Electrical resistivity of steel fiber reinforced concrete

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Abstract. Electrical resistivity is one of the key electro-physical characteristics describing the steel fiber reinforced concrete's ability to conduct electric current. The experiments were carried out to test the hypothesis for the occurrence of a short-circuit effect in steel-fiber concrete structures for the method of electrode heating. Further studies were made to determine the electrical resistivity for various compositions of steel fiber reinforced concrete. The mathematical regularity was found to determine the change of specific electrical resistance subject to the water-cement ratio, the percentage of fiber, the modulus of the fiber surface, and the size of the aggregates. Graphic nomograms (a group of line charts) were made to determine the value of the electrical resistivity for steel fiber reinforced concrete and choose the parameters of electrical heating and the appropriate operating mode of technological equipment.

1. Introduction

Steel-fiber reinforced concrete is one of the key materials in residential and industrial construction as it has a wide range of applications. It is obtained by introducing into traditional concrete a mixture of steel fibers evenly distributed throughout the volume of structures. The world and Russian experience of steel-fiber-reinforced concrete use showed its efficiency in many fields of construction [1-4]. However, in relation to the climatic conditions of Russia there is a problem of ensuring favorable conditions for its hardening at low temperatures, which can significantly expand the scope of its employment [5].

In regards to the above, we consider the possibilities of using traditional technologies of winter concreting [6] for steel-fiber-reinforced concrete. One of the most common and efficient methods for curing of reinforced concrete structures in winter period is the method of electrode heating [7,8]. To determine the technological parameters of electro-thermal processing of steel-fiber reinforced concrete we conducted a series of experiments.

The purpose of the initial experiments was to determine the nature of the change in the electrical resistivity of steel-fiber reinforced concrete mixtures, the effect of various technological factors and the composition of steel-fiber reinforced concrete on the value of the specific electrical resistivity.

2. Materials

Within the studies, we used portland cement 400 made at Korkinsky cement plant, 5-10 and 5-20 mm crushed stone (density - 2.53 g/cm^3, bulk density - 1.40 g/cm^3, compressive strength - 89 MPa) from Novo-Smolinsky quarry, sand from Fedorovsky quarry (density - 2.69 g/cm^3, bulk density - 1.54

g/cm^3, sand contamination with dust and clay particles - 3%, sand size modulus - 2.5) and tap water from Chelyabinsk water supply system.

Steel fibers were manufactured according to the TU-67-987-88 out of thin steel sheets in accordance with the technology developed at Chelyabinsk Polytechnic Institute, Chelyabinsk in 1982 (Figure 1). Their ends are bent relative to each other at an arbitrary angle, and the longitudinal axis is curved along the sloping helical line [9]. The fiber characteristics are given in table 1.

Figure 1. Steel fibre.

Table 1. Fiber characteristics.

Fiber characteristics	Value
Cross-sectional area	0.52 mm^2
Mass	160 mg
Lenght	40 mm
Breaking strenght	26.3 kg
Ultimate tensile strength	5.1 MPa
Length to diameter ratio	100

3. Test method

In the course of the experiments, we used several concrete mixes of the following composition: cement - 450 kg; sand – 890 kg; crushed stone – 800 kg. This compound was prepared based on a large number of previously conducted studies [10,11]. The water to cement ratio (*W/C*), the percentage of fiber (μ), the modulus of the fiber surface, that is the ratio of the lateral surface of the fiber to its volume (*S/V*), and the size of the aggregate (the fraction of crushed stone) were varied for the specimens. The compositions of steel-fiber reinforced concrete mixes used in the experiments are presented in table 2.

Table 2. Composition of steel-fiber reinforced concrete mixes.

mix number	W/C	μ,%	S/V	Crushed stone size
1	0,5	1,0	8,0	**5-10**
2	0,5	1,0	8,0	**5-20**
3	0,5	**0**	–	5-20
4	0,5	**0,5**	8,0	5-20
5	0,5	**1,5**	8,0	5-20
6	0,5	**2,0**	8,0	5-20
7	0,5	1,0	**5,7**	5-20
8	0,5	1,0	**10,0**	5-20
9	**0,55**	1,0	8,0	5-20
10	**0,6**	1,0	8,0	5-20

In order to determine the electrical resistance, the prepared steel fiber reinforced concrete mixture was laid in metal-textolite molds (300x100x100mm) and subsequently compacted on the vibrating platform. The temperature of the steel fiber reinforced concrete mixture in the center of the specimen between the electrodes was controlled by chromel-copel thermocouples and by the electronic automatic potentiometer, which provided for the measurement accuracy of ± 1,5^{o}C. The schematic diagram of the installation is shown in Figure 2.

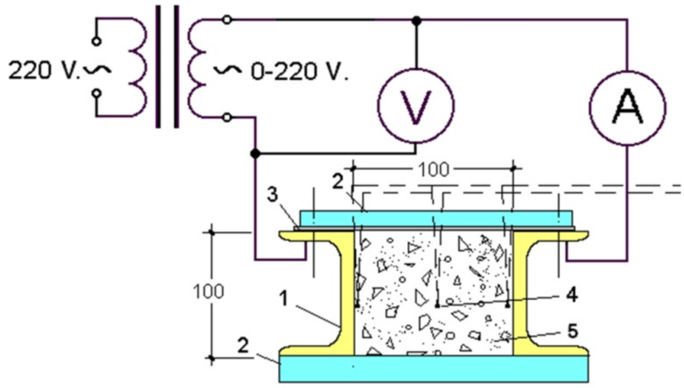

Figure 2. Installation to determine specific electrical resistance.
1 - steel channel bars of the mold; 2 - textolite lid and bottom; 3 - rubber lining; 4 - thermocouple; 5 – steel-fiber reinforced concrete.

In the series of experiments, the concrete specimens were cured at the temperatures of 20, 40, 60, 80^{o}C respectively. The volt-ampere measurements were recorded and used to determine the values of the electrical resistivity (Figure 3). The tests were carried out during 24 hours with the confidence interval of 10% and the experiment reliability factor of 0.95.

Figure 3. Measuring of electrical characteristics.

4. Results

4.1. Short-circuit
Primarily, we tested the hypothesis for the possibility of a "short circuit" during the electrode heating of steel-fiber reinforced concrete, a state at which the electric current could pass directly from the electrode to the electrode along a chain of steel fibers being in contact with one another. We deliberately studied the specimens with relatively high reinforcement percentages (2.0 ... 3.0% of fiber) due to the fact that in practice the production of steel-fiber reinforced concrete mixture with the percentage of fiber more than 2% is extremely rare.

The experiment did not detect any evidence of a "short circuit" effect in the process of electric heating of the concrete specimens with the reinforcement in the range of 0.25 ... 3.0%. It can be explained by the fact that each steel fiber is surrounded by a cement-sand mortar and does not directly contact other fibers [12]. It also should be noted that the thickness of the film covering each individual steel fiber is negligible, which certainly affects the value of the electrical resistance.

4.2. Electrical resistivity

As a rule, the calculation of the required voltage at the electrodes during the rise of the temperature in concrete during the process of electric heating is carried out according to the design value of the specific resistivity [13], determined by the equation (1).

$$\rho_{dsn} = (\rho_{int} + \rho_{min}) / 2 \tag{1}$$

where ρ_{dsn} – the design specific electrical resistivity; ρ_{int} – the initial specific electrical resistivity; ρ_{min} – the minimum specific electrical resistivity.

The values of the initial electric resistivity (ρ_{int}) and the minimum electrical resistivity (ρ_{min}), determined experimentally for each test composition, are shown in Table 3.

Table 3. Electrical resistivity of steel-fiber reinforced concrete.

Composition number	Initial electrical resistivity, ρ_{int}, Ohm·m	Minimum electrical resistivity, ρ_{min}, Ohm·m	Design electrical resistivity, ρ_{dsn}, Ohm·m
1	4.51	2.57	3.54
2	4.85	2.26	3.56
3	11.10	6.13	8.62
4	6.00	3.02	4.51
5	4.15	1.59	2.87
6	3.50	1.70	2.60
7	3.67	1.81	2.74
8	5.03	2.71	3.87
9	3.90	1.53	2.72
10	3.55	1.73	2.64

The table shows that the value of the specific resistivity (ρ) is within the range of 2 ... 4 Ohm m, which is 2 ... 2.5 times lower than the electrical resistivity of traditional concrete, used for in-situ structures (composition 3). A small value of the electrical resistance can significantly reduce the cost of reinforced concrete heating and provide substantial energy savings.

5. Conclusion

Mathematical processing of the results has allowed us to obtain the analytical expression to determine the value of the design specific electrical resistivity of steel fiber-reinforced concrete depending on the following technological parameters (equation (2)).

$$\begin{aligned}\rho = &\left(-0{,}0132 S/V^2 + 0{,}2804 S/V - 0{,}4011\right) ((181{,}71\mu - 1087{,}7) W/C^3 + \\ &+(-399{,}4\mu + 2031{,}8) W/C^2 + (282{,}51\mu - 1263{,}8) W/C + (-66{,}02\mu + 265{,}58)\end{aligned} \tag{2}$$

where ρ – the specific electrical resistivity of steel fiber-reinforced concrete; S/V – the modulus of the fiber surface; μ – the percentage of fiber in concrete; W/C – the water to cement ratio.

On the basis of the data, we have received a nomogram – a group of line charts (Figure 4), which shows the electrical resistivity of steel fiber reinforced concrete in the course of electric heating.

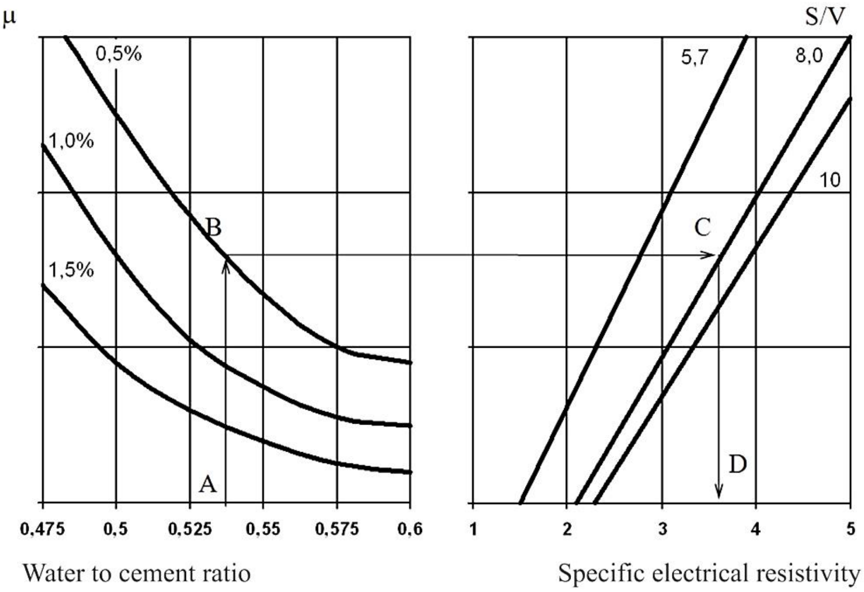

Figure 4. Nomogram to identify specific electrical resistivity.

These findings suggest that nomograms can be used to take changes in the design specific value of steel-fiber reinforced concrete into consideration and make necessary changes when calculating the parameters of electrical heating and choosing the appropriate operating mode of technological equipment.

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