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ENVIRONMENTALLY SAFE INSTALLATION FOR DETERMINING THE FIRE RESISTANCE OF COATINGS AND FIRE RESISTANCE TESTS OF SMALL FRAGMENTS BUILDING STRUCTURES

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The work substantiates the parameters of the test installation, the principle of which is to heat the inner space of the furnace with the help of electric heating elements. The use of electric heaters, unlike liquid fuel (diesel fuel, fuel oil, gas), does not harm the environment, the environment, and ensures the environmental friendliness of building construction tests. The designed and created installation makes it possible to increase or decrease the temperature on the heating surface of the test sample, not only with the help of the heating temperature regulator, but also in manual mode by moving the test sample closer or further away from the radiation panel along the guides. According to the results of experimental studies, it was established that the chamber of the installation warms up evenly and according to the standard fire temperature regime. The conducted studies confirm the necessary reproducibility of experimental results. An installation with a test chamber size of 500×500×500 mm was created, which makes it possible to investigate the fire-resistant efficiency (ability) of fire-resistant coatings and to preliminarily estimate the fire resistance limit of small-sized fragments of building structures.

Keywords: installation for fire resistance tests, standard temperature regime, fire protection efficiency, radiant heating panel, thermocouple, building structure, temperature controller, small fragment, ecological.

Introduction. Fires are an extremely big problem today. Taking into account the 2023 final report of the World Center for Fire Statistics [1], between 1993 and 2021, the average number of fires was 3.7 million each year. The average number of people died in fires is 40.1 thousand people every year. Material damage caused by fires is estimated at billions of dollars. It should be emphasized that this report collects statistical data from only 39 countries of the world (the average reporting rate of countries from 27 to 57 in different years of providing statistical data on fires). Taking this into account, it should be concluded that the number of fires and losses from them is much greater in the whole world.

It should be noted that 31.3% (763,092 units) of the total number of fires are fires that occur in industrial, public, residential and other buildings. Taking into account such statistics, the task of preventing the occurrence and spread of fires is urgent.

Problem statement. It is obvious that the fire resistance of building structures has the most important things and influence on the development and spread of fires in buildings and structures, which must be taken into account at the design stage. Building regulations both in Ukraine and in the world provide that all building structures used in the construction of buildings and structures must have defined limits (classes) of fire resistance.

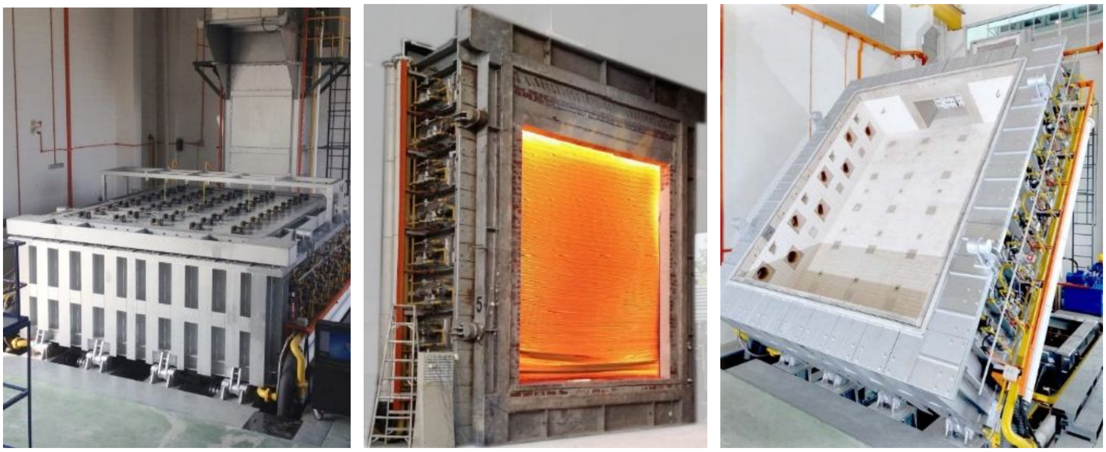
The procedure for testing building structures for fire resistance is used to establish the compliance of a structure or a certain structural element of a building with fire resistance requirements, which are defined by regulatory documents. Conducting fire experiments makes it possible to obtain the most complete information about the behavior of building structures under fire effects, however, the scale of field tests, laboriousness and energy consumption prompts the search and development of alternative methods that would ensure compliance with the conditions of conducting the experiment (standard fire temperature regime), and this would make it possible to preliminarily estimate the limit of fire resistance of a building structure in reduced dimensions or to experimentally determine the fire-resistant ability (efficiency) of fire-resistant coatings.

Analysis of recent research and publications. Thus, DBN V.1.1-7:2016 [2] stipulates that the limit of fire resistance of building structures is determined by means of fire tests in accordance with DSTU B V. 1.1-4 [3], according to standards on fire resistance test methods of specific types of building structures [4, 5, 6, 7], or by calculation methods that involve taking into account specific stages of calculation with the solution of heat engineering and static problems. According to Ukrainian, European and international standards [3, 8, 9, 10, 11, 12, 13] regarding fire tests of building structures, as a rule, the use of large-sized fire furnaces for testing building structures of standard sizes is assumed.

When using fire furnaces to reproduce the effect of fire on building structures, as a rule, liquid fuel is used, which undoubtedly affects the environmental friendliness of the testing process, since harmful emissions from the burning of fossil fuels in the 21st century have reached catastrophic proportions [14].

There are horizontal, vertical, hydraulic, and reduced furnaces for fire resistance tests.

In Fig. 1 and Fig. 2 present several variants of fire furnaces used to assess the fire resistance limit of basic building structures [15].

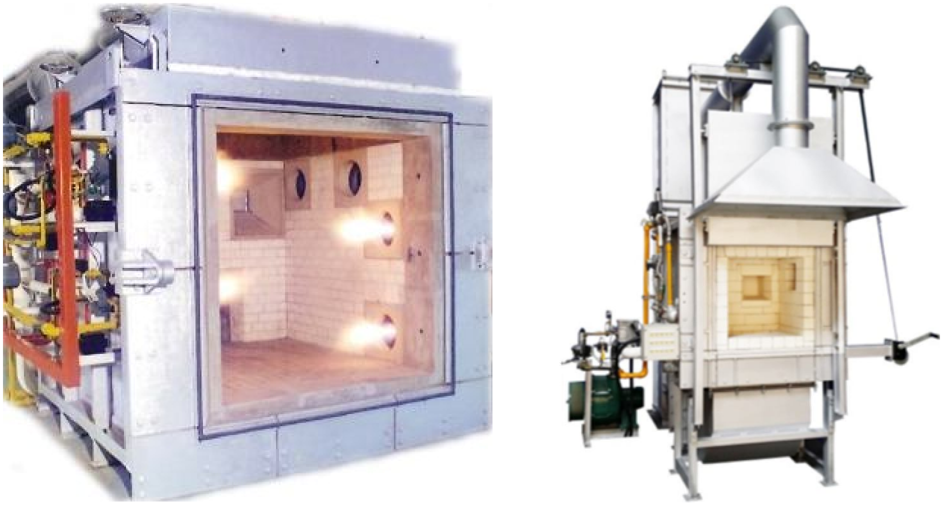


(a) (b) (c)

Fig. 1. Full-scale test fire furnaces:
(a) a full-scale horizontal/floor test furnace for evaluating the fire resistance of a horizontal structure, such as slabs, ceilings, beams, ventilation ducts, in a horizontal orientation (chamber dimensions: 4×3×1.2/2 m, 4×4×1.2/2 m, 4×5×1.2/2 m); (b) a full-scale vertical/wall-mounted test furnace for evaluating the fire resistance of building elements such as walls, doors, seams, penetration seals, etc. in a vertical orientation (chamber dimensions: 3×3×1.2 m, 4×3×1.2 m, 4×4×1.2 m, 5×4×1.2 m); (c) a full-scale hydraulic inclined dual-purpose test furnace that can be used to test walls, doors, dampers, seams, penetration seals, slabs, ceilings, beams, ventilation ducts, etc. in vertical or horizontal orientation (chamber dimensions: 4×3×1.2 m, 5×4×1.2 m)

These furnaces allow you to assess fire resistance in accordance with national and international standards, in particular: walls and partitions, doors and sash assemblies, columns and beams, ceilings, floors, glass structures, ventilation ducts, assess the effectiveness of fire protection, etc.

Today, researchers create and adapt new, alternative (standardized) installations and methods for evaluating the fire resistance of building structures and the effectiveness of fire-resistant coatings. For example, the authors [16] created a furnace for thermophysical tests of small-sized fragments of building structures and individual nodes of their butt joints, which allows to conduct fire tests of enclosing building structures without load (the size of the fire chamber is 1m × 1m × 1m). This furnace was widely used for experimental studies of multilayer enclosing structures of buildings and structures [17, 18, 19, 20]. Also, the design of this fire furnace allows conducting fire tests to evaluate the effectiveness of fire-resistant coatings for metal structures. The authors [21] use a fire furnace (fire chamber size 850×650×730 mm) created by the Ukrainian Research Institute of Civil Protection. The design of the furnace creates a fire effect according to the standard fire temperature regime on the test sample, which is installed in the furnace vertically or horizontally instead of a heat-insulating cover. This installation is also used to determine the characteristics of the fire-resistant ability of fire-resistant materials for load-bearing steel structures by testing a set of samples of steel structures with a fire-resistant coating. To determine the fire-resistant properties of reactive fire-resistant coatings for metal structures, the authors of [22] created a cylindrical chamber furnace of the mine type with an internal space diameter of 200 mm and a height of 300 mm, which makes it possible to set the heating modes with the help of silicon carbide electric heaters. The authors [23, 24], on the basis of the Training complex for the practical training of specialists of the Operational and Rescue Service of Civil Protection, Cherkasy Institute of Fire Safety named after Heroes of Chernobyl of the National University of Civil Protection of Ukraine created a prototype of a fire installation to determine the temperature distribution of small fragments of reinforced concrete structures. The peculiarity of this installation is the technical possibility of changing the size of the opening for the removal of combustion products, which allows you to additionally regulate the heating process of the furnace chamber and ensure the necessary temperature regime of the fire. The authors also substantiated the use of gas as a fuel to increase the environmental friendliness of fire tests. In [25], the authors investigated the influence of the design parameters of the furnace combustion chamber and the fuel and air supply system on the condition of compliance with the standard fire temperature regime during fire resistance tests of building structures. As a result of these studies, the technical parameters of the fuel supply and ventilation system were determined, which makes it possible to build an automated complex of the process of testing fire resistance of building structures.



(a) (b)

Fig. 2. Test fire furnaces for samples of reduced dimensions:
(a) Inductive fire resistance test furnace for testing a small sample of material or assembly for resistance to high temperatures according to international fire resistance test methods (chamber dimensions: 1×1×1 m, 1.2×1.2×1.2 m, 1.5×1.5×1.5 m, 2×1.5×1.5 m); (b) Mini-furnace for evaluating the fire resistance of small vertical samples (chamber dimensions: 0.5×0.5×0.5 m)

The authors [26] developed an oven according to the modified standard BS 476-22 [27] for evaluating the thermal insulation properties and integrity of building panels. The size of the furnace opening, where the panels are mechanically fixed, is 315×165 mm.

All considered fire chambers and installations have their advantages and disadvantages. The advantages include the possibility of testing small-sized fragments of building structures, the use of standard control and measurement equipment, and ease of research preparation. In most of the considered furnaces, the disadvantages will be: the difficulty of ensuring uniform heating of installations and test samples, the possibility of adjusting the temperature inside the fire chamber during the experiment (with deviations from the standard temperature curve), the time for preparing for the experiment. Also, one of the main disadvantages of most fire chambers is their operation on liquid fuel, which undoubtedly affects the environmental friendliness of the testing process. It should be noted that the provision of the necessary heating modes directly depends on the power of the combustion nozzles, which may lose their technical power characteristics over time, and accordingly will not be able to create the temperature and fire effect necessary for conducting experiments.

Since the intensity of fire development can differ significantly depending on the place of origin, and standard tests of building construction elements cannot always effectively reflect realistic fire scenarios, it is important to create and use special installations, test chambers that will meet research goals and reduce damage to the environment.

Formulation of research purpose. The main goal of the article is rationale use of an installation for determining the fire-resistant capacity (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures, taking into account the reduction of the harmful load on the environment.

Researchmethods. Analysis of the possibilities of assessing the fire resistance of building structures using standardized and alternative types of fire chambers. Determination of disadvantages and advantages when conducting fire tests of various types of building structures. Experimental studies to establish the reproducibility of the results regarding the provision of the standard fire temperature regime by the experimental plant.

Presentation of the main research material. In order to solve the set goal of the work, it is necessary to describe and justify the creation of an installation for determining the fire-resistant ability (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures. In particular, taking into account the review and analysis of the capabilities of existing types of fire chambers, their advantages and disadvantages, it is necessary to take into account the following main factors:

- environmental friendliness during use;
-economic efficiency;
- compact installation;
- determination of technical characteristics of the installation;
- provision of a standard fire temperature regime and the ability to adjust the temperature inside the chamber during the experiment;
- ease of preparation of the installation before the start of the test and its maintenance after the test.

Taking into account the above factors, a test facility was created, the principle of which is to heat the inner space of the furnace with the help of electric heating elements, which, unlike liquid fuel (diesel fuel, fuel oil, gas), do not harm the environment.

The temperature in the inner chamber of the furnace is controlled by thermocouples with the results recorded using a control and measuring device. The schematic image and the projected view of the installation are presented in Fig. 3.

The radiant heating panel consists of three heaters with a capacity of 4 kW each, powered by a voltage of 220 V from a three-phase network. Working zero is common.

During the test trials, a problem arose with the control and provision of a standardized temperature-time dependence in the thermal chamber. During the experiments, when fast heating was installed on the control device up to a temperature of 1000 ºC, the electronic heating elements (spirals) failed due to the high heating rate. As a result, the electric spirals did not have time to expand, which caused an inter-turn short circuit and destruction of the heating element. It was also observed that the temperature distribution inside the chamber was uneven. Accordingly, further research was impossible due to significant temperature deviations inside the chamber from the standard fire temperature regime. To solve this problem, a new control unit was developed - an AC voltage regulation module designed to gradually adjust the heating temperature of the radiation panel of the test chamber.

The connection diagram of the control unit is shown in Fig. 4.

The BP-10 heating temperature regulator (meter-regulator with a triac output) ensures a gradual rise and maintenance of the set temperature of the radiation panel. It is switched with three power triacs (TS-142-80) with the help of built-in optosymtors outputs and a connected thermal converter CATdesigned for temperatures up to 1200°C.

Also, taking into account the uneven distribution of temperatures inside the chamber (significant deviations of more than 30-40% from the standard fire temperature regime near the sample of the building structure being tested), a decision was made to reduce the length of the chamber from 1000 mm to 500 mm. Accordingly, the design of the test facility was created, the thermal chamber of which is cubic in shape with the side size of 500 mm.

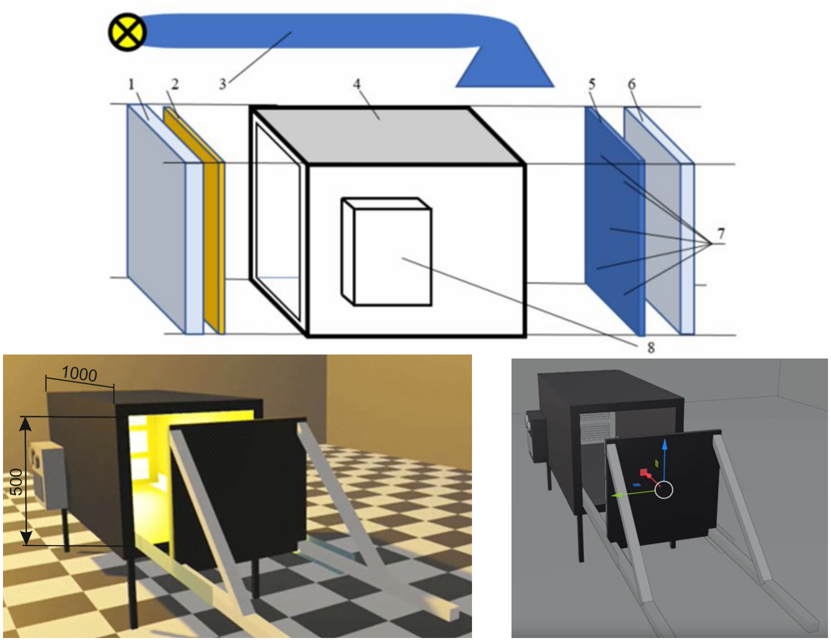


Fig. 3. Schematic representation and projected view of the installation for determining the fire-resistant capacity (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures, where: 1- thermal insulation of the radiation panel, 2- radiation panel, 3- ventilation system, 4- test chamber with thermal insulation, 5- test sample, 6- heat-protective material to protect against temperature loss (thickness 40 mm), 7- places of installation of thermal converters chromel-alumel thermocouple (CAT)to control the temperature on the experimental sample, 8- heating control unit of the radiation panel

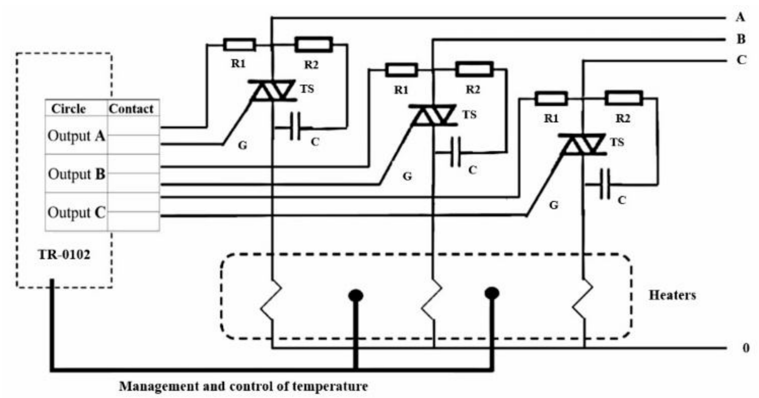


Fig. 4. Connection diagram of the regulator with optosymtorsoutputs for controlling power triacs (three-phase), where: R1 – switching resistance, (R2-C) – circuit for protection against switching overvoltage (protection against TS (symmetrical thyristor) breakdown), G – control electrode (gate)

Thus, reducing the size of the installation and creating a temperature regulator stabilized the operation of the installation and ensured compliance with the standard temperature regime of the fire with the additional possibility of lowering or increasing the temperature, in case of its deviation during the experiment. Also, a feature of the created test setup is the ability to increase or decrease the temperature on the heating surface of the test sample, not only with the help of the heating temperature regulator, but also in manual mode, by moving the test sample closer or further away from the radiation panel along the guides.

The results of the test tests on compliance with the standard fire temperature regime with updated installation parameters are presented in Fig. 5. The tests were performed three times with temperature measurement at two points (at the geometric center of the installation and near the test sample at a distance of 100 mm). Fig. 5 shows the average values from thermocouples based on the results of three tests.

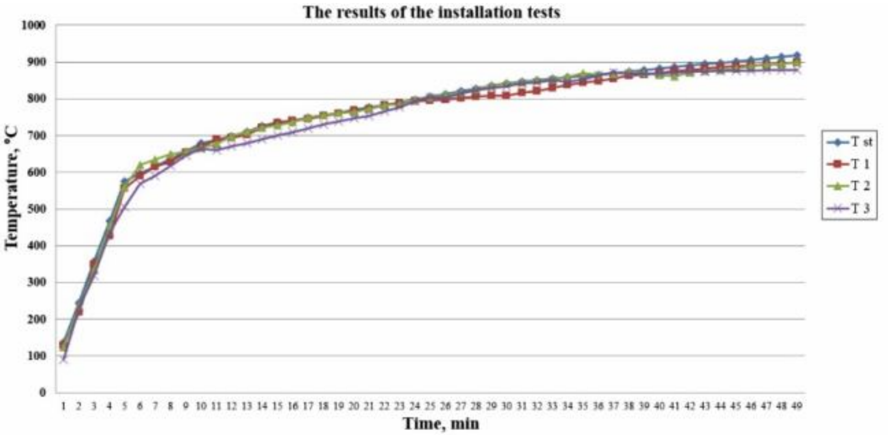
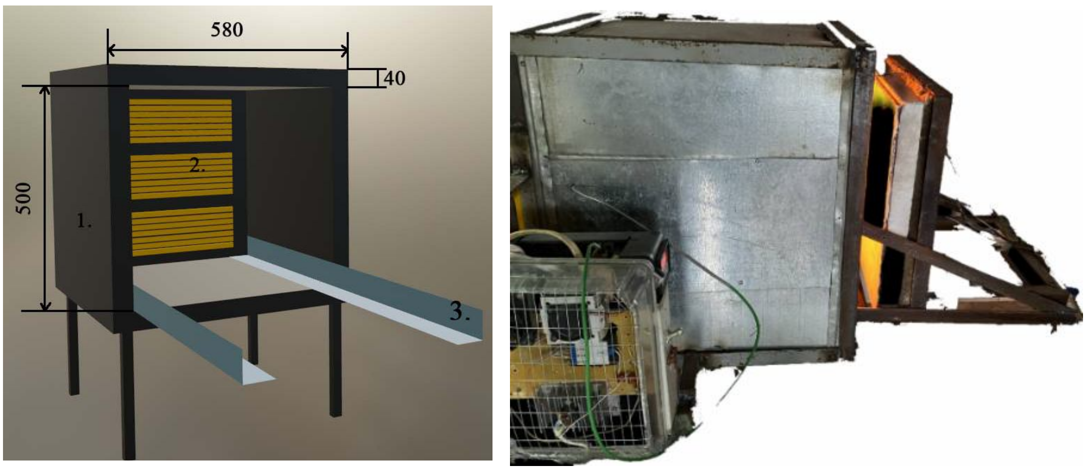


Fig. 5. Temperature-time dependence of the heating of the installation chamber where: Tst – normalized standard fire temperature regime, T1 – average value of the first test trial, T2 – average value of the second test trial, T3 – average value of the third test trial

The obtained data indicate that the size of the installation and the ability to adjust the heating temperature provide the necessary temperature-time dependence, which is regulated by the test standards.

The structural scheme and full-scale view of the test facility are shown in Fig. 6.



(a) (b)

Fig. 6. Structural diagram and full-scale view of the test setup: (a) 1 – heat-insulating body made of vermiculite plates (thickness 40 mm) sheathed with metal sheets, 2 – radiation heating panel, 3 – guides for installation and movement of the experimental sample; (b) the test rig with the installed sample is prepared for testing.

Conclusions. According to the results of the research, the parameters of the test installation, the principle of which consists in heating the inner space of the furnace with the help of electric heating elements, which, unlike liquid fuel (diesel fuel, fuel oil, gas), do not harm the environment.

The performed experimental study showed that the created installation provides the necessary temperature regime for determining the fire-resistant capacity (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures. According to the results of the experimental tests, it was established that the chamber of the installation warms up uniformly and according to the temperature-time dependence Ts = 345lg (8t+1)+20)), the temperature deviation does not exceed the permissible values regulated by the fire resistance test standards of building structures. At the same time, the temperature regulation process using BP-10 with triac output ensures stable operation of electric heating elements up to temperatures of 1000 °C. It is also possible to additionally decrease or increase the temperature on the heating surface of the test sample, in case of its deviation during the experiment, by moving the sample closer or further away from the heating panel.

Taking into account the obtained results, it will be promising to study the fire-resistant efficiency (ability) of fire-resistant coatings, as well as the possibility of preliminary experimental evaluation of the fire resistance of fragments of building structures measuring 500×500 mm, their comparison with the results obtained on large-sized furnaces and further theoretical justification based on the criteria of similarity.

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ЕКОЛОГІЧНО БЕЗПЕЧНА УСТАНОВКА ДЛЯ ВИЗНАЧЕННЯ ВОГНЕЗАХИСНОЇ ЗДАТНОСТІ(ЕФЕКТИВНОСТІ) ВОГНЕЗАХИСНИХ ПОКРИТТІВ ТА ВИПРОБУВАНЬ НА ВОГНЕСТІЙКІСТЬ МАЛОГАБАРАТНИХ ФРАГМЕНТНИХ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ

Актуальність. Беручи до уваги статистику пожеж, актуальним є завдання щодо запобігання виникненню та поширенню пожеж. Очевидним є той факт, що найважливіше значення та вплив на розвиток і поширення пожеж в будівлях і спорудах має вогнестійкість будівельних конструкцій, яка повинна враховуватись на етапі проектування. Проведення вогневих експериментів дає змогу отримати найбільш повну інформацію про поведінку будівельних конструкцій при вогневих впливах, проте масштабність натурних випробувань, трудомісткість, енергозатратність та шкода навколишньому середовищу спонукає до пошуку та розроблення альтернативних методів, які б забезпечили екологічність проведення випробувань, дотримання умов проведення експерименту (стандартний температурний режим пожежі), і при цьому дали б змогу оцінити межу вогнестійкості будівельної конструкції у зменшених розмірах чи експериментально визначити вогнезахисну здатність (ефективність) вогнезахисних покриттів. **Мета роботи.** Обґрунтування створення установки для визначення вогнезахисної здатності (ефективності) вогнезахисних покриттів та випробувань на вогнестійкість малогабаритних фрагментів будівельних конструкцій з урахуванням зменшення шкідливого навантаження на навколишнє середовище. **Основні результати.** Проведено дослідження та обґрунтовано конструктивні особливості установки, принцип роботи якої, полягає у нагріванні внутрішнього простору камери за допомогою електричних нагрівальних елементів які на відміну від рідкого палива (дизельного палива, мазуту, газу) не завдають шкоди навколишньому середовищу. Розроблено блок управління-модуль регулювання змінної напруги, призначений для регулювання температури нагріву радіаційної панелі випробувальної камери. Конструкція створеної установки для випробувань дає можливість збільшувати чи зменшувати температуру на обігрівній поверхні дослідного зразка, не тільки за допомогою регулятора температури нагріву, а й в ручному режимі, шляхом наближення чи віддалення дослідного зразка до радіаційної панелі по напрямним. **Висновки.** За результатами тестових експериментальних випробувань, встановлено, що камера установки прогрівається рівномірно та згідно стандартизованої температурно-часової залежності $T_s = 345\lg(8t+1)+20$). При цьому процес регулювання температури з використанням ВР-10 з симісторним виходом забезпечує стабільну роботу електричних нагрівальних елементів до температур 1000 °С. Особливістю створеної установки є можливість додаткового пониження чи підвищення температури на обігрівній поверхні дослідного зразка, у разі її відхилення під час проведення експерименту, за допомогою наближення чи віддалення зразка до нагрівальної панелі. Виконані дослідження підтверджують необхідну відтворюваність експериментальних результатів.

Ключові слова: установка для випробувань на вогнестійкість, стандартний температурний режим, вогнезахисна ефективність, радіаційна нагрівна панель, термопара, будівельна конструкція, регулятор температури, малогабаритний фрагмент, екологічність.

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ENVIRONMENTALLY SAFE INSTALLATION FOR DETERMINING THE FIRE RESISTANCE OF COATINGS AND FIRE RESISTANCE TESTS OF SMALL FRAGMENTS BUILDING STRUCTURES

Actuality. Taking into account fire statistics, the task of preventing the occurrence and spread of fires is urgent. It is obvious that the fire resistance of building structures, which must be taken into account at the design stage, is of the greatest importance and influence on the development and spread of fires in buildings and structures. Conducting fire experiments makes it possible to obtain the most complete information about the behavior of building structures under fire effects, however, the scale of field tests, labor-intensiveness, energy consumption and damage to the environment prompts the search and development of alternative methods that would ensure the environmental friendliness of the tests, compliance with the conditions of the experiment (standard fire temperature regime), and at the same time would make it possible to estimate the limit of fire resistance of a building structure in reduced dimensions or to experimentally determine the fire-resistant ability (efficiency) of fire-resistant coatings. **Purpose**. The main goal of the article is rationale use of an installation for determining the fire-resistant capacity (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures, taking into account the reduction of the harmful load on the environment. **Main results.** Research has been carried out and the design features of the installation have been substantiated, the principle of which is to heat the inner space of the chamber with the help of electric heating elements, which, unlike liquid fuel (diesel fuel, fuel oil, gas), do not harm the environment. A control unit-module of variable voltage regulation designed to regulate the heating temperature of the radiation panel in the test chamber has been developed. The design of the created test setup makes it possible to increase or decrease the temperature on the heating surface of the test sample, not only with the help of the heating temperature regulator, but also in manual mode, by moving the test sample closer or further away from the radiation panel along the guides. **Conclusions**. According to the results of experimental tests, it was established that the chamber of the installation warms up uniformly and according to the standardized temperature-time dependence Ts = 345lg (8t+1)+20). At the same time, the temperature regulation process using BP-10 with triac output ensures stable operation of electric heating elements up to temperatures of 1000 °C. A feature of the created installation is the possibility of additional lowering or raising of the temperature on the heating surface of the experimental sample, in case of its deviation during the experiment, by means of approaching or moving away from the sample to the heating panel. The conducted studies confirm the necessary reproducibility of experimental results.

Keywords: installation for fire resistance tests, standard temperature regime, fire protection efficiency, radiant heating panel, thermocouple, building structure, temperature controller, small fragment, ecological.

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У роботі обгрунтовано створенняустановки для визначення вогнезахисної здатності (ефективності) вогнезахисних покриттів та випробувань на вогнестійкість малогабаритних фрагментів будівельних конструкційпринцип роботи якої, полягає у нагріванні внутрішнього простору випробувальної камери за допомогою електричних нагрівальних елементів.

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The work substantiates the creation of an installation for determining the fire-resistant capacity (efficiency) of fire-resistant coatings and fire resistance tests of small-sized fragments of building structures, the principle of which is to heat the inner space of the test chamber with the help of electric heating elements.

Fig. 6. Ref. 27.

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