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DEPENDENCE OF BURNING OF MATERIALS FROM FIRE-PROTECTED WOOD, TAKING INTO ACCOUNT ITS HUMIDITY

The article discusses the dependence of the effectiveness of different flame retardants, in this article three different compositions are presented, with the same drawing method to protect building structures from wood from the degree of humidity of the finished building material of wood beams. At the same time, wood modification continues to be one of the main areas of research for its durability and fire safety. Research is now focused on the multicomponent nature of systems, of which only some are of practical use. The main reason for this is the incompleteness of research. The results of studies on obtaining a stable response of the rate of change of temperature on the quality of flame retardant treatment taking into account moisture during fire exposure at a standard temperature curve on samples of wooden beams are given. Since humidity is one of the important characteristics when studying the behavior of wooden structures in case of fire, since it affects ignition and even less burning, while this humidity also affects the mass of the structure, which in turn affects the strength characteristics of wooden structures. The effect of flame retardants on the structure of the surface layer and the need to study the effect of various flame retardants on the performance properties of wood and on strength capabilities are also considered. A variety of factors is shown that affect the quality of flame retardant treatment for wood construction constructions. It is concluded that it is necessary to develop instrumental and methodological support that allows quick and accurate studies to determine fire-retardant efficiency and control the quality of fire protection work by surface coating of the protective layer on wooden building structures during operation and further study of the interaction of fire-retardant coatings during their repeated application Operated wooden structure.

Key words: *combustion reaction mechanism, fire protection, humidity, and control of fire-retardant efficiency.*

Introduction. Assessing the quality of flame retardant processing of wood materials is an urgent task. To date, in Ukraine, assessment can only be done in laboratory conditions in accordance with the test methodology provided for in GOST 16363-98 on an OTM type installation [1].

Rapid analysis methods, which are so urgently needed not only for practitioners carrying out fire-retardant treatment, exploiting materials and structures made of fire-resistant wood, but also to regulatory bodies that are authorized for use and whose results would be not informational, but protocol acceptable, are absent.

In the European countries, the PMP-1 small-sized device has been developed, manufactured and operated, which allows for rapid analysis of the degree of fire-retardant processing of wood, but it only gives a qualitative characteristic of fire-retardant treatment. The qualitative characteristic of ignition, which is used in such installations, must be replaced by quantitative indicators that would ensure the reliability of assessing the degree of fire protection, and from them it would be possible to establish a group of fire-retardant efficiency of the tested product.

At the same time, flammability and the ability to burn wood independently depends on its moisture content. It was revealed [2] that, with a relative humidity of more than 60%, the wood does not ignite and does not burn. When exposed to a constant (heat flow from heaters, stoves, batteries, etc.) or variable (increasing during fire) heat flux, the moisture content of the wood decreases. The dynamics of moisture reduction is one of the main indicators characterizing the resistance of wood to ignition. In addition, the performance characteristics of wood, such as compressive strength, tensile strength, resistance to static bending, impact strength, etc., depend on moisture indicators [2].

Literature review and purpose of research. The fire exposure on the material samples leads to a strictly defined picture of the development of damage to the studied material sample. This individual picture is made up of indicators characterizing the sample, such as:

- the time from the beginning of the fire to the moment of ignition;
- time before carbonization, smoke, water evaporation;
~ speed (intensity) of flame propagation through the sample;
- the rate of temperature increase at certain points of observation.

To ignite the material, it is necessary to raise the temperature to the ignition temperature. The time required for this, ceteris paribus, depends on the ability of the material to absorb heat. Heat susceptibility is proposed [3,4] to characterize the thermal inertia of the material, this indicator is determined by the product of such physical properties of the material as:

- thermal conductivity (X);
- heat capacity (s);
- density (p).

The greater the thermal inertia of the material (A / sr), the more difficult it is to light up and the lower the speed of flame propagation [2, 3].

When processing wood products with flame retardants, all these indicators change with respect to the source wood, namely, the density of the surface layer increases due to the inclusion of inorganic components of a flame retardant composition, the heat capacity increases, so it will be the sum of the heat capacities of the wood material and the surface-absorbed salt components of the composition also changes the thermal conductivity.

Since the type of inorganic components (brand of flame retardant composition) and its amount in the surface layer (features of flame retardant treatment) will directly affect the heat capacity and density, and, accordingly, the thermal inertia of the material, it is possible to control the time until the sample reaches the ignition temperature, speed temperature rise and the time of flame propagation through the sample before attenuation (if this is observed) characterize the quality of flame retardant treatment on such a small sample, on which these indicators whether they will still be observed with accuracy sufficient to identify the quality of the flame retardant treatment.

In this case, the moisture contained in the wood, which is composed of free and bound moisture, affects combustion. Moisture located in the intercellular space is called free or capillary, and that contained in the cells is called bound or hygroscopic. Free moisture is similar to liquid poured into a wooden vessel, while bound moisture is similar to liquid impregnating the walls of a vessel [3].

The fiber saturation point indicates the moisture content of the wood. This point is temperature dependent, but for most types of wood, the absolute humidity at the saturation point is 30%.

The process of moisture loss continues until the moisture level in the wood reaches equilibrium humidity with the surrounding air, the relative humidity is also a variable depending on the temperature and absolute humidity.

In general, cohesive-dispersed systems, in which particles of the dispersed phase form more or less rigid skeletons, belong to wet materials [3-5]. Depending on the structure and colloidal physical properties, they are divided into three types:

1. Typical colloidal bodies (elastic gels). When moisture is removed, these bodies significantly change their size, but retain elastic properties.
2. Capillary-porous bodies. These bodies have a rigid skeleton, and when moisture is removed, they shrink little or do not change their size at all.
3. Capillary-porous colloidal bodies with the properties of the first two. The walls of their capillaries are elastic and swell when absorbed.

The moisture content in wood is a variable, because wood is a typical capillary-porous body.

Wood also refers to hygroscopic building materials, i.e. it has the ability to bind water vapor, absorbing them or to release back into the atmosphere of the room when the relative humidity of the air changes. When interacting with indoor air, wood performs the so-called “buffer function”: leveling jumps in the relative humidity of the room due to the moisture-absorbing and moisture-releasing ability that exists due to the hygroscopic structure [6].

The rate of moisture loss depends on the temperature and humidity of the environment in which the wood is located, external loads, the permeability of the outer layers.

At a temperature of 110 ° C and a humidity of 0, drying of wood from 60 to 10% takes 12 hours, that is, the specific rate (1%) of moisture loss is approximately 14 minutes [5]. With increasing temperature, the drying speed increases. The sequence of the drying process can be represented as follows.

Therefore, with a decrease in cell size, the formation of intercellular cavities occurs, through which water is desorbed from the next layer. This process is reversible, however, during the operation of wood there is a gradual decrease in the moisture content of the wood, and accordingly, an increase in its fire hazard [7]. Since after the loss of free moisture begins the gradual destruction of the cell walls (aging) and the loss of not only the bound moisture, but also the chemically bound moisture included in the molecules of the polymer structures. The cell swollen again does not completely acquire the same volumetric configuration, and the intercellular cavities remain.

Under external load, deformation of individual cells entails a more rapid formation of intercellular cavities, and moisture loss already occurs not only through the surface layer (analogy with the evaporation of fluids from the surface), but also from deeper layers (analogy of fluid boiling).

Formulation of the problem and its solution. In the process of applying fire-retardant impregnation (water-based) on wood, the humidity of the treated layers increases, while a hydrophilic salt layer is formed, which prevents the desorption of moisture. The requirement [7] for the amount of mass loss for classifying a treated wood sample as the first group of fire-retardant efficiency of the tested coating or impregnating composition determines it to be equal to 9%. This means that during the test, a complete loss of all moisture contained in the wood is not even achieved, since the initial moisture content of the wood before applying the flame retardant should not exceed 25%. However, the rate of heat flow during the fire test does not allow time to desorb all the moisture contained in the wood, and the upper layers begin to char.

Moreover, the power of fire exposure and the temperature-radical characteristic of the flame are of no small importance for assessing the quality of flame retardant treatment.

The first signs of thermal decomposition of wood - the darkening of its surface - occur at temperatures above 110 ° C. Active smoldering of wood begins at a temperature of about 300 ° C; spontaneous combustion of wood occurs at approximately 400 °C [8]. Therefore, the temperature of the flame source acting on the sample must exceed 400 °C, in order to cause precisely the phenomenon of ignition of the wood sample.

When drying or heating, free moisture first evaporates from the wood; during further drying, the process of evaporation of bound moisture begins. With the loss of bound moisture, a significant change in the physicomechanical, thermotechnical (including fire hazardous) properties of wood occurs.

After conducting exploratory research, a liquid hydrocarbon burner was selected that provided these conditions for exposure to the sample. As a result of test and search work, such sources of thermal fire exposure were rejected as: dry alcohol (flame heterogeneity in height and temperature); spirit lamp (low flame temperature and difficulty in ensuring a clear flame height); stearin suppository; gas burner and several others.

The samples were tested from pine with a size of 70x50x200 mm and processed with the compositions NEOMID, BS 13, SENEZH, STRAZH, VANN-1. The choice of these flame retardants was made reasonably. Compositions differ in the resulting fire retardant efficiency of wood, including depending on the processing method and consumption of the flame retardant. Samples are shown in Figure 1.

Figure 1 – The appearance of experimental samples

As a result of the studies, a clear pattern was revealed between the degree of fire protection of the wood sample and the type of temperature curve averaged for 20 samples taken at the characteristic point of the device being developed (Figure 2)

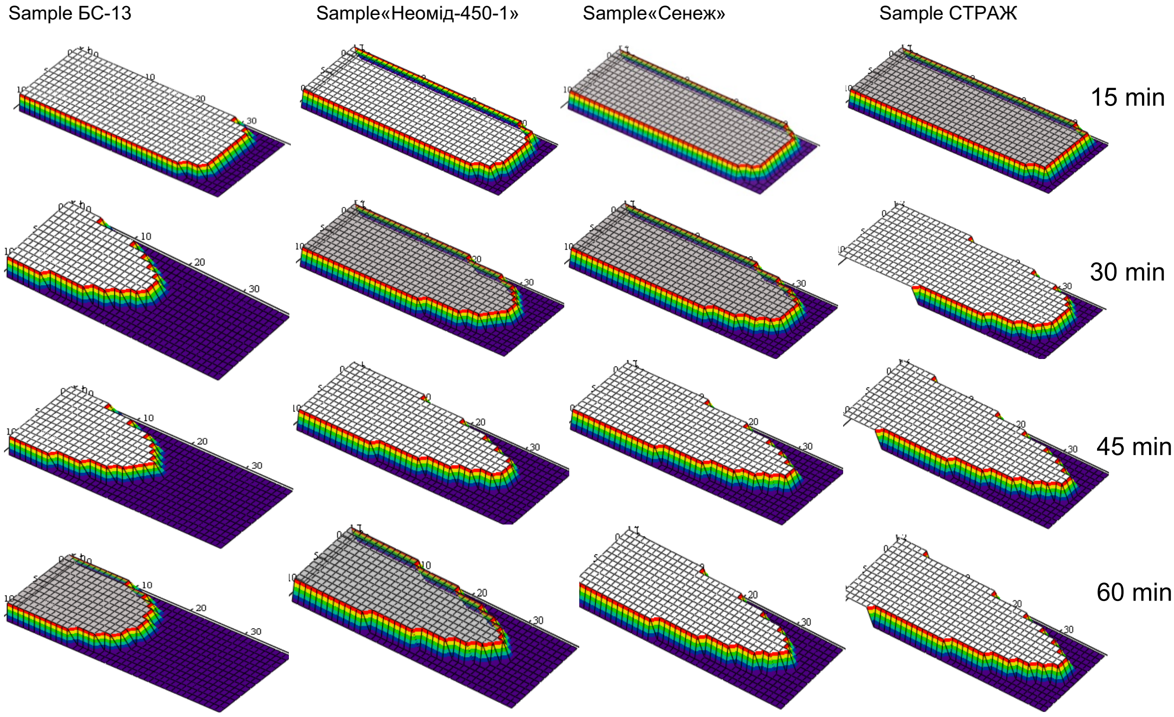

Figure 2 – The results of construction of the zone of carbonization of samples-fragments of wooden beams

Analysis of the rate of moisture loss depending on the external temperature or heat flux of samples of fireproof and unprotected wood.

The essence of the analysis was as follows. Samples of wood without fire protection treatment and with a layer of fire protection were placed in a thermal field, and after exposure to it, the surface condition was studied. The initial wood samples (pine) had a size of 70x50x200 mm. The samples were dried to a moisture content of 14 .. 16% (air drying in a desiccator) without additional heat.

During testing, the samples were placed for 15 minutes in the installation, the temperature in which was maintained 349..757 ° C.

Despite the relatively low humidity in the initial samples, in addition to a change in the color of the wood, the following decomposition was discovered during the decomposition process that started: cracks formed on the ends of the samples, the width of which reached 8 mm, up to 30 mm in length (Figure 3). Such significant cracks can be explained by the rather high temperature in the installation, where the sample is immediately placed, and also by the rate of heating of the samples (the time to enter the mode after opening the door did not exceed 10 seconds).

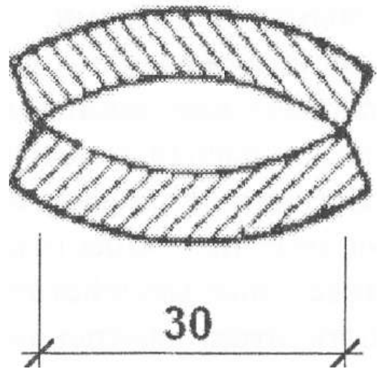

Figure 3 – The scheme of the formed cracks in the sample across the fibers.

This is explained by the fact that intense heat exposure in a wooden specimen results in stresses leading to cracking of wood in the initial period of the process, this is possible if tensile stresses exceed the tensile strength of wood across the fibers [6]. The formation of these cracks leads to an intensive loss of moisture not only from the surface, but from deeper layers of the wood, preparing it faster for ignition. Since cracks do not disappear upon cooling (and, accordingly, moisture absorption by the surface to the saturation point) of the samples, it means that the outer layers of the wood did not yet begin to lose chemically bound water when exposed to temperature for a short time, resulting in irreversible changes in the shape of the surface layer cells.

We can conclude that flame retardants change the structure of the outer layer, reduce the thermal conductivity of wood, prevent moisture loss (drying) of both absorption and bound moisture, and also change the degree of porosity of the samples, which affects the reactivity characteristics, the yield of volatiles and loss mass samples per unit time.

Crack opening (and, as a consequence, a decrease in the strength characteristics of wood) is explained by the creation of a surface coating with a low thermal conductivity coefficient in the volume of wood, which prevents the heating of the wood and its pyrolysis.

After thermal exposure, flame retardant bars were subjected to a fire test. The fire exposure was carried out in a test setup similar to that used in [8], with the resulting fire flow for 15 minutes. Unprotected wood was subjected to a similar fire exposure after thermal exposure.

In our opinion, one of the main mechanisms for increasing fire resistance is the change in the rate of moisture loss of wood samples treated with fire retardant impregnations.

Based on studies conducted [5, pp. 83-86], it was found that when the wood is heated to 150 ° C, its chemical composition almost does not change. When heated from 150 to 200 ° C, the decomposition of carbohydrates occurs with the formation of products soluble in caustic soda and alcohol benzene. When wood is heated to 250 ° C, some decay products turn into volatile substances, while others condense into high molecular weight substances. Prolonged exposure to heat causes chemical changes already at 100 ° C. The rate of these changes increases significantly at a temperature of 170..200 ° C. During the thermal decomposition of wood, volatiles are released and a carbon residue remains. The sequence of combustion (decomposition) of wood is presented in Figure 4.

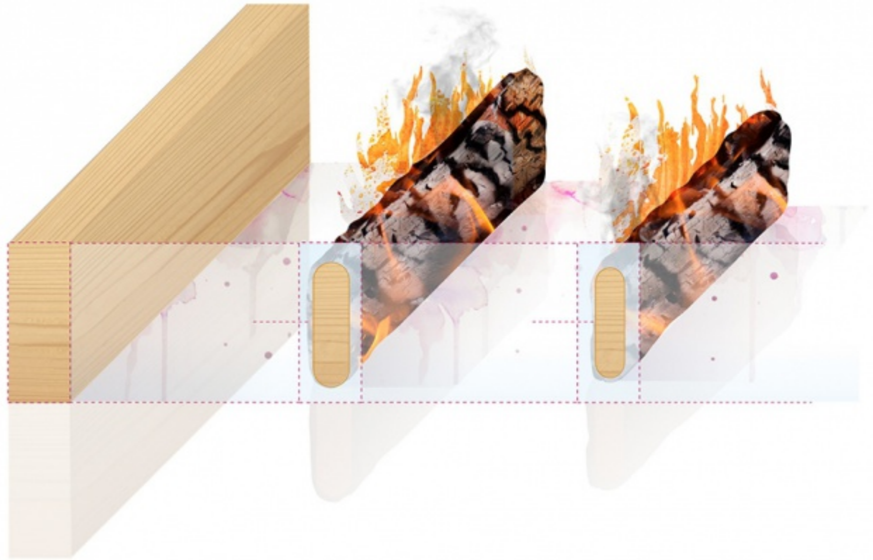

Figure 4 – The sequence of combustion (decomposition) of wood

The presented scheme, of course, does not reflect all the complexity and multi-stage (in space and time) cyclic and self-sustaining processes that occur during combustion and thermal decomposition of wood. However, it allows you to analyze possible methods to reduce the combustibility of wood.

In addition to changing the rate of moisture loss, and thus increasing the fire resistance of wood, other mechanisms leading to a decrease in the combustibility of wood after its fire retardant treatment are distinguished in the literature [9, p.23-34]. These mechanisms include:

- reducing the rate of thermal decomposition of wood by introducing substances that are thermal decomposition inhibitors into the surface layer of wood;
- the introduction of substances (catalysts) that accelerate or undergo decomposition reactions of wood, leading to the release of more non-combustible gases and carbonization of the carbon layer;
- the creation on the surface of wood coatings with a low coefficient of thermal conductivity, which interfere with the heating of wood and its pyrolysis (insulating mechanism);
- dilution of combustible gases with non-combustible gaseous substances released from flame-retardant materials, for example, water vapor, carbon dioxide, nitrogen (deflagration mechanism).

However, in addition to the above mechanisms and reactions that occur during thermal or fire exposure to wood, it is necessary to consider the effect of flame retardant treatment on the operational properties of wood, in particular, its interaction with components of fire retardant compositions. Impregnation components can interact with the functional groups of cellulose, hemicellulose and lignin. For example, an esterification reaction between the hydroxyl groups of cellulose and phosphoric acid is possible according to the scheme (Figure 5):

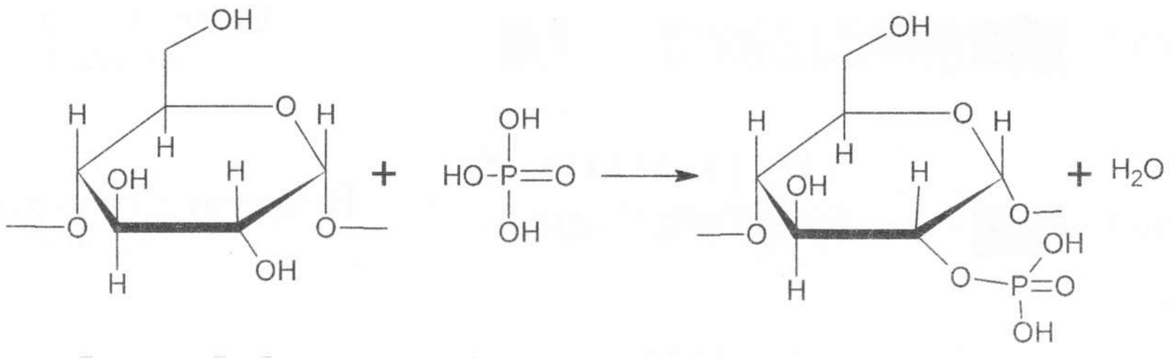

Figure 5 – The esterification reaction between the hydroxyl groups of the cellulose fragment with phosphoric acid

The introduction of an acid residue leads to a decrease in cohesive bonds between the individual chains of cellulose and changes (weakens) the elastic and other properties of wood fibers. The given reaction proceeds at normal temperatures at a low rate and a change (decrease) in the fiber strength can be observed only in time.

In practice, the most extensive group of flame retardants is composed of phosphorus compounds. This group includes compounds very diverse in type, from red phosphorus to phosphorus-containing polyesters and polyphosphazenes. With a wide variety of types of phosphorus-containing compounds used as flame retardants, they act by a variety of mechanisms. The variety of mechanisms is also explained by the fact that phosphorus-containing flame retardants are used both in the form of additives that do not react with the components of wood, and in the form of reactive compounds that enter into chemical interaction with the components of wood.

Since various phosphorus-containing compounds are used as flame retardants or components of flame retardant compounds, the reactions proceeding between the functional groups of wood elements and these phosphorus-containing components are very different.

Until now, the question of how fire retardant treatment of wood is interconnected with the moisture and strength characteristics of wooden structures has not been sufficiently resolved. Tests characterizing the change in the strength properties of wood with a long service life have yet to be performed.

As a method for monitoring fire-retardant efficiency by technical normative legal acts, the method of accelerated tests described in [7] is proposed. The disadvantages of this method of monitoring fire-retardant efficiency include, first of all, the fact that this method is strictly laboratory and, as a result, cumbersome, requiring a specialized laboratory base. In addition, we can talk about a certain subjectivity of this method, because test samples subjected to control during fire exposure, not in all cases are the result of fire protection carried out precisely at the construction site. Often during control one, two, three sides are exposed to fire protection during flame retardant treatment, and the remaining sides of the test specimen are brought to the required flame retardant efficiency after sampling the sample (sawing a bar from the construction volume). In addition, it is worth noting the fact of this cutting, as it is often fundamentally absurd from the point of view of the possibility and expediency of its execution at a construction site - to take a sample from a wooden (solid or glued) load-bearing structure, especially with a large span, does not always seem real according to GOST 16483.21, which makes requirements to the selection of wood samples after its technological processing.

And, finally, this method is not very sensitive and differentiates the flame retardant properties of the tested substances worse than others; when developing a new flame retardant composition, it takes a lot of time to develop its formulation. Naturally, the explanation of the flame retardant effect of various substances due to any one of the properties is unacceptable. Even when using flame retardants of the same type, a significant number of factors can influence the combustion process. In addition, the effect of two or more factors may turn out to be greater than the sum of these effects due to the manifestation of synergism [10, p. 87-91].

Experience in the construction operation of fire-resistant wood suggests that after 5-10 years, wood changes its properties and structural elements cease to fulfill their functions. This suggests that in the certification of flame retardants, it is necessary to begin to control such a parameter as a change in the strength properties of wood after a certain period of time. Otherwise, the decrease in combustibility is offset by the repeated replacement of structural wood products and a multiple increase in operating costs.

Given the fact that for more than 35 years technical normative legal acts propose to use practically the same criteria for determining fire-retardant efficiency, the main of which is the loss of mass of a sample, it seems interesting and necessary to conduct research work on the search, establishment and scientific - experimental substantiation of indicators that most accurately and fully characterize the quality of processing and fire-retardant efficiency of wood after fire protection.

In addition, the development of instrumental and methodological support allowing the determination of fire protection is interesting and sufficiently necessary.

Conclusion. After analyzing these results, we can draw the following conclusions on the nature of the behavior of the samples:

1. The rate of temperature rise and the burning rate of samples without flame retardant treatment are so high that non-flame retardant samples can be separated from the others without significant problems.

2. Samples treated with НЕОМИД-450 flame retardants behaved quite predictably and are common for wood that has a fairly weak degree of protection. When observing their combustion, a period from 0 to 15 minutes was clearly distinguished, after which there was an ignition of wood samples, which turned into stable flame burning. However, unlike unprotected samples, we did not observe a sharp increase in temperature, and in some cases even attenuation occurred. This can explain why the rate of rise of the averaged temperature for the samples treated with БС-13 was not so high as for the samples of wood without fire protection.

3. Samples that are flame retardant with the СТРАЖ composition did not ignite for 20-25 minutes from the start of the test due to higher protection. Even after ignition, attenuation often occurred (sometimes with subsequent ignition), the development of the flame was intermittent, inconstant.

4. The samples treated with the СЕНЕЖ flame retardant behaved most interestingly. It is clearly seen that these samples showed themselves, in general, similarly to samples processed by БС-13 (even slightly better). This can be explained by the fact that pine wood, when impregnated with protective agents, belongs to group 1 (easily impregnated) or group 2 (moderately impregnated), depending on whether the pine core or sapwood is impregnated. For this wood, a depth of wood impregnation of up to 3 mm is provided, i.e., the samples were completely impregnated, as in the case of autoclave processing, which was confirmed by visual observations of the color shades of the wood after flame retardant treatment. In this case, we can say that the wood has acquired a high degree of protection (fire retardant efficiency group I), but only to the depth of impregnation, which will not allow us to say the same about the massif of the overall wooden structure. At the same time, there is some doubt that wood with high surface protection behaves so badly in fire conditions and accept that the explanation of the flame retardant effect of various substances due to any one of the properties is unacceptable. Even when using flame retardants of the same type, a significant number of factors can influence the combustion process. In addition, the effect of two or more factors may be greater than the sum of these effects due to the manifestation of synergism.

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ЗАЛЕЖНІСТЬ ГОРІННЯ МАТЕРІАЛІВ ІЗ ВОГНЕЗАХИСНОЇ ДЕРЕВИНИ З УРАХУВАННЯМ ЇЇ ВОЛОГОСТІ

У статті обговорюється залежність ефективності різних вогнезахисних речовин. У цій статті представлені три різні композиції, з тим же методом нанесення для захисту будівельних конструкцій від деревини від ступеня вологості готового будівельного матеріалу деревних балок. У той же час модифікація деревини продовжує залишатися одним з основних напрямків досліджень її довговічності та пожежної безпеки. Зараз дослідження зосереджені на багатокомпонентності систем, з яких лише деякі практичні. Основна причина цього - незавершеність досліджень. Наведено результати досліджень щодо отримання стабільної реакції на швидкість зміни температури на якість обробки вогнезахисними засобами з урахуванням вологи під час впливу вогню при стандартній температурній кривій на зразках дерев'яних балок. Оскільки вологість є однією з важливих характеристик при вивченні поведінки дерев'яних конструкцій у разі пожежі, оскільки вона впливає на займання та ще менше горіння, тоді як ця вологість також впливає на масу конструкції, що в свою чергу впливає на міцнісні характеристики дерев'яних конструкцій . Враховано також вплив вогнестійких речовин на структуру поверхневого шару та необхідність вивчення впливу різних вогнезахисних речовин на експлуатаційні властивості деревини та на міцнісні можливості. Показано різноманітність факторів, які впливають на якість обробки вогнезахисних конструкцій для будівельних конструкцій з деревини. Зроблено висновок, що необхідно розробити інструментальний та методичний супровід, що дозволяє швидко та точно проводити дослідження для визначення ефективності пожежогасіння та контролю якості протипожежних робіт поверхневим покриттям захисного шару на дерев'яних будівельних конструкціях під час експлуатації та подальшого вивчення взаємодія вогнезахисних покриттів при їх багаторазовому застосуванні Експлуатується дерев'яна конструкція.

Ключові слова: *механізм реакцій горіння, вогнезахист, вологість і контроль вогнезахисної ефективності.*

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ЗАВИСИМОСТЬ ГОРЕНИЯ МАТЕРИАЛОВ ИЗ ОГНЕЗАЩИЩЕННОЙ ДРЕВЕСИНЫ С УЧЕТОМ ЕЕ ВЛАЖНОСТИ

В статье обсуждается зависимость эффективности разных антипиренов. В этой статье представлены три разных состава, с одинаковым методом нанесения для защиты строительных конструкций из дерева от степени влажности готового строительного материала из деревянных балок. В то же время, модификация древесины продолжает оставаться одной из основных областей исследований ее долговечности и пожарной безопасности. В настоящее время исследования сосредоточены на многокомпонентной природе систем, из которых только некоторые имеют практическое применение. Основной причиной этого является незавершенность исследований. Приведены результаты исследований по получению стабильного отклика скорости изменения температуры на качество огнезащитной обработки с учетом влажности при воздействии огня при стандартной температурной кривой на образцах из деревянных балок. Поскольку влажность является одной из важных характеристик при изучении поведения деревянных конструкций в случае пожара, поскольку она влияет на возгорание и даже меньшее горение, в то время как эта влажность также влияет на массу конструкции, что, в свою очередь, влияет на прочностные характеристики деревянных конструкций. Также рассматривается влияние антипиренов на структуру поверхностного слоя и необходимость изучения влияния различных антипиренов на эксплуатационные свойства древесины и на прочность. Показано множество факторов, влияющих на качество огнезащитной обработки деревянных строительных конструкций. Сделан вывод о необходимости разработки инструментально-методического обеспечения, позволяющего быстро и точно проводить исследования для определения огнезащитной эффективности и контроля качества противопожарных работ путем нанесения защитного слоя на деревянные строительные конструкции в процессе эксплуатации и дальнейшего изучения Взаимодействие огнезащитных покрытий при их многократном нанесении при эксплуатация деревянной конструкции.

Ключевые слова: *механизм реакций горения, огнезащита, влажность и контроль огнезащитной эффективности.*