing three specimens in each series were made in typical shuttering at the joint-stock company “Reinforced Concrete” Ltd. in Nizhny Tagil. The rings were 1000 mm in outer diameter, 800 mm in inner diameter and 1000 mm high. The rings of the first series (specimens R-1, R-2, R-3) were strengthened by spiral frames made of wire, 5 mm in diameter class Vr-1 and made of heavy concrete M300. The rings of the second series (specimens Rf-1, Rf-2, Rf-3) were made of steel fibrous concrete, and there were no reinforcing frames.

Specimens Rf-1 and Rf-2 contained 2 % dispersion reinforcement, and the specimen Rf-3 – 1.5%. In these specimens the volume of reinforcement was adopted a priori, with the aim of revealing the peculiarities of mixtures at concrete placement.

Motion-time study of the process of making rings of dispersion reinforced concrete showed that it differs by more adaptability to manufacture in comparison with the technology of making traditional rings. So, forming a dispersion reinforced ring took 6-8 minutes less than making a traditional ring. It is explained by additional waste of time for installing a reinforcing frame and by the fact that an installed frame prevents from filling the mould with concrete. Visual examination of rings after steaming showed high quality of the surface of steel fibrous concrete specimens in contrast to typical ones having contraction cracks, cavities, and concrete flow. For estimating strength characteristics of products rings and control specimens (cubes with an edge 100 mm high) were formed of concrete of the same composition. They were subjected to heat-and-moisture treatment. Rings of both series had undergone testing by static short-term load. The results of the testing are given in the table 1.
Table 1. The results of the testing reinforced pipe rings.

| № of the | Percentage of dispersion reinforcement, t, % | Strength of concrete rings after steaming, MPa | Strength of concrete at the moment of testing, MPa | Cracking load, kN | Failure load, kN |
|----------|-------------------------------------------|-----------------------------------------------|-----------------------------------------------|------------------|-----------------|
| R-1      | 0                                         | 28.0                                          | 36.4                                          | 75.0             | 80              |
| R-2      | 0                                         | 28.0                                          | 36.4                                          | 56.0             | 62              |
| R-3      | 2                                         | 27.4                                          | 37.8                                          | 115.0            | 135             |
| <=1      | 2                                         | 28.3                                          | 37.8                                          | 135.0            | 150             |
| <=2      | 1.5                                       | 27.4                                          | 37.0                                          | 95.0             | 105             |

During the process of testing deformations and loads at which the first cracks appeared and ring destruction took place, were fixed. The analysis of testing rings shows that deformation of rings made of dispersion reinforced concrete on the average is 30% lower and cracking load is 70-80% higher than that of usual rings. It is due to higher steel fibrous concrete resistance to tension. The way of cracking is the same for all rings. However, if the destruction of usual rings takes place just after cracking, steel fibrous concrete rings withstand load which is 15-20 kN higher than cracking load. To our mind, it is due to higher adhesion between dispersion reinforcement with concrete matrix, which breaks down gradually.

The experience of the factory making pipe rings showed that the operations of reinforcing and concreting were joined together at steel fibrous concrete placement. It results in increasing labour productivity and quality of products.

Besides, revealed strength reserves of dispersion reinforced rings and preliminary calculations open possibilities of reducing their thickness. It will allow to reduce 25-30% concrete consumption taking into account the percentage of concentrating the mixture by dispersion reinforcement.

Conclusions
Thus, using of steel fibrous concrete allows to get the construction of low pressure centrifuged pipe for drainage and water disposal systems at places of automobile and railway transport heavy traffic with higher tensile and bending strength, crack resistance for the work under conditions when the direction of the main tensile stresses is unknown.

It is also necessary to consider the type of fiber reinforcement and the work of the fibers after the formation of cracks. Numerous tests shows that steel fiber reinforced concrete member can sustain a significant extra load after the concrete has become ruptured all the way through.

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