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# Influence of the Fire Temperature Regime on the Fire-Retardant Ability of Reinforced-Concrete Floors Coating

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**Keywords:** hollow-core reinforced-concrete floors, fire-resistant quality, fire-retardant coating, fire-retardant ability, temperature regime of the fire.

**Abstract.** In the paper, the tests have been analysed for fire-resistant quality of the hollow-core reinforced-concrete floors with fire-retardant plaster covering under standard temperature regime of the fire. Using the methodology for determining the characteristics of fire-retardant coatings ability for reinforced-concrete floors, the dependences have been obtained of the fire-retardant coating thickness from the concrete protective layer of a hollow-core reinforced-concrete floor for a fire resistance limit of 180 minutes with a temperature regime of hydrocarbon fire and a tunnel curve according to the Netherlands standards (RWS). It has been concluded about the minimum required thickness of the studied fire-retardant coating to provide the required fire resistance limit of a hollow-core reinforced-concrete floor under the indicated fire regimes.

## 1 Introduction

Nowadays, the fire-resistant quality of reinforced-concrete structures and their elements, protected by fire-retardant coatings, is regulated and determined by tests for fire-resistant quality at a standard temperature regime of the fire, which does not always satisfy modern fire safety requirements for buildings and structures. An analysis conducted over the past few years of resonant fires that occurred at facilities using such and similar structures has revealed that one of the reasons of inconsistency of the fire resistance limit in structures and, as a result, the collapse of buildings and structures, is the incorrect dependence determination of the fire-retardant coating thickness on the thickness of the structure for providing normalized values of the fire resistance limit. It can be assumed that the determination of the characteristics of fire-retardant coatings ability under fire regimes that correspond to the actual operating conditions would allow avoiding such events.

Determining characteristics of the fire-retardant ability of coatings for reinforced-concrete floors is currently being performed using data from the tests for fire-resistant quality of such floors at a standard temperature regime [1–2]. This does not always satisfy the requirements to reinforced-concrete structures when applied in other buildings and structures, such as tunnels, underground parking lots, garages, oil refinery facilities. At these facilities, fires are characterized by a high rate of temperature rise in the initial stage, and the thickness of fire-retardant coating, calculated under standard temperature regime, may not satisfy the safety requirements for other temperature regimes of the fire, for example, a tunnel curve, a hydrocarbon curve.

## 2 Actual Scientific Researches and Issues Analysis

There are many works devoted to the issues of determining the fire resistance limit of building structures, coated with fire-retardant agents [3–6]. In the work [3], the methods for increasing the fire resistance limits of ship and building structures using fire-retardant coatings at hydrocarbon temperature regime for metal structures are described. The work [4] describes the risk assessment of hydrocarbons explosion and fire hazards in offshore installations, and in the work [5], the studies are presented of the risk assessment of fire and hydrocarbons explosion on metal offshore platforms. In the work [6,7], the experimental studies results are presented of the strength characteristics for various types of concrete under the conditions of hydrocarbon fire. The authors of the work [8] present experimental and computer studies of reinforced concrete beams under high-temperature influences in the conditions of a standard temperature regime of the fire. And in the work [9], the combined influence on a steel column of an explosion is described, which causes deformation and subsequent fire.

In all these works, the tests of structures coated with fire-retardant agents were carried out in a standard temperature regime of the fire, or in other regimes, but with a certain fire-retardant coating thickness. However, the issues of such coatings performance in other temperature regimes of the fire, as well as determining the dependences of the fire-retardant coating thickness on the required fire resistance limit of the structure under consideration, have been insufficiently studied.

## 3 Formulation of the Problem and its Solution

The purpose of the work is to reveal the influence peculiarities of temperature regimes of the fire on the characteristic of fire-retardant ability of coatings for the hollow-core reinforced-concrete floors during their operation in other temperature regimes, differing from a standard temperature regime of the fire. It is necessary to raise the question of how the methodology for determining the fire-retardant ability of coatings for reinforced-concrete floors will operate in other temperature regimes of the fire different from the standard ones, and what kind of fire-retardant coating thickness at a specified thickness of the concrete protective layer will provide the required fire resistance limit for the hollow-core reinforced-concrete floors with this coating.

## 4 Main Part

To solve this problem, a method was used based on mathematical modelling of thermal processes in the hollow-core reinforced-concrete floors with a fire-retardant coating [1]. A one-dimensional mathematical model of the reinforced-concrete floors thermal state has been chosen with a floor slab breakdown into 6 layers [10].

The total thickness of the floor with coating is the sum of the separate floor layers' thicknesses. When testing, the floor lower surface is heated by convection-radiation heat transfer mechanisms from hot gases in a furnace with a temperature $T_{C1}$, which is close to the curve of the standard fire [10]. The floor upper surface is cooled by convection into the ambient air with a temperature of $T_{C2} = 12^{o}C$.

Inside the floor, heat is transferred not only by thermal conductivity, but also convection-radiation heat transfer mechanisms in the floor cavities. The condition is being accepted of ideal thermal contact between the separate floor layers.

The purpose set in the work was achieved by solving a number of test problems of thermal conductivity according to the computational experiment (CE) data, that is by solving a number of direct heat conduction problems (DHCP) with the assigned thermophysical characteristics (TFC) of concrete and fire-retardant coating.

The solution scheme was selected as close as possible to tests for fire-resistant quality of the hollow-core reinforced-concrete floors. For conducting computational experiment, the hollow-core reinforced-concrete floor slabs PK 48-12-8t have been selected with dimensions of 4780 × 1190 mm, thickness of 220 mm and "Endotherm 210104" fire-retardant coating with an average thickness of 37 mm. The heat-exchange coefficient on surface exposed to heating was taken as equal to 25 W/(m$^2$·K), the heat-exchange coefficient between the floor surface unexposed to heating and ambient air $\alpha_{c2}$ was assumed to be temperature-dependent according to the law of free convective heat transfer from a horizontal surface [9], the emissivity factor of concrete was taken as equal to 0.7. The thermophysical characteristics (TFC) of concrete layers 1, 3 and 5 were set from [11], and the TFC of layer 2 (a layer of voids with concrete bridges) was found by solving the inverse heat conduction problems (IHCP) according to the method described in more detail in [10]. The TFC of fire-retardant coating was found by solving the inverse heat conduction problems: the temperature-dependent heating constant, (Fig. 1), specific heating capacity constant and equal to $1.01 \cdot 10^6$ J/(m$^3$·K).

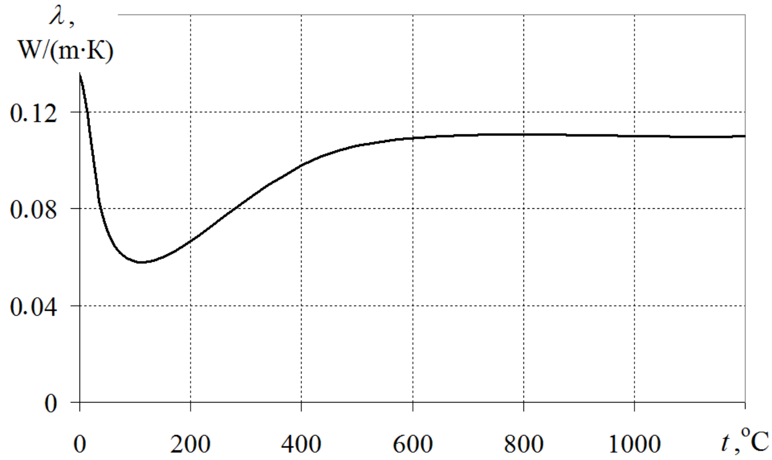


Fig. 1. Dependence of the effective thermal conductivity coefficient of the plaster covering on the temperature determined by solving IHCP according to the data of tests for the fire-resistant quality

In test problems, using the mathematical and computer models, specified TFC and boundary conditions (BC), by solving the DHCP, an unsteady temperature distribution has been obtained in the hollow-core reinforced-concrete floor and fire-retardant coating. Firstly, it was conducted in the standard temperature regime, and then in the tunnel curve regime according to the Netherlands standards (RWS) and hydrocarbon curve (Fig. 2). When solving the DHCP series, the limiting structure state on fire-resistant quality was used, if a critical temperature of 500°C is achieved on the reinforcement from the side of the fire exposure at the level of loading specified in the test.

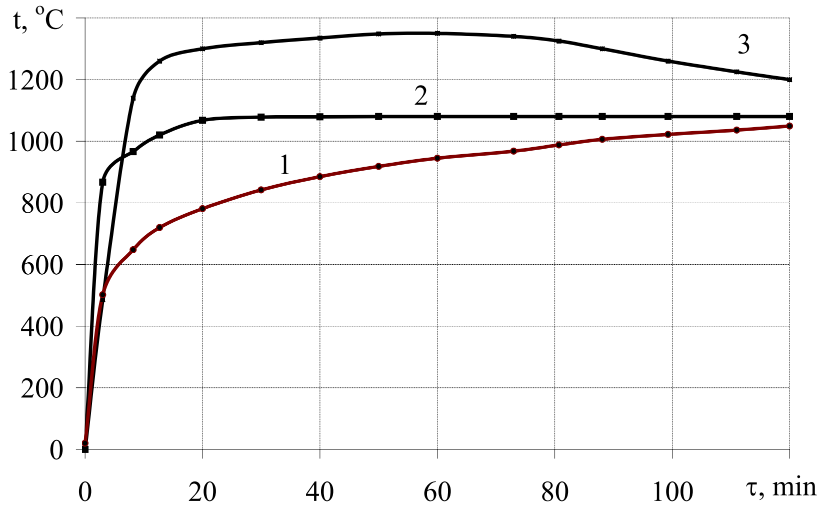


Fig. 2. Dependence of temperature changes from the fire exposure duration in different regimes of the fire, where:

1 – standard temperature curve according to ISO 834 and GOST 30247.0-94;
2 – hydrocarbon curve according to EN 1363-2: 1999;
3 – tunnel curve according to the Netherlands standards (RWS)

Ignition of various hydrocarbon fuels (volatile flammable liquid and combustible liquid) is characterized by a rapid temperature rise to 1100°C (Fig.2, curve 2). Such fires are possible at the facilities of the oil-and-gas and petrochemical complexes. In this case, to assess the fire-resistant quality of building structures, a “hydrocarbon curve” is used, which is characterized by the dependence:

$$T=1080[1-0{,}325 \exp(-0{,}167t)-0{,}675 \exp(-2{,}5t)+20]. \tag{1}$$

Another possible type of various hydrocarbon fuels combustion is a fire in a tunnel. In these conditions, when it is difficult to reject heat from the source, an intense temperature regime is created – a “tunnel curve”. The temperature of the fire can reach 1200°C and above in 5–10 minutes already. In the Netherlands, the RWS temperature curve is used to assess the thermal and mechanical properties of fire-retardant tunnels coating, in which the transporting of dangerous goods is permitted. This curve (Fig. 2, curve 3) is characterized by a rapid increase in temperature up to 1200°C in the first minutes and its further slower increase up to 1350°C.

These temperature regimes are characterized by a more rapid increase in temperature. In view of the large dimensions, complex structure and spatial shape of the building structures of this type underground facilities, the experimental determination of their actual fire resistance limits involves unreasonably high costs.

Therefore, the computational-experimental method has been chosen as the most effective method for conducting studies to determine the influence of the temperature regimes of the fire on the fire-retardant ability (FRA) of reinforced-concrete floors coating. This method is a combination of experimental and calculation procedures that make it possible to determine the desired characteristic of the studied object with the required accuracy.

By solving the DHCP series, on the basis of a one-dimensional mathematical model of the reinforced-concrete floor thermal state, the thicknesses of “Endotherm 210104” fire-retardant plaster covering have been obtained for the required fire resistance limit of the floor for 180 minutes (Table 1).

Table 1. The values of the minimum thickness of “Endotherm 210104” coating to provide the required fire resistance limit of the floor for 180 min

| Concrete protective layer thickness for a hollow-core reinforced-concrete floor, [mm] | Minimum thickness of the fire-retardant coating, [mm] | | |
|---|---|---|---|
| | Standard temperature regime | Regime of hydrocarbon fire | Tunnel fire regime according to the Netherlands standards (RWS) |
| 10 | 15.5 | 17.3 | 20 |
| 30 | 10.98 | 12.7 | 15.1 |
| 40 | 8.85 | 10.55 | 12.7 |
| 60 | 4.73 | 6.3 | 8.1 |

Therewith, it was assumed that, in order to solve the DHCP for determining the FRA of a coating at hydrocarbon fire regime and a tunnel fire regime according to the Netherlands standards (RWS), the assigned thermophysical characteristics of the fire-retardant coating have been determined by solving the IHCP, using the tests data of the fire-resistant quality of a hollow-core reinforced-concrete floor in a standard temperature regime of the fire.

Dependences of “Endotherm 210104” fire-retardant coating thickness with a concrete protective layer thickness of 10-60 mm in order to provide the required fire resistance limit of the floor for 180 min are shown in Fig. 3.

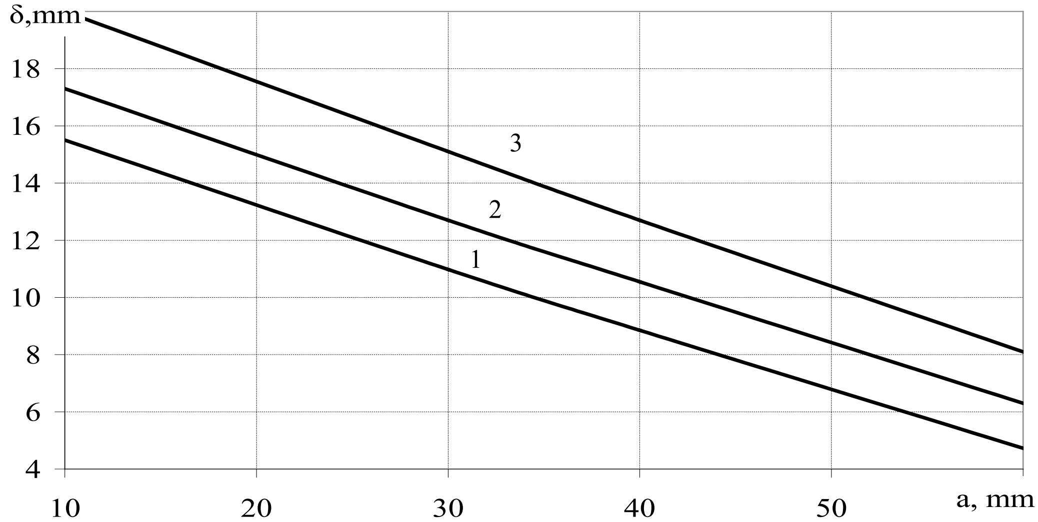


Fig. 3. Characteristics of the fire-retardant ability of "Endotherm 210104" plaster covering according to the criterion of achieving the critical temperature (500°C) on the reinforcement for the fire resistance limit of 180 min: 1 – for standard temperature regime; 2 – for the regime of hydrocarbon fire; 3 – for tunnel fire regime according to the Netherlands standards (RWS)

As it can be seen from Fig. 3, the minimum thickness value of "Endotherm 210104" fire-retardant coating, providing the required fire resistance limit for a hollow-core reinforced-concrete floor, which was calculated for a standard temperature regime of the fire, is significantly less than the value for other temperature regimes. As a result, it has been determined that the difference between the required thickness values of "Endotherm 210104" fire-retardant coating for a standard temperature regime and a temperature regime of hydrocarbon fire is about 12%. The difference between the required thickness values of "Endotherm 210104" fire-retardant coating for a standard temperature regime and a temperature regime according to the Netherlands standards (RWS) is 29%.

## 5 Conclusion

The influence has been determined of the fire temperature regimes on the characteristics of the fire-retardant ability of the studied "Endotherm 210104" fire-retardant coating for providing the required fire resistance limit of a hollow-core reinforced-concrete floor. Therewith, it has been revealed that the maximum values of the minimum coating thickness from 8.1 to 20 mm are specified for a temperature regime of the fire according to the Netherlands standards (RWS), and the minimum values from 4.73 to 15.5 mm for a standard temperature regime.

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