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Increase of fire resistance of reinforced concrete structures with polypropylene microfiber

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Abstract. The increase in the construction of high-rise, technically complex buildings and structures is a prerequisite for the widespread use of structures of heavy concrete. In this work, a special type of destruction of this type of concrete is considered in the fire action - explosive spalling. One method of protection is polypropylene microfiber, the objective of which is to increase the fire resistance of concrete and reinforced concrete structures. The fire resistance tests of the reinforced concrete structure with the use of microfiber and without it have been carried out. It is shown that polypropylene microfiber can completely prevent explosive spelling of concrete. In addition, the introduction of additives in the form of fibrous materials into the concrete mix is the most optimal from the point of view of labor intensity and material costs.

1 Introduction

One of the tendencies of the development of the construction complex is an increase in the volume of construction of high-rise, technically complex, especially dangerous and other unique buildings and structures. Constructions from heavy concrete and high-strength concrete are widely used at such types of objects [1–4].

Fires have a big impact on buildings and structures as directly when the source of fire is on the site itself, and indirectly [5]. Therefore, in the number of emergency influences [6] fire effects arising from a fire must be included. For example, the fire effect significantly changes the parameters of creep of concrete [7], thermo-stressed state in massive concrete structures in a fire is equivalent to that arising during setting of concrete [8], which causes cracks formations. In this way, the design of fire protection is a mandatory requirement in the design of structures [9–11].

Complex physical, chemical and mechanical processes occur in concrete when high-temperature heating [12]. The concrete strength under the action of high temperatures depends on the properties of binders, on the dispersed composition of aggregates [13].

Heavy high-strength concrete has such a significant drawback as the tendency to explosive spalling when exposed to a fire [14–16]. This is due to tensile stresses arising from the vapor pressure of physical moisture in the pores, and also because of the softening of the concrete after losing its bound water. The concrete softening can contribute to its destruction

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not only because of the vapor pressure in the pores, but also under the influence of thermal stresses, and also because of the difference in the expansion coefficients of temperature of various concrete fillings. According to the data of observations of real fires and fire tests of reinforced concrete structures, pieces of concrete with a spacing of up to 10-15 meters begin to fly away from the heated surfaces of structures with claps and crack during the 9th to 15th minute [17,18]. As a result, there is a rapid decrease in the working cross-section of the structure, destruction of the protective concrete layer, exposure of working reinforcement, the emergence of through cracks and holes, an abrupt decrease of the fire resistance of the entire structure.

Figure 1. Explosive spalling of concrete

The behavior of concrete under fire exposure is affected by its humidity: the higher the humidity of the concrete, the lower temperature is required to initiate explosive spalling. In construction, monolithic reinforced concrete structures are widely used, in which hardening of concrete occurs in the conditions of the outer atmosphere. At the same time, the high humidity of concrete persists for a long time, during which a fire can occur that can cause explosive spalling.

There are various ways to increase the fire resistance of reinforced concrete structures [19]. To reduce the consequences of explosive spalling of concrete in the protective layer of building structures, anti-crack grids are installed or fire retardant coatings are used to reduce the intensity of concrete heating during a fire [20]. However, modern research has shown that the most effective way to protect concrete from explosive spalling is to introduce additives in the form of fibrous materials into the concrete mix from the point of view of labor intensity and material costs [21–23].

Dispersed reinforcement forms in the concrete a three-dimensional power structure that counteracts the tensile forces arising in concrete under mechanical action and during its setting shrinkage. This type of concrete is called fiber-reinforced concrete, because its structure includes fiber – microfiber, uniformly reinforcing concrete in all planes. According to numerous studies, fiber has a positive effect on concrete exposed to elevated temperatures [24–28].

In [29,30], mechanical properties of concrete with the addition of several types of fibers after the fire impact are investigated.

An empirical formula is proposed in [31] for predicting the relative maximum pore pressure in concrete with the addition of fibrous materials exposed to fire.

In the paper, polypropylene microfiber "PROZASK IGS" is considered as a fire protection for reinforced concrete structures. It is a short fiber length of 6-12 mm, diameter less than 0.02 mm, made of polypropylene. The main function of such fiber is to increase the fire resistance limit by loss of integrity (E) and bearing capacity (R) of concrete and reinforced concrete structures. In addition, the use of such microfiber can be used to reduce the segregation and water gain of concrete mixes, to reduce cracking from shrinkage in the early stages of concrete hardening, to improve the manufacturability of concrete products, and to increase resistance to abrasion. For the purpose of increasing fire resistance, microfiber is an economical option, since the recommended consumption is 1 kg/m3 of concrete.

2 Methods

Consider the behavior of the reinforced concrete structure with the addition of polypropylene fiber "PROZASK IGS" and without it under the conditions of the standard fire.

The characteristics of polypropylene microfiber "PROZASK IGS" are given in Table 1.

Table 1. Properties and characteristics of polypropylene microfiber "PROZASK IGS"

Composition	Polymeric material with high elasticity
Length	6 mm/12 mm (+/- 5%)
Geometric shape	Monofilament
Coating	The special coating for improved dispersion and the creation of a homogeneous matrix
Density	~0.91 kg/dm3
Tensile strength	~ 400 MPa
Moisture absorption	No
Conformance to requirements	Russian State Standards: FZ-123 "Technical Regulations on fire safety requirements", GOST 30247.1-94 "Elements of building constructions. Fire-resistance test methods. Load bearing and separating constructions»
Melting temperature	>155 / 165 °C
Dosage	From 1.5 kg/m3 to 5 kg/m3 concrete mix

For fire tests, 4 experimental small-sized samples of reinforced concrete slabs of solid sections of series A and M were presented. The dimensions of all slabs presented for testing were 1100x1100x50 mm.

Figure 2. General view of a fire installation with samples with an applied load

The difference in the markings of samples is due to the difference in the types of concrete used in their manufacture. 2 samples of series A are made of ordinary heavy concrete of class B45 on granite aggregate, 2 samples of M series - from ordinary heavy concrete of class B45 with the addition of polypropylene microfiber.

The reinforcement of the panels is provided with wire-mesh reinforcement Ø5 with a cell of 200x200 mm made of reinforcement of class Vr-1 (It corresponds to Russian State Standard GOST 6727-80). The thickness of the lower protective layer of concrete (from the side of the heated surface during the fire tests) was 15 mm.

The tests of prototypes were carried out in order to determine their actual fire resistance limit in accordance with Russian State Standards GOST 30247.0-94 "Elements of building constructions. Fire-resistance test methods. General requirements" and GOST 30247.1-94

"Elements of building constructions. Fire-resistance test methods. Load bearing and separating constructions".

The prototypes were installed on an experimental fire installation and subjected to one-sided thermal action according to the standard temperature regime in accordance with Russian State Standard GOST 30247.0.

The tests were carried out under the action of a constant uniformly distributed load equal to 400 kg for each sample (without taking into account the own weight of the sample). The value of the load was determined in accordance with the technical specification of the customer. Supporting the prototypes of slabs on the walls of the fire furnace was carried out on 4 sides. The working span of the small prototype slab was 1000 mm.

During the fire tests, the temperature in the fire chamber of the furnace was measured by furnace thermocouples uniformly distributed along the length of the slabs. The temperature of the reinforcement heating was controlled with the help of thermocouples installed in the production of slabs. The temperature of the unheated surface of the slabs was controlled by thermocouples mounted on an unheated surface.

In the fire tests carried out, the basic limit state was the loss of integrity and thermal insulation capacity of the slab samples. In this case, the criterion for loss of heat-insulating capacity was the heating temperature up to 220 ° C of one of the thermocouples installed on an unheated surface (according to Russian State Standard GOST 30247.1). The remaining fire resistance criteria were not controlled in these tests.

Fire tests of small-sized samples of reinforced concrete slabs were carried out on a fire installation for thermophysical studies and tests for fire resistance of small-sized fragments of flat structures and individual units of their butt joints and fastenings.

3 Results and Discussion

In the course of tests on fire resistance of experimental samples of reinforced concrete slabs, the following characteristic features of their behavior are fixed.

Table 2. Characteristic features of the behaviour of prototypes under fire exposure

Sample	Feature of behaviour
A1	– at the 10th minute from the beginning of the fire impact - the beginning of explosive spalling (characteristic claps); – at the 25th minute intensive explosive spalling of concrete, the deflection is noticeable visually, a crack appeared in the region of the left staple from the side of the unheated surface (smoke was not observed through the crack); – at the 35th minute the explosive spalling of concrete has stopped; – at the 45th minute explosive spalling of concrete is absent, a noticeable increase in deflection; – at the 59th minute the indication of one of the thermocouples located on the unheated surface was 220 ° C; – at the 75th minute explosive spalling of concrete is absent, the increase in deflection continues; – at the 90th minute the deflection was - 50 mm, the fuel cut-off.
A2	– at the 10th minute from the beginning of the fire impact - the beginning of explosive spalling (characteristic claps); – at the 25th minute intensive explosive spalling of concrete; – at the 35th minute the explosive spalling of concrete has stopped; – at the 45th minute explosive spalling of concrete is absent, a noticeable increase in deflection; – at the 58th minute the indication of one of the thermocouples located on the unheated surface was 220 ° C;

	– at the 75th minute explosive spalling of concrete is absent, the increase in deflection continues; – at the 90th minute the deflection was - 50 mm, the fuel cut-off.
M1	– at the 10th minute explosion spalling was not recorded; – at the 25th minute explosive destruction of concrete is absent; – at the 45th minute explosive destruction of concrete is absent; – at the 60th minute explosive destruction of concrete is absent; – at the 75th minute the indication of one of the thermocouples located on the unheated surface was 220 ° C; – at the 90th minute the deflection was 30 mm; – at the 120th minute a noticeable increase in deflection (about 50 mm), fuel supply stopped.
M2	– at the 10th minute explosion spalling was not recorded; – at the 25th minute explosive spalling of concrete is absent; – at the 60th minute explosive spalling of concrete is absent, a noticeable manifestation of deflection; – at the 76th minute explosive spalling of concrete is absent, the indication of one of the thermocouples located on an unheated surface was 220 ° C; – at the 90th minute a noticeable increase in deflection (about 30 mm), fuel supply stopped.

Figure 3. Characteristic type of sample A1 on the 75th minute of the test (left) and characteristic type of sample M2 at the 90th minute of the test (right)

The general results of fire tests are given in Table 3.

Table 3. Summary table of fire tests

Sample	Duration of fire test, min	Information on the occurrence of limit states	Fire resistance limit
A1	90	– The temperature on the unheated surface of 220 ° C was reached after 59 minutes from the start of the test; – No through cracks and holes were observed; – The explosive spalling of concrete from the side of the heated surface of the slab was present for 25 minutes.	I 59
A2	90	– The temperature on the unheated surface of 220 ° C was reached after 58 minutes from the start of the test; – No through cracks and holes were observed; – The explosive spalling of concrete from the side of the heated surface of the slab was present for 25 minutes.	I 58

M1	120	– The temperature on the unheated surface of 220 ° C was reached after 75 minutes from the start of the test; – No through cracks and holes were observed; – Explosive spalling of concrete of the heated surface of the slab was not observed.	I 75
M2	90	– The temperature on the unheated surface of 220 ° C was reached after 76 minutes from the start of the test; – No through cracks and holes were observed; – Explosive spalling of concrete of the heated surface of the slab was not observed.	I 76

For this design, the time of the onset of the limiting state with the use of polypropylene microfiber increased by an average of 17 minutes.

As a result of the test, we can make conclusions:

- When a polypropylene microfiber "PROZASK IGS" is added to the reinforced concrete structure, explosive spalling of the concrete does not occur;
- The use of microfiber increases the time until the limit state of the construction, that is, the limit of fire resistance.

Analysis of numerous tests of reinforced concrete structures using polypropylene fiber "PROZASK IGS" showed that the use of this material makes it possible to completely prevent explosive spalling of concrete during the entire time before the onset of the limiting state of the structure.

Knowing the behavior of a structure with polypropylene fiber under the conditions of a standard fire regime, it can be concluded that using this material in other constructions, explosive spalling also does not occur during the entire time before the onset of the limiting state of the structure.

Concrete is exposed to explosive spalling in conditions of elevated temperatures [14–16], which is proved by the tests carried out during the work. Fibrous material in its composition allows to completely prevent explosive spalling, which is obtained in other works [21,23]. And it can be both polypropylene fiber, as in this work, and steel fiber [22,24].

4 Conclusions

A fire resistance test of a reinforced concrete structure using polypropylene microfiber was carried out. It is proved that the use of microfibre allows to completely prevent explosive spalling of concrete during fire exposure. Thus, the use of microfiber "PROZASK IGS" allows to increase the fire resistance of the structure while maintaining the original thickness of the structure and the original diameter of the reinforcement.

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