

# Influence of steam curing on properties of fiber-reinforced concrete during hardening

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**Abstract.** To increase the efficiency of steel-fiber concrete production, the existing technological operations that could reduce the costs should be optimized. This process requires scientific research and analysis of the existing results to improve the efficiency of each production stage. One of the important stages in the steel-fiber concrete production is steam curing, which is responsible for forming the cementitious matrix structure. To increase the efficiency of this production stage, a study was conducted to develop the steam curing conditions according to the rules of steel-fiber concrete structure formation and the methods of improving durability indicators. Tests on several steel-fiber concrete compositions were conducted, and the relations between its thermal conductivity and the reinforcement coefficient of concrete were revealed. The results of the tests let us conclude that with the increase of the reinforcement coefficient its thermal capacity decreases. The temperature gradient charts along the cross-section of samples with different cement/sand ratios and reinforcement coefficients were built. According to the data obtained, the optimal industrial conditions of steam curing were discovered. The dependences determining the increase of mechanical performance of steel-fiber concrete due to the formation of prestressed fiber structure in the material were revealed.

## 1 Introduction

An extensive study devoted to steel fiber concrete indicated that continuously reinforced concrete possesses high mechanical and performance characteristics [1-5]. So the question of increasing the efficiency of the steel fiber concrete technology is very actual. Due to the development of the technical standards for the design and manufacturing of steel fiber concrete products and structures, favorable conditions are created for more intensive introduction of this material in the construction industry [6, 7], but at the same time, higher costs of production, as compared to conventional reinforced concrete, a deterrent.

Continuing research suggests that there is more than enough capacity to increase the efficiency and reduce the cost of production of steel fiber reinforced concrete and it is

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necessary to use all available technological methods to achieve this goal. Such an approach will ensure high economic competitiveness of steel-fiber reinforced concrete and its wider application. One of the most affordable and easiest ways to reduce costs in the manufacture of steel-fiber reinforced concrete products is to optimize the process of heat and moisture treatment.

Today a sufficient amount of research on the design and manufacture of prefabricated steel and fiber concrete products by domestic and foreign experts have been carried out [8-11]. However, the question of optimizing the technology for the steel-fiber concrete production, taking into account its various thermal properties, was not taken into account in the proper way. By optimizing the stage of steam curing with the correct selection of the operation mode of the steam curing chamber, it is possible to obtain products with high mechanical characteristics in a shorter processing time. It is known that with a prolonged steam curing of more than 14 hours of concrete with a low water/cement ratio (0.3), the compressive strength of the final product is decreased [12]. Therefore, in order to improve the quality of the final product, the reduction of steam curing span is required.

The increase of the thermal conductivity coefficient of steel-fiber concrete allows to accelerate the time of rise and fall of temperature of heat and moisture treatment, thereby increasing the turnover of the forms and the productivity of the enterprise as a whole. The main factor in determining the optimum rate of temperature rise for concrete is the temperature gradient arising in the sample during its processing.

The studies carried out to determine the numerical values of the temperature gauges in steel-fiber concrete during its heat and moisture treatment showed that the maximum permissible temperature gradient is equal to 0.6°C / cm; it is precisely at these and lower values that the strength of the composite at the age of 28 days does not decrease due to the microdefects of the structure at the initial stage [13]. The time of preliminary exposure of steel-fiber concrete before heat treatment is determined taking into account the peculiarities of structure formation at this stage [14].

## 2 Materials and methods

Portland cement M500 (without inclusions of active mineral additives, with normalized clinker composition) was used for the tests, what meets the requirements of GOST 10178.

During the tests, natural quarry sand was used as a fine aggregate for concrete. Its properties are given in Tables 1.

**Table 1.** Granulometric composition of sand.

Type of sieve residue	Sieve residue, %					Passed through the sieve size N016, %
	2.5	1.25	0.63	0.315	0.16	
Local	10.1	18.3	33.6	29.3	7.3	1.4
Full	10.1	28.3	61.9	91.3	98.6	-

Steel wave brass-coated fiber was used in the tests. It was produced according to Specifications (S) 1221-001-71968828-2005, the main characteristics of which are given in Table 2.

**Table 2.** Characteristics of fiber.

Type, standard	Geometric dimensions, mm			Tensile strength, MPa
	<i>d</i>	<i>l</i>	<i>l/d</i>	
Steel wave fiber with brass coating, Specifications 1221-001-71968828-2005	0.3	15	50	2900

The compressive strength and tensile strength at bending were assigned in accordance with GOST 10180 on cubes with a rib length of 100 mm and prisms of 100 × 100 × 400 mm.

To assign the temperatures at the center and on the surface of the steel-fiber concrete samples, thermocouples of the TXL type (chromel-drip thermocouples) were used.

As preliminary tests have shown, the most accurate values of the central and surface temperature of the steel-fiber concrete can be gained by setting the end of the thermocouple to the point at which the temperature is to be determined when the thermos electrode connection site is taken away from the steaming chamber. Determining the temperature outside the steaming chamber and using the previously defined dependences of the thermoelectric power developed at the temperature difference for a given thermocouple, it is possible to accurately define the temperature at the given point.

### 3 Results

The determining effect, which allows to optimize the process of steel-fiber concrete steam curing, is a significant change in its thermophysical properties due to different nature of the materials used. Analysis of the thermal properties of steel fiber-reinforced concrete, as well as its initial components - fine-grained concrete and steel, obtained by the calculation method, is given in Table 3.

The coefficient of thermal conductivity of steel-fiber concrete in comparison with conventional fine-grained concrete, depending on the coefficient of dispersed reinforcement ( $\mu$ ), increases from 1.5 to 4.4 times. At the same time, the specific heat of steel-fiber concrete varies insignificantly, and the thermal build-up increases more than twofold.

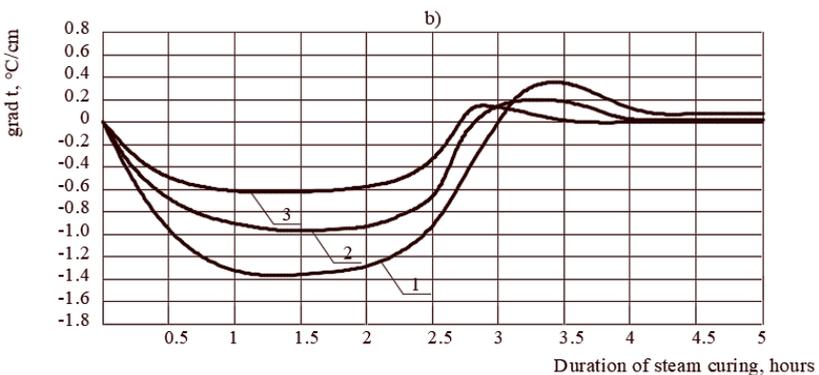
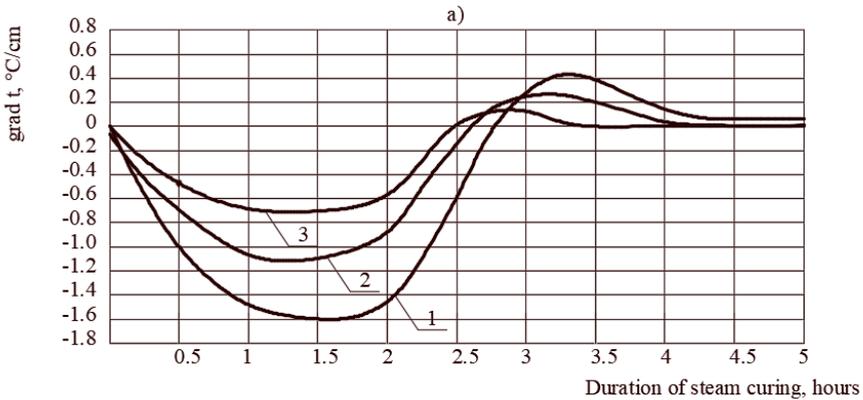
**Table 3.** Thermal properties of steel-fiber concrete.

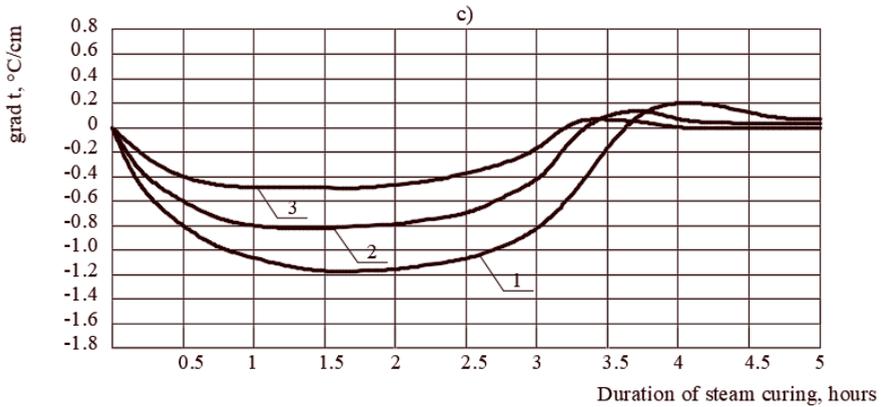
No	Material	Properties	Density, $\rho_0$ , kg/m <sup>3</sup>	Thermal capacitance, $c_0$ , kJ/(kg×°C)	Temperature conductivity coefficient $\lambda_0$ , W/(m×°C)	Heat absorption, Wt/(m <sup>2</sup> ×°C)
1	Fine-grain concrete		1800	0.84	0.76	9.6
2	Steel		7850	0.48	58	126.5
3	Steel-fiber concrete, $\mu=0,5\%$		1830	0.84	1.05	11.9

4	Steel-fiber concrete, $\mu=2,5\%$	1950	0.83	2.19	17.6
5	Steel-fiber concrete, $\mu=4,5\%$	2070	0.82	3.34	22.4

In fact, the metal fiber in the matrix of fine-grained concrete forms sections with different thermal properties, over which the distribution of heat fluxes occurs in case of a temperature gradient. On the basis of the conducted research it is discovered that with a reinforcement factor of up to 2.5% for any fiber size, the coefficient of thermal conductivity of steel-fiber concrete is less than the calculated, and at a reinforcement factor of more than 3% it exceeds the calculated values. Exceeding the theoretical coefficient of thermal conductivity of steel-fiber-reinforced concrete is caused by a decrease in the inter-fiber space and the formation of channels within the composite of increased thermal conductivity, which are separate steel fibers that come into contact or are very close to each other and permeate the entire volume of material.

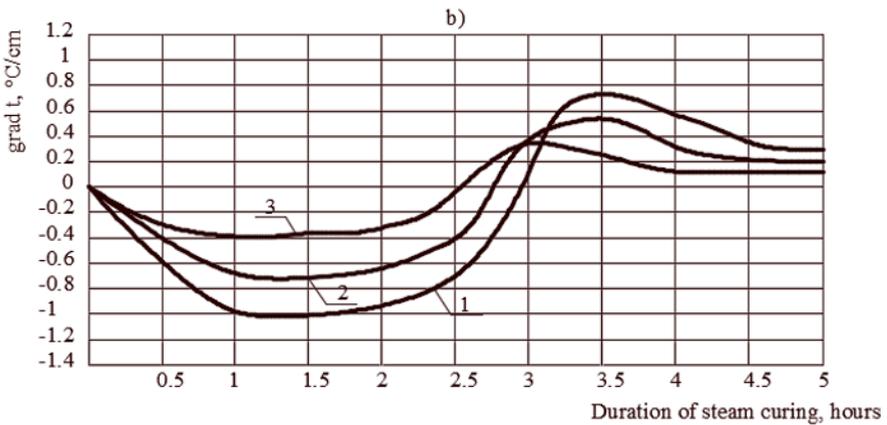
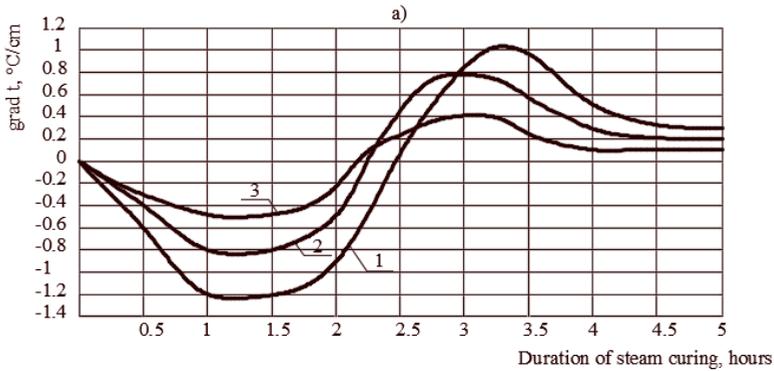
The value of the reinforcement factor for each type of fiber, at which the thermal conductivity coefficient exceeds the theoretical value, indicates that the distribution of heat fluxes, at given values, will primarily occur along the grid of dispersed reinforcement. This effect will allow more intensive redistribution of heat fluxes in the composite and achieve a uniform temperature in the shortest time possible with thermal gradients occurring along its cross section. To assess the possibility of controlling the steam curing of steel-fiber concrete, tests were carried out to determine the distribution of temperature fields in steel-fiber concrete samples. Test results are shown in Figures 1 and 2.

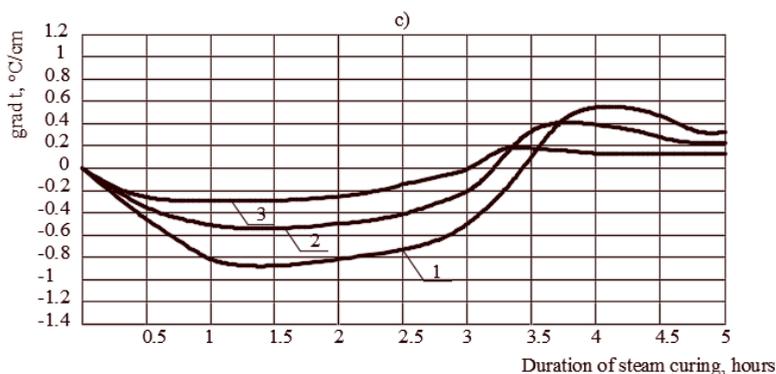




1 - reinforcement factor - 0.5%; 2 - the same 2.5%; 3 - the same 4.5%.

**Fig. 1.** Temperature gradient over the section of steel-fiber concrete samples with a cement-sand ratio of 1: 3 subjected to heat treatment: a) at a temperature rise rate of 30 °C / h; b) the same at 25 °C / h; c) the same at 20 °C / h.





**Fig. 2.** Temperature gradient over the cross-section of steel-fiber concrete samples with cement-sand ratio 1 : 1 subjected to heat treatment: a - at a temperature rise rate of 30 °C / h; b - the same at 25 °C / h; in - the same at 20 °C / h.

As was found in the tests, the main factors affecting the temperature gradient across the cross-section of steel-fiber concrete samples during steam curing are cement-sand ratio and reinforcement factor. Analyzing the found values of the temperature gradient over the section of the steel-fiber concrete samples during the heat curing, we can distinguish two stages of the heat flux distribution over the sample.

At the first stage, samples are heated from the outer layers to the center, with the temperature gradient directed from the surface to the center being negative in the given coordinate system. At the second stage (which takes place during isothermal exposure), after heating the sample throughout the entire section, the cement-sand matrix of steel-fiber concrete begins to gain strength intensively, which is accompanied by exothermic reactions that lead to a temperature rise at the center of the samples.

As a result, the temperature gradient changes direction (from the center to the surface) and becomes positive in its value in the given coordinate system.

Recommended optimal modes of steam curing, that take into account the peculiarities of steel-fiber concrete structure formation and draw on the data of the temperature fields distribution, are given in Table 4.

**Table 4.** Optimal modes of steel-fiber concrete steam curing.

Steel-fiber concrete composition			Curing conditions	
C:S	W/C	$\mu_v, \%$	Preured period, h.	Temperature rise, h.
1:1	0.3	0.5	not less than 2	2.5
		2.5	2...4	2.5
		4.5	3...5	2
	0.4	0.5	not less than 3	2.5
		2.5	3...6	2.5
		4.5	3...6	2
	0.5	0.5	not less than 4	2.5
		2.5	4...7	2.5
		4.5	4...7	2
1:2	0.3	0.5	not less than 2	3

	0.4	2.5	2...6	2.5	
		4.5	3...6	2	
		0.5	not less than 3	3	
	0.5	2.5	3...6	2.5	
		4.5	3...6	2	
		0.5	not less than 4	3	
1:3	0.3	2.5	4...7	2.5	
		4.5	4...7	2	
		0.5	not less than 2	3.5	
	0.4	2.5	2...6	2.5	
		4.5	3...6	2	
		0.5	not less than 3	3.5	
	0.5	2.5	3...7	2.5	
		4.5	3...7	2	
		0.5	not less than 4	3.5	
		0.5	2.5	4...8	2.5
			4.5	4...8	2
			0.5	not less than 4	3.5

The formation of a prestressed fiber framework is the second important feature, which allows to reduce the costs in production of prefabricated steel fiber-reinforced concrete products. It improves the physical properties of the composition. The most effective change in the properties of steel-fiber-reinforced concrete happens due to the formation of a prestressed fiber framework, which results from the introduction of expanding additives into the cement matrix [13, 14]. However, this effect should also be taken into account in steel fiber-reinforced concrete steam curing. The mechanism of occurrence and dependence describing the effect of the appearance of a prestressed fiber framework during steam curing and its effects on steel fiber concrete properties are given in [15].

## 4 Conclusions

As a result of the conducted studies aimed at studying the structure formation of steel-fiber concrete during heat and moisture treatment and the effect of dispersed reinforcement on the distribution of heat flow within the body of concrete, the values of the optimal heat treatment regimes as well as the dependences determining the change in its basic strength characteristics, depending on the composition, were obtained. The results of the work performed can be used in steel-fiber concrete production, significantly increasing the technical and economic efficiency of the enterprise and the quality of the products.

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