Досліджено вплив вогнезахисних покриттів на основі неорганічних та органічних в'яжучих на ефективність захисту деревини за показником втрати маси і приросту температури димових газів. Встановлено, що при дії високотемпературного полум'я магнію, вогнезахисні покриття здатні до захисту від руйнування деревини, а оцінювання дієвості вогнезахисту покриттів характеризується зниженням швидкості та глибини обвуглювання

Ключові слова: вогнестійкість, покриття, деревина, втрата маси, обвуглювання, температура, полум'я, оброблення поверхні

Исследовано влияние огнезащитных покрытий на основе неорганических и органических вяжущих на эффективность защиты древесины по показателю потери массы и прироста температуры дымовых газов. Установлено, что при воздействии высокотемпературного пламени магния огнезащитные покрытия способны к защите от разрушения древесины, а оценка действенности огнезащиты покрытий характеризуется снижением скорости и глубины обугливания

Ключевые слова: огнестойкость, покрытие, древесина, потеря массы, обугливание, температура, пламя, обработка поверхности

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EVALUATION OF EFFECTIVENESS OF WOOD FIRE PROTECTION UPON EXPOSURE TO FLAME OF MAGNESIUM

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1. Introduction

Fire is one of the oldest types of weapons, and the main damaging effect of incendiary weapons is evolution of heat and combustion products toxic to human beings at the time of their application. Incendiary compound or mixture is a specially selected substance or mixture of substances which can ignite and burn steadily with the release of large amounts of thermal energy. Incendiary agents cause damage not only to manpower but they can disable weapons, military equipment, ammunition, field fortifications, warehouses etc. Incendiary agents can cause injury to both forces acting near the front-line and to rear facilities.

The following items are used to protect personnel from the damaging effect of incendiary weapons: closed fortifications where weapons and military equipment stored and natural shelters (ravines, pits, caves, and stone buildings). A variety of local materials are applied, i. e. wood, all-weather raincoats, and cloak cape available upon delivery. Thickly diluted and liquid clays are used as fire-retardant coatings for wooden constructions. Thickly diluted coatings are applied to the surface with a spatula or directly by hand, and liquid ones are applied with brushes and rollers. Thickness of the coating shall be 0.5 to 1 cm, and this is achieved by applying 2 to 3 layers. The second (third) layer is applied after complete drying of the previous one. Impregnating agents are not waterproof and are to be prepared prior to their application, so this is a short-term fire retardant treatment which is lost with the course of time.

Primary material for the manufacture of building structures at such facilities is wood which belongs by its combustibility to the group of moderate flammability combustible materials. But fire retardant treatment of wood renders it ability to resist flame effect, flame spread by its surface, and prevent free access of oxygen. So, in order to reduce a great deal or to eliminate possible fire and structural failure this material requires some fire retardant treatment [1].

Research evidence [2] that untreated model sample of wooden product can ignite and spread flame by the surface upon its ignition with "napalm" model mixture which leads to the structural failure. In turn, treated samples did not catch fire and, accordingly, structural failure did not occur.

Considering that besides liquid incendiary mixtures characterized by flame temperature between 900 to 1100 °C some ones containing combustible metals which are capable of evolution of temperatures over 2200 °C are widely used, the necessity arises to establish fire resistance rating of wood and efficiency of fire retardant coatings against effects of such temperatures.

2. Literature review and problem statement

A specific feature of fire retardant treatment of wooden structures with state-of-the-art means lies in the creation of elements of heat insulating screens on the surface that can withstand high temperatures and direct impingement of fire and allow maintaining its function for the specified period of time.

The simplest high-temperature protection and flame retardant means based on inorganic binding materials contain bound water which evaporates when heated and blocks heat transfer to the protected surface [3].

Inorganic fire-retardant coatings based on alkali aluminum-silicate binding material, mineral fillers and porous filling materials are becoming widely used [4]. Wood treated with these coatings refers to the hardly burning materials with low smoke-forming ability. However, to provide fire protection they shall be characterized by a considerable thickness of the protective layer when being applied and have a rigid structure [5] which forms cracks under operation conditions and consequently coatings are short-lived.

During the last decade within the proposed areas of research, paper [6] is known which was aimed at synthesis of coatings with organic lacquers and refractory oxides and silicates which form thermal and heat-resistant ceramic phase in the process of heating. The most common are enamel and glass ceramic coatings, however, they cannot provide reliable protection of structures at temperatures over 1000 °C since the destruction of organic components takes place at higher temperatures and the coating applied becomes porous which greatly impairs its service properties.

Up-to-date methods of fire retardant treatment include the use of intumescent coatings which are complex systems of organic and inorganic components and have the high intumescent ability. Efficiency of application of flame retardant coatings based on organic compounds was shown in [6] where significant influence on the formation of the porous foam coke layer can be reached through the action of flame retardants based on polyphosphoric acids and foaming agents. Significant increase of stability, density and strength of the coke layer is achieved as a result of the directional formation of polymer additives [7]. However, these studies were aimed at obtaining polymer and inorganic fire retardant coatings working under conditions of short time exposition to elevated temperatures and cannot provide fire resistance of building structures at temperatures over 2000 °C [8].

Therefore, a long-term issue is to establish the efficiency of fire retardant treatment when exposed to the aforementioned temperatures and the influence of the components contained in their composition as well as determination of their roles in ensuring fire resistance and fire protection mechanisms. All this leads to the necessity for the research in this field.

3. The goal and objectives of the research

The goal of the research was to determine the performance of fire protection of wooden structures with coatings of various natures as well as to establish their resistance to high temperatures evolved at the burning of incendiary agents containing metals.

The following objectives were solved in order to achieve the goal:

– to determine specific features of fire retardant treatment of wood when applying coatings based on inorganic and organic-mineral compounds upon it under temperature influence conditions;

– to establish the efficiency of application of various types of coatings after thermal exposure of incendiary mixtures which are characterized by high temperature effect.

4. Materials and research methods

4. 1. Test materials and equipment used in the experiment

In order to establish the combustibility group of wood coated with fire retardant coating, we used wood samples measuring 150×60×30 mm which were treated with coating agents based on inorganic materials – coating agent for wood [9] at a rate of 360 g/m^2 and geocement refractory coating with heat reflecting screen at a rate of 420 g/m^2 as well as coating agent based on organic-mineral compounds at a rate of 270 g/m^2.

In order to study the efficiency of fire retardant coating when exposed to high-temperature flame evolved at metal burning, we used the following model patterns of wooden structures made of wood boards 19 mm thick (Fig. 1) average sizes of those were 190×155 mm and 140 mm in height:

a) untreated one (sample № 1);

b) samples treated with fire retardant agent, i. e. samples of the package were treated with the following fire retardant coatings:

– fire retardant coatings based on organic-mineral compounds (sample № 2);

– fire retardant coatings based on inorganic compounds [9];

– geocement refractory fire retardant coatings with heat reflecting screens (sample № 4).

Fig. 1. Model patterns of wooden structures: 1 — untreated one, 2 — fire retardant coating on organic-mineral bases; 3 — fire retardant coatings based on inorganic compounds [9]; 4 — geocement refractory fire retardant coatings with heat reflecting screens

We used magnesium turnings as fuel burning of which is accompanied by the evolution of temperature of about 2200 °C [10].

4. 2. Method for determining performance characteristics of the samples

We used the same raw materials which were reflected in our previous paper [2].

Studies to determine the combustibility group of wood treated with the proposed coatings were carried out in accordance with valid regulatory framework [4]. The essence of the test method for the experimental determination of belonging of solids and solid materials to hardly combustible or combustible group consists in exposing of the sample disposed within the ceramic tube of "OTM" installation to the flame with specified parameters (temperature of the combustion gases at the outlet of the ceramic tube is 200 °C ± 5 °C) which is registered by analog-to-digital converter set on a PC followed by its processing in Excel environment. When conducting experimental studies, we record maximum temperature increase of combustion gases (Δt) and loss of the weight of the sample (Δm). According to the test results the materials are classified as follows:

– hardly combustible ones: Δt<60 °C and Δm<60 %;

– combustible ones: Δt≥60 °C and Δm≥60 %.

Determination of fire retardant efficiency of the package manufactured of wood was carried out with a working method which consisted in the experimental determination of the efficiency of fire retardant treatment of the structure made of wood and processed with wood protection means sample of which was exposed to magnesium flame (model is solid incendiary substance) with the specified parameters and registration of the loss of the weight of the sample after the test.

The incendiary mixture was placed upon the cover and below the sample. The fuel was ignited and the sample of the wood package was kept in the flame produced by fuel burning for the time interval needed for its entire burnout up to lack of unassisted burning and smoldering.

Criteria for the determination of the efficiency of fire retardant treatment of the package were matching of its weight loss which shall not exceed 15 % as well as residual burning after the fuel exhaustion, material burnout and time interval to triggering of pyrocartridges.

5. Results of the studies of the efficiency of fire retardant treatment of wood with coatings based on inorganic and organic compounds

In order to establish the efficiency of fire retardant treatment when developing coatings, studies were conducted for the determination of the wood combustibility group upon its treatment with such compositions. The results of the studies for the determination of the loss of the weight of the sample (Δm, %) and increase of the maximum temperature of combustion gases (Δt, °C) at the time of burning of wood samples treated with fire retardant agents conducted under laboratory conditions are shown in Fig. 2, 3.

The studies showed that wood treated with fire retardant agents withstood thermal impact and belonged to hardly combustible materials by weight loss index. The initial temperature of the combustion gases being T=200 °C, impingement of the burner flame on the sample protected with an inorganic coating (curve 1) led to combustion gas temperature T≤260 °C, and weight loss did not exceed 2.9 % (Fig. 2). Even greater efficiency was shown by samples treated with geocement refractory coating with heat-reflective screen (curve 2) with the weight loss of 2.5 % as well as coating based on organic-mineral compounds (sample 3) (Fig. 1, 2).

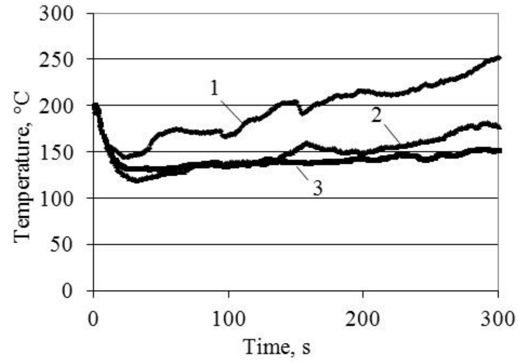

Fig. 2. The dynamics of growth of the flue gas temperature during the test of fire-retardant wood: 1 — fire retardant coatings based on inorganic compounds, 2 — geocement heat-resistant coating with heat reflecting screen, 3 — coatings on organic-mineral bases

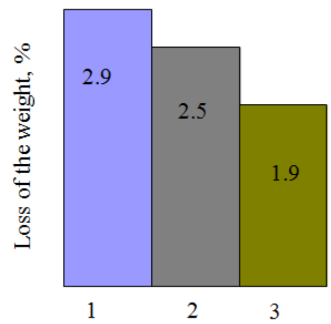

Fig. 3. The results of the loss of the weight of the samples of burning of wood: 1 — fire retardant coatings based on inorganic compounds, 2 — geocement heat-resistant coating with heat reflecting screen, 3 — coatings on organic-mineral bases

Bearing in mind that the combustion temperature of the metal containing incendiary devices exceeds a great deal that of gas burner, full-scale tests were carried out using samples, in particular, of wooden structural model ones in order to determine the efficiency of the fire retardant treatment of wood.

Fig. 4 shows results when testing the untreated sample, Fig. 5 – when testing the sample treated with organic-mineral compounds based protective coating, Fig. 6 – when testing the one treated with protective coating [9] and Fig. 7 – when testing the sample treated with refractory geocement coating with the heat-reflective screen.

According to the results of full-scale tests with the combustion of magnesium turnings, we revealed the formation of a slag layer on the surface of the material below which thermal decomposition process of the material went on, and depending on the properties of the coating its termination took place in different ways and reflected in the depth of charring.

Fig. 4. The results of testing the model untreated sample

Fig. 5. The results of testing the model sample treated with organic-mineral compounds based protective coating

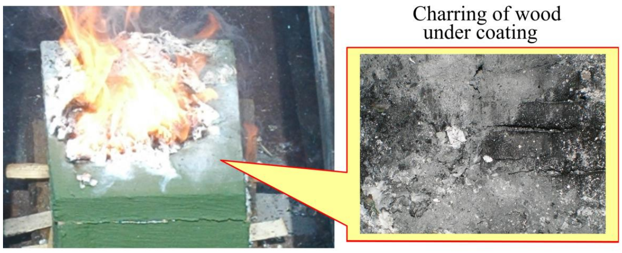

Fig. 6. The results of testing the model sample treated with inorganic compounds based protective coating

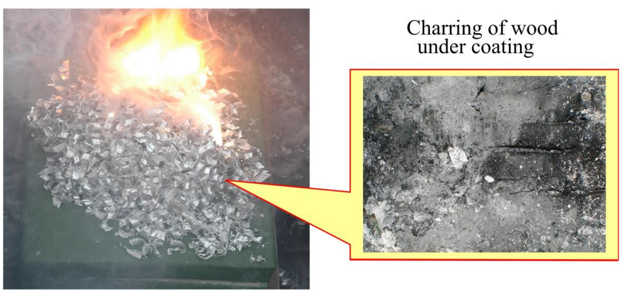

Fig. 7. The results of testing the model sample treated with refractory geocement coating with heat-reflective screen

The full-scale tests of coatings conducted using model samples of wooden building constructions under influence of magnesium flame showed the following:

– untreated model sample of wooden structure is able to ignite and spread flame by its surface upon its ignition with model fire based on magnesium turnings, and at that upon the magnesium exhaustion charring depth reached 15 to 17 mm in some areas;

– model sample of wooden structure treated with coating based on organic-mineral compounds was not burning after cessation of burning of magnesium turnings based model fire, and structural failure did not occur, respectively, and at that intumescence of the protective coating was observed when exposed to flame, in particular, in the lower and upper parts of the structure, which effectively prevented passage of heat to the material, the wood was charred to the depth of up to 1 mm;

– model sample of wooden structure treated with protective coating [9] upon burnout of model fire based on magnesium turnings was not burning, and at that detachment and shedding of the protective coating from the wood was observed in some areas at the time of thermal exposure, and in the areas of magnesium burning charring of wood was observed to the depth of 4 to 4.5 mm;

– model sample of wooden structure treated with geocement refractory coating with heat-reflective screen was not burning following burnout of the model fire based on magnesium turnings, intumescence and detachment of the protective coating from the wood was observed when exposed to the flame, and at the areas of magnesium burning charring of wood was observed to the depth of 4 to 5 mm.

6. Discussion of the results of the research of the fire retardant treatment effect on the stability of wooden structures

According to the research presented in [11], it was found that the duration of burnout of wooden structures depends on the rates of burning and charring process.

Given the above, the duration of the magnesium flame impingement on the surface of wood treated with fire retardant agents can be estimated provided that the depth of its charring is known using the equation (1).

$$t=\frac{x_e^{1,23}}{s}, \qquad (1)$$

where t – time of fire impact, m.; s – charring speed, mm/m.; x_e – depth of charring, mm.

Respectively prediction of medium charring speed was proposed to conduct using the dependence (2):

$$c=\frac{\upsilon}{\rho_w}, \qquad (2)$$

where m – combustion rate of the wood, kg/(m^2·s); ρ_w – wood density in the dry state (humidity is 10÷12 %), 450 kg/m^3.

The rate of the loss of the weight of wood was calculated by the equation:

$$\upsilon=\frac{\Delta m}{\tau\cdot S}, \qquad (3)$$

where Δm – the rate of the mass loss after the test; τ – duration of the test; S – damage area of the sample.

Table 1 shows the duration of the test, the damaged area of the sample and rate of the loss of the weight of the construction element after the tests.

As can be seen from Table 1, combustion rate of the untreated wood is within the range of 0.0151 kg/(m^2·s) which exceeds the appropriate value when being ignited by hydrocarbon flame which equals to 0.011 kg/(m^2·s). Corresponding values of the burning rate of wood treated with fire-retardant coatings also increased; in particular, this took place in case of coatings based on inorganic compounds which form porous low-expanded layer capable of transmitting more heat than the ones based on organic-mineral compounds.

Table 2 shows the results of testing of charring lowers and time of magnesium flame on the surface of fire resistant wood.

As can be seen from Table 2, the sample treated with organic-mineral coating due to the formation of the swelled coke layer prevents the influence of high temperature and rate of wood charring lowers.

Thus, it was found that depending on the nature of the fire retardant coatings they respond differently to high temperature magnesium flame. In particular, coatings based on inorganic compounds form porous structures on the wood which prevents its ignition, but such coatings detach from the substrate under the influence of temperature with the time and heat is passed leading to charring of the material surface to a depth of 4 to 5 mm. Coating based on organic-mineral compounds reduces the process of wood destruction more effectively due to intumescence and interaction of fire retardants with magnesium flame. The results of these studies together with those obtained in [2] allow the purposeful development of efficient means for wood protection against effects of incendiary agents both in building structures and for packing of explosive products.

Table 1

Combustion rate of the untreated and treated samples of package

Samples	Loss of the weight Δm, kg	Duration of the test τ, s	Damage area of sample S, m^2	Combustion rate of the sample υ, $kg/(m^2 \cdot s)$
untreated	0.283	720	0.026	0.0151
treated with organic-mineral coating	0.020	720	0.025	0.0010
treated with coating based on inorganic compounds	0.048	720	0.021	0.0032
treated with geocement refractory coating with heat-reflective screen	0.051	720	0.019	0.0037

Table 2

Time of magnesium flame on wood surface

Samples	Charring lowers, mm/m	Time of magnesium flame on surface of material t, m.
untreated	2,015	16,2
treated with organic-mineral coating	0,148	6,75
treated with coating based on inorganic compounds	0,430	12,81
treated with geocement refractory coating with heat-reflective screen	0,497	11,07

7. Conclusions

These studies established the efficiency of mixtures of inorganic and organic compounds as fire protective coatings for wood, in particular:

– in case of heat influence from the standard flame of burner on samples that have been treated with coatings based on inorganic compounds, weight loss and combustion gas temperature did not exceed specified value, but one shall apply protective layer of substantial thickness to the building structure in order to ensure its protection; but in case of sample treated with coating based on organic-mineral compounds fire resistance of wood increases significantly due to the formation of the swollen coke layer with minimum consumption rate of the coating;

– full-scale tests using model samples of wooden building structures under the influence of magnesium flame showed that the coatings based on inorganic compounds can withstand high temperatures, but they will eventually become stiff, resulting in loss of adhesive properties, detachment and crumbling, but organic-mineral coating effectively prevents passage of heat to the material due to formation of swollen layer that affects charring rate and depth.

Further research will be aimed at studying the processes of structure formation of the protective layer and establishing a relationship between the components natures and such properties of the coatings as foam coke formation as well as heat and weather resistance.

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DEVELOPMENT OF A TWO-STEP TECHNOLOGY OF SCOURING WOOL BY THE METHOD OF HIGH-ENERGY DISCRETE TREATMENT

Розроблено двостадійну технологію очищення вовни від природних забруднень на основі застосування високоенергетичної дискретної обробки. Визначено оптимальні параметри запропонованої технології. Встановлено, що попередня високоенергетична дискретна обробка вовни протягом 3 хв на стадії промивки дозволяє досягти необхідного ступеня очищення вовни, а також поліпшити фізико-хімічні характеристики та ступінь вилучення вовняного жиру

Ключові слова: цигайська вовна, Сульсід, залишковий вміст жиру, кислотне число

Разработана двухстадийная технология очистки шерсти от природных загрязнений на основе применения высокоэнергетической дискретной обработки. Определены оптимальные параметры предложенной технологии. Установлено, что предварительная высокоэнергетическая дискретная обработка шерсти в течение 3 мин на стадии промывки позволяет достичь необходимой степени очистки шерсти, а также улучшить физико-химические характеристики и степень извлечения шерстного жира

Ключевые слова: цигайская шерсть, Сульсид, остаточное жиросодержание, кислотное число

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1. Introduction

The quality and outward appearance of woolen cloths and products, as well as their wear resistance in the process of operation in many respects depend on the pretreatment of wool. In Ukraine and in foreign countries, every year more attention is paid to the studies of improvement in the technological process of pretreatment of wool. The incorrect or imperfect technology of pretreatment of wool leads to enormous losses of woolen fiber both at the preprocessing plants and at wool processing enterprises. Special attention should be paid to the problem of extraction of wool grease from the used washing waters – at present, no wool preprocessing plant in Ukraine extracts wool grease from the used wool washing water.

Along with the application of contemporary methods of treatment, the cost-efficiency of technological process is of great significance. Therefore, the studies directed toward the search and implementation of the most economically advantageous technological modes of the wool pretreatment are relevant.

2. Literature review and problem statement

Traditional technology of the wool pretreatment consists of the following main operations [1, 2]:

– scutching unwashed wool with the purpose of separating it from plant (straw, leaves, parts of branches and stems of plants) and mineral (sand, clay) impurities as well as loosening wool for the best penetration of the washing solution;

– washing and quality control of the washed wool. The stage of washing of contaminated wool is performed at the equipment of continuous action with washing solutions of surface active substances (SAS), and what it is more