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Assessment of decorative nano-plaster for fire safety

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ABSTRACT

Introduction. In tests for fire and explosion hazard of materials, various factors influence the desired value and its variation. All these factors affect the correct classification of a material into a fire hazard group, which ultimately determines its potential use. For instance, on escape routes from a building, it is essential to use non-combustible materials (Group NC) for finishes. For example, on escape routes from the building, it is necessary to use non-combustible materials (group NC) for finishing. Therefore, to determine the actual group (class), it is necessary to determine not only the desired value, but also its data spread. **Methods and materials.** Baumit Nanopore decorative plaster was tested for flammability parameters to classify the material as either flammable or non-flammable. **Results. Discussion.** Tests of decorative plaster Nanopor "Baumit" showed the following results: loss of mass of the sample is $P = 7.0\pm0.3\%$; temperature increase in the furnace is 4,6±1,7 ℃; duration of stable flame combustion is 1.0± 0.1 s. In accordance with p. 5.2 of GOST 30244-94 this building material is referred to non-combustible materials, because the values of flammability parameters are within the permissible norm. Loss of mass of decorative plaster samples after fire exposure decreased by only 7%, due to the loss of moisture during heating of plaster samples. And the uncertainty on the mass loss of decorative plaster is about 4%. The temperature increase in the oven during the tests of plaster is about 5 ℃, while the norm is not more than 50 ℃. Relative expanded uncertainty on the temperature rise in the furnace is 36%. Duration of stable flame combustion of plaster is 1 s, while the norm is not more than 10 s. The spread of data on this indicator is 10%. **Conclusion.** The analysis of the obtained data showed that the expanded uncertainty on flammability parameters ranges from 4 to 40%, which significantly affects the deviation of the measurement result from the true value, as well as the correctness of assigning the group (class) of fire danger to the material.

KEYWORDS: flammability of Nanopore decorative plaster, uncertainty in mass loss of the decorative nanoplaster sample, uncertainty in duration of sustained flame burning, uncertainty in Type A, uncertainty in Type B, flammability group

Оценка декоративной наноштукатурки на пожароопасность

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АННОТАЦИЯ

Введение. В испытаниях на пожаровзрывоопасность материалов на искомое значение величины и ее отклонение оказывает воздействие множество различных факторов. Все это влияет на правильность отнесения материала к той или иной группе (классу) пожароопасности, что в конечном итоге определяет его возможное использование. К примеру, на путях эвакуации из здания необходимо использовать при отделке негорючие материалы (группы НГ). Поэтому для определения фактической

группы (класса) необходимо определять не только искомое значение величины, но и его разброс данных. **Методы и материалы.** Проводились испытания декоративной штукатурки Нанопор «Baumit» по параметрам горючести для отнесения данного материала к группе: горючим или негорючим. **Результаты и обсуждение.** Испытания декоративной штукатурки Нанопор «Baumit» показали следующие результаты: потеря массы образца составляет P = 7,0±0,3%; прирост температуры в печи составляет 4,6±1,7 ºС; продолжительность устойчивого пламенного горения составляет 1,0±0,1 с. В соответствии с п.5.2. ГОСТ 30244-94 данный строительный материал отнесен к негорючим материалам, т.к. значения параметров горючести находятся в пределах допустимой нормы. Потеря массы образцов декоративной штукатурки после огневого воздействия уменьшилась всего на 7% из-за потери влаги при нагревании образцов штукатурки. Причем неопределенность по потере массы декоративной штукатурки составляет около 4%. Прирост температуры в печи при испытаниях штукатурки составляет около 5 ºС при норме не более 50 ºС. Относительная расширенная неопределенность по приросту температуры в печи составляет 36%. Продолжительность устойчивого пламенного горения штукатурки составляет 1 с, при норме не более 10 с. Разброс данных по данному показателю составляет 10%. **Заключение.** Анализ полученных данных показал, что расширенная неопределенность по параметрам горючести составляет от 4 до 40%, что существенно влияет на отклонение результата измерений от истинного значения, а также на правильность присвоения группы (класса) пожарной опасности материалу.

КЛЮЧЕВЫЕ СЛОВА: горючесть декоративной штукатурки Нанопор, неопределенность по потере массы образца декоративной наноштукатурки, неопределенность продолжительности устойчивого пламенного горения, неопределенность по типу А, неопределенность по типу В, группа горючести

INTRODUCTION

In fire explosion testing, various factors can influence the final measurement and its accuracy. These include: sample characterization and preparation for testing (product variability, geometric size variations, conditioning errors, etc.), equipment preparation for testing (equipment calibration errors), test conditions, and the execution of tests (errors in measuring instruments, test equipment, and testers), among other factors. In addition, in most cases, such measurements are referred to indirect measurements, when the desired value of a quantity is calculated from the functional dependence of several physical quantities, which are obtained directly from measuring instruments. Indirect measurements are less accurate than direct measurements, as each physical quantity will have its own error, which add up and affect the deviation of the measurement result.

All this affects the correctness of assigning the material to a particular group (class) of fire hazard, which ultimately determines its possible use to ensure the safety of people in case of fire. For example, on the evacuation routes from the building it is necessary to use non-combustible materials (Group NC) for finishing. Therefore, in order to accurately classify substances and materials by fire-explosion hazard indicators and correctly assign them to any group (class), it is necessary to determine not only the result, but also to calculate the exact indicators. In accordance with RMG 29-2013 the accuracy indicators include the total standard and expanded uncertainty.

Calculation and estimation of measurement uncertainty is carried out by different methods: using in-lab-oratory studies on validation of analysis methodology, least squares method, etc. [1–5]. The method of least squares is used if the measurement result is established by the dependence graph, for example, when determining the toxicity of materials $H_{CL_{50}}$, which is revealed by the dependence of $H_{CL_{50}}$ (g/m^3) on the lethality of white mice, L (%) [6–20].

The aim of this study was to calculate the uncertainty for indirect measurements under different measurement models as well as direct measurements to classify a building material as combustible/non-combustible.

According to the objective, the following objectives were set:
— to test samples of decorative plaster;
— analyze the obtained measurement models for the flammability of decorative plaster and process the test results with regard to their accuracy and reliability.

MATERIALS AND METHODS

In accordance with GOST 30244-94 Method 1 "Construction materials. Methods of testing for combustibility" (Method I) were tested decorative plaster Nanopor 'Baumit' to attribute this material to combustible (G) or non-combustible (NG) building materials. For this purpose, cylindrical samples of the decorative plaster were made from the decorative plaster and subjected to fire exposure on a non-combustibility test rig for building materials. As a result, the following flammability parameters are determined: mass loss for each sample, temperature increase in the furnace, duration of steady flame combustion. According to the results obtained, the decora-

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tive plaster is attributed to the group of combustible or non-combustible. In order to ensure the accuracy and reliability of the definition of this group it is necessary to assess the scatter of values for these parameters.

The results of tests of samples of decorative plaster mixture on combustibility are presented in Table 1.

The model of measurement by mass loss for each sample of decorative plaster is an indirect measurement with nonlinear dependence and measurement error of input quantities, which do not depend on each other. The functional dependence f of the output quantity (mass loss (P_i)) on the input quantities (sample mass before testing (m_{1i}), sample mass after testing (m_{2i}) is determined.

$$P_i = f(m_{1i}, m_{2i}) = \frac{(m_{1i} - m_{2i})}{m_{1i}},$$

where m_{1i} – sample mass before testing, g;
m_{2i} – sample mass after testing, g;
i – sample number;
P_i – sample mass loss, g.

Estimation of mass loss of decorative plaster samples (%) $P = (\Sigma_{i=1}^{n} P_i) / n = 36/5 = 7\%$.

The spread of values (measurement uncertainty) for sample mass loss is composed of the standard uncertainty for Type A and Type B. Type A uncertainty is determined on the basis of statistical data and is characterized by the scatter of values of random variables. Type B uncertainty takes into account all non-excluded systematic errors that arise as a result of a given measurement (test).

The standard uncertainty on Type A $u_A(x_i)$ corresponds to the sample standard deviation of the mean value of all input quantities on the determination of the mass loss of the plaster sample

$$u_A(x_i) = S_{\bar{x}} = \sqrt{\frac{\Sigma_{j=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}, \qquad (1)$$

where x_i – individual measurement result;

$\bar{x}$ – mean value of the measurement result;
n – number of measurements;
$S_{\bar{x}}$ – sample standard deviation of the mean value.

The Type A standard uncertainty for the mass of the plaster sample before testing m_{1i}, the mass of the sample after testing m_{2i} of the plaster was determined using formula 1, calculated in the program ExceL and presented in Table 2 and Table 3.

Type A standard uncertainty for the mass of the decorative plaster sample before testing (m_{1i})
$u_A(m_1) = 2.6$ g; $\overline{m}_1 = 72.7$ g.

Type A standard uncertainty for the mass of the decorative plaster sample after testing (m_{2i})
$u_A(m_2) = 2.2$ g; $\overline{m}_2 = 67.6$ g.

According to the sample mass loss model, which refers to indirect measurements with nonlinear dependence, the total standard uncertainty of uc(y) [5] is determined by the formula

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (\frac{\partial f}{\partial x_i})^2 \ u^2(x_i)} =$$

$$= \sqrt{(\frac{\partial f}{\partial x_1})^2 \ u^2(x_1) + (\frac{\partial f}{\partial x_2})^2 \ u^2(x_2) + \cdots + (\frac{\partial f}{\partial x_i})^2 u^2(x_i)}, \qquad (2)$$

where $u(x_1)$, $u(x_2)$, $u(x_i)$ – the standard uncertainty of the input quantity estimated by Type A or Type B;
$\partial f / \partial x_i$ – partial derivatives of input quantities.

Total Type A standard uncertainty for sample mass loss

$$u_{cA} = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)} =$$

$$= \sqrt{\left(\frac{m_2}{(m_1^2)}\right)^2 \times u_A^2(m_1) + \left(-\frac{1}{m_1}\right)^2 \times u_A^2(m_2)} =$$

$$= \sqrt{(\frac{67,6}{(72,72^2)})^2 \times (2,6)^2 + \left(-\frac{1}{72,72}\right)^2 \times (2,2)^2} =$$

$$= 0,05 \%$$

Table 1. Test results of Baumit Nanopor decorative plaster samples on combustibility parameters

№ of test sample	Furnace temperature, °C			Temperature rise in the furnace $T_{p.p.} = T_{p.m.} - T_{p.k.}$	The temperature at the surface of the sample, °C		Temperature rise on the surface $T_{p.o.} = T_{p.o.m.} - T_{p.o.c.}$	Temperature at the center of the sample, °C		Temperature rise in the center of the sample	Duration of stable of flame combustion of the sample, s	Sample mass, g		Sample mass loss, %
	initial, $T_{p.p.}$	maximum, $T_{p.m.}$	final, $T_{p.k.}$		maximum, $T_{p.o.m.}$	final, $T_{p.o.c.}$		maximum, $T_{c.m.}$	final, $T_{c.k.}$			before the test	after the test	
1	750	756	752	4	786	782	4	738	733	5	1	71.2	66.5	7
2	751	756	750	6	800	796	4	742	738	4	1	71.2	66.2	7
3	750	756	752	4	798	793	5	740	735	5	1	73.2	68.0	7
4	744	755	751	4	795	792	3	740	734	6	1	73.9	68.2	8
5	750	755	750	5	792	788	4	741	737	4	1	74.1	69.2	7
Arithmetic mean of the results of five tests				4.6			4			5	1			7

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Table 2. Type A uncertainty calculation for the mass of the Nanopore decorative plaster sample before testing

No. p/p	Sample mass before the test, g	$(x_i-\overline{x})$	$(x_i-\overline{x})^2$	Type A uncertainty $u_A(m_1)$, g
1	71.2	−1.52	2.31	
2	71.2	−1.52	2.31	
3	73.2	0.48	0.23	
4	73.9	1.18	1.39	
5	74.1	1.38	1.90	
	72.70		8.15	
	Average value		Sum (Σ)	2.59

Table 3. Type A uncertainty calculation for the mass of the Nanopor decorative plaster sample after testing

No. p/p	Sample mass before the test, g	$(x_i-\overline{x})$	$(x_i-\overline{x})^2$	Type A uncertainty $u_A(m_2)$, g
1	66.5	−1.12	1.254	
2	66.2	−1.42	2.016	
3	68.0	0.38	0.144	
4	68.2	0.58	0.336	
5	69.2	1.58	2.496	
	67.6		6.24	
	Average value		Sum (Σ)	2.24

The uncertainty of Type B is determined on the basis of non-excluded systematic errors, which are formed as a result of testing, they include, mainly, errors of measuring equipment, which are involved in these measurements. The errors of the measuring equipment, in our case, are subject to the law of uniform distribution, because they are described by a symmetric rectangular distribution in the interval with lower − Θ and the upper limit + Θ.

Standard uncertainty for Type B u_B for uniform distribution

$$u_B = \frac{|\pm\sum\Theta|}{\sqrt{3}} \qquad (3)$$

Θ − non-excluded systematic errors of measurement results.

The measuring equipment involved in the measurement of input quantities contribute their error to the final measurement result and its deviation, these errors are superimposed on each other and summarized among themselves.

For each measuring equipment, the non-excluded systematic error is established in absolute form and according to the formula 2 Type B uncertainty is calculated. Type B relative uncertainty is determined (u_B), the relative uncertainty is squared u_B^2 and summarize u_B^2 for all measuring equipment.

The Type B standard uncertainty for the mass of the sample before the test is equal to the error of the scales.

Whereas the mass of the sample after the test, was determined for all measuring instruments and test equipment that participated in this measurement and calculated in the program ExceL (Table 4).

Type B standard uncertainty for the mass of the sample before testing

$\overline{m}_1 = 72.7$ g; $u_{B1}(m_1) = 0.3$ g.

Type B standard uncertainty for the mass of the samples after testing

$\overline{m}_2 = 67.6$ g; $u_{B2}(m_2) = 3.3$ g.

The total standard uncertainty in Type B mass loss of the sample was calculated according to formula 2, by summing the type B uncertainties of the input quantities

$$u_{cB} = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)} =$$

$$= \sqrt{\left(\frac{m_2}{(m_1^2)}\right)^2 \times u_{B1}^2(m_1) + \left(-\frac{1}{m_1}\right)^2 \times u_{B2}^2(m_2)} =$$

$$= \sqrt{\left(\frac{67{,}6}{(72{,}72^2)}\right)^2 \times (0{,}3)^2 + \left(\frac{1}{72{,}72}\right)^2 \times (3{,}3)^2} = 0{,}15\%.$$

Expanded uncertainty in sample mass loss at confidence level 95%, $k = 2$ (U)

$$U(P) = k\sqrt{(u_{cA})^2 + (u_{cB})^2} =$$

$$= 2\sqrt{(0{,}05)^2 + (0{,}15)^2} = 0{,}3\ \%.$$

Table 4. Type B standard uncertainty for the mass of the sample after testing

No. p/p	Name of measuring instruments, deviations	Measurement error (accuracy class)	Measuring range	Measured value	Absolute error	u_B	Relative uncertainty u_B in shares	$u_B{}^2$
1	Laboratory electronic scales Pioneer, modification PA4102C	Uncertainty: 0.1–0.3 g	(0.01–120) g	72	0.3	0.3	0.002	0.00001
2	Laboratory electronic scales Pioneer, modification PA4102C	Uncertainty: 0.1–0.3 g	(0.01–120) g	67.62	0.3	0.2	0.003	0.00001
3	Deviation from average furnace temperature		(745–755) ºC	755	2	1.2	0.002	0.00000
4	Thermoelectric converters type TP, modification TP-0198 XA(K)	Tolerance class 1; ±0.0075 t	40 to +850 ºC	756	5.67	3.3	0.004	0.00002
5	Thermoelectric converters type TP, modification TP-0198 XA(K)	Tolerance class 1; ±0.0075 t	40 to +850 ºC	800	6	3.5	0.004	0.00002
6	Thermoelectric converters type TP, modification TP-0198 XA(K)	Tolerance class 1; ±0.0075 t	40 to +850 ºC	742	5.565	3.2	0.004	0.00002
7	Eight-channel temperature control device УКТ 38-Щ4, modification УКТ38-Ш4-ТП	±0.5%	–50 to +1300 ºC	756	3.78	2.2	0.003	0.00001
8	Eight-channel temperature control device УКТ 38-Щ4, modification УКТ38-Ш4-ТП	±0.5%	–50 to +1300 ºC	742	3.71	2.1	0.003	0.00001
9	Eight-channel temperature control device УКТ 38-Щ4, modification УКТ38-Ш4-ТП	±0.5%	–50 to +1300 ºC	800	4	2.3	0.003	0.00001
10	Metal measuring ruler trademark "Calibron"	±0.30 mm	0–300 mm	45	0.3	0.2	0.004	0.00001
11	Deviation of linear dimensions of samples by sample diameter	±2 mm	43–45 mm	45	2	1.2	0.026	0.00066
12	Deviation of linear dimensions of samples by sample height	±3 mm	47–53 mm	50	3	1.7	0.035	0.00120
13	Metal measuring ruler trademark "Calibron"	±0.30 mm	0–300 mm	50	0.3	0.2	0.003	0.00001
	$u_B{}^2$							0.002
	u_B							0.058

Thus, the mass loss of the sample is $P = 7.0\pm0.3\%$ at confidence level $P_д = 0.95$.

The results show that the mass loss of decorative plaster samples after fire exposure decreased by only 7%, due to moisture loss during heating of plaster samples. And the uncertainty in the mass loss of plaster is about 5%, this scatter of data is mainly due to the error of measuring instruments, calibration of testing equipment, as well as geometric dimensions of samples.

The combustibility parameter by the temperature increase in the furnace is determined by the indirect method with a linear dependence of the result (output) value ($T_{p.p.}$) of the inputs ($T_{p.m.}$, $T_{p.k.}$) and the absence of correlation between the measurement errors of the input quantities.

$$T_{p.p.} = f(T_{p.m.}, T_{p.k.}) = T_{p.m.} - T_{p.k.},$$

where $T_{p.p.}$ — furnace temperature rise, ˚C
$T_{p.m.}$ — maximum furnace temperature, ˚C
$T_{p.k.}$ — final furnace temperature, ˚C.
Type A uncertainty calculation for maximum furnace temperature ($T_{p.m.}$) and the final temperature in the furnace ($T_{p.k.}$) is performed according to formula 1 and the results are presented in Tables 5 and 6.

Table 5. Type A uncertainty calculation for maximum furnace temperature

No. p/p	Maximum oven temperature, ℃	$(x_i-\bar{x})$	$(x_i-\bar{x})^2$	Type A uncertainty $u_A(T_{p.m.})$, ℃
1	756.0	0.4	0.16	
2	756.0	0.4	0.16	
3	756.0	0.4	0.16	
4	755.0	−0.6	0.36	
5	755.0	−0.6	0.36	
	755.6		1.20	
	Average value		Sum (Σ)	0.2

Table 6. Type A uncertainty calculation for the final furnace temperature

No. p/p	Final temperature in the furnace, ℃	$(x_i-\bar{x})$	$(x_i-\bar{x})^2$	Type A uncertainty $u_A(T_{p.k.})$, ℃
1	752.0	1	1	
2	750.0	−1	1	
3	752.0	1	1	
4	751.0	0	0	
5	750.0	−1	1	
	751.0		4	
	Average value		Sum (Σ)	0.4

According to the furnace temperature rise measurement model, which refers to indirect measurements with linear dependence [5] the total standard uncertainty $u_c(y)$ is determined by summing the uncertainties of the input quantities and is calculated by the formula

$$u_c(y) = \sqrt{\sum_{i=1}^{n} u^2(x_i)} =$$

$$= \sqrt{u^2(x_1) + u^2(x_2) + \cdots + u^2(x_i)}, \qquad (4)$$

where $u(x_1)$, $u(x_2)$, $u(x_i)$ – the standard uncertainty of the input quantity estimated by Type A or Type B.

Total standard uncertainty in Type A for the furnace temperature rise

$$u_{cA(Tp.p)} = \sqrt{u_{A(Tp.m)}^2 + u_{A(Tp.k)}^2} =$$

$$= \sqrt{(0,2)^2 + (0,4)^2} = 0,83 \,°\text{C}.$$

Type B uncertainty is determined on the basis of the results of the error of measuring equipment: thermoelectric converters, temperature control device, equipment calibration.

Type B uncertainty for maximum and final furnace temperature

$$u_B(T_{p.m.}) = u_B(T_{p.k.}) = 4.6 \times 0.012 = 0.06 \,°\text{C}.$$

Total standard uncertainty in Type B for the furnace temperature increment

$$u_{cB(Tp.p.)} = \sqrt{u_{B(Tp.m)}^2 + u_{B(Tp.k)}^2} =$$

$$= \sqrt{(0,006)^2 + (0,006)^2} = 0,009 \,°\text{C}.$$

Expanded uncertainty in furnace temperature rise at confidence level 95%, coverage rate $k = 2$ at $P_{д} = 0.95$

$$U(P) = k\sqrt{(u_{cA})^2 + (u_{cB})^2} =$$

$$= 2 * \sqrt{(0,83^2) + (0,009^2)} = 1,7 \,°\text{C}.$$

The calculation of the temperature increase in the furnace is 4.6±1.7 ℃ at confidence level $P_{д} = 0.95$. The relative expanded uncertainty on the temperature increase in the furnace is $U(P) = 36\%$, the scatter of data is mainly influenced by random error (standard uncertainty in Type A $u_{cA}(T_{p.p.}) = 0.83$ ℃), at that systematic errors (standard uncertainty on type B $u_{cB}(T_{p.p.}) = 0.009$ ℃) are small and may not be accounted for in these results.

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The flammability parameter, to which the duration of steady flame combustion refers, is estimated by a direct method, in which the measurement result is established directly from the experimental data, in this case the time of steady flame combustion was determined using a stopwatch.

Average value of the duration of stable flame combustion $\bar{t} = 1$ s. The standard uncertainty for Type A for the duration of sustained flame combustion of a sample is $u_{A(tg)} = 0$.

The Type B uncertainty for the duration of steady flame combustion of a sample is composed of uncertainties associated with non-excluded systematic errors from measuring equipment: stopwatch, thermoelectric transducers, temperature control device, and equipment calibration.

The Type B uncertainty for the duration of steady flame combustion of the sample is

$u_{B(tg)} = 1 \times 0.015 = 0.015$ s.

Expanded uncertainty for the duration of steady flame combustion of the sample at the confidence level 95%, coverage rate $k = 2$ at $P_{\text{д}} = 0{,}95$

$$U\,(P) = k \sqrt{(u_{A(tg)})^2 + (u_{B(tg)})^2} =$$

$$= 2 * \sqrt{(0{,}015^2)} = 0{,}06 \text{ s.}$$

The calculation of the duration of steady flame combustion is as follows 1.0 ± 0.1 s at confidence level $P_{\text{д}} = 0.95$. The relative expanded uncertainty on the duration of steady flame combustion is 10%, this spread of data is influenced by systematic errors (mainly stopwatch error).

RESULTS AND DISCUSSION

Tests of decorative plaster Nanopor according to GOST 30244-94 with the processing of measurement results for attribution to combustible or non-combustible showed the following results:

— mass loss of the sample is $P = 7.0 \pm 0.3\%$;
— temperature increase in the furnace is 4.6 ± 1.7 °C;
— the duration of steady flame combustion is 1.0 ± 0.1 s.

In accordance with paragraph 5.2. of GOST 30244-94, this building material is classified as non-combustible materials, because the values of flammability parameters are within the permissible norm. Loss of mass of samples of decorative plaster Nanopor after fire exposure decreased by only 7%, due to loss of moisture during heating of samples of decorative plaster. And the uncertainty of the mass loss of decorative plaster Nanopor is about 4%, this scatter of data is mainly due to the error of the equipment and deviations of geometric parameters of samples (deviations of linear dimensions of samples in height and diameter of the sample).

The temperature rise in the furnace when testing Nanopor decorative plaster is about 5 °C, at the norm not more 50 °C. The relative expanded uncertainty on the temperature increase in the furnace is 36%, this shows that the furnace temperature has a scatter of data over time, which depends on various random factors.

The duration of sustained flame combustion of Nanopor decorative plaster is as follows 1 s, at the norm not more 10 s. The variation of data on this indicator is 10% and arises due to the error of the measuring instrument (stopwatch).

CONCLUSION

Analysis of the obtained data showed that when measuring the fire hazard parameters of building materials it is necessary to calculate the accuracy indicators (measurement uncertainty), which ranges from 4 to 40% and is composed of various random and non-excluded systematic errors. These deviations should be taken into account when assigning a material or substance a certain group (class) of fire danger.

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ADDITIONAL INFORMATION

The authors declare that generative artificial intelligence technologies and technologies based on artificial intelligence were not used in the preparation of the article.

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