Effectiveness of fire protection of wood with an organic-mineral coating with the addition of aluminum hydroxide

Yuriy Tsapko[1], *Aleksey Tsapko*[2], *Olga Bondarenko*[3], Natalya *Lialina*[4], Dmitry Anopko[5], *Alina Yushchenko*[6]

[1, 2, 3, 4]Kyiv National University of Construction and Architecture
Air Force Avenue, 31, Kyiv, Ukraine 03037
[1]juriyts@ukr.net, orcid.org/0000-0003-0625-0783
[2]alekseytsapko@gmail.com, orcid.org/0000-0003-2298-068X
[3]bondolya3@gmail.com, orcid.org/0000-0002-8164-6473
[4]lialina1975natali@gmail.com, orcid.org/0000-0002-9364-0925
[5]anopko1973@gmail.com, orcid.org/0000-0002-2585-2512
[6]alinka29yushchenko@gmail.com, orcid.org/0009-0002-0936-5789

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Abstract. Today, there are two methods of fire protection for wood. The first is impregnation with flame retardants, most often based on inorganic salts. When wood is moistened, fire retardants dissolve in a humid environment and gradually wash out to the surface, and then the fire retardant effect decreases over time. Acid-based products do not have a significant leaching problem due to changes in wood moisture, but penetrating deep into the wood structure and interacting with the cellulose, they reduce strength parameters. Therefore, it is not safe to use this product for critical load-bearing structures. The second method is to apply an organic or inorganic binder coating to the wood surface. Organic binder-based products have increased smoke generation and toxic substances, so their use is dangerous. Therefore, coatings capable of forming a heat-insulating layer on the surface of a building structure, which significantly reduces the processes of heat transfer to the material, have recently become widespread. As a result of the studies, it was found that the introduction of aluminium hydroxide into the composition of the organo-mineral coating in the amount of 2…8% reduces the swelling coefficient from 30 to 18 to a certain extent. However, for a coating containing 4%, an increase in the efficiency of fire protection of wood was found, namely a decrease in the loss of sample mass and flue gas temperature due to the formation of heat-resistant compounds on the surface of the fire protection layer when aluminium hydroxide interacts with ammonium polyphosphate. The use of aluminium hydroxide in the fireproofing composition provides the required level


Yuriy Tsapko
Doctor of Technical Sciences, Professor


Aleksey Tsapko
PhD of Technical Sciences, Associate professor


Olga Bondarenko
PhD of Technical Sciences, Associate professor


Natalya Lialina
Doctor of Technical Sciences, Professor


Dmitry Anopko
PhD of Technical Sciences, Associate professor


Alina Yushchenko
Student

of protection of wood from thermal effects at the required amount of 4%, which leads to a reduction in cost and an increase in the efficiency of the coating. In further studies, it is planned to investigate other types of fillers, their properties and impact on the fire protection efficiency of wood in fireproof organic-mineral coatings.

Keywords: wood, fire protection, organo-mineral coatings, aluminum hydroxide, fire retardant properties, efficiency.

INTRODUCTION

Wood as a building material is increasingly being used in construction and architecture because of its significant positive performance properties. However, due to its high flammability, it is a fire hazardous material, which limits the scope of its application, especially in multi-storey wooden construction. It is possible to increase the degree of safe operation of facilities where wood materials and products are used by means of its fire protection treatment. The essence of wood protection is to provide it with the ability to resist the effects of flame, flame spread over the surface, to counteract thermal oxidation degradation and inhibit the ignition process.

Therefore, the study of the effectiveness of fire protection of wood with organic-mineral coatings with the addition of aluminum hydroxide and the establishment of its optimal concentration is an unresolved component of fire resistance and, accordingly, determines the need for such studies.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The construction of both civil and industrial facilities involves the use of wood, which is very sensitive to high temperatures and is able to retain its properties during operation.

With this in mind, regulatory documents were adopted that require the design of wood structures to take into account their resistance to combustion and to carry out fire protection treatment of structures with special means. The essence of wood protection is interpreted as inhibition of thermal decomposition of components, reduction of the reaction rate constant and activation energy, isolation from flame and oxygen access [1 – 3].

Today, the most common method of fire protection of wood is impregnation with flame retardant compositions, which contain salts based on inorganic acids [4 – 6]. When moisture gets on the wood, these salts dissolve and gradually migrate to the surface, which reduces the fire protection effect [7 – 8]. Acid-based agents do not have a significant leaching problem due to changes in wood moisture, but penetrating deep into the wood structure and interacting with the cellulose, they reduce strength parameters. Therefore, it is not safe to use this product for critical load-bearing structures. The second method is to apply a fire retardant coating to the surface. Some products are characterized by the release of toxic combustion products during thermal exposure and have increased smoke generation, and therefore are of limited use [9 – 11].

In this regard, coatings that form a heat-insulating foam layer on the surface of wood under thermal action, which reduces heat transfer processes, have become widespread.

The paper [12] shows that a chemical substance such as polydimethylsiloxane modified with a silica geopolymer creates a new hybrid coating on the surface of wood that can inhibit combustion. The effect of polydimethylsiloxane viscosity of 350 cps (cone viscometer) on fire resistance was also investigated. In turn, the inclusion of polydimethylsiloxane leads to a decrease in weight loss during combustion to 52.51%, as well as a decrease in the average burning speed to 0.0674 m/s and significant smoke suppression. The excessive viscosity of polydimethylsiloxane manifests itself in a decrease in the fire resistance of a hypopolymer coating based on silica.

To increase the fire resistance of wood, the paper [13] proposes the use of thermally expanded graphite and carbon nanotubes. The effect of these materials on the fire protection and smoke suppression of this coating was investigated by experimental fire resistance tests, as well as thermogravimetry on a differential scanning calorimeter, smoke test, and water resistance tests. The results of the fire protection tests showed that the fire resistance of the coatings was increased by adding 1% of carbon materials. In turn, the analysis of thermogravimetric tests showed that carbon materials increase the residual weight and heat resistance of the coating. After immersing the coating samples in water for 360 hours, carbon materials can form a barrier to increase the water resistance of wood.Graphite, which showed the best results, is particularly water resistant.However, it is not specified what the binder was.

The article [14] proposes an interfacial coating strategy to inhibit combustion rather than increase the amount of flame retardants. The aqueous composition of polyelectrolyte complexes consists of polyethyleneimine and ammonium polyphosphate. The formed coating on this basis has high fire resistance and demonstrates a high oxygen index of 43% and a 47% reduction in the rate of heat release for cone calorimetry tests. In addition, the polyethyleneimine and ammonium polyphosphate coating increased the interaction between the carbon fibers and the matrix and improved the glass transition temperature of the composite and, consequently, the mechanical properties. Therefore, these studies represent a strategy for the development of fiber-reinforced composites with high fire protection and mechanical properties. However, there are still some unresolved issues related to the mechanism of foam coke formation. The reason for this is the subtleties of the formation of the thermal insulation layer, which makes such research quite difficult.

Therefore, modern methods of fire protection of wooden building structures are based on the use of coatings that form a layer of foam coke, which are complex systems of both organic and inorganic components, but are capable of gradual burnout under prolonged exposure to flame and, accordingly, a decrease in fire resistance of the structure, requiring an increase in substances capable of forming a stable heat-insulating layer of foam coke.

Thus, it has been established that fireproof coatings are capable of forming a protective thermal insulation layer on the surface of wood against the effects of fire during its operation, but the parameters that ensure the effectiveness of fireproof coatings to the effects of fire flames have not been determined. Therefore, the study of the parameters of fire protection of wood and the effect of coatings on fire protection necessitated research in this area.

THE PURPOSE OF THIS WORK

The purpose of this work is to study the effectiveness of fire protection of wood with an organic-mineral coating when aluminum hydroxide is added and to determine its optimal concentration.

MATERIALS AND METHODS OF RESEARCH

A mixture based on an organic binder, gas-forming agents, pyrophores, and minerals was used to develop an effective fireproofing coating for wood. Studies were conducted according to [15 – 16] to determine the flammability group of wood treated with the proposed coating.

The essence of the test method for the experimental determination of the group of flammable and combustible solids and materials according to [15 – 16] is to expose the sample, placed in the ceramic pipe of the OTM device, to a burner flame with a temperature of gaseous combustion products of 200 °C ± 5 °C for 300 s. During the tests, the increase in the combustion temperature is recorded (Δt) and the mass loss of the sample is determined (Δm). According to the test results, the materials are classified as:

– flammable – $\Delta t < 60$ °C and $\Delta m < 60\%$;

– combustibles – $\Delta t \geq 60$ °C or $\Delta m \geq 60\%$.

Combustible materials, in turn, are divided depending on the time (τ) for reaching the maximum temperature of volatile combustion products into:

– highly flammable – $\tau > 240$ s;

– medium flammability – 30 s $\leq \tau \leq$ 240 s;

– flammable – $\tau < 30$ s.

RESEARCH RESULTS

The results of research on the determination of the increase in the maximum temperature of gaseous combustion products (Δt, °C) and the loss of mass of samples (Δm, %) of both untreated and fire-protected wood are presented in Fig. 1, 2.

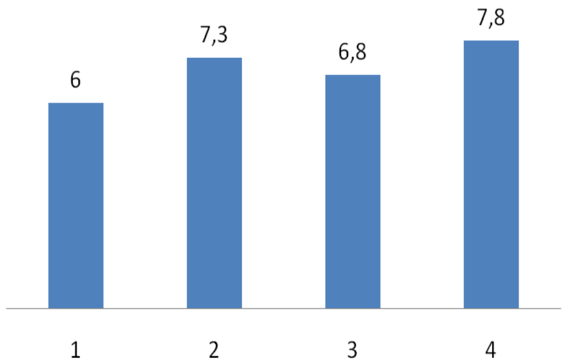

Figure 1. The results of studies on the weight loss of wood samples after fire tests Δm, % with the amount of aluminum hydroxide in the coating: 1 – 0%; 2 – 2%; 3 – 4%; 4 – 8%

For studies of the wood flammability group, samples of pine wood measuring 150x60x30 mm were prepared. The samples were conditioned at a temperature of 20±2 °C. The surface of the wood samples was coated in two layers with intermediate drying after 3 hours.

Studies have shown that when the coating is applied (with a consumption of 260±5 g/m^2) with the addition of aluminum hydroxide in the amount of 2% and 8%, the fireproofed wood is classified as a medium flammable material. This amount of coating does not provide the required fire protection and requires an increase in the coating layer. At the initial temperature of the gaseous combustion products at the furnace outlet T = 200 °C, when the burner flame was exposed to the fireproof sample No. 1 and 3, the temperature of the gaseous combustion products was T ≤ 260 °C, which ensured the flame retardant properties. Taking into account the heterogeneity of the material (wood), it is proposed to study the mechanism of the coating to establish the feasibility of using mineral additives.

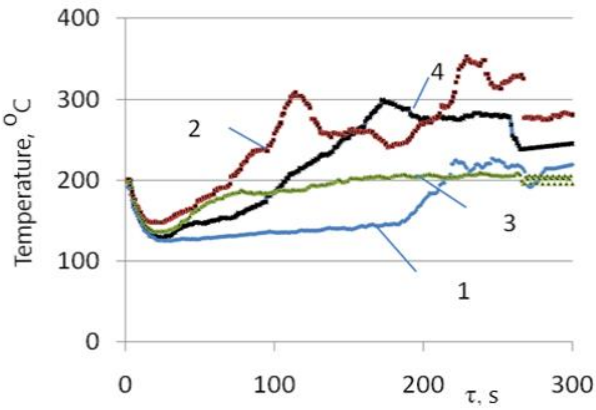

Figure 2. Dynamics of flue gas temperature rise during testing of fire-resistant wood with the amount of aluminum hydroxide in the coating: 1 – 0%; 2 – 2%; 3 – 4%; 4 – 8%

To determine the effectiveness of aluminum hydroxide for coatings, the swelling coefficient of the coating samples was tested according to the method [17 – 18]. The results of the data obtained are shown in Table 1.

Table 1. Coating swelling coefficient after testing

Coating sample	Coating thickness, mm	Furnace temperature, °C	Swelling coefficient, after testing
Base	0,2	500	30,1
Base 2% $Al(OH)_3$	0,2	500	29,0
Base + 4% $Al(OH)_3$	0,2	500	20,4
Base + 8% $Al(OH)_3$	0,2	500	18,0

As can be seen from Table 1, the most efficiently swelling base coating is the one consisting of ammonium polyphosphate, melamine, pentaerythritol and a binder based on polyvinyl acetate dispersion. The addition of aluminum hydroxide reduces the coefficient of swelling to a certain extent, but forms refractory compounds on the surface of the coating that do not burn out and form a heat-resistant layer.

Indicators of the main properties of the coating samples are shown in Fig. 3.

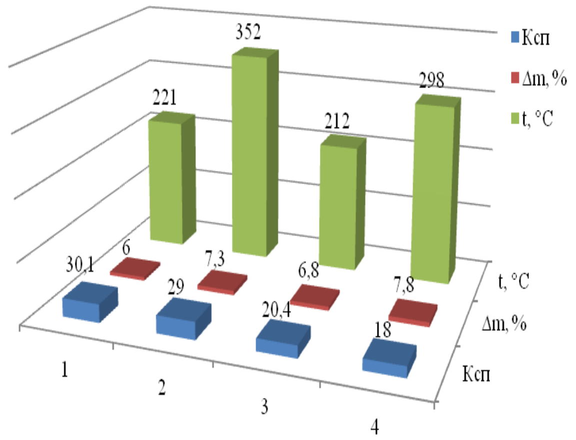

Figure 3. Indicators of the main properties of coating samples with the amount of aluminum hydroxide in the coating: 1 – 0%; 2 – 2%; 3 – 4%; 4 – 8%

As a result of the experimental studies, it was found that the introduction of aluminum hydroxide into the coating in the amount of 2...8% reduces the swelling coefficient from 30 to 18 to a certain extent, but for a coating containing 4%, an increase in the efficiency of fire protection of wood was found, namely, a decrease in the loss of sample mass and flue gas temperature due to the formation of heat-resistant compounds on the surface of the fireproof layer when aluminum hydroxide interacts with ammonium polyphosphate (Fig. 3).

CONCLUSIONS

Thus, the use of aluminum hydroxide in the fireproofing composition provides the required level of protection of wood from thermal effects at the required amount of 4 %, which leads to a reduction in the cost and increase in the efficiency of the coating.

Further research will be aimed at studying other types of fillers, their properties, and their impact on the fire protection efficiency of wood in fireproof organic-mineral coatings.

REFERENCES

1. **Tsapko Yu.V., Lomaga V.V., Tsapko O.Yu.** (2023) Vognezakhyst derevyny organo-neorganichnymy kompozytsiyamy: Monografiya, Kyiv: FOP Yamchynskii O.V., 160 (in Ukrainian).
2. **Tsapko Yu., Tsapko A., Bondarenko O.** (2019) Establishment of heat-exchange process regularities at inflammation of reed samples. Eastern-European Journal Enterprise Technologies, 1, 10 (97), 36-42; DOI: 10.15587/1729-4061.2019.156644 (in Ukrainian).
3. **Tsapko Yu., Tsapko A.** (2018) Establishment of fire protective effectiveness of reed treated with an impregnating solution and coatings. Eastern-European Journal Enterprise Technologies, 4, 10 (94), 62-68; https://doi.org/10.15587/1729-4061.2018.141030 (in Ukrainian).
4. **Tsapko Yu., Bondarenko O., Tsapko A.** (2019) Effect of a flame-retardant coating on the burning parameters of wood samples. Eastern-European Journal Enterprise Technologies, 2. 10 (98), 49-54; DOI: 10.15587/1729-4061.2019.163591 (in Ukrainian).
5. **Zhartovskyi V.M., Barylo O.G., Tsapko Y.V., Moroz V.M., Lyashenko S.A.** (2004) Fire and bio protection of paper and paper materials. Scientific Bulletin of UkrNDIPB, 2 (10), 86-90 (in Ukrainian).
6. **Zhartovsky V.M., Tsapko Y.V., Lyashenko S.A., Barylo O.G.** (2004) Determination of the optimal formulation of the composition for fire and bio protection of paper. Collection of scientific papers – Lviv: LIPB, 5, 128-133 (in Ukrainian).
7. **Nine J., Tran D. N. H., Thanh Tung T., Kabiri Sh., Losic D.** (2017) Graphene-Borate as an Efficient Fire Retardant for Cellulosic Materials with Multiple and Synergetic Modes of Action. School of Chemical Engineering, 9 (11), 10160-10168.
8. **Carosio F., Alongi J.** (2016) Ultra-Fast Layer-by-Layer Approach for Depositing Flame Retardant Coatings on Flexible PU Foams within Seconds. Acs applied materials & Interfaces, 8 (10), 6315-6319.
9. **Khalili P., Tshai K.Y., Hui D., 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; DOI: 10.1016/j.compositesb.2017.01.049 (in Ukrainian).
10. **Krüger S., Gregor J., Gluth G., Watolla M-B., Morys M., Häßler D., Schartel B.** (2016) Neue Wege: Reaktive Brandschutzbeschichtungen für Extrembedingungen. Berlin, Bautechnik, 93/8, 531-542;

DOI: 10.1002/bate.201600032.
11. **Janetti M.B., Wagner P.** (2017) Analytical model for the moisture absorption in capillary active building materials. Building and Environment, 126, 98-106.
12. **Wan Y., Zhao J., Chen J.** (2020) Effect of polydimethylsiloxane viscosity on silica fume-based geopolymer hybrid coating for flame-retarding plywood. Construction and Building Materials, 239, 117814; DOI:10.1016/j.conbuildmat.2019.117814.
13. **Zhan W., Chen L., Cui F., Gu Z., Jiang J.** (2020) Effects of carbon materials on fire protection and smoke suppression of waterborne intumescent coating. Progress in Organic Coatings, 140, 105491; DOI:https://doi.org/10.1016/j.porgcoat.2019.105491.
14. **Shi X.-H., Chen L., Zhao Q., Li Y.-M., Wang Y.-Z.** (2020) Epoxy resin composites reinforced and fire-retarded by surficially-treated carbon fibers via a tunable and facile process. Composites Science and Technology, 187, 107945;
DOI:10.1016/j.compscitech.2019.107945.
15. **DBN V 1.1-7:2016** (2017) Pozhezhna bezpeka obyektiv. Zagalni vymogy [In force since 2017-01-01], 20 (in Ukrainian).
16. **DSTU 8829:2019** (2020) Pozhezhovy-bukhonebezpechnist′ rechovyn i materialiv. Nomenklatura pokaznykiv i metody yikhn′oho vyznachennya. Klasyfikatsiya [In force since 2020-01-01], 20 (in Ukrainian).
17. **Tsapko Yu.V., Kryvenko P.V., Guziy S.G. etc.** (2017) A device for determining the swelling kinetics of a fire-resistant coating. Utility model patent, 11355 Ukraine, IPC G01N 23/00 [In force since 2017-02-10], Bul. No. 3, 3 (in Ukrainian).
18. **Tsapko Yu.V., Kryvenko P.V., Guziy S.G. etc.** (2017)Express method for determining the swelling kinetics of a fire-resistant coating. Utility model patent, 1356 Ukraine, IPC C09K 15/02, E04B 1/92 [In force since 2017-02-10], Bul. No. 3, 3 (in Ukrainian).

Ефективність вогнезахисту деревини органомінеральним покриттям з додаванням гідроксиду алюмінію

Юрій ЦАПКО, Олексій ЦАПКО, Ольга БОНДАРЕНКО, Наталя ЛЯЛІНА, Дмитро АНОПКО, Аліна ЮЩЕНКО

Анотація. Сьогодні існує два способи вогнезахисту деревини. Перший – просочення антипіренами, найчастіше на основі неорганічних солей. При зволоженні деревини антипірени розчиняються у вологому середовищі і поступово вимиваються на поверхню, після чого вогнезахисний ефект з часом зменшується. Засоби на основі кислот не мають значної проблеми вимивання через зміну вологості деревини, але, проникаючи глибоко в структуру деревини і взаємодіючи з целюлозою, вони знижують показники міцності. Тому використовувати цей продукт для критично важливих несучих конструкцій небезпечно. Другий спосіб полягає в нанесенні на поверхню деревини покриття на основі органічних або неорганічних сполучних речовин. Засоби на основі органічних сполучних мають підвищене димоутворення та токсичні речовини, тому їх використання є небезпечним. Тому останнім часом широкого розповсюдження набули покриття, здатні утворювати на поверхні будівельної конструкції теплоізоляційний шар, який значно зменшує процеси передачі тепла до матеріалу. В результаті проведених досліджень встановлено, що введення до складу органомінерального покриття гідроксиду алюмінію в кількості 2...8% певною мірою знижує коефіцієнт набухання з 30 до 18. Однак, для покриття, що містить 4%, виявлено підвищення ефективності вогнезахисту деревини, а саме зменшення втрати маси зразка та температури димових газів за рахунок утворення термостійких сполук на поверхні вогнезахисного шару при взаємодії гідроксиду алюмінію з поліфосфатом амонію. Використання гідроксиду алюмінію у складі вогнезахисної композиції забезпечує необхідний рівень захисту деревини від термічних впливів на рівні 4%, що призводить до зниження собівартості та підвищення ефективності покриття. У подальших дослідженнях планується вивчити інші види наповнювачів, їх властивості та вплив на вогнезахисну ефективність деревини у вогнезахисних органомінеральних покриттях.

Ключові слова: деревина, вогнезахист, органо-мінеральні покриття, гідроксид алюмінію, вогнезахисні властивості, ефективність.