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Results of Experimental Investigations of Reinforced Concrete Wall Elements According to the Standard Temperature Mode of Fire

PEREHIN Alina[1,a*], NUIANZIN Oleksandr[1,b], BORYSOVA Anna[2,c], NUIANZIN Vitalii[1,d]

[1]National University of Civil Defence of Ukraine, 94 Chernyshevska street, Kharkiv, Ukraine, 61023

[2]Institute of Public Administration and Research in Civil Defence, 21 Vyshhorodska street, Kyiv, Ukraine, 04074

[a]alinayanish23@gmail.com, [b]alexandrnuyanzin@gmail.com, [c]borysova_anna@ukr.net, [d]nuyanzin@gmail.com

Keywords: method, test, small fragment, compact fire installation, reinforced concrete wall, experimental study, temperature, Fisher's test, reproducibility of experimental data.

Abstract. Methods for determining the actual limit of fire resistance of reinforced concrete building structures in case of fire are analyzed. On the basis of the offered methods the technique which gives the chance to receive data of temperature distributions on a surface of a fragment of a wall and in its section is created. The method of conducting a fire test to calculate the limit of fire resistance of a small fragment of the load-bearing wall and verify the reproducibility of experimental data is described. The distribution of temperatures over the entire area of the fire furnace, the studied fragment was checked and the obtained results were analyzed. According to the results of this work, the following was established: the aim of the work was to obtain the results of temperature distributions on the surface, in the points of integration in the cross sections of fragments of reinforced concrete walls for further calculation of their fire resistance limit and check reproducibility of experimental data. It is established that the temperature obtained as a result of the fire test corresponds to the standard temperature of the fire and this method of fire test to determine the temperature distributions of a small fragment of the load-bearing wall in fire conditions is acceptable for use. The error between the experimentally determined and theoretically calculated limit of fire resistance is not more than 3 %.

1 Formulation of the Problem

The main reasons that lead to the destruction of buildings and structures during a fire are the presence of open flames and high temperatures, which lead to rapid heating of building structures. According to [1] the degree of fire resistance of the house is determined by the limits of fire resistance of its building structures and the limits of fire spread on these structures. Various fire barriers are to be installed to prevent the spread of fire between rooms. Ignoring the problems of fire resistance of building structures, fire barriers and utilities can lead to death and cause significant economic problems.

2 Analysis of Recent Achievements and Publications

There are known methods of testing for fire resistance [2–4], which are that samples of building structures should be tested under load. These standards allow testing without loading of samples of building structures with fire-retardant coating and cladding, as well as without loading samples of reinforced concrete structures, for which it is impossible to reproduce the load conditions in the laboratory adopted in the calculation scheme due to technical reasons.

These standards state that samples of building structures must correspond to the design dimensions of the building structure, as well as the fact that it is possible to examine fragments of samples.

Testing of such structures is problematic because it requires large financial investments and labor costs. Therefore, the idea of conducting an experimental study with verification of experimental data, which allows to test the fire resistance of small fragments of reinforced concrete structures and makes it possible to verify the adequacy of experimental data.

3 Problem Statement and its Solution

This article describes the method of conducting a fire test to predict the behavior of reinforced concrete structures in fire conditions and analysis of the results of temperature distributions and strength characteristics of the material in the cross section of the reinforced concrete wall.

To solve the goal, the task is set:

1. To describe the stages of creating small fragments of reinforced concrete wall for fire tests.
2. To describe the methodology and means of conducting an experimental test.
3. To analyze the temperature regime on the surface and points of integration in the cross sections of fragments of reinforced concrete walls.
4. To verify the experimental data obtained during the fire test.

4 Presentation of the main material of the study with a full justification of the results

A prototype of a compact fire installation was used to conduct a fire experiment [5].

A fragment of a reinforced concrete wall was a spatial structure. Reinforcement of wall structures, as well as materials used: concrete and reinforcement, corresponded to those used in the construction of residential buildings from monolithic reinforced concrete. A fragment of the wall for the study was made using standard collapsible formwork.

Fig. 1 is a photo of a pre-prepared fragment, sample № 1, for testing for fire resistance.

a *b*

Fig. 1. A small fragment of a reinforced concrete wall made in advance of the test: a – transportation of the fragment; b – a fragment of the wall installed at the test site, before the test; 1 – walls of the fire furnace; 2 – fragment of reinforced concrete wall for testing

As it can be seen in (Fig. 1), the samples were stored indoors, then transported to the test site and installed in a fire oven.

Small fragment of reinforced concrete wall was made in advance of the test, in the amount of 3 pcs.

The fragment was made in the following proportions for 1 m^3: portland cement of brand «500» - 460±10 kg; quartz sand – 660±10 kg; granite rubble – 1150±10 kg; water.

The reinforcement corresponded to the construction of the walls of modern residential buildings made of monolithic reinforced concrete that was actually used. Reinforcement is mostly wire of class Wr-I with the diameter of 5 mm.

To study the influence of concrete structure on thermophysical parameters, three groups of 1 sample with different water-cement ratios were made.

Water / cement = 0,3×(water – 138±10 kg); with the same fractions of granite aggregate (crushed stone) – 10–20 mm.

Dosing of components is performed using weight dispensers of the factory concrete mixing plant. Mixing of concrete mix is executed in the concrete mixer of free falling by volume 0.75 m^3. Sealing of concrete mix is made by deep vibrators.

The structure was manufactured using standard collapsible formwork.

The samples were kept in the formwork for seven days. After stripping, the fragment was stored for 28 days.

After 28 days, the fragments were stored under normal conditions of temperature and humidity until the start of the test.

5 Methods of the Experiment

The method of testing in a compact fire installation without mechanical load is the influence of the standard temperature of the fire when heating the element of the reinforced concrete wall on one side, on the basis of which it will be possible to estimate the fire resistance of the building structure.

This test was conducted on the basis of the Training complex of practical training of specialists of the Operational and Rescue Service of Civil Protection Service of ChIFS named after Chornobyl Heroes of NUCD of Ukraine.

Prior to the start of the test, the date of the study, the ambient temperature is recorded. Before the start, the overall dimensions of the sample, the thickness of the sample are measured and the set data are recorded.

External conditions: date of testing: 05.08.2021; air temperature: 26^{+1} ºC; air humidity: 58 %.

3 samples were made, their overall dimensions: 1193×1195 mm; 1198×1194 mm; 1201×1199 mm.

The test specimen is mounted in the front of the installation. The upper part of the installation is closed with a lid. Mineral wool and lime cord were used for tight fit. Figure 2 shows a diagram of the installation of a small sample of reinforced concrete wall for testing.

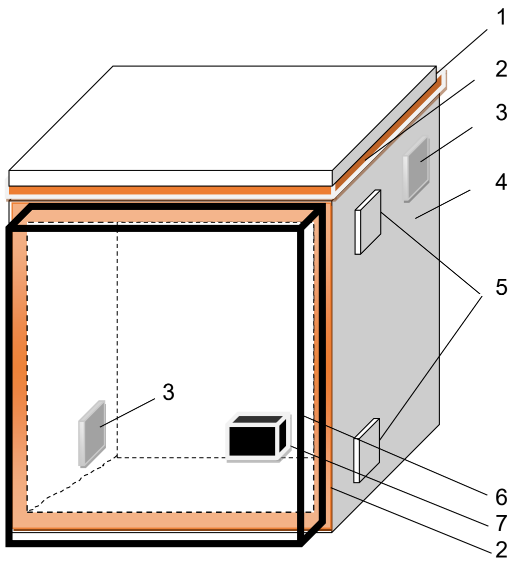

Fig. 2. Scheme of installation of a sample for tests: 1 – cover covering the top of the installation; 2 – sealant made of mineral wool and lime cord; 3 – burners that create the temperature in the furnace chamber; 4 – furnace fencing; 5 – places for burners that are not used during fire tests of walls; 6 – the sample under study, 7 – hole for combustion products

Two burners are used when testing the walls. They are placed at the top and bottom of the far part of the installation so that the flame torches are not in contact with each other and are 80 cm to the test specimen (Fig. 3). During the tests of the wall, the places for unused burners were covered with bricks and mineral wool to prevent the exit of furnace gases through these holes.

The placement of burners and holes for the removal of combustion products affects the uniformity of temperature distribution on the heating surface of building structures.

Prior to the test, thermocouples and thermistors were installed in the space of the fire furnace chamber and on the test sample: in the fire furnace chamber there are 3 thermocouples of THA type to control the temperature regime and ensure its compliance with the standard; on the heating surface of sample 3 thermocouples of TCA type; on the non-heating surface 2 thermistors and on the valve level 3 thermistors with a measuring range of 5 - 300 .

The diagram (Fig. 3) shows the location of thermocouples and thermistors in the projection connection, taking into account their visibility in the projections.

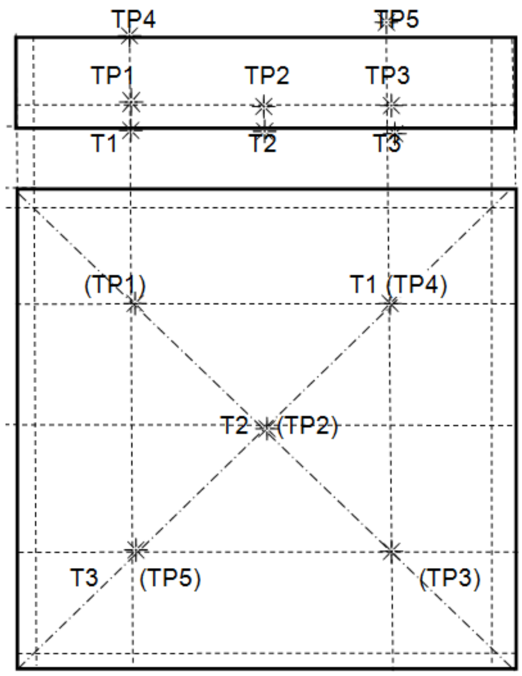

Fig. 3. Layout of measuring equipment in the cross section of the reinforced concrete wall-sample for testing

The diagram shows the measuring equipment, which was installed before the test and numbered as follows: on the heating surface of the sample thermocouples T1-T3 are installed; at the level of fittings thermistors: TP1-TP3; on non-heated surface (0.03 m from the surface) thermistors TR4-TR5.

Measuring equipment used during the fire test is shown in the table 1.

Table 1. Means of measuring equipment

№	Name of equipment or appliance	Measuring range	Measurement error
1	Thermocouple TCA-2388 with ADC module [6]	from -200 to +700 [°C] from +700 to +1350 [°C]	± 2.0 [°C] ± 4.0 [°C]
2	Thermistor	from +5 to +300 [°C]	± 1.0 [%]
3	A measuring ruler	from 0 [mm] to 1000 [mm]	± 1 [mm]
4	Stopwatch COC pr-2b-2-000	from 0 [s] to 60 [s], from 0 [s] to 60 [min]	$\pm\left(\frac{0.4}{60}\tau\right)$ $\pm\left(0.4+\frac{1.5}{3540}(\tau-60)\right)$
5	Aspiration psychrometer MV-4M	from 10 [%] to 100 [%] from – 10 [°C] to 50 [°C]	± 4 [%] ± 0.2 [°C]
6	Calipers SC-1	from 0 [mm] to 125 [mm]	± 0.1 [mm]
7	Aneroid barometer M67	600 - 800 [mm] of mercury column	± 1 [mm] of mercury column
8	Anemometer ACO-3	from 0.3 [m/s] до 5 [m/s]	± (0.1+0.05 V) [m/s]

Thermocouples were used to measure the temperature in the furnace

TCA-2388 with a wire diameter of 1.25 mm, which can be used to measure temperature in the range from 0 to 1300 ^{0}C.

The thermistor MF 52 was used to measure the temperature in the test sample, it can be used to measure the temperature in the range

from –30 to 300 ^{0}C.

To capture digital values of temperature in the places of installation of measuring equipment, a special technical means was used, namely: the module of analog-to-digital conversion (ADC) of the signal of thermocouples and thermistors. This measuring technical means is specially developed in institute, it allows to carry out temperature measurements with sensitivity in 0.25 ^{0}C. The module is based on the chip max. 31855, it takes into account the temperature of cold junctions and automatically corrects the temperature measurement values.

All analog-to-digital converters of a signal of sensors of control of temperature were placed in the block of the combined calculation of temperatures (fig. 4).

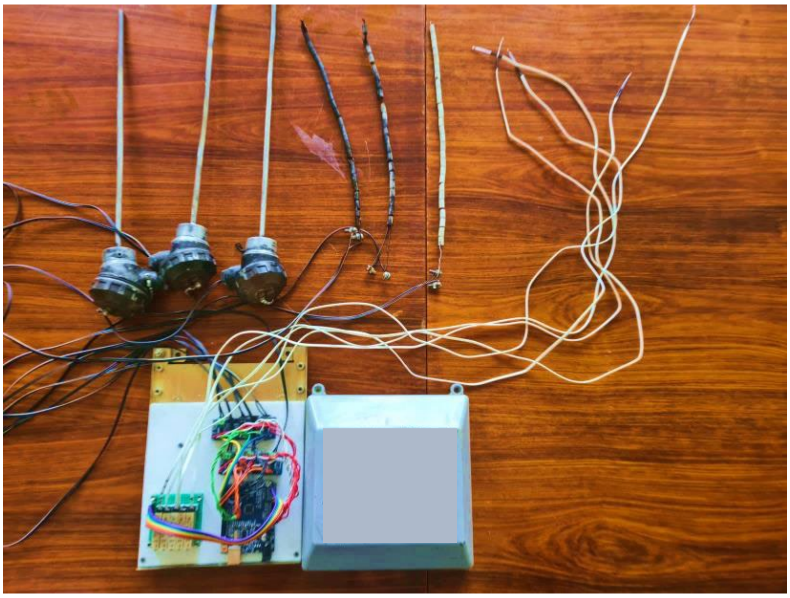

Fig. 4. A special means of reading information - a unit of combined temperature calculation

The PLX DAQ plug-in for Microsoft was also used to control in real time numerical temperature values and designing the corresponding graphs.

During the test, the temperature in the furnace met the requirements of the standard. Visual inspection revealed that the loss of integrity, thermal insulation and load-bearing capacity of the sample did not occur, but (Fig. 5) shows that its destruction began with the release of moisture and steam inside.

Fig. 5. Small fragment of reinforced concrete wall after the test

Figure (Fig. 6) shows a graph of temperature-time dependence of the heating chamber of the fire furnace.

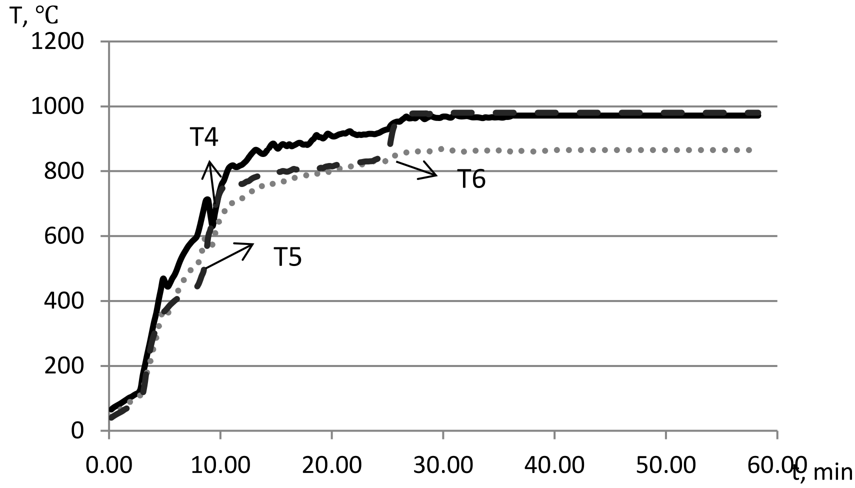

Fig. 6. Linear heating rate of the furnace chamber when testing a reinforced concrete wall, where: T4-T6 thermocouples installed in the walls of the fire furnace

According to the data of thermocouple heating (Fig. 7), the linear heating rate of the furnace chamber corresponded to the «standard» temperature curve of the fire, and is within the limits defined by the standard [7]. When the value of 980 ^{0}C was reached, the steady state was set by adjusting the heating power of the furnace. The test lasted 60 minutes.

(Fig. 7–8) shows the results of thermocouple readings on the heating, non-heating surface and at the level of the fittings.

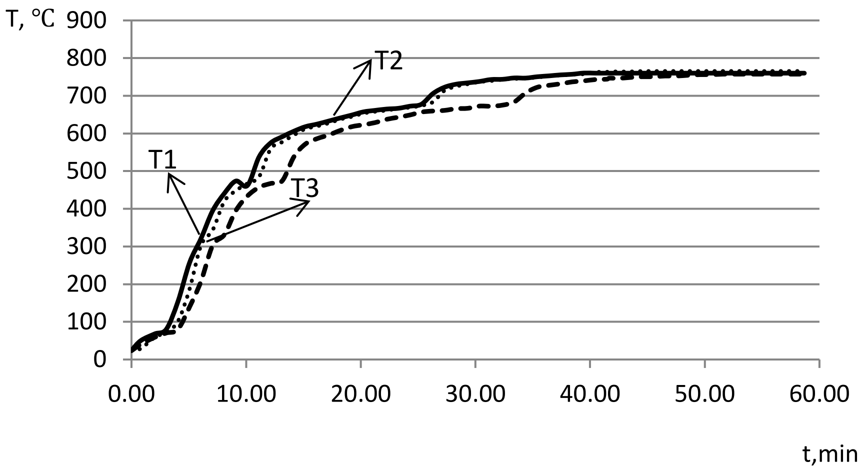

Fig. 7. The results of measuring the temperature of the test sample: T1-T3 – indicators of thermocouples, which are installed on the heating surface

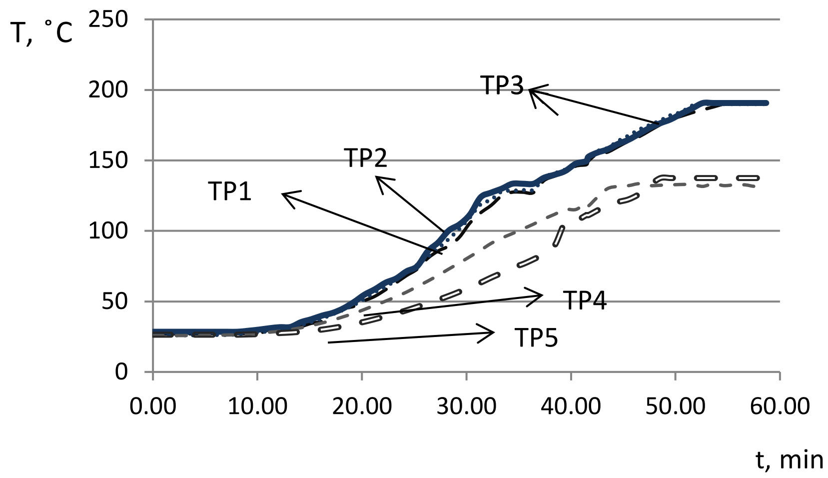

Fig. 8. The results of readings of thermistors in a fragment of the test sample: TP1-TP3 – indicators of thermistors are set at the level of fittings, TP4-TP5 – values of thermistors installed on a non-heating surface.

After analyzing the data obtained from the results of experiments, the following conclusions were obtained:

– two gas burners are able to ensure compliance with the "standard" temperature in the furnace chamber during a fire;

– during the heating of reinforced concrete, the release of moisture and steam inside the material was observed: on the heating surface this process took place from 15 to 25 minutes, on the non-heating from 35 to 57 minutes (Fig. 9) and at the reinforcement level from 32 to 52 minutes (Fig. 9);

– heating of the structure at all levels was uniform in the planes of thermocouples (Fig. 8–9);

– maximum temperature at the level of reinforcement scale 190 ^{0}C, was observed at the last minute of the experiment and continued to rise linearly after leaving the plateau;

– the maximum temperature on the non-heating surface is 137 ^{0}C, observed at the last minute of the experiment and continued to rise linearly after leaving the plateau;

– the obtained experimental data are sufficient for further calculation of temperature fields inside the structure and assessment of fire resistance of structures.

To determine the ability of experiments to reproduce the results, it is necessary to obtain quantitative indicators of the adequacy of the tests. Adequacy testing was performed on the basis of experimental information obtained as a result of fire tests of building structure fragments, during which the processes of interest to us are noticeable [8]. In our case, 3 experiments were performed on the standard temperature of the fire in the prototype of the fire installation of identical and simultaneously manufactured structures under the same external conditions.

Relative, absolute errors of experimental data were calculated as well

Fisher's F-test for sequential comparison of variances of temperature readings of each thermocouple located in the structure with the variance of reproducibility of experimental studies. Using Fisher's test, it is possible to test the hypothesis of equality of general variances, temperature distribution at each minute of testing.

$$F = \frac{S_{xy}^2}{S_y^2} \tag{1}$$

where S_{xy}^2 – variance of adequacy, S_y^2 – reproducibility variance.

The variance of adequacy is calculated as the deviation between the readings of a particular thermocouple and the average temperature in all three experiments of the corresponding place of temperature measurement.

$$S_{xy}^2 = \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n} \quad (2)$$

where n – number of temperature measurements, y_i – the value of the criterion during modeling, x_i – the value of the criterion during the test.

The reproducibility variance is calculated as the deviation of the temperature of a particular thermocouple and the average temperature for all experiments at its location, taking into account the error of thermocouples [7].

$$S_y^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y} + 1)^2 \quad (3)$$

where n – number of temperature measurements, $\overline{y}+1$ – average thermocouples, taking into account the error [table 1], y_i – thermocouple indicators directly at the measurement site.

Table 2. Dispersion parameters of the results of fire tests of reinforced concrete walls according to the results of three experiments

Thermocouple zone (fig. 4)	Absolute average deviation, [°C]	Relative deviation, [%]	F-criterion	Critical value of F-criterion.
T1	4.56	1.49	1.04	4.49
T2	4.91	1.41	1.13	
T3	4.84	1.66	1.01	
TP1	8.4	2.21	1.01	
TP2	8.7	1.95	1.32	
TP3	8.6	2.06	2.06	
TP4	8.6	2.31	1.02	
TP5	8.6	2.73	1.01	

As can be seen from table 2, the relative deviation did not exceed 3 %, and the calculated adequacy criteria (Fisher's F-test) are below the critical value, which confirms the adequacy of experimental data.

6 Conclusions

The conducted fire test showed that the obtained results can be used to verify the adequacy of experimental data of fire tests of fragments of building structures. The experiment to determine the temperatures at the control points on the heating, non-heating surfaces and at the level of reinforcement of wall fragments was carried out in accordance with the requirements of the standards for testing load-bearing walls for fire resistance. The results obtained during the tests are reliable.

According to the results of this work, the following is established:

1. The stages of creation of 3 small-sized fragments of reinforced concrete wall from heavy concrete with reinforcement are described. Overall dimensions: 1193×1195 mm; 1198×1194 mm; 1201×1199 mm. They were kept in a special room for at least 28 days.

2. The method of conducting an experimental test is described. Carrying out the test in a compact fire installation without mechanical load is the influence of the standard temperature of the fire when heating the element of the reinforced concrete wall on one side. Thermocouples were used to measure the temperature in the furnace THA-2388 with a wire diameter of 1.25 mm, which can be used to measure temperature in the range from 0 to 1300 ^{0}C. To measure the temperature in the sample thermistor MF 52 is used, it can be used to measure temperature in the range from –30 to 300 ^{0}C.
3. According to the experimental test, the heating surface of the studied small fragment has a uniform temperature distribution, the maximum temperature was 765 ^{0}C, the maximum temperature at the valve level was 190 ^{0}C, observed at the last minute of the experiment and continued to grow linearly after leaving the plateau; the maximum temperature on the non-heating surface is 137 ^{0}C, observed at the last minute of the experiment and continued to rise linearly after leaving the plateau;
4. The adequacy of the experimental data was confirmed: the relative deviation did not exceed 3 %, and the calculated adequacy criteria (Fisher's F-test) were below the critical value.

References

[1] Building Code B.1.1-7-2016 «Fire safety of construction sites. General Requirements», 2016.

[2] DSTU B V.1.1–19: 2007 Zakhyst vid pozhezhi. Perekryttia ta pokryttia. Metod vyprobuvan na vohnestiikist (EN 1365-2: 1999, NEQ). Kyiv, 2007 [in Ukrainian].

[3] T. Shnal, S. Pozdieiev, O. Nuianzin, S. Sidnei, Improvement of the Assessment Method for Fire Resistance of Steel Structures in the Temperature Regime of Fire under Realistic Conditions. In Materials Science Forum Trans Tech Publications Ltd, **1006** (2020) 107–116.

[4] O. Nuianzin, O. Tyshchenko, S. Zhartovskyi, P. Zaika, & A. Peregin, The research of carrying capacity of reinforced concrete walls under uneven warming. In IOP Conference Series: Materials Science and Engineering, **708 1** (2019) 012063.

[5] A. Perehin et al., Technique for creating the prototype of a compact fire plant for tests to determine the fire resistance of reinforced concrete structures. The scientific heritage: 38 (2021).

[6] MAX31855 Cold-Junction Compensated Thermocouple-to-Digital Converter. https://datasheets.maximintegrated.com/en/ds/MAX31855.pdf

[7] DSTU B.1.1-4-98*. Fire Protection. Building Constructions. Fire Resistance Test Methods. General Requirements, 1998.

[8] S. Pozdeev, O. Nuianzin, S. Sidnei, S. Shchipets, Computational study of bearing walls fire resistance tests efficiency using different combustion furnaces configurations. MATEC Web of Conferences, **116** 02027.