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# DESIGN OF FIRE-RESISTANT HEAT- AND SOUNDPROOFING WOOD WOOL PANELS

**Yu. Tsapko**
Doctor of Technical Sciences**
V. D. Glukhovsky Scientific Research Institute
for Binders and Materials***
E-mail: juriyts@ukr.net
**D. Zavialov**
Posgraduate student*
E-mail: lazarovuch@ukr.net
**O. Bondarenko**
PhD, Associate Professor
Department of Building Materials***
E-mail: bondolya3@gmail.com
**O. Pinchevs'ka**
Doctor of Technical Sciences, Professor*
E-mail: olenapinchevska@nubip.edu.ua
**N. Marchenko**
PhD, Associate Professor*
E-mail: nv_marchenko@ukr.net
**S. Guzii**
PhD, Senior Researcher
V. D. Glukhovsky Scientific Research Institute
for Binders and Materials***
E-mail: sguziy@ukr.net
*Department of Technology and
Design of Wood Products**
**National University of Life and
Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041
***Kyiv National University
of Construction and Architecture
Povitroflotsky ave., 31, Kyiv, Ukraine, 03037

***Проведеними дослідженнями встановлено можливості виготовлення тепло- та звукоізоляційних матеріалів для облаштування приміщень. Сировиною для їхнього виробництва є деревні волокна, які виготовляють у виді плоских плит. Встановлено механізми процесу тепло- та звукоізоляції при передаванні енергії через матеріал, що дає можливість впливати на цей процес. Доведено, що вони полягають у зниженні пористості матеріалу. Так, зі зменшенням об'ємної маси матеріалу, теплопровідність і передача звуку зменшується, і навпаки. Крім того, тепло- та звукоізоляційні будівельні матеріали з деревини повинні задовольняти наступним вимогам: мати стабільні теплоізоляційні і акустичні показники протягом усього періоду експлуатації та бути вогнестійкими і не виділяти в навколишнє середовище шкідливих речовин. Експериментальними дослідженнями підтверджено, що матеріал на основі деревної шерсті і неорганічного в'яжучого при співвідношенні 1:1 відноситься до горючих матеріалів, оскільки, під час температурного впливу було зафіксовано його тління. Так, під термічною дією протягом 90 с матеріал зайнявся і полум'я поширилося по першим трьом зонам протягом 41 с. Натомість, підвищення кількості в'яжучого на неорганічній основі та застосування органо-мінерального в'яжучого, не призводить до загорання матеріалу. При цьому максимальна температура димових газів становила близько 120 °C, а індекс горючості складав 0 за рахунок розкладання антипіренів під дією температури з виділенням негорючих газів, які гальмують процеси окиснення матеріалу та суттєво підвищують утворення на поверхні матеріалу теплозахисного шару коксу. Це приводить до гальмування теплопередачі високотемпературного полум'я до матеріалу. Завдяки цьому стало можливим визначення умов вогнестійкості матеріалу шляхом утворення бар'єру для теплопровідності. Це дозволяє стверджувати про відповідність виявленого механізму формування властивостей матеріалу на основі деревної шерсті і неорганічного та органо-мінерального в'яжучого та практичну привабливість запропонованих технологічних рішень. Останні, зокрема, стосуються визначення кількості складової в'яжучого, оскільки при малих кількостях проходить процес горіння. Таким чином, є підстави стверджувати про можливість спрямованого регулювання процесів формування деревинних тепло- та звукоізоляційних матеріалів шляхом використання деревної шерсті і неорганічного та органо-мінерального в'яжучого, які здатні утворювати на поверхні матеріалу вогнезахисну плівку***

***Ключові слова: тепло- та звукоізоляційні матеріали, деревна шерсть, теплопровідність, звукоізоляція, неорганічне і органо-мінеральне в'яжуче***

## 1. Introduction

To date, environmentally safe materials made of wood, which are referred to flammable materials by the flammability group, are becoming increasingly popular. Raw materials for their manufacture are wastes of woodworking industry, wood chips, wool and the other, but these materials have one common drawback – flammability.

Wood is one of the effective sound-absorbing materials, because sound is absorbed not only through friction in the

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pores of wood, but also due to internal friction during the deformation of a flexible skeleton. Porous acoustical materials, which include wood, must satisfy general requirements: sound absorption coefficient at low frequencies (125 Hz) must be not less than 0.20 and at medium frequencies (500–2,000 Hz) – not less than 0.40. In addition, they must be non-combustible or difficultly combustible, as well as durable; have a small bulk weight (not more than 300–400 kg/m$^3$); be biologically stable; should not give off chemically harmful substances.

Basic requirements for fire resistance of natural combustible materials involve the ability to resist the action of fire and not to spread flame around the surface. A change in decomposition of such material during fireproofing treatment is directed toward the formation of non-combustible gases and difficultly combustible coke residue, as well as oxidation inhibition in the gas and condensed phase.

Modern methods of fireproofing of building structures are based on the use of coatings that swell, which represent complex systems of organic and inorganic components, capable of forming a protective coke layer [1, 2]. The use of the compositions of polymeric substances and fire retardants converts organic material to difficultly flammable and makes it possible to delay the ignition process for longer periods [3, 4].

The simplest fireproofing means based on inorganic binding materials contain bound water, which evaporates during heating and blocks up heat transfer to the surface that is protected. Sodium liquid glass, Portland cement, aluminous cement, phosphate and aluminosilicate binders are mostly used as binders. Such materials are characterized by slight elasticity, they give off to the environment only water vapor under the influence of the temperature factor [3].

The formation of heat- and soundproofing wood panels with the use of non-combustible binders may increase fireproofing of the material due to the formation of a protective coke layer. It will make it possible to develop a new type of fireproofing roofing means for building structures.

The treatment of the surface of heat- and soundproofing panels with fireproofing coatings are not always appropriate, because after a long thermal action, the combustion stage can be transferred to the middle of the material by smoldering.

That is why the manufacture of fire-resistant heat- and soundproofing wood materials, the study of fire protection and the influence of the components that make up their composition on this process is an unsolved part of fire resistance of building structures. And, therefore, they determine the need for such research.

## 2. Literature review and problem statement

In recent years, there are well-known studies that are focused on the development of fireproof panels for heat and sound insulation. They are based on pressing a mixture of vegetable fibers with mineral admixtures, which use asbestos, mica and basalt, mixed with the hydrophobic components [5, 6]. Paper [5] studied the impact of the amount of vegetable fiber (flax fiber – cotton fiber) on the density and flexibility of the material produced by aeration deposition. It also considered the influence of the binder based on vegetable raw materials on the properties of flexible insulation materials, however, the issue that is associated with combustibility, which decreases the quality of the results obtained, remains unresolved. In paper [6], the implementation of the method for obtaining wood and mineral composite material is based on wood reinforcement with basalt particles during swelling in the water medium taking into consideration the surface properties of wood and basalt. The semi-finished product formation and its drying are considered after the separation of solid phase of the reaction suspension and addition of a binder based on a mixture of finely dispersed basalt and polysilicate systems. However, the products belong to the materials, characterized by low adhesion.

Article [7] presents data on the production technology, thermal properties of the material, made from hemp and binding gypsum and the possibility of its use as a heat- and soundproofing material. However, the issues about the manifestation of the joint action of components during the thermal insulation remain unresolved. The materials presented in paper 8 are characterized by high heat- and soundproofing ability, but the technology of their production and mechanical characteristics were not presented.

The expediency of using dolomite clay is proved by a change in the structure of coked foam and a significant decrease in thermal characteristics, that is caused by the formation of intermediate compounds that create a substantial number of nanostructures [9]. However, the relevant physical and chemical calculations were not given to prove this process. This, first of all, is caused by the wide range of temperatures during the decomposition of organic-inorganic hybrid material with a peak at 353 °C, which is far above the temperature of self-ignition of the material [10]. In the framework of this research [11], a mathematical model that describes the dynamics of heat propagation and retaining on the fiber insulation coating with regard to the «internal» features a heat insulator (granularity and porosity of fibrous insulation). However, this model does not take into account how exactly the shape of pores affects heat transfer to the structure itself.

In addition, a lot of heat- and soundproofing materials have a series of drawbacks, such as the introduction of particular components, loss of functional properties at an increase in temperature [12]. This means that it was not determined how the process flows under temperature conditions in the range of material decomposition. From the practical point of view, it can cause difficulties related to determining the optimal number of inert additives.

The studies of insulating materials produced from mixed carpet wastes with the solution from colemanite ore, one of the boron minerals and the solution with the addition of colemanite wastes were conducted [13]. It was shown that due to the established optimal ratios, it becomes possible to adjust the content of the components to ensure the heat- and soundproofing process.

That is why the development of heat- and soundproofing panels, research into the influence of the components that make up their composition and their role in ensuring fire resistance cause the need for conducting research in this field, specifically, the creation of fire-resistant heat- and soundproofing panels.

## 3. The aim and objectives of the study

The aim of the present research is to identify the heat- and soundproofing parameters of the wood wool panels and to establish their fire-resistant properties.

To accomplish the aim, the following tasks have been set:

– to explore thermal conductivity and soundproofing properties of the materials based on wood wool and aluminosilicate and organic-mineral binding agents;

– to identify the features of combustion of heat- and soundproofing wood materials under the temperature influence of fireproofing action on combustion suppression.

## 4. Materials and methods used in the development of heat- and soundproofing materials

### 4. 1. Examined materials that were used in the experiment

The samples of heat- and soundproofing material based on wood wool and a binder were prepared by the method of pressing in metal press-forms of the dimensions of 350×300×30 mm. Wood wool previously made of low quality pine wood and dried to the moisture content of 10 % was used as the filler for panels. The dimensions of fibers (wool threads) were of the following: the length was 50–400 mm, the thickness was 0.5 mm and the width was 5 mm, respectively. Preparation of the binder involved bringing its viscosity up to 10 s and 17 s (at a two-fold increase) by the viscosity meter VZ-4 with the use of water. A fireproofing coating on the inorganic base (patent of Ukraine for the useful model No. 95440 «Fireproofing coating for wood») and the coating on organic-mineral base («Skela-w») were used as binders.

Wood wool and the binder were placed into a container and stirred. Stirring continued up to complete wetting of wood wool, then the prepared raw material mixture was placed in a sieve for 60 s and the press mold was filled. The filled mold was subjected to hot pressing under the pressure of 0.02 MPa at a temperature of 100–110 °C and kept for 30 s per every millimeter of the pressed product. Then, the temperature was lowered up to 75 °C and kept for 60 s per every millimeter of thickness of the pressed product. After the load removal, the samples were kept for 1 day at room temperature and relative air humidity close to 65 %.

Heat- and soundproofing material was prepared at the following ratios of weight fractures of the filler and the binder (Fig. 1):

1) wood wool – binder (on inorganic base) at the ratio of 1:1;

2) wood wool – binder (on inorganic base) at the ratio of 1:2;

3) wood wool – binder (on organic-mineral base) at the ratio of 1:1.

Fig. 1. Model samples of heat- and soundproofing material: *a* — based on wood wool — inorganic binder at the ratio of 1:1, *b* — based on wood wool — inorganic binder at the ratio of 1:2, *c* — based on wood wool — organic-mineral binder at the ratio of 1:1

After the panels were produced, the test samples, the edges of which were sawed around the perimeter, were cut out from them. Thus, the dimensions and density of samples for different variants of the binder made up:

1) wood wool – binder at the ratio of 1:1:

– for inorganic (patent of Ukraine for useful model No. 95440 «Fireproofing coating for wood») – 300×300×28 mm, a density of 147 kg/m$^3$;

– for organic-mineral («Skela-w») – 300×300×28 mm, a density of 143 kg/m$^3$;

2) wood wool – binder (on inorganic base) at the ratio of 1:2 – 300×300×27 mm, a density of 274 kg/m$^3$.

### 4. 2. Procedure for determining the indicators for properties of samples

The normal sound absorption coefficient was determined on the samples of the standard wood chipboard panel and fire-resistant heat- and soundproofing panel made from wood wool. The sound absorption capability of the material is characterized by arithmetic mean reverberation sound absorption coefficient ($\alpha$) in each of the three frequency ranges:

– in the low-frequency range (100–315 Hz);

– in the medium-frequency range (400–1,250 Hz);

– in the high-frequency range (1,600 – 8,000 Hz).

In this case, depending on the magnitude of arithmetical mean reverberation sound absorption coefficient ($\alpha$) in each of the indicated ranges, sound absorbing materials belong to one of three classes:

– class 1 – at $\alpha > 0.8$;

– class 2 – at $\alpha = 0.4–0.8$;

– class 3 – at $\alpha = 0.2–0.4$.

It should be noted that the magnitudes of reverberation coefficient of sound absorption of a particular material are usually slightly larger than the magnitudes of the normal sound absorption coefficient. However, for the purpose of the reference evaluation of sound absorption properties of the tested samples, we will determine whether this material belongs to a particular class by the magnitudes of arithmetical mean normal sound absorption coefficient in the range of frequencies:

– the magnitude of arithmetical mean normal coefficient of sound absorption of the tested samples of fire-resistant heat- and soundproofing panels in the low-frequency range is 0.21 and in this frequency range belongs to sound absorbing materials of class 3;

– the magnitude of arithmetical mean normal coefficient of sound absorption of the tested samples of fire-resistant heat- and soundproofing panels in the low-frequency range is 0.25 and in this frequency range belongs to sound absorbing materials of class 3;

– the magnitude of arithmetical mean normal coefficient of sound absorption of the tested samples of fire-resistant heat- and soundproofing wood fiber panels in the low-frequency range is 0.42 and in this frequency range belongs to sound absorbing materials of class 2.

According to the given requirements, in the general case, the materials that have sound absorption coefficient $\alpha \geq 0.4$ at the frequency of 1,000 Hz belong to sound absorbing materials.

Results of research into sound absorbing properties of wood chipboard panel (Table 1) showed [14] that this material in the low- and medium-frequency range belongs to class 3, and in the high-frequency range – to class 2 of sound absorbing materials.

Table 1

Sound absorption coefficients of materials and structures

| Material | Arithmetic mean frequencies of octave bands, Hz | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 | 8,000 |
| Wood chipboard panel, $\Delta=20$ mm | 0.29 | 0.29 | 0.27 | 0.33 | 0.32 | 0.39 | 0.46 | 0.46 |

The task of thermal insulation of buildings is to reduce heat losses in cold period of the year and provide the relative temperature constancy in premises during the day at the variations in outside air temperatures. That is why effective materials, which can significantly reduce the thickness and decrease the weight of structures, are used for thermal insulation.

The research results revealed that the coefficient of thermal conductivity of wood chipboard panel of the thickness of 20 mm is 0.12 W/(m·K) [15], the thermal conductivity indicators were not found for heat- and wood wool soundproofing panels. Therefore, thermal-physical indices of heat- and soundproofing panels from wood wool (density, thermal conductivity in the dry condition) were determined based on the experimental research. Normative values of density, thermal conductivity in dry condition, moisture content of the material under conditions A and B, as well as thermal conductivity under these conditions are listed in Table 3 [16]. The essence of the method for thermal insulation testing is that the tested material is subjected to heat influences that imitate the operation conditions of the material in enclosure structures and determine the changes of thermal-physical characteristics of the material.

As Table 2 shows, the products from wood chipboard panel belong to heat-insulating materials.

The studies on the experimental determining the ignition parameters of heat- and soundproofing wood wool panels were carried out using the procedure that involved the sample being placed into a test chamber and subjected to radiation influence.

Table 2

Normative values of thermal-physical parameters of wood chipboard panels [16]

| Characteristic in dry state | | Estimated moisture content under operation conditions $w$, % | | Estimated characteristics under operation conditions | |
|---|---|---|---|---|---|
| | | | | Thermal conductivity λ, W(m·K) not exceeding | |
| Density $\rho_0$, kg/m$^3$ | Thermal conductivity $\lambda_0$, W/(m·K) not exceeding | A | B | A | B |
| 200 | 0.06 | 10 | 12 | 0.07 | 0.08 |
| 400 | 0.08 | 10 | 12 | 0.11 | 0.13 |
| 600 | 0.11 | 10 | 12 | 0.13 | 0.16 |
| 800 | 0.13 | 10 | 12 | 0.19 | 0.23 |
| 1,000 | 0.15 | 10 | 12 | 0.23 | 0.29 |

The ignition time, maximum temperature of combustions products and the time to achieve it, the time of the passage through a surface section by the flame, the length of the burnt section of the sample were measured after the sample ignition [2].

Higher heat $Q_{B,V}$ was determined experimentally in accordance with DSTU B EN ISO 1716:2011 [17] in the calorimeter IKS 6000 Isoperibol with the isothermal shell. Lower heat of combustion was determined by calculating from higher heat.

## 5. Results of research into heat- and soundproofing wood materials and their resistance under temperature influence

Normal sound absorption coefficient was determined on the samples of a wood panel based on wood wool and the organic-mineral binding agent of density of 143 kg/m$^3$ and the inorganic binding agent of density of 274 kg/m$^3$. Fig. 2 shows the dependence of normal coefficient of sound absorption of oscillation frequency for samples of wood fiber panels for various ranges and gives the equations of approximating curves that satisfactorily describe the resulting data array.

The data were processed using the Microsoft Excel function:

$$\alpha = a \cdot \omega^{b}, \tag{1}$$

where empirical constants $a$ – sound absorption coefficient, $b$ – oscillation frequency, Hz.

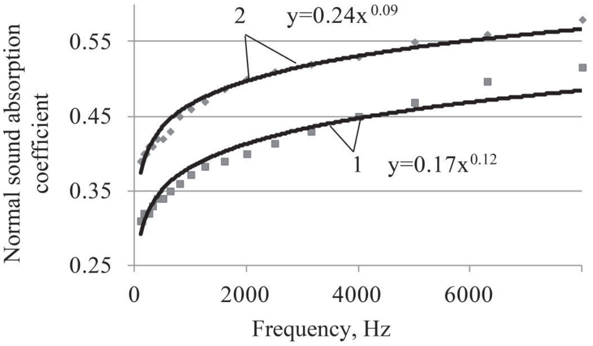

Fig. 2. Dependence of normal sound absorption coefficient on oscillation frequency for the samples of wooden panel, which are described by approximation curves: 1 — based on wood wool and inorganic binder; 2 — based of wood wool and organic-mineral binder

According to Fig. 2, at approximation of curve 2, we have: $a=0.24$; $b=0.09$ Hz, normal sound absorption coefficient will be:

$$\alpha = 0{,}24 \cdot 1000^{0{,}09} = 0{,}44. \tag{2}$$

Instead, for the panel made of inorganic binder, normal sound absorption coefficient is 0.39.

The results of the acoustic tests (Fig. 2) showed that for the samples of wooden panels based on wood wool and inorganic binder, the magnitude of normal coefficient of sound absorption is slightly lower due to increased density and brings them to soundproof materials of class 3. For the samples of wood panels based on wood wool and organic-mineral binder, the magnitude of normal absorption coefficient is higher and refers them to soundproofing materials (Table 3).

The samples of the wood panel based on wood wool and inorganic binder and organic-mineral binder were subject to thermal insulation testing. The results of determining density, moisture and thermal conductivity are shown in Table 3.

Table 3

Magnitude of normal sound absorption coefficient for wood panel based on wood wool and the binder

| Range of frequency of octave bands, Hz | Magnitude of normal sound absorption coefficient | |
|---|---|---|
| | of wood panels based on wood wool and inorganic binder | of wood panels based on wood wool and organic-mineral binder |
| Low-frequency (100–315 Hz) | 0.32 | 0.4 |
| Medium-frequency (400–1,250 Hz) | 0.36 | 0.44 |
| High-frequency (1,600–8,000 Hz) | 0.44 | 0.53 |

The obtained results of the indicators of thermal engineering properties of the panel based of wood wool and inorganic and organic-mineral binder showed that they meet the requirements of Table 2 by the thermal conductivity indicator [16].

Table 4

Results of testing thermal technical properties of wood-based panels

| Indicator | Values of indicator for | |
|---|---|---|
| | panels from wood wool and inorganic binder | panels from wood wool and organic-mineral binder |
| Density, kg/m$^3$ | 274 | 143 |
| Initial moisture content, % | 8.3 | 7.9 |
| Thermal conductivity in damp state, W/(m·°C) | 0.0943 | 0.0648 |
| Thermal conductivity in dry state, W/(m·°C) | 0.0821 | 0.0451 |

Fig. 3, 4 show the process of ignition and flame propagation by wood material.

Results of the studies on determining the increment of the maximum temperature of the gaseous products of combustion ($\Delta t$, °C) of wood material, carried out under laboratory conditions are shown in Fig. 5, Table 5.

The studies showed (Fig. 5) that the material based of wood wool and inorganic binder at the ratio of 1:1 belongs to combustible materials, because there was smoldering during the temperature influence.

*a* *b*

Fig. 3. Results of testing the process of ignition and flame propagation of a material: *a* – flame influence on the sample, *b* – combustion of material based on wood wool and inorganic binder at the ratio of 1:1

*a* *b*

Fig. 4. Results of testing the process of ignition and flame propagation by the material: *a* – based on wood wool and inorganic binder at the ratio of 1:2; *b* – based on wool wood and organic-mineral binder at the ratio of 1:1

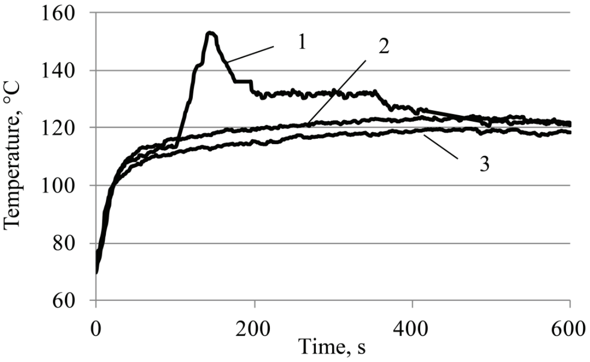

Fig. 5. Dynamics of increasing the temperature of flue gases during testing the material: 1 – based on wood wool and inorganic binder at the ratio of 1:1; 2 – based on wood wool and organic-mineral binder at the ratio of 1:1; 3 – based on wood wool and inorganic binder at the ratio of 1:2

Table 5

Time of flame front passing the control points

| Sample of material based of wood wool and | Flue gases temperature, °C | | Ignition time, s | Time of flame front passing the sections of samples, s | | | | | | | | | Time of reaching maximum temperature of flue gases, s | Duration of sample combustion, mm | Flammability index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $T_1$ | $T_{max}$ | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | |
| Inorganic binder at the ratio of 1:1 | 71.3 | 151 | 6 | 12 | 17 | 16 | – | – | – | – | – | – | 141 | 96 | 35.7 |
| Organic-mineral binder at the ratio of 1:1 | 69.6 | 121 | – | – | – | – | – | – | – | – | – | – | 600 | 0 | 0 |
| Inorganic binder at the ratio of 1:2 | 72.4 | 119 | – | – | – | – | – | – | – | – | – | – | 600 | 0 | 0 |

Under the influence of the radiation panel on the samples of wood material (curve 1, Fig. 5) the temperature of gaseous combustion products increased up to 150 °C. It was found that during testing of the sample of the material based on wood wool and inorganic binder at the ratio of 1:1, the sample ignited at second 90, the flames spread rapidly around the first three zones within 41 s, and then passed to the smoldering phase. Instead, an increase in the amount of the binder on the inorganic base and application of the organic-mineral binder does not lead to ignition of the material, the maximum temperature of flue gases was around 120 °C and flammability index was 0 (Table 5).

Thus, it was found that the sample of the material based on wood wool and inorganic binder at the ratio of 1:1 at high temperatures is capable of ignition and combustion, which is insufficient for protection and the amount of the flame retardant needs increasing.

The manufacture of the material based of wood wool and inorganic binder at the ratio of 1:2 and with the application of organic-mineral binder at the ratio of 1:1 prevents combustion and flame propagation.

## 6. Evaluation of fire resistance of heat- and soundproofing wood materials

To assess the resistance of heat- and soundproofing wood materials to thermal influence, we considered the rate of weight loss during testing. Table 6 shows the testing time, area of sample damage and rate of weight loss by the element of the structure after testing.

The rate of weight loss by the samples was calculated from equation [18] as the ratio of weight loss to the area of sample damage within a period of thermal influence.

To determine the characteristics of heat release by the materials during their combustion, we used the equation that relates the rate of heat release during combustion of a material to the rate of combustion and lower heat of combustion [17]:

$$Q = \eta m Q_l S, \tag{3}$$

where $\eta$ is the coefficient of completeness of combustion of light products of decomposition of a substance in the flame (accepted as 0.85); $m$ is the weight rate of material combustion, kg/(m$^2$·s); $Q_l$ is the lower heat of combustion of material, kJ/kg; $S$ is the area of the sample surface, exposed to thermal influence, m$^2$.

Table 6

Rate of combustion of non-treated and treated samples of containers

| Sample of material based on wood wool and | Weight loss $\Delta m$, kg | Testing time $\tau$, s | Area of sample damage $S_0$, m$^2$ | Rate of sample combustion $\upsilon$, $10^{-3}$ kg/(m$^2$·s) |
|---|---|---|---|---|
| Inorganic binder at the ratio of 1:1 | 0.022 | 600 | 0.016 | 0.0023 |
| Organic-mineral binder at the ratio of 1:1 | 0.008 | 600 | 0.008 | 0.0015 |
| Inorganic binder at the ratio of 1:2 | 0.0012 | 600 | 0.005 | 0.0004 |

Heat of combustion of material based on wood wool and the inorganic and the organic-mineral binder (Table 7).

Thus, the sample of the material based on wood wool and the inorganic binder at the ratio of 1:2 and organic-mineral binder at the ratio of 1:1 decreases the heat of combustion of material and, respectively, heat release by more than 2 times, which is proved by research results in Fig. 5.

Table 7

Higher and lower heat of wood combustion

| Sample of material based on wood wool and the binder | Combustion heat, kJ/kg | | Surface area of the sample, exposed to thermal influence, m$^2$ | Heat release, kJ/kg |
|---|---|---|---|---|
| | higher | lower | | |
| Inorganic binder at ratio of 1:1 | 18,965 | 17,257 | 0.036 | 1.219 |
| Organic-mineral binder at ratio of 1:1 | 12,846 | 11,775 | 0.036 | 0.54 |
| Inorganic binder at ratio of 1:2 | 11,943 | 10,957 | 0.036 | 0.144 |

## 7. Discussion of results of determining the fire resistance efficiency of heat- and soundproofing wood materials

The treated fibrous materials are used for arrangement of the premises where there are increased requirements for the exterior of sound absorbers. Raw materials for their production are wood fibers that are made in the form of flat panels (ceiling or wall panels) or curved and voluminous elements. In fibrous absorbers, dissipation of energy of air vibration and its conversion into heat occurs at several physical levels due to the friction that arises as a result of oscillation in air particles of the inter-fibrous space; air friction on fibers, friction of fibers on one another, as well as oscillation of fibers themselves. This is due to the fact that the highest values of coefficient of sound absorption of fibrous materials are characteristic of mid and high frequencies (Tables 1, 3, Fig. 2).

When it comes to thermal conductivity, the process of heat energy transfer from heated parts of the premises to less warm parts and energy exchange will take place until the temperature is balanced. Coefficients of thermal conductivity of some building materials depend on many factors: the nature of the material, its structure, porosity degree, the nature of pores, humidity and average temperature, at which heat transfer occurs. Materials with closed pores are less heat conductive than the materials with joint pores. Finely porous materials have lower thermal conductivity than those with large pores. This is due to the fact that in large and joint pores, there occurs the air movement that is accompanied by heat transfer. Heat conductivity of homogeneous material depends on the volume weight (Table 4). Thus, at a decrease in volume weight of the material, thermal conductivity decreases, and vice versa. In addition, heat- and soundproofing construction materials and wood products should meet the following requirements: to have stable thermal insulation and acoustic indicators throughout the operation period and to be fire resistant, not to give off harmful substances to the environment. This is in line with the data given in papers [6, 7], the authors of which also relate the efficiency of creation of heat- and soundproofing materials from organic raw materials and their thermal protection.

In contrast to the findings of the authors of papers [9–11], the obtained data on the influence of the structure on the heat and sound transfer process and the change in insulation properties make it possible to assert the following:

– density and porosity of the material are the main regulator of the process, because high density and low porosity results in quick balancing of temperatures and noise, and at a high moisture content and damping of walls of the building, the indicator of passing through them will be higher;

– a significant impact on the process of protection of combustible material at the application of wood material takes place towards non-combustible binding substances on the surface of natural combustible material.

The results of detection of the ignition process and flame propagation by the material based on wood wool and inorganic and organic binder and related to the formation of the heat insulating layer (Fig. 4, 5) indicate the ambiguous impact of fire proofing on the change of the binder's effectiveness. This uncertainty can not be solved in the framework of the conducted study, because to do so, it would be necessary to conduct additional experiments in order to obtain more reliable data. In particular, this implies the availability of the data that are sufficient for high-quality conduction of combustion inhibition process and detection of time moment, when a decrease in thermal resistance begins. Such detection will make it possible to explore the conversion of the surface of material based on wood wool and the organic binder that is moved in the direction of elevated temperature with the formation of coke and to determine the variables that significantly influence the beginning of conversion of this process.

This work is continuation of the studies reported in [1–4], which fully show the mechanism of fire protection of organic natural materials, transition and isolation of elevated temperature.

## 8. Conclusions

1. The mechanisms of the heat- and soundproofing process during energy transfer through the material were found, which makes it possible to influence this process. It was proved that they involve a decrease in porosity of the material. Thus, at an decrease in volume weight of material, sound transfer decreases, in particular, the magnitude of normal sound absorption coefficient for wood panels based on wood wool and the inorganic binding agent of density of 274 kg/m$^3$ is within 0.32÷0.44, instead, it is by 1.25 times higher for the panels based of wood wool and the organic-mineral binding agent of the density of 143 kg/m$^3$. At a decrease in density, thermal conductivity, in turn, also decreases for the panels obtained on the base of the inorganic binder and is 0.0943 W/(m·°C), and for the panels on the organic base, it is 0.0648 W/(m·°C), respectively.

2. The tests of the model samples of the wood panel revealed that the material based on wood wool and inorganic binder is characterized by heat absorption and oxidation inhibition in the gas and condensed phase and the formation of a thermal protective ceramic layer on the wood surface. Instead, the coating forms a significant swelling coefficient under the influence of elevated temperatures, promotes the formation of the heat insulation layer of coke, which prevents combustion of wood and high temperature passing to the material. Under the influence of the radiation panel on the samples of the material based on wood wool and inorganic binder at the ratio of 1:1, the temperature of gaseous products of combustion increased up to 150 °C, the sample ignited at second 90, the flames propagated rapidly around the first three zones and passed to the phase of smoldering. Instead, an increase in the amount of the binder on inorganic base and application of the organic-mineral binder did not lead to ignition of the material, the maximum temperature of flue gases was around 120 °C, and combustibility index was 0.

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