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Fiberglass thermal barrier for building safety

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ABSTRACT
The state of the issue of fire protection from landscape fires is studied and discussed. We set tasks to evaluate the recovered samples of two rolled fiberglass systems by modifying them in various ways: "fiberglass + refractory foam" and "fiberglass + aluminum foil". The first method involves applying a single layer of refractory foam Penosil Premium to the exposed surface of the samples. The second method is to modify the exposed surface by wrapping a layer of aluminum foil. The possibility of resisting an impacting landscape fire with a certain heat flux density was studied. We described the methods of conducting bench tests of a difficult-to-burn material under the influence of a constant heat flow, determine the temperature change of fiberglass from the heating time of the samples, the loss of their mass, determine the reliability of the empirically obtained data. A method for restoring a protective barrier made of fiberglass after damage by a landscape fire is proposed. At the same time, the temperature of the back side of the samples recovered using aluminum foil is reduced by half in relation to samples with refractory foam on the surface and is 173.2 °C (with the application of a single layer of foam 337.1 °C).

KEYWORDS
landscape fire • protective barrier • weakly combustible fiberglass • bench tests

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Introduction

Fires at buildings and structures protection facilities can occur when dry grassy and other vegetation ignites. They lead to serious environmental consequences and the failure of expensive equipment [1–7]. Fire is presented as a complex physical and chemical process. At the same time, intense heat generation occurs. This is followed by catastrophic consequences for humans and the environment. The analysis of fire statistics in Russia for 2019 - 2022 is carried out [8]. The data are presented in Table 1.

In Table 1, in the period from 2019 to 2022, there is a tendency to reduce the number of fires in almost every type of facility. Over the past two years, the number of fires in open areas and in residential buildings and adjacent buildings has increased by 8000 cases. Their combined number exceeds 60 % of the total number of fires. The need for measures to ensure the protection of buildings is urgent.

To study this problem in more depth, some available research results are analyzed. In order to increase the limits of fire resistance of equipment, a method for reducing the impact of heat and convective flows on an object is proposed by Fisher R. et al. [9]. This method is based on fencing the protected object with a fire-retardant screen. A coolant

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medium is created in the structure of the porous materials of this screen. The process of transferring combustion products during fires over a large area is considered in [10]. Fires in open areas are characterized by a high rate of combustion propagation, where aerodynamics play a major role. Currently, the construction of buildings made of wood is widely popular [11,12]. Prusakov V. et al. [13] paid attention to the issues of studying the fire resistance of structures with a fire-resistant coating based on ultrathin basalt fiber for fire-resistant sealing of joints of reinforced concrete structures [13–21].

Table 1. Fires in Russia at certain facilities in 2019-2022

The object of the fire	Number of fires, thousand units.			
	2019	2020	2021	2022
Industrial buildings	3.5	3.4	3.6	1.9
Warehouse buildings, structures	1.6	1.5	1.5	0.8
Buildings, structures and premises of trade enterprises	2.8	2.6	2.7	2.4
Educational buildings	0.3	0.3	0.3	0.3
The building of Public Health and Social Services	0.3	0.3	0.3	0.3
Buildings, public service facilities	1.2	1.1	1.2	1.3
Administrative buildings	0.9	0.9	0.8	1.0
Buildings, structures and premises for cultural and leisure activities of the population and religious rituals	0.4	0.3	0.3	0.3
Buildings for temporary stay (residence) of people	0.4	0.3	0.3	0.3
Residential buildings and outbuildings (including an apartment building)	115.4	114.3	114.4	110.7
Buildings and structures for agricultural purposes	0.7	0.7	0.7	0.6
Industrial structures and installations	0.9	0.9	0.9	1.2
Building (structures) under construction (under reconstruction)	17.9	17.1	17.2	15.1
Unused building (structure)	1.7	1.5	1.2	1.2
A place of open storage of substances, materials, agricultural land and other open areas (including garbage), including dry grass (hay, reeds, etc.).	116.0	146.3	122.5	118.9

In [22], it was proposed to isolate the object of protection from the external environment by creating a mesh screen above its surface. A thermal insulation layer is formed on the outside of the screen over its entire area. This method is effective only in case of fire. The "dome" created in this way is local in nature and is carried out using a mobile robot. The engineering and technical solution of the proposed method is very complex in its execution and implies significant material resources for implementation.

The solution described in Fig. 1 is partially similar to [22]. A distinctive feature is the ability of the device to transform into separate modules and into a single fire barrier for installation directly next to the protected object or through its possible environment. This solution is aimed at ensuring the safety of building equipment from the effects of landscape fires at the stages of fire prevention, localization and elimination. When a landscape fire is exposed to fiberglass at high temperature, the amount of the protective layer of plastic on the surface of the protective cloth decreases. During the operation of damaged fiberglass, its destruction may occur due to negative environmental influences. The damaged surface must be repaired. A comparative analysis of the two methods of such activity allows us to determine the most acceptable option.

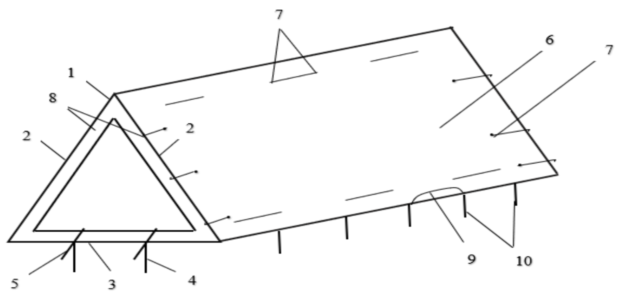


Fig. 1. Device for preventing the spread of landscape fire: 1 – support frame, 2 – sides of the support frame, 3 – base of the support frame, 4 –hooks in the soil, 5 - horizontal supports in the form of plates, 6 – fire–resistant cloth, 7 - fastening elements of the cloth, 8 – connecting devices, 9 – steel cables, 10 – additional hooks in the soil [23,24]

The object of the study is damaged refractory fiberglass and the method of its restoration. The first method involves applying a single layer of refractory foam Penosil Premium to the exposed surface of the samples. The second method is to modify the exposed surface by wrapping a layer of aluminum foil.

The subject of the study is the temperature dynamics of the back side of the studied samples of reconstituted fiberglass, depending on the values of the heat flux density.

The purpose of the work is to study the changes in the basic parameters of fiberglass over time under thermal influence. To achieve the goal of the work, it is necessary to solve a number of tasks:

1. to conduct a search for patent and scientific research;
2. to propose a methodology for conducting bench tests of samples of damaged refractory fiberglass separately in the first and second ways;
3. to determine the pattern of temperature changes on the back of the test samples over time of exposure to the exposed surface of different densities of heat fluxes;
4. obtain equations to describe the dynamics of the process under study and determine the reliability of the data based on the results of the study;
5. to establish the dependence of the heating time on the loss of mass and temperature changes on the back of the fiberglass using the Statistica software package.

Research methods

To determine the effect of heat flow on fiberglass in its various modifications, a number of bench tests were carried out using a standardized technique, the scope of which is reduced to testing building materials for flammability [25]. For this purpose, samples of weakly combustible fiberglass with a square shape with sides of 16.5 × 16.5 mm were made. The thickness of all test samples is not more than 0.18 mm. 100 g of fiberglass contains: fiberglass (the basis of the material) – 34 g with the addition of chemical compounds (glycerin -15 g, titanium dioxide -13.6 g, kaolin – 19.4 g, epoxy resin – 18 g). Tests of each sample were carried out for 10 minutes using an installation for determining the flammability of building structures (Fig. 2).

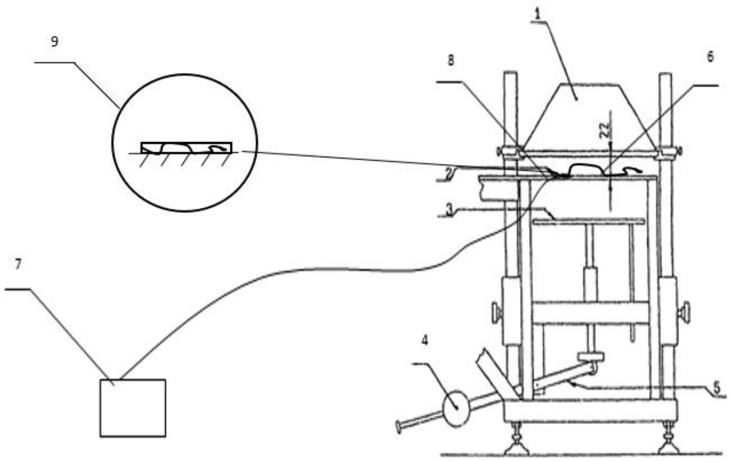
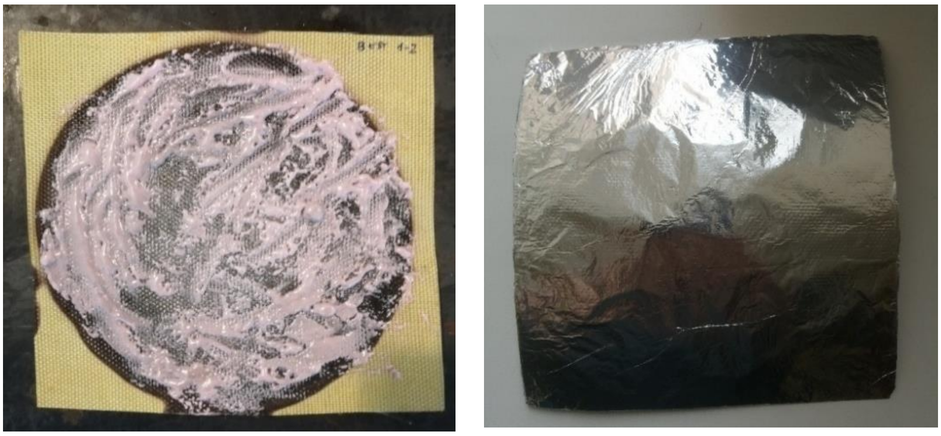


Fig. 2. Installation for determining the temperature of the back of the sample: 1 – radiation panel, 2 – protective plate, 3 – movable platform for the sample, 4 – counterweight, 5 – lever, 6 – test sample, 7 – microprocessor–controlled two-channel regulator 2 TRM 1, 8 – thermocouple, 9 – fiberglass

The studies of the recovered fiberglass were carried out under the same conditions. The heat flow exposure power for the test unit is 39 kW/m^2. The indoor air temperature is 27.1 °C. To comply with the conditions of the first method, a layer of refractory foam was applied using a metal spatula to the exposed surface. The thickness of the layer was 1.5 mm each. The test sample is shown in Fig. 3(a). According to the second method, the samples were recovered using aluminum foil with a layer thickness of no more than 0.2 mm. A sample for this condition is shown in Fig. 3(b) [24–32].



(a) (b)

Fig. 3. Samples of reconstituted weakly combustible fiberglass:
(a) the first method; (b) the second method

Three samples were selected for each of the methods for testing. The temperature of the back side of the samples was measured using thermocouples. The determination of this parameter is necessary to prevent the spread of a landscape fire through an obstacle after it is heated to the ignition temperature of dry vegetation. The test facility is calibrated before the start of the research.

Table 2 shows the results of bench tests of refractory fiberglass in the "fiberglass + refractory foam" system. Table 3 shows the results of bench tests of refractory fiberglass in the "fiberglass + aluminum foil" system.

Table 2. Bench tests in the "fiberglass + refractory foam" system

Experiment number	Time, min	Fiberglass sample 1		Fiberglass sample 2		Fiberglass sample 3	
		Temperature of the back of the sample, °C	Sample mass loss Δm, g	Temperature of the back of the sample, °C	Sample mass loss Δm, g	Temperature of the back of the sample, °C	Sample mass loss Δm, g
1	1	316.1	2.53	317.2	2.56	315.4	2.54
2	2	337.1	5.15	333.5	5.15	334.6	5.14
3	3	331.0	8.15	330.2	8.14	329.9	8.02
4	4	323.2	11.14	326,1	11.17	327.1	11.01
5	5	321.9	15.05	324.1	15.1	323.3	14.9
6	6	326.1	18.59	324.3	18.58	325.4	18.42
7	7	322.1	21.12	321.8	20.92	323.6	20.99
8	8	319.3	23.54	317.7	23.3	318.2	23.38
9	9	324.0	24.78	322.1	24.49	323.7	24.59
10	10	321.7	25.96	320.2	25.63	321.5	25.76

Table 3. Bench tests in the "fiberglass + aluminum foil" system

Experiment number	Time, min	Fiberglass sample 1		Fiberglass sample 2		Fiberglass sample 3	
		Temperature of the back of the sample, °C	Sample mass loss Δm, g	Temperature of the back of the sample, °C	Sample mass loss Δm, g	Temperature of the back of the sample, °C	Sample mass loss Δm, g
1	1	139.5	0.14	138.4	0.13	137.8	0.12
2	2	163.2	0.29	161.7	0.29	164.5	0.28
3	3	168.4	0.46	166.2	0.43	166.1	0.44
4	4	171.2	0.63	170.8	0.59	173.2	0.63
5	5	171.5	0.83	171.2	0.76	172.7	0.83
6	6	166.8	1.02	164.7	0.95	163.8	1.02
7	7	167.6	1.14	165.1	1.13	168.2	1.2
8	8	166.5	1.25	165.5	1.27	166.1	1.39
9	9	163.1	1.37	162.8	1.42	164.3	1.56
10	10	164.3	1.53	161.8	1.56	160.7	1.71

Results and Discussion

Figure 4 shows photographs of fiberglass samples in various modifications after the end of high-temperature exposure during bench tests. Figure 4 shows the fiberglass recovered by the first and the second methods after repeated high-temperature exposure.

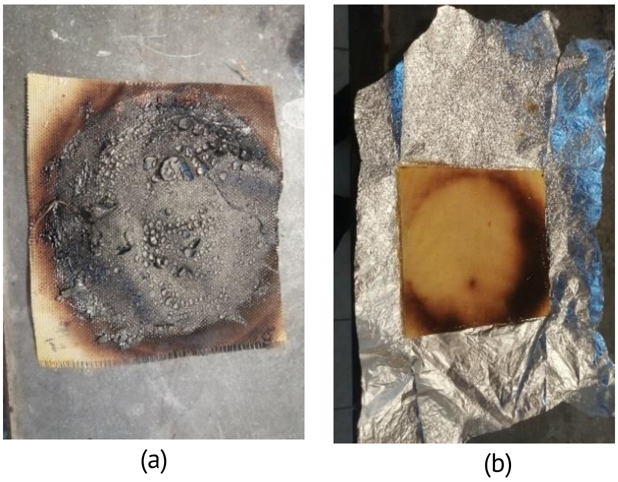


Fig. 4. Samples of recovered fiberglass after repeated high–temperature exposure: (a) recovered by the first method; (b) recovered by the second method

The results of measuring the temperature of the back side of the fiberglass samples recovered by the first method are shown in Fig. 5. After the experimental data were approximated, the coefficient of determination ($R^2 \leqslant 1$) was calculated.

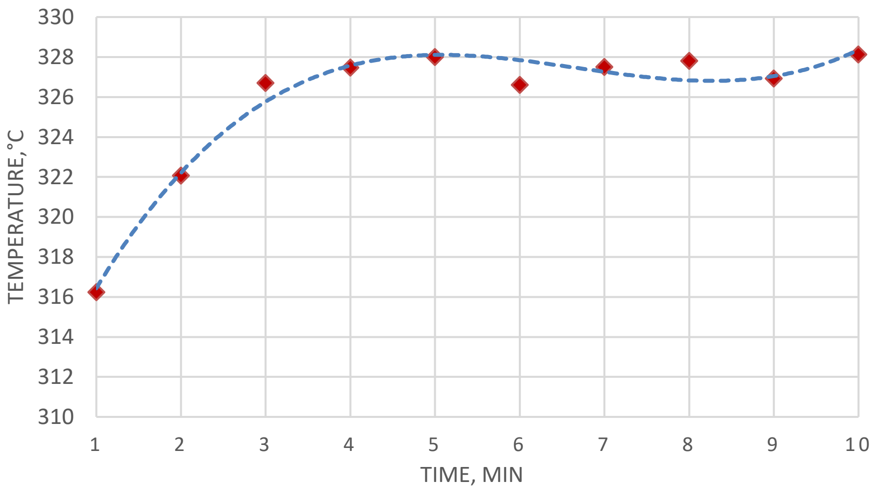


Fig. 5. Dependence of the temperature of the back side of the fiberglass of the samples recovered by the first method on the heating time

To describe the dependence of the temperature change of the back side of fiberglass and the mass loss of the samples recovered by the first method on the heating time, static data processing was performed in Fig. 5 and 6. The data obtained from the results of the experiment were processed using the Statistica software package.

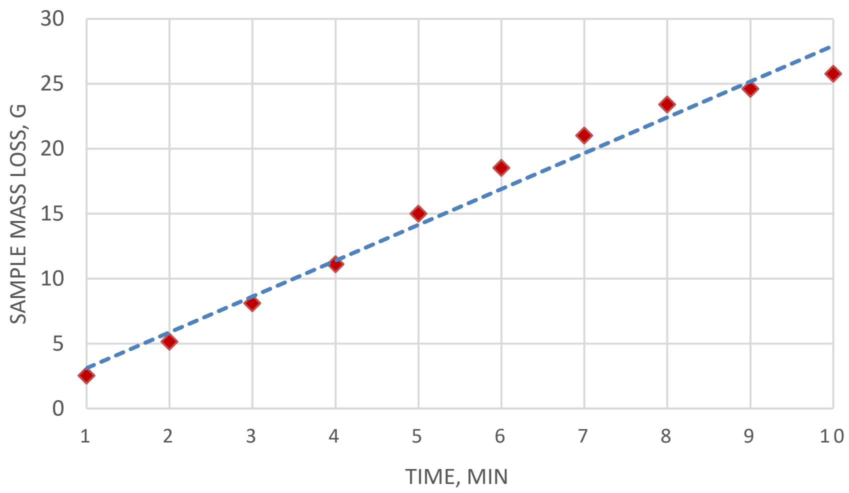


Fig. 6. Dependence of the mass loss of the samples recovered by the first method on the heating time

Based on the results of processing the empirically obtained data, the equations are compiled:

$T_1(\tau) = 0.079\ \tau^3 - 1.590\ \tau^2 + 9.994\ \tau + 307.95,$ (1)

where $T_1(\tau)$ is the temperature of the back side of the fiberglass sample recovered by the second method, °C, g, at 0 min ⩽ τ ⩽ 10 min, τ is the time of exposure to heat flow on this sample, min. For the dependence of temperature on the time of high-temperature exposure in Fig. 5, the coefficient of determination R^2 = 0.972. The approximation error of Eq. (1) is no more than 3 %.

$m_1(\tau) = 2.759\ \tau + 0.350,$ (2)

where $m_1(\tau)$ is the mass loss of the fiberglass sample recovered by the second method, g, at 0 min ⩽ τ ⩽ 10 min, τ is the time of exposure to the heat flux on this sample, min. For the dependence of the mass loss of the sample on the time of high-temperature exposure, the coefficient of determination R^2 = 0.979 is shown in Fig. 6. The approximation error of Eq. (2) is no more than 3 %.

(a) (b)

Fig. 7. Samples of reconstituted fiberglass after high-temperature exposure, which lost the greatest mass at the end of high-temperature exposure

Figure 7 shows photographs of fiberglass samples recovered by the first method. The restoration was carried out using refractory foam. The samples lost the greatest mass at the end of high-temperature exposure during bench tests. Figure 6(a) shows a fiberglass sample 1 recovered with refractory foam after high-temperature exposure. The maximum mass loss of this sample was 3.91 g. At the same time, the temperature of the back side was 321.9 ° C. Figure 6(b) shows a recovered fiberglass sample 2 after high-temperature exposure. The mass loss was 3.93 g. The temperature of the thermocouples was 324.1 °C.

A tensile (rupture) test of fiberglass was performed on the R-5 bursting machine before and after exposure to a radiant heat flux on the sample. The studied fiberglass has almost identical characteristics before and after high-temperature exposure. This indicates its ability to resist high temperatures.

Fiberglass has the following characteristics: the dielectric constant is 1.8 − 4.6, the tangent of the dielectric loss angle is 0.004 – 0.0214, the tensile strength at high temperature exposure along and across the fibers are 10.8 and 5.8 MPa, respectively, the tensile strength after high temperature exposure are 10.5 MPa (along the fibers) and 5.2 MPa (across the fibers).

Next, the samples recovered by the second method were examined. The temperature was measured from the back of the samples. The data are shown in Figs. 8 and 9. Data processing was carried out, the coefficient of determination was calculated.

To describe the dependence of the temperature change of the back side of fiberglass and the mass loss of the samples recovered by the second method on the heating time, static data processing was carried out in Figs. 8 and 9.. The data obtained from the results of the experiment were processed using the Statistica software package. A slight decrease in temperature after 5 min in Figs. 6 and 8 is due to the parameters of the installation (Fig. 2). This is due to the operation of the regulator and the need to maintain the set values of the thermal effect.

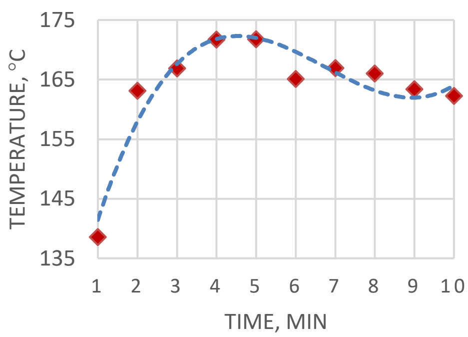


Fig. 8. Dependence of the temperature of the back side of the fiberglass of the samples recovered by the second method on the heating time

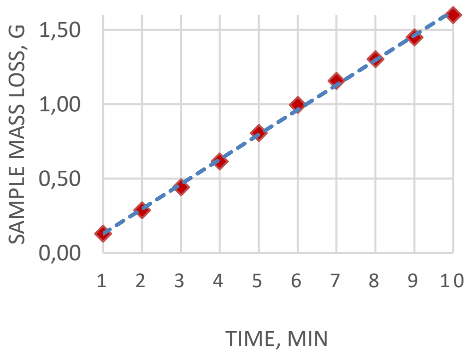


Fig. 9. Dependence of the mass loss of the samples recovered by the second method on the heating time

Based on the results of processing the empirically obtained data, the equations are prepared:

$$T_2(\tau) = 0.243\,\tau^3 - 4.911\,\tau^2 + 29.571\,\tau + 116.55, \quad (3)$$

where $T_2(\tau)$ is the temperature of the back side of the fiberglass sample recovered by the second method, °C, g, at 0 min ⩽ τ ⩽ 10 min, τ is the time of exposure to heat flow on this sample, min. For the dependence of temperature on the time of high-temperature exposure in Fig. 8, the coefficient of determination R^2 = 0.912. The approximation error of Eq. (3) is no more than 9 %.

$m_2(\tau)$ = 0.167 τ -0.037, (4)

where $m_2(\tau)$ is the mass loss of the fiberglass sample recovered by the second method, g, at 0 min ⩽ τ ⩽ 10 min, τ is the time of exposure to the heat flux on this sample, min. For the dependence of the mass loss of the sample on the time of high-temperature exposure in Fig. 9, the coefficient of determination R^2 = 0.993. The approximation error of Eq. (2) is no more than 1 %.

After comparing the results of the study and their comparative analysis for fiberglass samples recovered by two methods, it should be noted the advantages of the second method over the first. According to the results of bench tests, the layer of refractory foam is significantly destroyed within 10 minutes. This leads to a loss of mass of the sample. The restoration of samples using aluminum foil is a fairly effective tool. This application significantly reduces the temperature on the back of the sample by half. This method makes it possible to increase the fire protection of buildings from landscape fires in case of fire of dry grass and shrubs [11–17].

Conclusion

The fiberglass protective barrier requires restoration after damage by a landscape fire. An experiment was carried out to establish the regularity of the effect of heat flux density on fiberglass recovered in various ways. The results of this experiment allowed us to draw the following conclusions:

1. a search for patent and scientific research has been conducted;
2. a method for conducting bench tests of fiberglass samples restored after damage by a landscape fire is proposed;
3. the dependence of the temperature change of the back side of fiberglass and the mass loss for the recovered in each of the two methods is determined;
4. equations (1)–(4) are obtained to establish with a certain degree of reliability the parameters for the use of fiberglass in fire barriers in order to protect against landscape fires;
5. the advantage of the second method of recovering fiberglass samples over the first method has been established. As a result of high-temperature heating for 10 min, the layers of refractory foam are significantly destroyed. This leads to a loss of mass of the sample. The restoration of samples using aluminum foil is a fairly effective tool.

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