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Research of Fireproof Capability of Coating for Metal Constructions Using Calculation-Experimental Method

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Abstract. Determination of characteristic of fireproof capability of examined fire-retardant coating by experiment-calculated method solving the inverse heat conduction problems based on the firing tests data. With the aim of determining the fire-resistance time of metal sheets with fire-retardant coating there are used experimental research methods of patterns behavior during heating according to the requirements of National Standards of Ukraine B.V. 1.1–4–98* are used; mathematical and computer modelling of processes of unsteady heat transfer in the system "metal sheet – fire-retardant coating"; determination of thermal characteristics and characteristic of coating fireproof capability. Firing tests of metal sheets covered by the flame retardant "Amotherm Steel Wb" are carried out. Based on the obtained data (temperature from the unheated sheet surface) there are determined the thermal characteristics of formed coating depending on temperature and the characteristic of fireproof capability of examined coating for 30 minutes fire-resistance time. The effectiveness of intumescent coating "Amotherm Steel Wb" is proved and the dependence between its heat conduction coefficient and temperature during heating in experimental stove of metal sheet with this coating in standard temperature conditions is specified. The co-relation between the thickness of intumescent coating "Amotherm Steel Wb" and fire-retarding quality of metal constructions is identified. Besides the necessary minimum thicknesses of such coating from the thickness of metal sheet for importance of 30 minutes fire-resistance time are calculated.

1 Introduction

Steel structures are widely used in the construction, expansion, reconstruction, technical re-equipment, but have a low limit of fire resistance, which limits the use of such structures in buildings and structures with high requirements for their fire resistance. Therefore, increasing the fire resistance of steel structures due to the application of flame retardants forming a coating on the protected surface, and the study of the flame retardant ability of such coatings is an urgent scientific and technical task and purpose of this work.

2 Actual Scientific Researches and Issues Analysis

Among the variety of flame retardants, a special place is occupied by the ones that under the influence of temperature swell, forming a layer of porous coating that has good thermal insulation properties. To the issues of the study of the flame retardant coating capacity a sufficient number of

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works [1–4] is given, in which the evaluation of flame retardant coatings is carried out with the help of a large number of disadvantages using the experimental method, which has, along with advantages: it is possible to determine the limit of fire resistance of a structure with only one thickness of the coating. In the work [1] an express method for estimating the fire-retarding ability of coatings of metal structures was developed, based on the results of testing such structures at a standard temperature regime. The authors [2] describe the effect of the heterogeneity of the thickness of the flame retardant coating for metal structures on the flame retardant efficiency, taking into account the deformation of the coke layer under the thermal action. In the work [3] methods of increasing the limits of fire resistance of ship and building structures using fireproof coatings at hydrocarbon temperature for metal structures are described, and also [4, 5] the combined effect on the steel column of the explosion, which causes deformation and subsequent fire are described.

3 Formulation of the Problem and its Solution

Therefore, the purpose of the work is to determine the characteristics of the flame retardant ability of the investigated flame retardant design and experimental method of solving inverted thermal conductivity problems based on test data under fire conditions at the standard fire temperature.

4 Main Part

To determine the flame retardant ability of coatings of steel structures, it is proposed to use the design and experimental method, which has proven itself well in many papers [6–10] and is defined as a set of experimental and computational procedures to determine the required characteristics of the object under study (Fig. 1), in particular, the dependence of the thickness of the coating on the thickness (reduced thickness) of the metal for the normalized values of the limit of fire resistance of the structure.

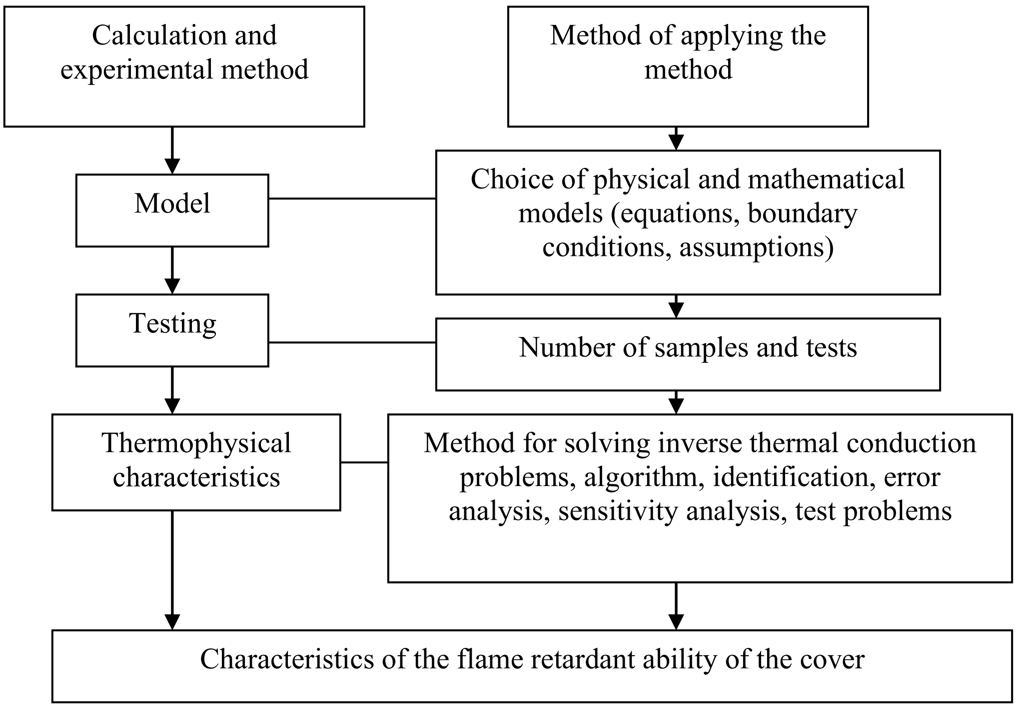

Fig. 1. Scheme of application of the calculation and experimental method of determining the flame retardant coatings

According to the algorithm shown in Fig. 1, fire tests were prepared and conducted of two steel plates, of a size 500×500×5 mm with applied fire retardant “Amotherm Steel Wb”, that swells, water-based production of an Italian company Amonn Fire S.r.l. White paint of a high density was used for the application, equal to 1200-1300 kg/m^3, based on vinyl polymers in aqueous dispersion and special reagents. After applying the paint, a white matte surface was formed on the plate.

A layer of primer GF-021, 0.065 mm thick, was applied to the heating surface of the steel plate before applying the flame retardant. The substance was applied in a mechanized manner by an airless spraying unit in accordance with the fire protection regulations [11]. To measure the thickness of the fire retardant formed, thickness gage was used, with the help of which 9 points were measured (Fig. 2), the average thickness was 0.507 mm.

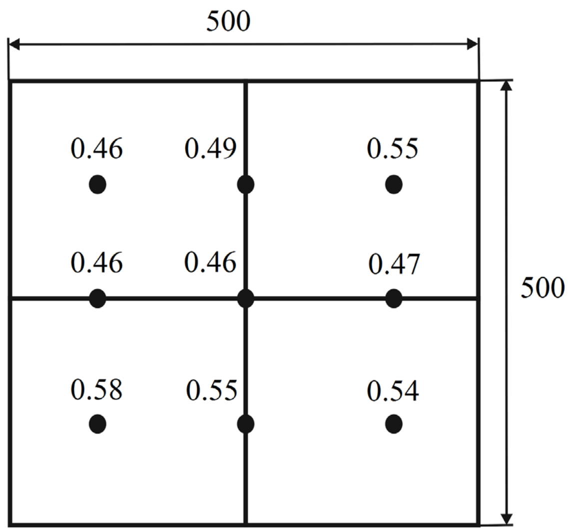

Fig. 2. Scheme for measuring the thickness of the flame retardant coating

Figures in Fig. 2 denotes the thickness of the coating at the point of measurement.

To measure the average and maximum temperature from a non-heated surface of a steel plate, 3 thermocouples of the THA type were installed (Fig. 3) with wire diameter 0.5 mm (T1–T3), one thermocouple (T2) two in the center of the sample (T1, T3) at a distance 100 mm from the edges of the plate.

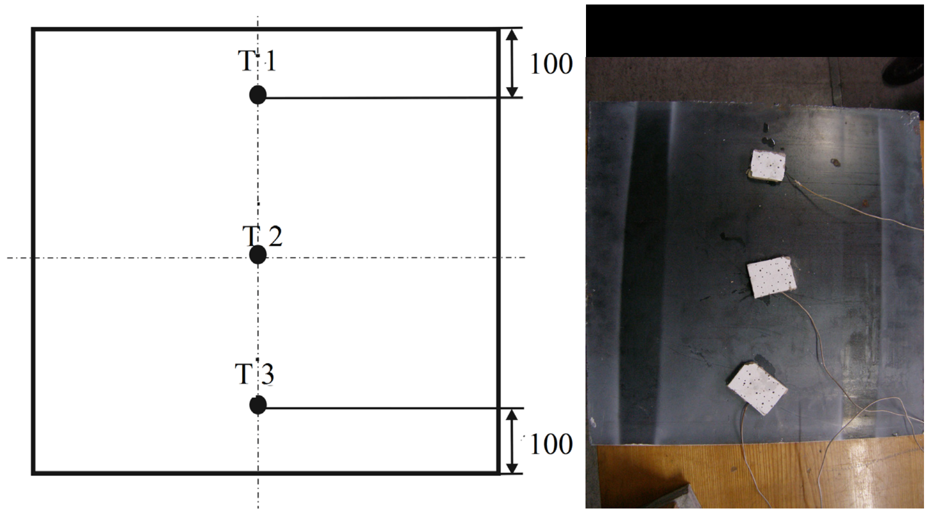

Fig. 3. Allocation scheme of thermocouples from a non-heated surface of a steel plate

From the non-heating surface, the plate was protected by two layers of multisiliceous felt, 20 mm thick, and mineral wool slab, 75 kg/m^3 density and 50 mm thick. The essence of the test was to create a temperature regime in the furnace, regulated [12], during thermal action on the test sample and determining the time from the onset of thermal action to the onset of the limit state for the test sample, when the temperature of 500 °C from a non-heating surface is reached. The tests were carried out at air temperature 2 °C, relative humidity 68 % and pressure 754 millimeters of mercury.

Tests of the samples were carried out under conditions close to the standard temperature regime for 30 minutes (Fig. 4).

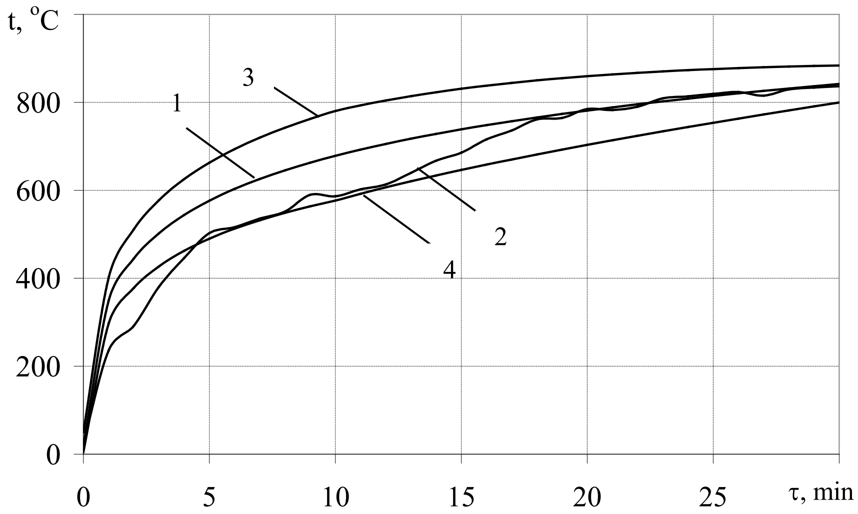

Fig. 4. Dependence of oven temperature on duration of fire exposure: 1 – standard temperature curve, curve 2 – real curve of temperature change in the furnace; 3 – the maximum admissible values of the temperature in the oven when tested; 4 – allowable for testing minimum values of temperature in the furnace

After testing at visual inspection of samples it is established:

- fire retardant “Amotherm Steel Wb”, applied to a metal plate, that is 500×500×5 mm with a primer ГФ-021, has satisfactory adhesion strength;
- detachment of the formed coating from the test sample by area was not observed;
- the average thickness of the swollen layer after testing was 12 mm (11-14 mm).

Fig. 5 presents graphs of the temperature change from the time of fire exposure on the unheated surface of the steel plate.

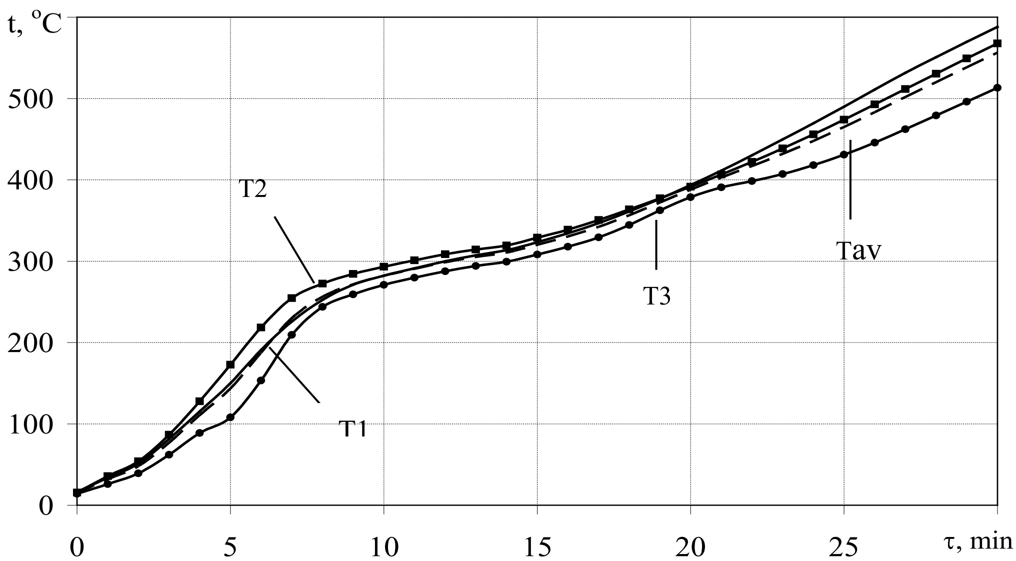

Fig. 5. Temperature dependence of the time of fire exposure on a non-heated surface of a steel plate with a flame retardant “Amotherm Steel Wb”: T1 – thermocouple installed at a distance of 100 mm from the upper edge of the plate; T2 – thermocouple installed in the center of the plate; T3 – thermocouple installed at a distance of 100 mm from the lower edge of the plate; Tav. – average value of thermocouples

As can be seen from Fig. 5, the warming dynamics of the steel plate in different parts of the temperature measurement coincide. The differences in the rate of heating observed can be explained by the heterogeneity of the thickness of the flame retardant coating (Fig. 2) or the effect of sliding from the steel plate of the top layer of flame retardant with increasing temperature. The figure shows that the top of the steel plate warms up most at the place of installation of the thermocouple T1. But for thermal calculations, the average of the readings of three thermocouples installed from a non-heating surface was taken.

According to the algorithm (Fig. 1), a physical model (Fig. 6) was constructed, which includes the geometry of a steel plate with a flame-retardant coating and consists of two layers with the thickness δ_1, δ_2 (Fig. 7). The total thickness of the flame retardant plate $X = \delta_1 + \delta_2$.

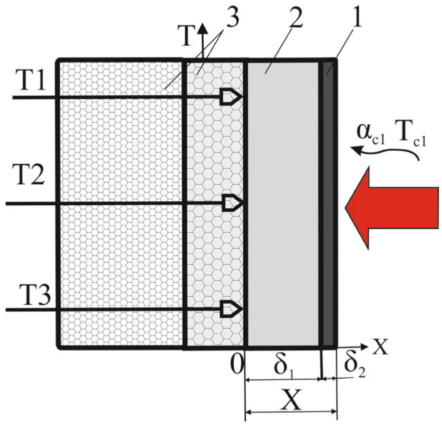

Fig. 6. Scheme of a steel plate with a fireproof coating in one-dimensional formulation: 1 – layer of flame retardant, thickness δ_2; 2 – steel plate, thickness δ_1; 3 – layer of thermal insulation

When tested for fire resistance, the right surface of the plate (x = X) is heated by convective radiation from hot gases in a furnace with temperature T_{C1}, close to the standard fire curve and the heat transfer coefficient α_{c1} = 25 W/m^2·K. Radiation coefficient of the heated surface ε = 0,85. The left unheated surface (x = 0) is cooled by convection and radiation into the environment with temperature T_{c2}. The coefficient of heat transfer between the surface of a non-heated steel plate and the environment α_{c2} is considered equal 7 W/(m^2·K). Inside the plate, heat is transferred by thermal conductivity.

The mathematical model of the thermal conductivity process in such a two-layer system, which describes the physical model discussed above (Fig. 6), has been repeatedly described in the literature [7, 10] and is a one-dimensional equation of thermal conductivity with a combination of radiation heat transfer and boundary conditions of the 3rd kind on a heated surface, and the boundary conditions of the 3rd kind on a non-heated surface, taking into account the ambient temperature and the heat transfer coefficient.

On the basis of the experimental data (temperature from the non-heated surface of the plate), using the physical and mathematical models of the thermal state of the sample, by solving the inverse problems of thermal conductivity, the thermophysical characteristics of the investigated coating were obtained: constant value of the specific volumetric heat capacity $C_v = 1 \cdot 10^5$ J/m^3·K and thermal conductivity as a function of temperature (Fig. 7).

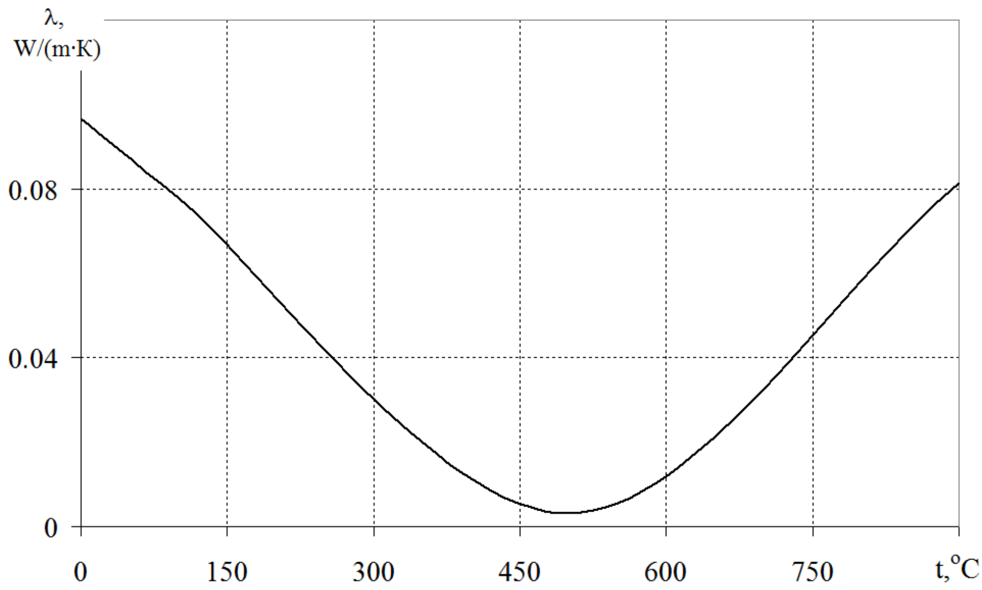

Fig. 7. Scheme of a steel plate with a fireproof coating in one-dimensional formulation: 1 – layer of flame retardant, thickness δ_2; 2 – steel plate, thickness δ_1; 3 – layer of thermal insulation

As can be seen from Fig. 7, in the temperature range from the initial temperature to 500 °C the value of the coefficient of thermal conductivity of the coating "Amotherm Steel Wb" falls and passes through a minimum value of 0.003 W/m·K (at the temperature 500 °C), which can be explained by the flattening of the coating and the increase in its porosity. The increase of the coefficient of thermal conductivity in the temperature range from 500 °C to 800 °C, apparently, is explained by the appearance of the radiation component in the pores of the coating in combination with its high-temperature shrinkage and charring.

Based on the obtained thermophysical characteristics of the investigated coating (Fig. 7), using models (Fig. 6), solving a series of direct problems of thermal conductivity, the characteristic of the flame retardant coating "Amotherm Steel Wb" ability was determined for the value of the limit of fire resistance of steel structures 30 min (Fig. 8).

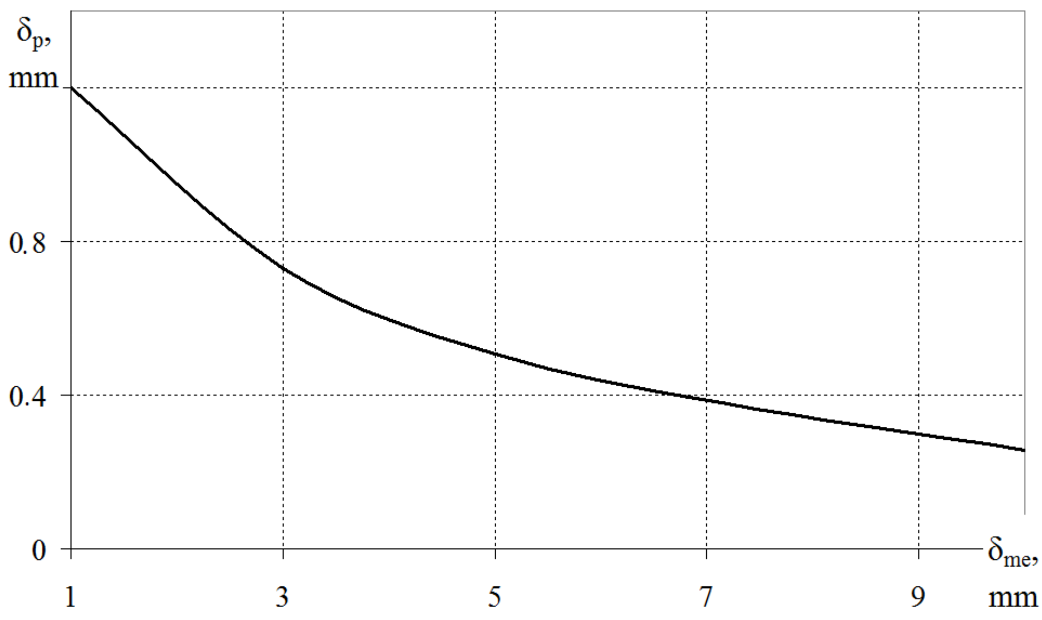

Fig. 8. Dependence of minimum thickness of flame retardant coating "Amotherm Steel Wb" from the thickness of the steel plate to a critical steel temperature of 500 °C and the normalized duration of fire exposure 30 min

Using the dependency shown in Fig. 8, it is possible to determine the required minimum thicknesses of the specified coating and steel structure to ensure the normalized value of the limit of fire resistance of 30 min.

5 Conclusion

1. The results of fire tests of a steel plate (5 mm thick) coated on one side with a fire extinguishing agent “Amotherm Steel Wb”, that swells, under heating conditions in a furnace at a standard fire temperature.
2. According to the results of fire tests (temperature from the unheated surface of the steel plate), the effective coefficient of thermal conductivity and the specific volumetric heat capacity of the coating “Amotherm Steel Wb” were found by solving inverted thermal conductivity problems.
3. The effectiveness of fire retardant coating “Amotherm Steel Wb”, that swells, was proved, and the dependence of the coefficient of its thermal conductivity on the temperature in the conditions of heating in the test furnace of a steel plate with this coating at a standard temperature regime is established. t was found that in the temperature range from 0 °C to 500 °C, the value of the thermal conductivity coefficient falls by an order of magnitude compared to the original value and passes through a minimum extreme value of 0.003 W/m·K (at a temperature of 500 °C), and then increases linearly to initial value.
4. A relationship was found between thickness of a fire extinguishing agent “Amotherm Steel Wb”, that swells, and the fire resistance of steel structures, as well as the required minimum thicknesses of such coating from the thickness of the steel plate are calculated to ensure a limit value of fire resistance of 30 minutes.

References

[1] O.P. Borys, A.P. Polovko, T.B. Yuzkiv, Ekspres-metodyka otsiniuvannia vohnezakhysnoi zdatnosti vohnezakhysnykh materialiv, Naukovyi visnyk UkrNDIPB. 26 (2012) 95–99.

[2] S.V. Bazhenov, Yu.V. Naumov, Vliyanie neodnorodnosti tolshchiny vspuchivayushchegosya pokrytiya dlya metallicheskikh konstruktsiy na ognezashchitnuyu effektivnost s uchetom deformatsii koksovogo sloya pri teplovom vozdeystvii (usloviya pozhara), Pozharnaya bezopasnost. 6 (2004) 57–62.

[3] I.V. Abramov, M.V. Gravit, E.I. Gumerova, Povyshenie predelov ognestoykosti sudovykh i stroitelnykh konstruktsiy pri uglevodorodnom temperaturnom rezhime, Gazovaya promyshlennost. 5 (2018) 108–117.

[4] J.K. Paik, J. Czujko, Assessment of hydrocarbon explosion and fire risks in offshore installations: Recent advances and future trends, IES Journal Part A: Civil and Structural Engineering. 4 (2016) 167–179.

[5] A. Vasilchenko, E. Doronin, B. Ivanov, V. Konoval, Effect of Residual Deformation of a Steel Column on its Fire Resistance under Combined Exposure “Explosion-Fire”, In Materials Science Forum. 968 (2019) 288−293.

[6] A. Kovalov, Y. Otrosh, T. Kovalevska and S. Safronov, Methodology for assessment of the fire-resistant quality of reinforced-concrete floors protected by fire-retardant coatings, IOP Conf. Series: Materials Science and Engineering. 708 (2019) 012058.

[7] A. Kovalov, Y. Otrosh, S. Vedula, O. Danilin, T. Kovalevska, Parameters of fire-retardant coatings of steel constructions under the influence of climatic factors, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 3 (2019) 46–53.

[8] A.I. Kovalov, Ye.V. Kachkar, N.V. Zobenko [ta in.], Eksperymentalne doslidzhennia vohnezakhysnoi zdatnosti pokryttia «Amotherm Steel Wb» pry temperaturnomu rezhymovi vuhlevodnevoi pozhezhi, Pozhezhna bezpeka: teoriia i praktyka. 17 (2014) 53–60.

[9] F. Wald, L. Simões Da Silva, D.B. Moore, T. Lennon, M. Chladna, A. Santiago, M. Beneš, L. Borges, Experimental behaviour of a steel structure under natural fire, Fire Safety Journal. 7 (2006) 509–522.

[10] A. Kovalov, V. Konoval, A. Khmyrova, K. Dudko, Parameters for simulation of the thermal state and fire-resistant quality of hollow-core floors used in the mining industry, E3S Web of Conferences. 123 (2019) 01022.

[11] Rehlament robit z vohnezakhystu dlia vohnezakhysnoi rechovyny «Amotherm Steel Wb», shcho spuchuietsia, dlia stalevykh konstruktsii / DITB Ukrainy, 2012. – № 95/1/36946711. – 29 p.

[12] DSTU B V.1.1–4–98* Zakhyst vid pozhezhi. Budivelni konstruktsii. Metody vyprobuvan na vohnestiikist. Zahalni vymohy. Kyiv, 2005 [in Ukrainian].