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Features of studying the efficiency of fire protection of a wooden wall with external exposure to the flame of combustible substances

Y Tsapko^{1,2,3}, O Bondarenko¹, O Pinchevska², N Buys'kykh² and Y Lakida²

¹ Kyiv National University of Construction and Architecture, Scientific research Institute for binders and materials named after V. Glukhovskii, Povitroflotsky Avenue 31, 03037, Kyiv, Ukraine

² National University of Life and Environmental Sciences of Ukraine, Heroes of Defense st. 15, 03041, Kyiv, Ukraine

³ Email: juriyts@ukr.net

Abstract. The article analyzes the physical ways to provide the necessary limit of fire resistance of wooden structures, which have significant disadvantages, namely, leading to significant material costs and increase the volume of structures. Modern methods of fire protection of building structures are based on the use of blocking coatings, which are complex systems of organic and inorganic components. Studies of the combustibility of wood have shown that a raw specimen of timber construction is capable of engaging and spreading flames on the surface. Instead, the structure treated with the organo-mineral protective coating did not burn after combustion of the model hearth, respectively, and did not break down. The swelling of the protective coating was recorded, and the temperature on the reverse floor was less than 140°C. As a result, it was ascertained that the effectiveness of the shredded image of the tree's construction was 4.4 times higher for the protected organic and mineral coatings 3.3 times higher - for the clear protection of non-organic ones. It's necessary to assimilate a coke ball on the surface of the construction, which will add to the temperature and the temperature glyphine, with which the hour of reaching the boundary temperature will be improved.

1. Introduction

Recently, Ukraine has become more interested in the results of scientific developments in the field of creation of highly effective means of protection building structures from the effects of fire and their implementation. In this regard, it is determined the need to develop works in this direction, with particular attention to the development of effective flame retardants for their use in the construction of both general construction and special purpose for storage of various products, where the use of flame retardants is ineffective.

Therefore, setting the parameters of the flame of a combustible liquid, investigating the process of suppressing the penetration of high temperatures and the effect of the coating on this process is an unresolved component of ensuring fire resistance.

In recent years, in the field of fire protection research, there are known works that are aimed at the synthesis of coatings using organic varnishes, refractory oxides and silicates. Such materials in the process of heating form thermo- and heat-resistant are ceramic phases [1, 2]. The most common enamel and glass crystalline coatings [3], however, they cannot provide reliable protection of



structures at long-term temperatures because they do not form the necessary coke layer, heat up and collapse.

Modern fire protection methods include the use of interlocking coatings, which are complex systems of organic and inorganic [4] components and are characterized by high intumescent capacity. The description of the behavior of intumescent coatings, one of the tasks of which is to relate experimental data to existing theoretical models, is devoted to the work of [5, 6]. It allows us to evaluate the simplifications made in principle, so we consider a thermos-physical model whose solution is given by polynomials that are not related to the physical content.

The mathematical model of warming up of a fireproof coating based on the laws of conservation of matter and energy is considered. The models immediately predict a specific type of functional dependencies with a set of uncertain coefficients, and the task is to determine the numerical value of these coefficients, which is associated with high inaccuracy [7].

The article estimates the coefficient of thermal conductivity of flame retardant coatings on the basis of numerical simulation, where the phase transitions in the coating did not take into account [8]. The authors present an analytical model for calculating the thermal conductivity of the porous foam structure of a flame retardant coating, which takes into account the pore shapes, but this model does not take into account which phase transformations of the coating occur.

In addition, many coatings have a number of disadvantages, such as the application of individual components, the loss of functional properties with increasing ambient temperature [9, 10]. This means that it has not been determined how the process proceeds under the conditions of the temperature range of the fire retardant coating.

Therefore, the establishment of thermal conductivity of the wooden structure in the swelling of the flame retardant, the influence of the components that are part of them, on this process necessitated the need for research in this direction.

The research aimed to determine the heat transfer characteristics through the wall of a fire-proofed wooden structure against the effects of heat.

To achieve the goal, the following tasks were solved:

- to determine the burning characteristics of fireproof wood during the thermal action of gasoline flames;
- evaluate the effectiveness of fire retardant woodworking for the storage of combustible and explosive articles.

2. Raw materials and test methods

To investigate the effectiveness of fire protection under the influence of high-temperature flames in the combustion, we used model samples of wooden structures made of 19 mm thick wood with an average size of 400x400 mm and a height of 140 mm:

a) Untreated (sample 1);

b) Fireproof specimens and specimens of timber structures were treated with fireproof coatings:

- fireproof coating on an inorganic basis (patent of Ukraine for utility model No. 95440 "Fireproof coating for wood", sample 2);
- organic-mineral flame retardant coating (Experimental sample 3).

A sample of the wooden structure was mounted on the supports (figure 1).

The sample and the inside of the sample were fitted with thermocouples that connected to the unit of measurement. Under the sample, set up a metal deck for fuel and pour the appropriate amount of gasoline at the rate of 2.0 dm³ per 0.5 m² of container area. The fuel was burned and the sample was kept in the flames for the time of burning the gasoline and without self-burning and smoldering. Controlled parameter is the temperature on the inner surfaces of the specimen (flame-reversed).

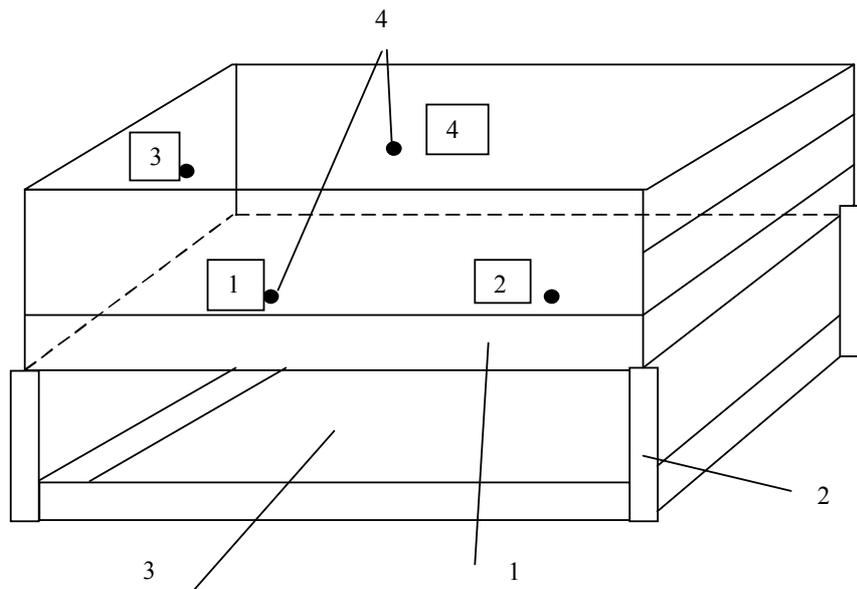


Figure 1. General view of the model center and layout of thermocouples:
 1 – container; 2 – supports; 3 – a stack for burning stack; 4 – thermocouples.

3. Results and discussion

In figure 2 shows the test results of a raw wood structure specimen, figure 3 is a sample of a wooden structure treated with an inorganic fire retardant coating, in figure 4 is a sample of a wood structure treated with an organic-mineral fire retardant. In figure 5 shows the temperature values on the inner surfaces of the woodwork specimens.

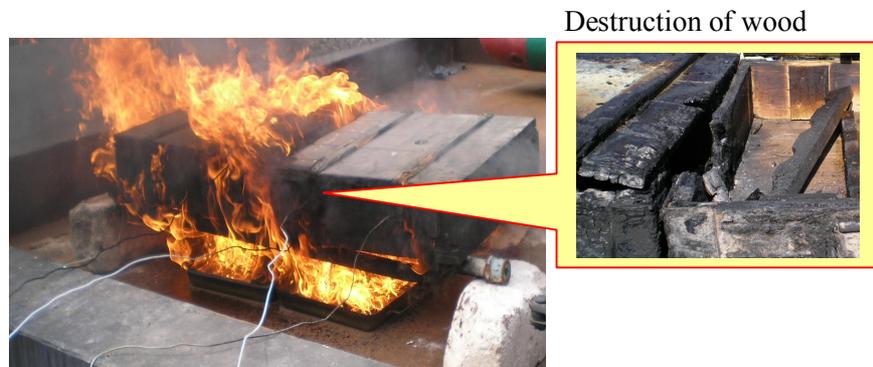


Figure 2. Test results of the raw model sample.



Figure 3. Test results of the inorganic-treated model sample.

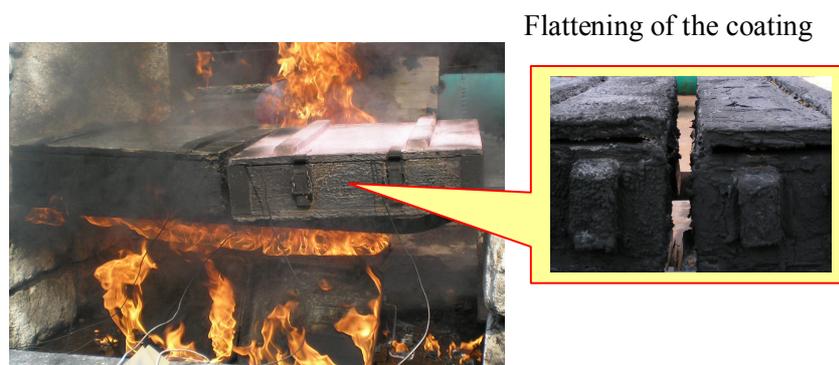


Figure 4. Test results of the model sample treated with organic-mineral protective coating.

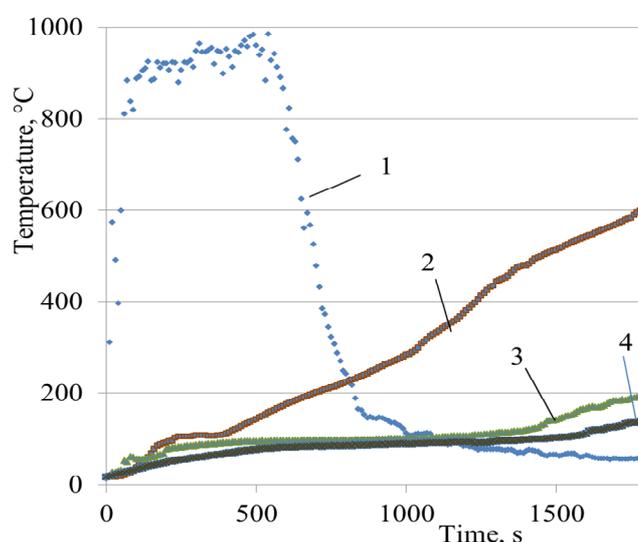


Figure 5. Dependence of temperature on the surface of a wall with a wooden structure on the duration of fire exposure: 1 – heating temperature curve; on the unheated bottom surface: untreated (2); flame retardant coating: inorganic base (3), organic-mineral base (4).

As a result of the tests it is established:

- a raw model specimen of a timber structure capable of igniting and spreading the flame on the surface after igniting its model hearth, resulting in the destruction of the structure, with the combustion temperature in the middle reaching more than 600°C;
- model of a wooden structure treated with an inorganic protective coating after the burning of the model hearth in separate places flare up, which did not lead to the destruction of the structure, with a temperature at the inner walls of about 200°C, which is unacceptable for storage of certain types of materials and products (fixed materials), radio products, etc.);
- model sample of the wooden structure treated with organic-mineral protective coating after burning the model hearth did not burn, respectively, and there was no destruction of the structure, with the swelling of the protective coating during the action of flame, in particular the lower and upper parts of the structure, which effectively prevented the passage of high temperature to the material, with a fixed temperature on the inner walls of less than 140°C.

To evaluate the effectiveness of flame retardant wooden structure developed a method of determining the flame retardant efficiency, in which the efficiency of flame retardant, determine the

ratio of mass burn rate of untreated and treated samples, and calculated due to the loss of mass of the sample and the area of its damage during testing and measuring the action of high-temperature flames, and the combustion characteristics are evaluated after the coefficient test K_{ef} :

$$K_{ef} = \frac{v_u}{v_t} \cdot \left(1 - \frac{\theta_t}{\theta_r} \right), \tag{1}$$

where $\theta_r = Tu_i/\tau_r^n$ is the ratio of the critical temperature on the inner surfaces of the raw sample (Tu_i) to the time of reaching (τ_r^n); $\theta_t = Tu_i/\tau_r^n$ is the ratio of the critical temperature on the inner surfaces of the treated sample (Tu_i) to the time of reaching (τ_r^n); τ_r^n – is the time of reaching the critical temperature on the unheated surface of the rough wooden structure; τ_f^n – is the time of reaching the critical temperature on the non-heated surface of a fireproof wooden structure; v_u, v_t – the mass burn rate of the untreated and treated specimens calculated by the formula:

$$v_{u(t)} = \frac{\Delta m}{\tau \cdot S}, \tag{2}$$

where Δm – the weight loss of the sample after testing; τ – the test time; S – the area of sample damage. The results of the calculation of the mass rate of burning of untreated and treated samples of the container are given in table 1.

Table 1. Mass burn rate of untreated and treated timber samples.

Fireproofing sample of wooden structure	Weight of the sample, kg		Weight loss Δm , kg	Test time, τ , s	Damage area of the specimen S , m ²	The mass rate of burnout of the sample v , kg/(m ² ·s)
	before the tests	after the tests				
Untreated	13.7	4.1	9.60	1800	0.544	0.0098
Treated with an inorganic coating	14.6	13.6	1.1	1800	0.340	0.0018
Treated with an organic-mineral coating	14.8	13.7	1.0	1800	0.335	0.0016

The table 1 calculates that the mass rate of burnout of a fire-proof specimen of a wooden structure is reduced by 6 times compared to the untreated one. Calculated according to (1) the coefficients of efficiency of fire protection (K_{ef}) for combustion of a wooden structure, which are shown in table 2.

Table 2. Coefficients of efficiency of fire protection (K_{ef}).

Fireproofing sample of wooden structure	Time to reach critical temperature, s	Speed of temperature rise, °C/s	Coefficients of efficiency of fire protection, K_{ef}
Untreated	700	0.286	
Treated with an inorganic coating	1800	0.111	3.3
Treated with an organic-mineral coating	2400	0.083	4.4

The coefficient of fire protection of the treated wood structure sample increases 4.4 times for the fireproof organic-mineral coating and 3.3 times for the fireproof sample of the inorganic coating.

4. Conclusion

As a result of the conducted researches the effectiveness of the use of mixtures of inorganic and organic substances as fire retardant coatings for wood was established, in particular:

- at the temperature influence on the samples, which were treated with coatings on the basis of inorganic substances, continued to burn after the combustion of the fuel, and therefore the protection required the application of a considerable thickness of the protective layer on the building structure; for the sample treated with the coating on the organic-mineral basis, due to the formation of a flattened layer of coke, significantly increases the fire resistance of the wood at a lower flow rate;

- field tests on model specimens of wooden building structures under the action flame showed that coatings based on inorganic substances withstand high temperature, but over time become rigid, which leads to loss of adhesive properties, peeling and shedding, instead organic-mineral coating, due to the formation of a swollen layer, effectively prevented the passage of high temperature to the material, which affected the speed and depth of charcoal.

Further studies may be directed to the theoretical and experimental study of the processes of burning wood, establishing the relationship between the components and properties of remedies.

5. References

- [1] Krivenko P, Pushkareva E, Sukhanevich M, Guziy S 2009 Fireproof coatings on the basis of alkaline aluminum silicate systems *Developments in strategic Materials* 129-142
- [2] Tsapko Y, Tsapko A and Bondarenko O 2019 Establishment of heat-exchange process regularities at inflammation of reed samples *Eastern-European Journal of Enterprise Technologies* **1/10 (97)** 36-42
- [3] Tsapko Yu, Bondarenko O and Tsapko A 2019 Effect of a flame-retardant coating on the burning parameters of wood samples *East European Journal Enterprise Technologies* **2/10(98)** 49-54
- [4] Na Xiao, Xue Zheng, Shuping Song and Junwen Pu 2014 Effects of Complex Flame Retardant on the Thermal Decomposition of Natural Fiber, *United States: BioResources* **9(3)** 4924-4933
- [5] Zhao P, Guo C and Li L 2018 Flame retardancy and thermal degradation properties of polypropylene/wood flour composite modified with aluminum hypophosphite/melamine cyanurate *Journal of Thermal Analysis and Calorimetry* 1-9
- [6] Nine Md, Tran D, Tung Tran Thanh, Kabiri S and Losic D 2017 Graphene-Borate as an Efficient Fire Retardant for Cellulosic Materials with Multiple and Synergetic Modes of Action *School of Chemical Engineering, The University of Adelaide, ACS Appl. Mater. Interfaces, Australia* **9 (11)** 10160-10168
- [7] Ciripi B, Wang Y and Rogers B 2016 Assessment of the thermal conductivity of intumescent coatings in fire *FSJ* **81** 74-84
- [8] Nasir K, Sulong Ramli, Johan M and Afifi A 2018 An investigation into waterborne intumescent coating with different fillers for steel application *PRS* **47/2** 142-153
- [9] Erdoan Y 2016 Production of an insulation material from carpet and boron wastes *Bulletin of the Mineral Research and Exploration* **152** 197-202
- [10] Khalili P, Tshai K Y, Hui D and Kong I 2017 Synergistic of ammonium polyphosphate and alumina trihydrate as fire retardants for natural fiber reinforced epoxy comp *Composites Part B: Engineering* **114** 101-110