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Non-combustible composite materials for fire curtains: thermal analysis and microscopy

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Abstract. Fire protection systems are used to prevent fires and the spread of combustion products from one room to another. The systems include screens, curtains, drapes, etc. The article is devoted to the study of fire resistance and thermoanalytical properties of non-combustible materials used in passive fire protection system. Samples based on silica mat (No. 1); ultrafine basalt fiber (No. 2); quartz aerogel (No. 3), and ceramic mat (No. 4) were studied. Sample No. 1 was covered with carbon impregnated fabric. Samples No. 2, 3, 4 were covered with silica fabric with vermiculite coating. During standard fire test, all samples showed fire resistance limit (FRL) E 60. In terms of thermal insulation capacity, sample No. 2 turned out to be the best with the FRL I 30. Thermoanalytical study showed that the maximum weight loss (12.7 %) was recorded in sample No. 1. The minimum weight loss (0.823 %) was recorded in sample No. 2 in a nitrogen atmosphere. Thus, the material filled with ultrafine basalt fiber showed the best results, and it is recommended to be used as part of fire barriers to create fire-resistant casings, covers and fire-resistant curtains.

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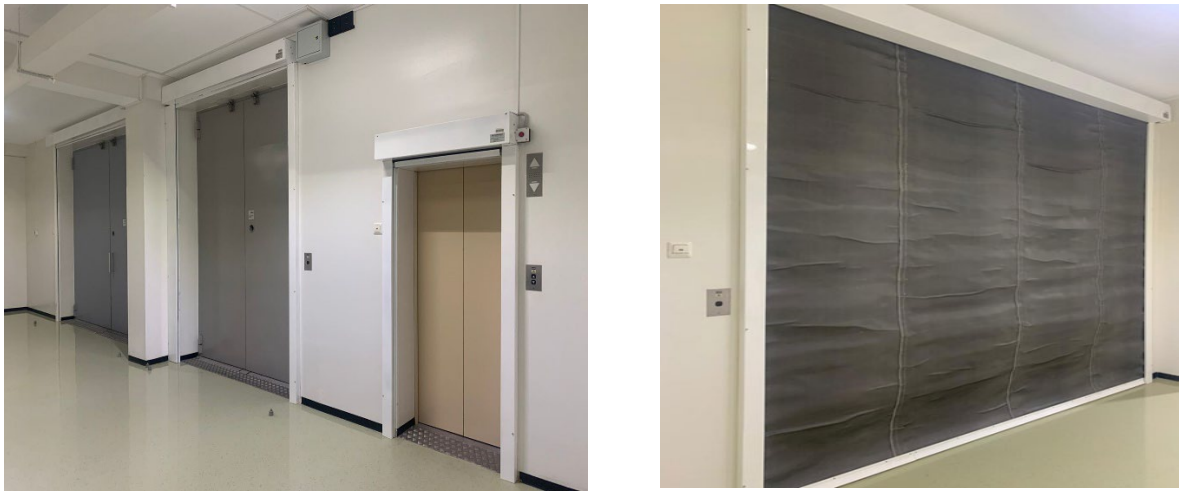
1. Introduction

With population growth and urbanization, the problem of fire safety of buildings is becoming more acute. 21st century buildings are characterized by a variety of geometries, large volume of rooms, high heights, open spaces, dynamic and glass facades, etc., but these complex elements and structures can be a weak point in terms of fire safety. In the last decade, there is a trend towards underground construction of shopping malls, warehouses, subway lobbies, and parking lots, from where timely evacuation in case of fire is quite difficult [1, 2]. In this regard, when designing buildings, it is necessary to take into account all measures to prevent fire and be able to manage the growth and consequences of accidental or intentional fires. In the regulatory aspect, fire safety of buildings is ensured through a combination of active and passive fire protection systems. Active fire protection systems (sprinklers, heat and smoke sensors, etc.) are designed to detect and control or extinguish a fire at its initial stage [3, 4]. Passive fire protection systems (load and non-load bearing elements of the building) are designed to ensure the stability of the building

during fire exposure and to contain its spread. The main purpose of a passive fire protection system is to provide sufficient time for extinguishing fire and rescue operations, as well as to minimize monetary losses [5]. Transformable fire barriers (TFBs) are the most innovative and advanced fire protection solution and combine both systems. For the effective functioning of flexible TFBs, the correct choice of materials and design solutions is of great importance. The fire barrier must meet the required fire resistance parameters, have a low density (light weight) and a small thickness so that it can be easily rolled up and rolled out.

Such products are a type of building structures that have a standardized fire resistance limit (FRL) and a class of structural fire hazard, and their main feature is the ability of the enclosing part of the structure to roll up and roll out. TFBs are adaptive structures, as they are able to adapt to changing conditions and come into action automatically after the fire alarm is activated. These structures are installed in wall openings as partitions and ceilings, effectively separating rooms from each other and providing protection from the spread of fire and combustion products (Fig. 1).

For example, they are actively used in large shopping malls because they do not block the view of goods, unlike stationary massive fire barriers [6].



(a) **(b)**

Figure 1. Fire curtains (a) rolled up (b) rolled out. Photo by the authors.

Fire barriers are also used in rooms where, for one reason or another, there is no possibility of emergency evacuation. One example of such premises is hospital wards, where patients are in different states of health, which affects their ability to move quickly [7]. Fire barriers are effectively used in a road tunnel in Moscow to divide it into fire compartments and organize smoke zones [8], as well as in public buildings, such as shopping malls and hotels [9, 10].

According to paragraph 2 of Article 88 of Federal Law No. 123-FZ [11], “fire resistance limits and types of building structures that perform the functions of fire barriers, the corresponding types of filling of openings and airlocks are given in Table 23 of the appendix to this Federal Law”.

According to paragraph 3 of Article 88 of the Federal Law No. 123-FZ [11], “fire resistance limits for the corresponding types of filling of openings in fire barriers are given in Table 24 of the appendix to this Federal Law”.

Fire curtains, according to Table 24 of the appendix of the Federal Law No. 123-FZ, belong to the first type of filling openings in fire barriers, therefore their FRL must be at least EI 60. Blinds and screens can be of types 1, 2, 3 and their FRL can be, respectively, E 60, E 30, E 15.

The article [12] presents a version of fireproof curtain with the following composition: fiberglass, mesh with intumescent composition, foil material (total thickness of the curtain is 12 mm), with FRL when exposed to standard temperature conditions E 60 (loss of integrity) and I 15 (loss of thermal insulation capacity) according to the national standard of the Russian Federation GOST R 53307–2009 “Elements of building constructions. Fire doors and gates. Fire resistance test method” [13].

Fire curtains should not be a source of smoke and toxic gaseous substances, so the use of non-combustible materials for fire curtains is a great advantage [14, 15].

The article [16] describes an experiment with curtain walling, which are designed to prevent the spread of fire, as well as to ensure the safe evacuation of people. Four panels with overall dimensions of 1000 × 1000 mm and a thickness of about 30 mm each were installed as a thermal insulation sheathing on the heated side of the structure. Each of the panels consisted of two layers of rolled, foil-coated basalt fire-

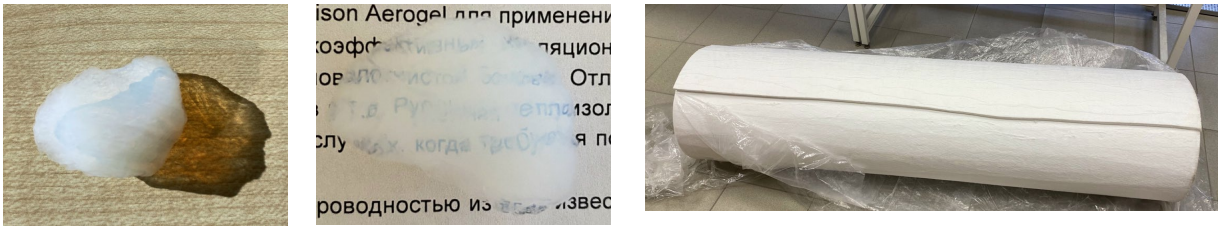
retardant material MBOR-5F, glued together (with non-foil sides) with a fire retardant compound OVPF-1M. Fire retardant consumption is 8.0–8.7 kg/m^2.

In our article we would like to discuss passive fire protection measures using non-combustible materials based on silica mat, basalt ultrafine fiber, quartz aerogel, and ceramic mat. Each of these materials is unique. The disadvantages of such materials include relatively high cost, high adsorption of dust and gases, and relatively large thickness (for example, in comparison with thin-layer coatings).

A distinctive feature of silica materials is their good stability at high temperatures and under oxidizing conditions, therefore they are effectively used in the construction industry as electrolytes [17], adsorbents of hazardous pollutants [18], fire-resistant aggregates [19] and in thermal insulation mortars [20].

The main advantages of ultrafine basalt fiber include: production exclusively from basalts without admixtures of other minerals, good thermal insulation properties, lack of combustibility, high thermal and chemical resistance, preservation of its characteristics and geometric shape under sudden temperature changes and durability of operation, even in a humid environments [21].

One of the promising developments in the construction market is a non-combustible nanomaterial aerogel and materials based on it. In its natural form it is transparent (Fig. 2a, 2b), and then with special processing it is applied to fabric (fiberglass, basalt or carbon) and delivered to the construction site already in the form of a roll (Fig. 2c). Aerogel in its natural form has a low coefficient of thermal conductivity 0.014 W/m·K at 10 °C [22]. Aerogel as a thermal insulating material was used in the “Space Shuttle” orbital craft, “Mars Pathfinder,” and “Spirit” rovers [23]. Aerogel-based roll materials are used as heat insulators of steel pipelines, buildings and structures [24, 25].



a **b** **c**

Figure 2. Aerogel (a) (b) in its natural state (c) on fabric material as a roll. Photo by the authors.

Ceramic fibers are promising materials as reinforcement materials for composite materials in the industry of high-temperature structural materials [26, 27].

The listed non-combustible materials in combination with non-combustible lining fabric, usually silica [12], form a fire-resistant fabric and can be part of fire curtains, screens, covers, caps, etc.

The purpose of this work is to FRL of the materials under study when the temperature changes by an average of 140 °C for 60 minutes on an unheated surface.

To achieve this goal, the following tasks were solved:

- standard fire tests for four thermal insulation non-combustible materials were conducted;
- thermoanalytical dependencies and microscopic photography of material samples before and after fire tests were obtained.

It is expected that the minimal mass loss during thermal analysis and the preservation of physical characteristics visible under microscopy in micro-samples will be reflected in the fire resistance characteristics of compositions made from such materials for fire curtains.

2. Method and Materials

2.1. Materials

All materials were commercially available technical products. Characteristics of the tested samples are shown in Table 1. Sample No. 1 consists of silica fabric from the company “Beltekhnolit” [28], and the filler is a mat “Supersilica” from “RLB Silica” [29]. Sample No. 2 consists of a lining silica fabric with vermiculite coating PS-1000V from the manufacturer “Polotsk-Steklovolokno” [30], and as a filler a layer of fire retardant material OBM-5 from “Votkinsk plant of thermal insulation materials VZTM” [31] is used. In samples No. 2, 3, 4, the same lining fabrics were used. The filler in sample No. 3 is a silica-based aerogel Insuflex 650 from the Chinese manufacturer NINBO EAS MATERIAL TECHNOLOGY CO., LTD (official representative in Russia of ETS Korda LLC [32]), and in sample No. 4, the filler is refractory ceramic material

in a roll from “Sukholozhsky Refractory Plant” [33]. The fabric and the filler are connected to each other by an aramid thread with a metal core [34].

Table 1. Characteristics of fillers of tested samples.

Samples	Filler	Thickness, mm	Weight, kg/m^2
No. 1	Silica mat Supersilica S	6.5–7	2.9
No. 2	Basalt superfine fibers OBM-5	6.5–7	2.5
No. 3	Silica-based aerogel Insuflex 650	11.5–12	4
No. 4	Ceramic mat	6.5–7	2.8

For sample No. 1, the fabric contained dressed carbon fibre in black color. Finishing of carbon fibers is carried out in order to increase its strength, as well as to improve its compatibility with the binder and increase the physical and mechanical characteristics of composite materials obtained from fibers, which can be used in various industries to create products and structural elements exposed to elevated temperatures [35]. The filler in sample No. 1 is silica needle-punched mat Super Silica S (with thickness of 4–6 mm), which is produced from silicon oxide fibers (96 %) without chemical binder. The innovative technology of silica materials production is based on the aerodynamic method of fiber layout, which ensures uniform weaving of canvas by needle-punching matrixes, without binders and additives. The thread is aramid with a metal core.

Samples No. 2, 3 and 4 were reinforced by V-spraying of an aqueous dispersion of vermiculite to the fabric. Heat resistance of the fabric is 900 °C, at short-term use is 1350 °C. In sample No. 2, as a filler with thickness of 5 ± 1.9 mm the fireproof material OBM-5 made of basalt superfine fiber was used. In the sample No. 3, the aerogel based on quartz Insuflex 650 was used. The thickness of the layer is equal to 10 mm. Sample No. 4 consists of silica fibers compressed into roll of fabric, with the density of 96 kg/m^3, produced by Sukholozhsky Refractory Plant, with vermiculite coating PS-1000V. The main characteristics of the materials are shown in Tables 2 and 3. This information is extracted from the official websites of material manufacturers.

Table 2. Material characteristics of the tested samples [29, 31–33].

Characteristics	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Filler density, kg/m^3	160	70–100	200	96
Chemical composition of lining fabric, %	Na_2O (0.33–0.8), Si_2O (94–95.9)	SiO_2(98)	SiO_2(98)	SiO_2(9)
Heat resistance, °C	1200–1700	900–1350	900–1350	900–1350

Table 3. Thermal conductivity of filler material, W/(m·K) [29, 31–33].

Temperature, °C	25	125	200	300	400	600	800	1000
Sample No. 1								0.34
Sample No. 2	0.035	0.055		0.095				
Sample No. 3			0.022	0.025	0.029		0.065	
Sample No. 4			0.05		0.07	0.12	0.18	0.27

2.2. Methods

2.2.1. Thermal analysis tests

According to the national standard of the Russian Federation GOST 53293–2009 “Fire hazard of substances and materials. Materials, substance and fire protective means. Identification by thermal analysis methods” [36], thermal analysis includes the following methods:

- thermogravimetric analysis (TGA);
- thermogravimetric by derivative (derivative thermogravimetry (DTG));
- differential thermal analysis (DTA) or differential scanning calorimetry (DSC).

The STA 6000 synchronous thermal analyzer was used for thermal analysis (PerkinElmer, USA) [37]. The thermal analyzer is a measuring complex that combines the functions of a differential scanning calorimeter and highly sensitive analytical scales. This design solution allows to carry out simultaneously in one experiment and one sample measurements of calorimetric values at different thermodynamic transitions, to measure the temperature of these transitions and to register at the same time changes in the sample mass. The main technical characteristics of the STA 6000 analyzer are shown in Table 4 [38].

Table 4. Technical Specifications STA 6000.

Temperature range	15 °C to 1000 °C
Weight measurement range / sensitivity	1500 mg / 0.1 µg
Calorimetric accuracy / reproducibility	± 2 %
Scanning speed	0.1 º/min to 100 º/min
Cooling time	1000 °C to 100 °C – less than 12 min
Sample crucibles	Al_2O_3, 180 µl
Cooling	air, liquid
Gas flow controller	for 2 gases, automatic switching

The following study conditions were chosen for thermogravimetric analysis: atmosphere (air or nitrogen), initial temperature 30 °C, final temperature 900 °C, gas flow rate – 60 ml/min, heating rate 20 °C/min. Samples of materials before and after the fire test were subjected to the study.

2.2.2. Microscopy

To conduct a microscopic examination of the fillers, an Altami SM0745 stereomicroscope (Russian Federation) was used. The device is designed to observe three-dimensional images of objects in reflected or transmitted light.

The images were taken under the following conditions: without heating (25 °C) and with heating the sample to a temperature of 1050 °C and maintaining it for 30 minutes.

2.2.3. Fire tests

Elements of fire curtains were tested according to the national standard of the Russian Federation GOST 53307–2009 “Elements of building constructions. Fire doors and gates. Fire resistance test method” [13];

The limiting state of loss of integrity (E) is achieved as a result of the formation of through cracks or holes (slits) in the structure through which the products of combustion or flame penetrate, namely:

- the appearance of a stable flame on the unheated surface of the prototype lasting 10 seconds or more;
- fire or smoldering with glow of a cotton swab as a result of exposure to fire or hot gases within 10 seconds after being brought to the prototype;
- formation of through holes in the construction of the prototype with dimensions that ensure penetration of a probe with a diameter of 6 mm and movement along the hole to a distance of at least 150 mm or unhindered penetration of a probe with a diameter of 25 mm into the through hole;
- falling out of the sample mesh from the box or the box itself from the enclosing structure.

Achieving the limiting state for loss of thermal insulation capacity (I) occurs due to an increase in the temperature on the unheated surface of the samples by an average of more than 140 °C compared to the temperature of the surface of the prototype (taking into account the temperature at the beginning of the test) [13].

The samples were tested using a vertical firing furnace (installation) with fuel supply and combustion system (Fig. 3a). The size of the furnace opening was 2.45 × 2.5 m and provided the possibility of simultaneous testing of four samples with design dimensions of 1 × 1 m. Before installation, the combined fabric was assembled from samples No. 1–4 on the stand and mounted on the frame (Fig. 3b).

a b

Figure 3. Preparation for the test: a) furnace; b) assembly of the combined web on the stand.

The temperature regime in the firing chambers of the furnace was ensured by burning natural gas. The temperature of the medium in the fire chamber of the furnace was measured by thermoelectric converters (thermocouples). The average temperature on the unheated surface of the enclosing structure samples was determined as the arithmetic mean of the thermocouple readings. The experiment used sensors (thermocouples) TPL011–0.5/1.5, which were located on the surface of the fabric according to the following principles:

a) a thermocouple in the center of the fabric section(s) of the prototype;

b) a thermocouple in the center of each quarter of the fabric section(s) of the prototype.

For every 1.5 m^2 of furnace opening intended for testing enclosing structures, at least one thermocouple must be installed. After installing the sensors, the frame with the combined sheet was placed in the furnace opening for fire test (Fig. 4).

a b

Figure 4. Installation of the combined sheet in the furnace opening:
(a) appearance of the sheet before testing with attached thermocouples (b) side view.

A standard temperature regime was created in the furnace, characterized by the following relationship:

$$T - T_0 = 345 \cdot \log_{10}(8t + 1), \quad (1)$$

where T is temperature in the furnace corresponding to time *t*, °C; T_0 is temperature in the furnace before the start of heat exposure *t*, °C; t is time calculated from the beginning of the test, min.

The test conditions are shown in Table 6.

Table 6. Test conditions.

Parameter	Value
Ambient temperature, °C	23
Atmospheric pressure, kPa	99.8
Relative air humidity, %	49.6
Air velocity, m/sec	0.1

3. Results and Discussion

3.1. Results of thermal analysis before fire tests

The results of thermal analysis of samples No. 1–4 before the fire tests are shown in Fig. 5–8. The thermoanalytical curves in the figures are designated as follows: DSC – red, DTG – blue and TG – blue, going down. The images are arranged in the following order: air atmosphere tests (top), nitrogen atmosphere tests (bottom).

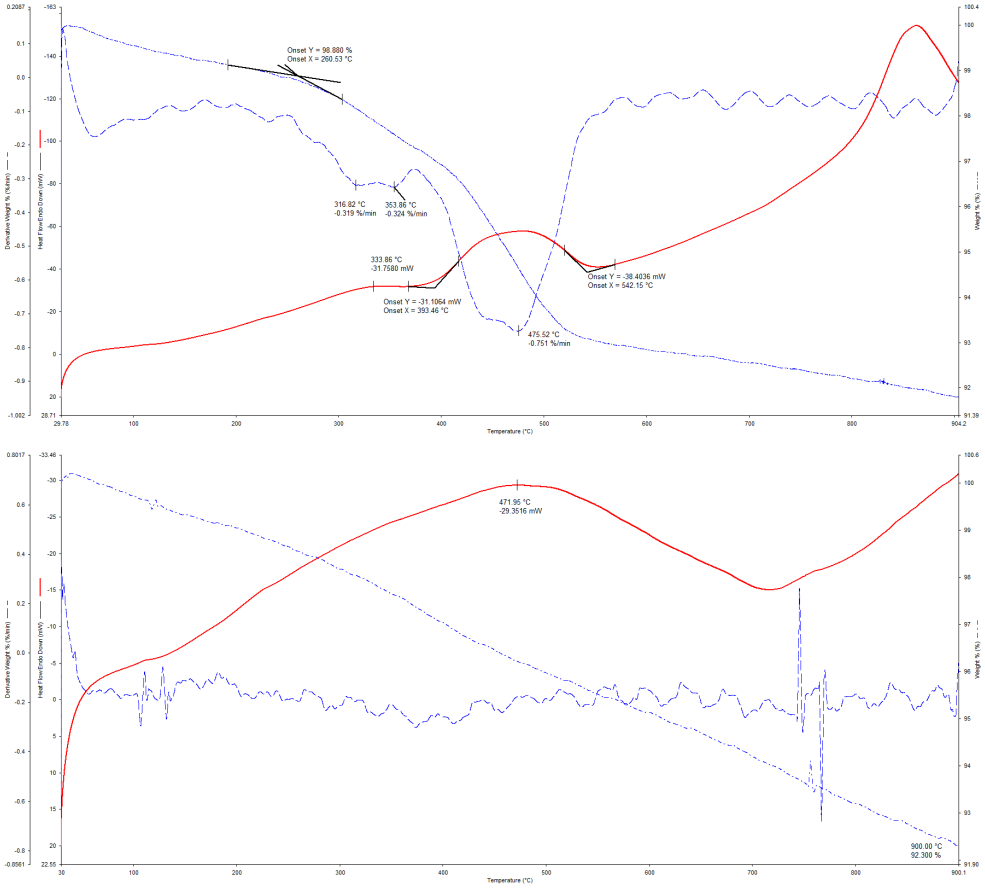
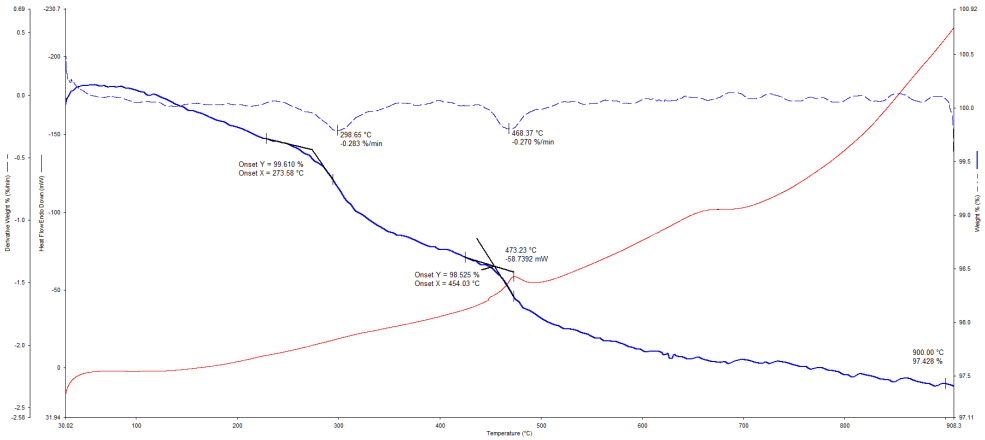


Figure 5. TA-curves for sample No.1: in air atmosphere and in nitrogen atmosphere.



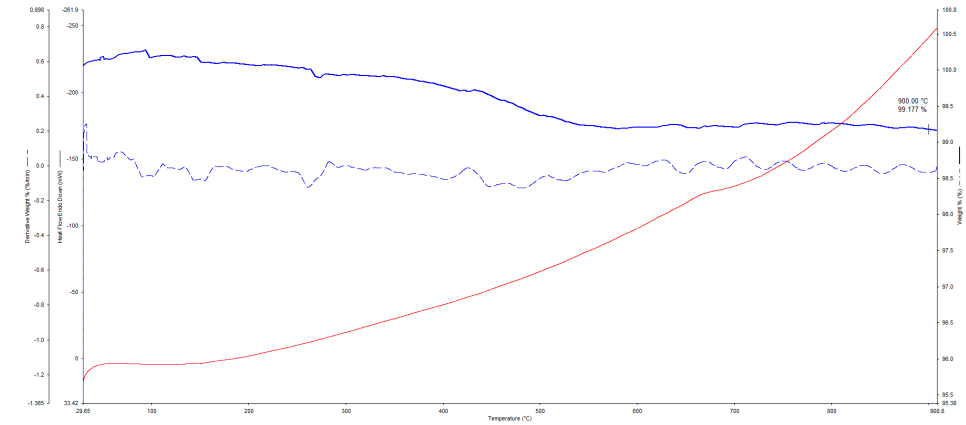


Figure 6. TA-curves for sample No. 2: in air atmosphere and in nitrogen atmosphere.

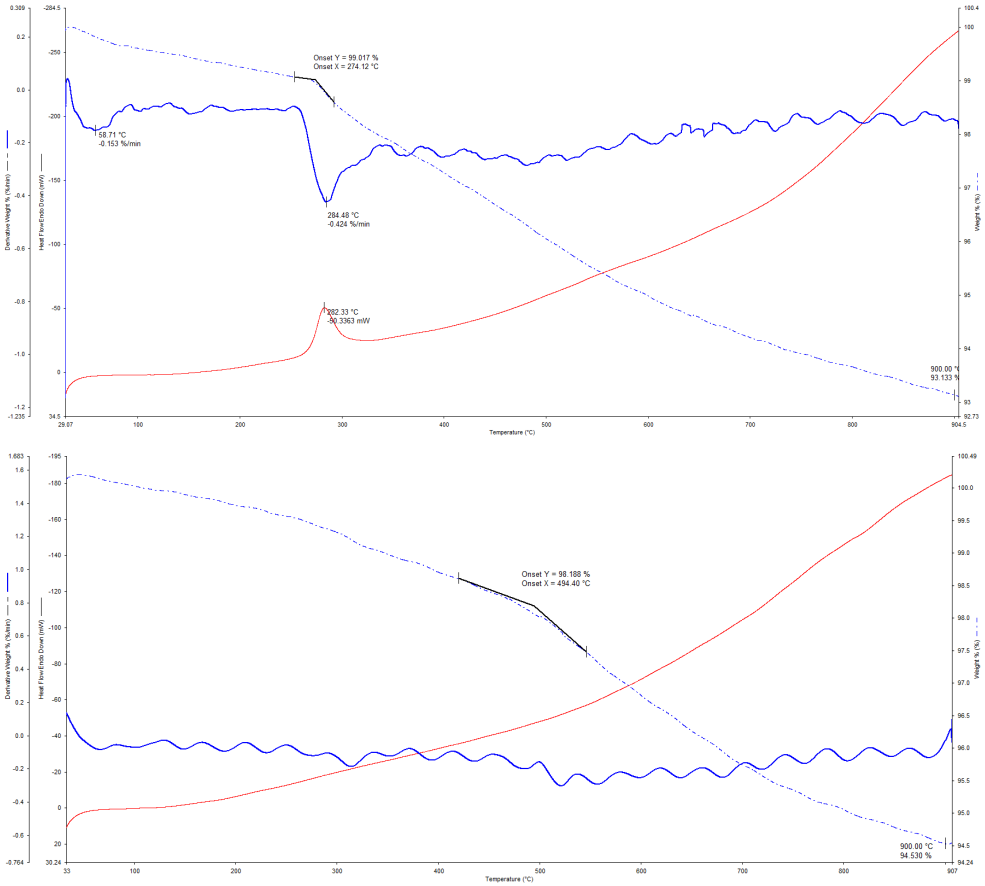
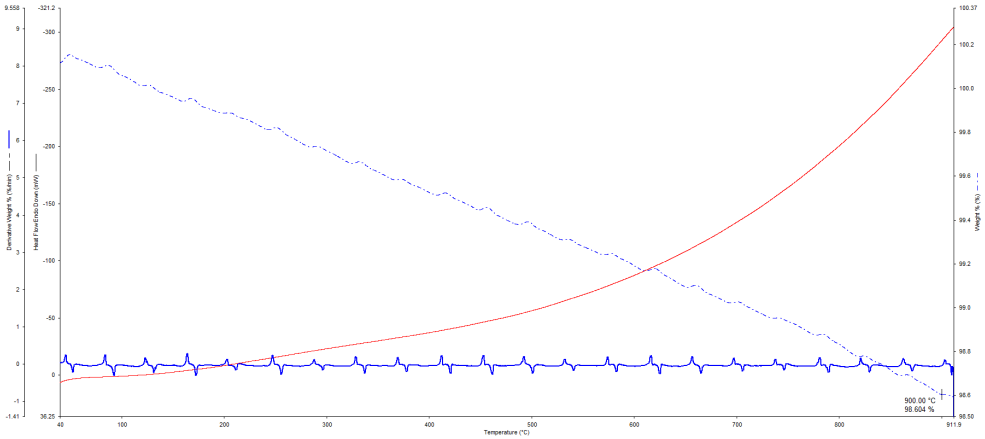


Figure 7. TA-curves for sample No. 3: in air atmosphere and in nitrogen atmosphere.



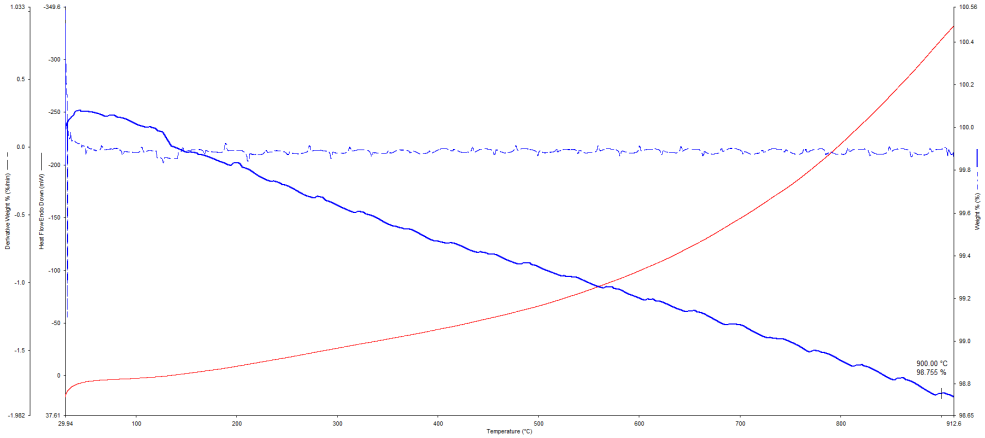


Figure 8. TA-curves for sample No. 4: in air atmosphere and in nitrogen atmosphere.

At constant linear heating to 900 °C, the maximum weight loss was recorded for sample No. 1 in nitrogen atmosphere (7.7 %). In air atmosphere, the greatest weight loss was recorded for sample No. 3 (6.8 %). The weight loss indicates that intensive reactions occurred in the samples, which led to the destruction of the samples. The smallest weight loss was recorded for sample No. 2 in nitrogen atmosphere. It amounted to only 0.823 %. In air atmosphere, the least weight loss was recorded for sample No. 4 (1.3 %).

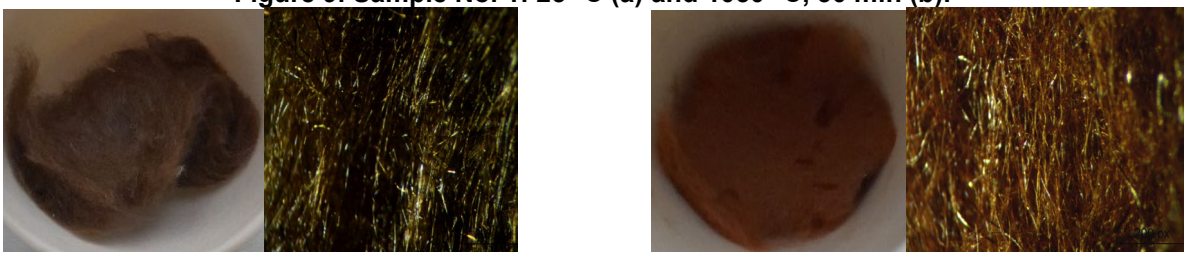
Peaks of exothermic reactions were detected on DSC-curves only for samples in an air atmosphere, which indicates the occurrence of oxidative processes in the samples. Oxidative decomposition of the binder occurs. For sample No. 3, taken prior to the fire test, the exothermic peak on the DSC-curve occurs at a temperature of 282.33 °C. The best performance during standard tests was predicted for sample No. 2.

3.2. Results of microscopic examination of sample fillers prior fire tests

Before the fire test, the fillers of the studied samples No. 1–4 were examined using an Altami SM0745T microscope (Fig. 9–12). Magnification 30x.

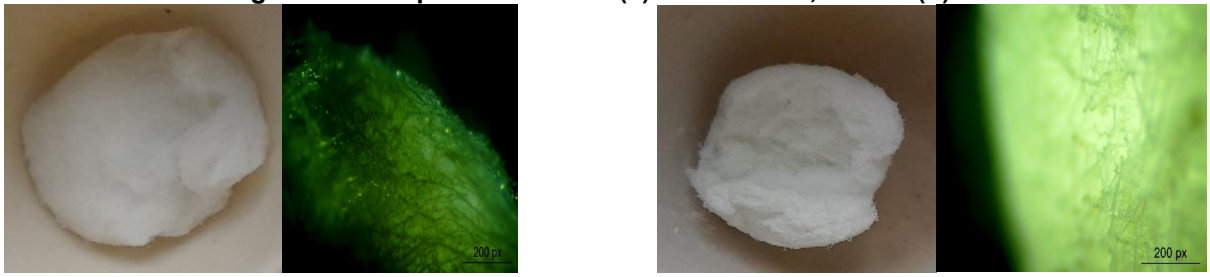
a **b**

Figure 9. Sample No. 1: 25 °C (a) and 1050 °C, 30 min (b).



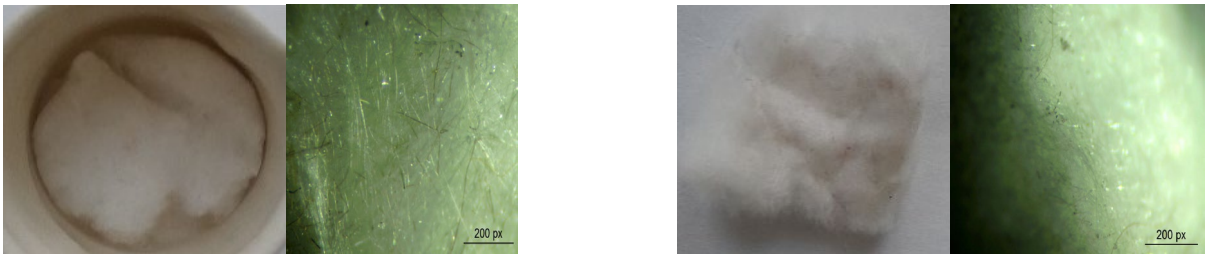
a **b**

Figure 10. Sample No. 2: 25 °C (a) and 1050 °C, 30 min (b).



a **b**

Figure 11. Sample No. 3: 25 °C (a) and 1050 °C, 30 min (b).



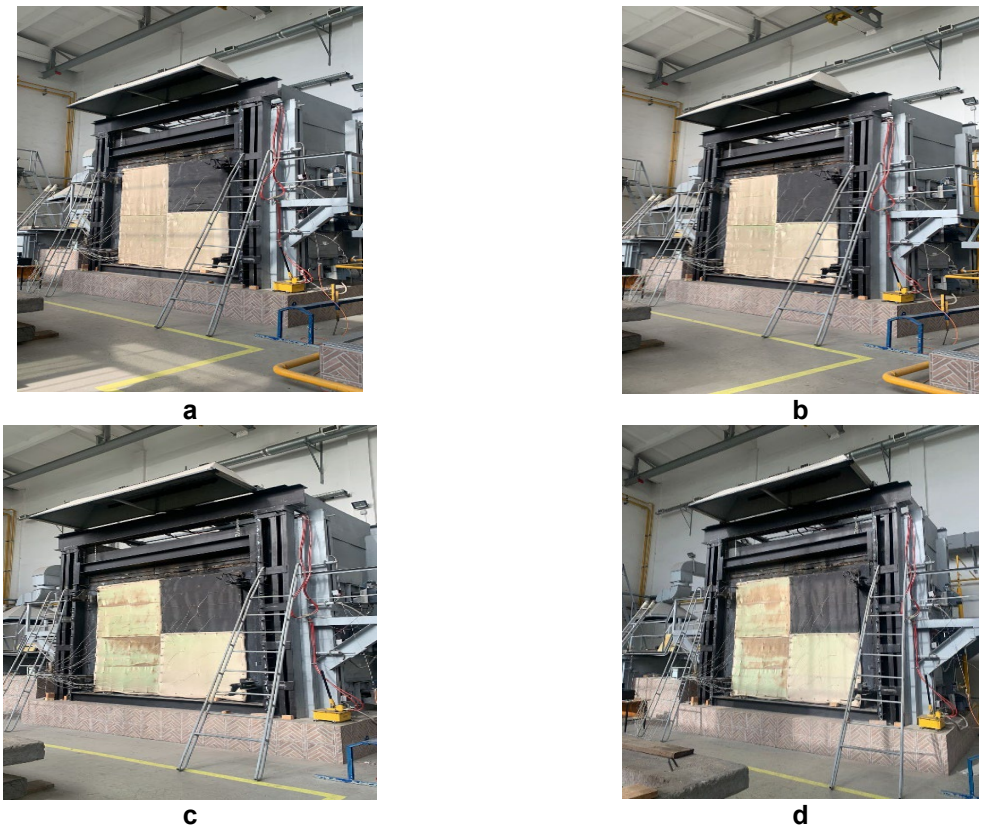
a b

Figure 12. Sample No. 4: 25 °C (a) and 1050 °C, 30 min (b).

As follows from the physicochemical characteristics of basalt [39] and ceramic fibers (Table 1), up to a temperature of 1200 °C only softening of the mineral phases of basalt and ceramic fibers can be observed. As follows from Fig. 9–12, the structure under the microscope has not undergone visible changes. The following transformations were recorded: small inclusions appear, the samples become green and brown, and small phenocrysts of the incipient melt are clearly visible against the background of the total mass of the glass-fibrous structure. Oven temperatures during standard tests reach 900–950 °C for 60 minutes, and therefore discoloration is expected on composite sheets containing these thermal insulation materials.

3.3. Results of fire tests

During the testing, all possible changes in the appearance and condition of the samples were recorded. At the 21st minute, smoke from sample No. 3 was noticed. At the 25th minute, the smoke stopped, and barely noticeable green stripes and areas began to appear on samples No. 2 and 3 (Fig. 13a); over time, the stripes and areas became brighter and larger (Fig. 13b). At the 34th minute, the green area on sample No. 2 became more significant, it occupied the upper right corner, the green area on sample No. 3 grew more slowly. At the 34th minute, a brown area and a stripe also appeared on samples No. 2 and No. 4. At 45 minutes, the brown areas became larger. The test was stopped at the 60th minute on instructions from the technical customer, but observation continued. At the 65th minute, the upper right corner of sample No. 2 turned brown, and almost the entire rest of the canvas became green. Sample No. 4 also became almost entirely green, except for a wide brown stripe in the central part of the canvas. The upper half of sample No. 3 also became light green (Fig. 13c). At the 73rd minute, there were more brown areas on samples No. 2 and 4; on sample No. 3 the green area began to occupy two-thirds of the sample area (Fig. 13d).



a b

c d

Fig. 13. Testing of samples: a) at the 25th minute of fire exposure; b) at the 29th minute of fire exposure; c) at the 65th minute of fire exposure; d) at the 73rd minute of fire exposure.

No through cracks, holes, or stable flames were found on the surface of the samples during testing, i.e. all samples retained their integrity, and the integrity FRL of E 60 was achieved.

Based on the results of recorded temperatures from sensors, graphs of temperature versus time were constructed (Fig. 14). The initial temperature of the samples was 23 °C.

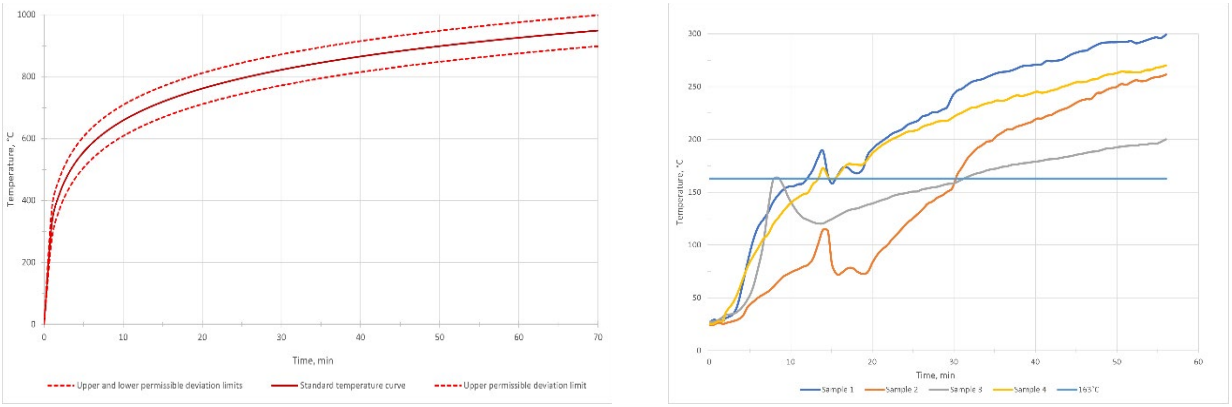
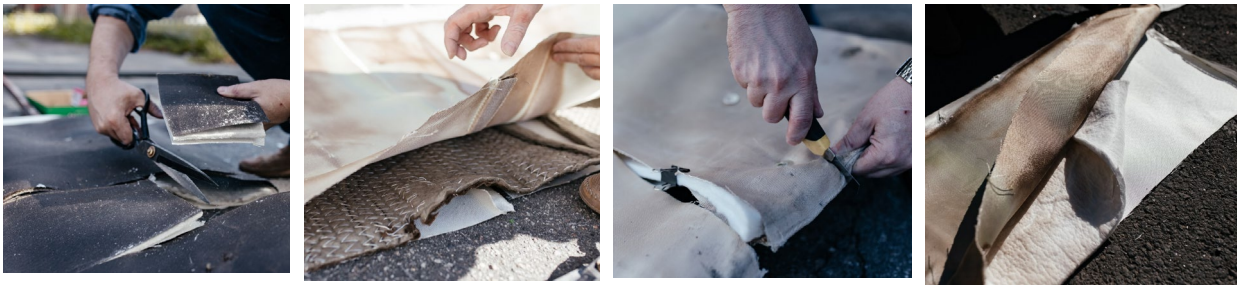


Figure 14. Temperature curves for heating the medium in the furnace (left) and experimental temperature curves for samples No. 1–4 (right).

According to Fig. 14, sample No. 2, consisting of a PS-1000V vermiculite-coated silica lined fabric with basalt filler, showed the best value of thermal insulation capacity FRL I 30 (the specimen reached a temperature of 163 °C at the 1863rd second, i.e. 31st minute). Sample No. 3, consisting of a PS-1000V vermiculite-coated silica cladding fabric with aerogel filler, performed the worst; it lost its thermal insulation capacity at the 496th second, i.e. 8th minute.

Looking at the temperature values from each thermocouple individually, rather than the arithmetic average, the same conclusion can be drawn. Sample No. 2 reached 163 °C later than the other samples, and sample No. 3 reached 163 °C correspondingly earlier than all other samples.

After dismantling the structure, each sample was examined individually, and small pieces of the tested webs were taken for further studies of the properties of fire protection materials based on silica mat, basalt superfine fiber, quartz aerogel, and ceramic mat (Fig. 15).



a **b** **c** **d**

Figure 15. Inspection of samples after testing: a) sample No. 1; b) sample No. 2; c) sample No. 3; d) sample No. 4.

3.4. Results of thermal analysis after the fire tests

The results of thermal analysis of samples No.1–4 after the fire tests are shown in Fig. 16–19. The thermoanalytical curves in the figures are designated as follows: DSC – red, DTG – blue and TG – blue going down. The images are arranged in the following order: air atmosphere tests (top), nitrogen atmosphere tests (bottom).

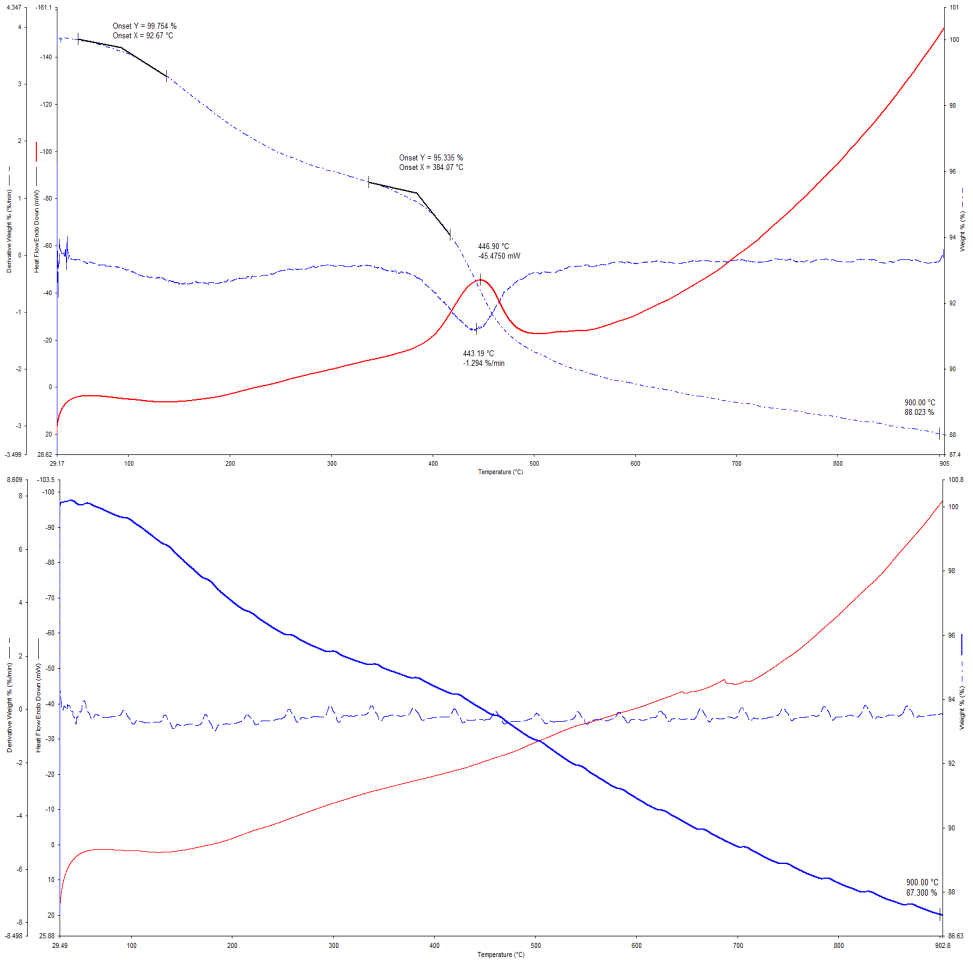


Figure 16. TA-curves for sample No. 1 after the fire test: in air atmosphere and in nitrogen atmosphere.

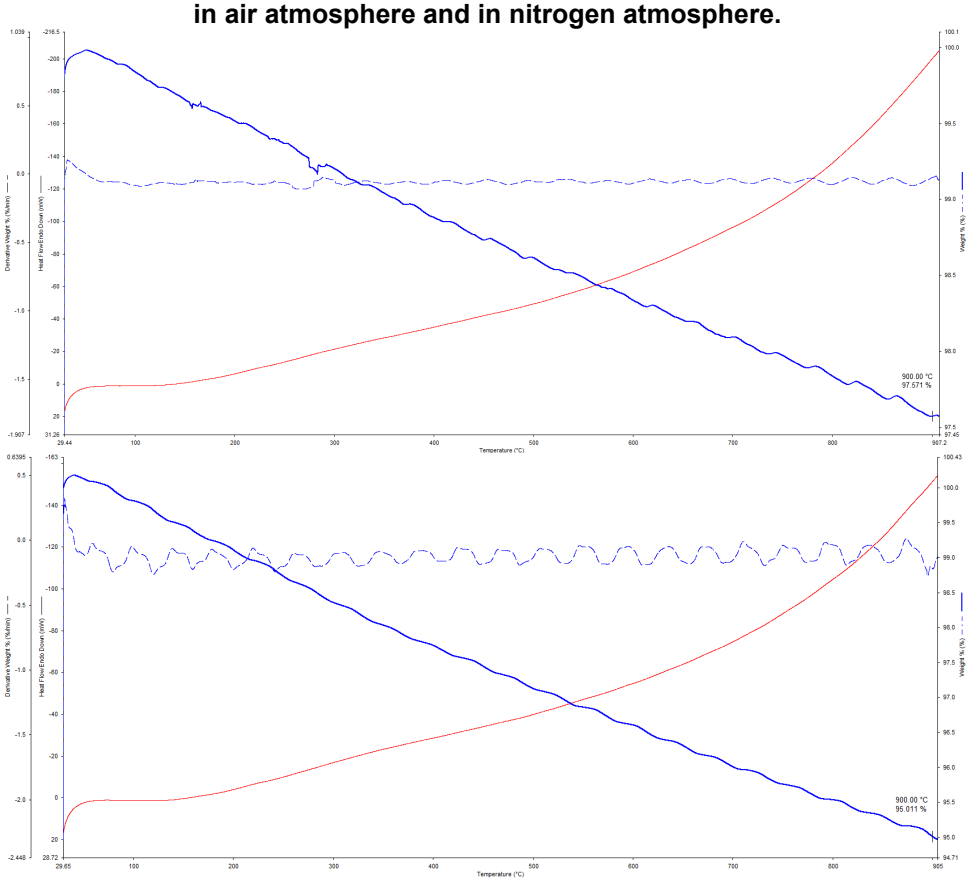


Figure 17. TA-curves for sample No. 2 after the fire test: in air atmosphere and in nitrogen atmosphere.

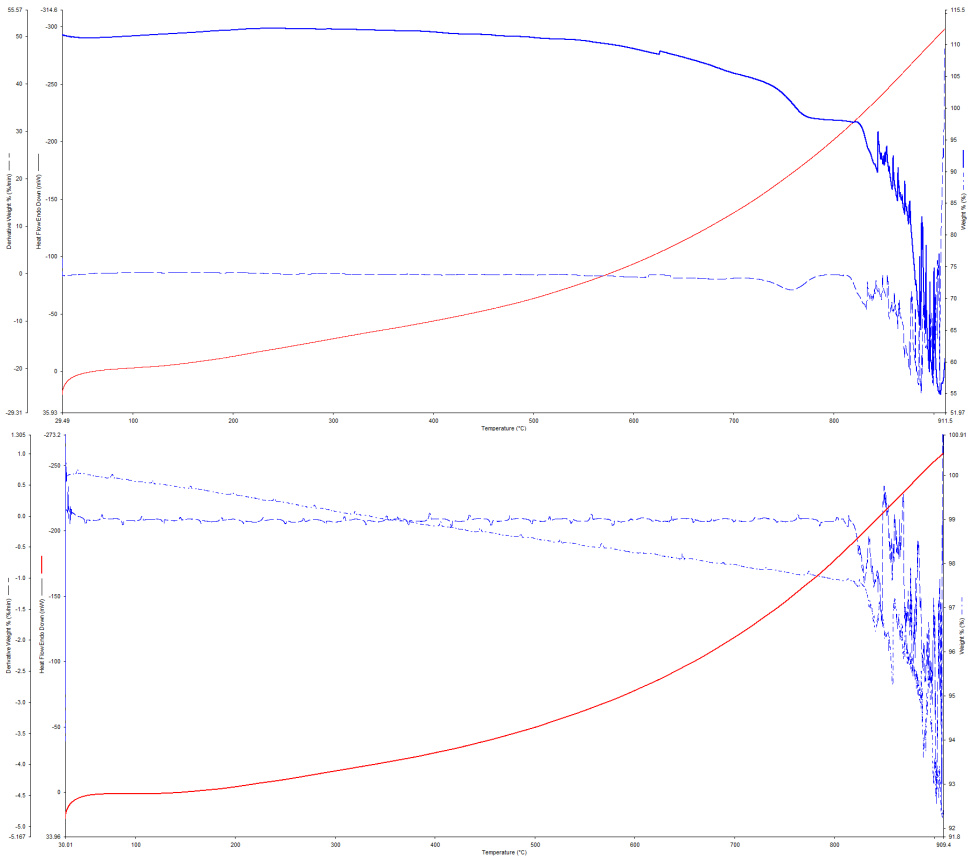


Figure 18. TA-curves for sample No. 3 after the fire test: in air atmosphere and in nitrogen atmosphere.

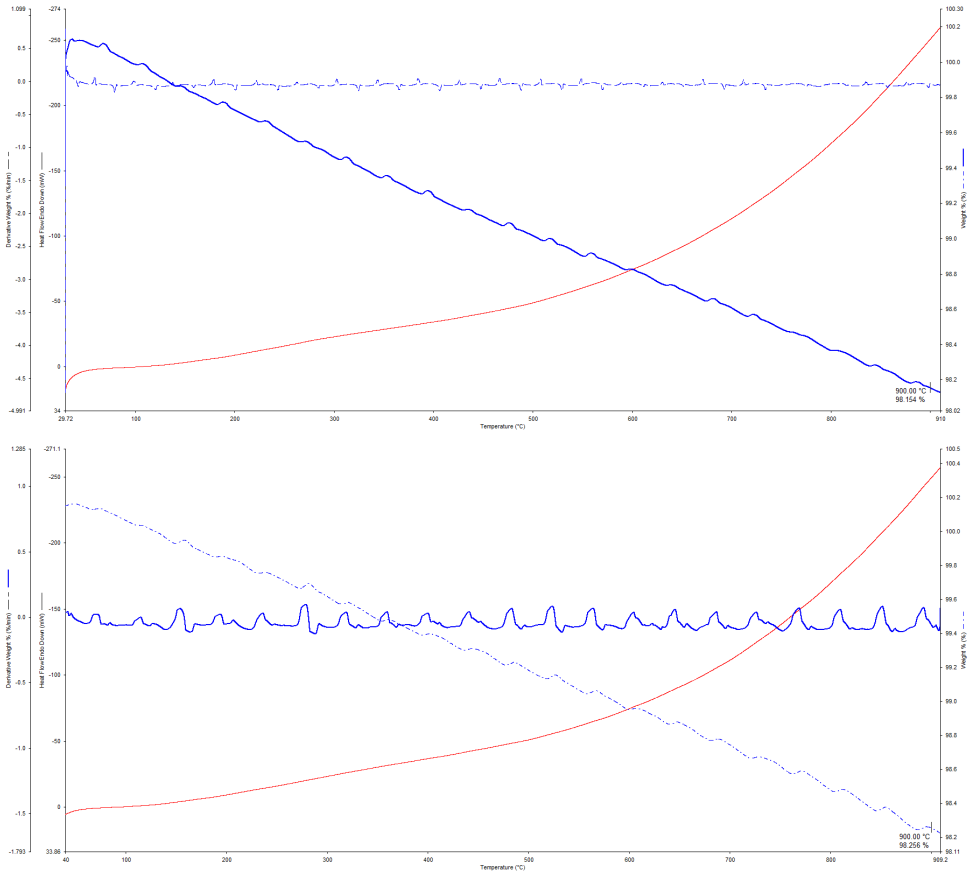


Figure 19. TA-curves for sample No. 4 after the fire test: in air atmosphere and in nitrogen atmosphere.

The samples studied earlier in the fire test were subjected to linear heating, i.e. re-tested at high temperatures. Linear heating showed that all specimens had also reduced their mass. Compared to the heating of samples not previously fire tested (paragraph 3.1), the weight of samples had changed more significantly the second time. The maximum weight loss was shown by sample No. 1 in nitrogen atmosphere. Its weight decreased by 12.7 %. In air atmosphere it also showed the highest weight reduction (11.9 %). After the fire test, thermogravimetric analysis showed the least weight loss in sample No. 4 at 1.744 % in nitrogen atmosphere. In air atmosphere it also showed the lowest value of weight reduction (1.8 %).

Thus, the fire-tested samples show greater weight loss on heating, but the weight loss values are similar for both air and nitrogen atmospheres.

4. Conclusions

Modern thermal insulation materials with the minimum possible technological thickness (5–7 mm) have been studied to obtain satisfactory characteristics for loss of integrity and thermal insulation capacity of a fire-resistant fabric. Such composite fabrics can be used for fire-resistant curtains, covers, casings in fire barriers and protecting products from fire. It is necessary that, with the required fire resistance, such composite materials can be rolled up and rolled out, i.e. would not be very thick.

Before the fire test, the maximum weight loss during thermal analysis during heating was shown by sample No. 1 in a nitrogen atmosphere, and the smallest minimum was shown by sample No. 2. During linear heating after the fire test, the masses of the samples decreased more significantly in percentage terms. The greatest weight loss was again recorded in sample No. 1, and the smallest in sample No. 4.

As a result of fire tests, it was established that after 60 minutes the presented fire-retardant materials based on silica mat (Sample No. 1), basalt ultrafine fiber (Sample No. 2), silica aerogel (Sample No. 3), and ceramic mat (Sample No. 4) retained their integrity. Thus, samples No. 1–4 have an FRL of E 60. During the fire test, sample No. 1 visually did not undergo any changes, unlike samples No. 2–4. The lining fabric of the listed samples began to change color starting from the 25th minute. Green and brown areas began to appear on the samples. Sample No. 1, in general, showed the worst characteristics both in terms of thermal analysis studies and in terms of loss of thermal insulation capacity.

The best, from the point of view of the obtained thermoanalytical characteristics (minimum mass loss) and further from the point of view of thermal insulation capacity, was sample No. 2, consisting of a lining silica fabric with a vermiculite coating and a basalt filler 7 mm thick. FRL for thermal insulation capacity is I 30. This material is recommended to be used in the future to create fire-resistant enclosures, covers, and fire curtains.

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