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Research of the behavioral of the wooden beams with fire protection lining under fire loading

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Abstract. This article highlights the current issues of ensuring the fire resistance of wooden beams as load-bearing structures. Scientists have studied various types of fire protection of wood from the effects of fire. In the existing methods of fire protection, fire-retardant impregnating materials, fire-retardant paint, commercial fire-retardant coverings are presented. In addition, a study on the creation of fire-retardant materials was conducted. Therefore, in the field of our research there are the issues of using fire-protective plywood as a fire-retardant cladding method of protection of wooden structures. This article describes the process of manufacturing fire-retardant plywood made of 2-millimeter sheet of veneer and impregnated with a flame retardant using the method of technological baths and glued in a pressed machine to the appropriate thickness. Then in the experimental setup, fire tests were performed at standard temperature for three intervals of exposure to determine the depth of charring. These studies make it possible to draw conclusions about the effectiveness of the proposed method of fire protection of wooden structures and to determine the calculated class of fire resistance for these structures.

1. Introduction

The industrial development of construction every year dictates increased requirements for fire safety. Therefore, the conformity of building materials with the fire resistance class depending on the normative limit states is determined by DNB B 1.1-7: 2016 [1]. The substantiation of fire protection of wooden building constructions with preservation of durability, functional and aesthetic properties remains relevant.

Modern building and construction is impossible without the use of wooden building structures, because they have significant advantages, such as environmental friendliness, durability, strength, and



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economy. The most common wooden building structures are trusses, beams, ceilings. One of the most promising ways to use wooden beams is to improve their properties.

Wooden beams must not only meet the strength and rigidity requirements, but also the fire safety requirements. Due to the high temperatures of the fire, the strength of the timber structures decreases, sometimes their complete destruction occurs, so ensuring the fire resistance level of the wooden beams is an urgent task.

In literature [2, 3] the studies of improvement of the properties of fireproofing agents for the timber structures were carried out.

Such studies consider this task incompletely, because they don't take into account the fire resistance of such structures.

Although in literature [4, 5] these issues were solved, the fireproof coating material of wooden beams in the form of fireproof plywood, was not considered. This material, however, is the most common in building nowadays.

2. Literature review and purpose of research

In the modern building industry, for the last ten years, plywood takes one of the leading places among coating materials because it has durable properties, environmentally safe, cheap, easy to use, has a wide range of applications, often used for decoration. These properties provide the maximum shelf life and cost-effectiveness. Plywood is a layered glued structure consisting of three or more sheets of wood with mutually perpendicular arrangement of fibers in adjacent layers. This gives the plywood increased strength in different directions, shape stability, which is a distinct advantage over natural wood. Plywood, like wood, is easy workable. Its surface can be arranged in different ways: laminated, covered with veneer, painted, varnished.

Different scientists have been studying this issue in different years. A.S. Belekov, M.Ya. Roitman, S.V. Pozdeeva studied fire resistance of different structures. Providing fire-retardant materials to wooden structures - T.M. Shnal, V.M. Zhartovsky, Y.V. Tsapko, S.L. Fomina. Foreign researchers who have studied the fire-resistant properties of wood products – White R.H., Forauter A., Kruppa G., Lie T.T. The available views on the issue of ensuring the fire resistance of wooden beams by the method of facing with fire-retardant plywood can be classified as not a study in full. Therefore, research on this issue is in the spotlight [2-4, 6, 10, 11].

The aim of the article is to establish the dependences of systemic signs of charring zone change on the analyzed type of fire protection of wooden beams using a standard temperature curve for hydrocarbon fire, as normatively accepted to determine the class of fire resistance of building structures. The study of this problem is a scientific basis for determining the assessment of fire resistance of wooden beams with the most effective way of fire protection.

Much attention has been paid to surface treatment issues that can be achieved using fireproofing and paints. All these measures affect the required level of fire resistance of structures. But these issues are not learned yet: increasing the level of fire resistance of plywood, additional load on the structure, large labor costs in processing, the behavior of fire-resistant plywood during fire exposure and also physical fire exposure -chemical properties of plywood and the effect of fire-retardant treatment on the fire resistance of such structures.

The topicality of our studies is to study the behavior of a wooden beam with fireproofing plywood coating during fire, as well as to loading the fire resistance class of a wood beam with flame retardant cladding and the depth of its charcoal.

Literature [4, 6] shows that in a fire condition, the failure of general structural stability usually occurs due to the destruction of the most loaded elements (columns, beams), as they are the main supporting elements in the building frame. During the destruction of beams losses reach a high level as at loss of their carrying capacity there is a destruction of technological equipment and destruction of a premise. Therefore, maintaining the load-bearing capacity of beams in a fire for a given time is an urgent task. Taking into account the mentioned above, the goal was formulated and tasks were set.

3. Basic theoretical provisions for the calculation

The purpose of this article is to investigate the behavior of wooden beams with fireproofing plywood coating under the action of fire when tested under standard temperature conditions. To achieve this goal, we were assigned the following tasks:

- to analyse the kind of plywood;
- to prepare test samples and conduct experimental studies of the fire resistance of wooden beams with fireproofing plywood coating at standard temperature conditions;
- to process the results of the experiment with the determination of the coefficient of charring.

Presentation of the main material with full explanation of the obtained scientific results. For the production of the experimental examples, a 2 mm birch veneer of the highest grade was used, which was impregnated with the Immersion in Technology Bathtubs method, since this method provided impregnation of the wood to 4 mm, which ensured complete impregnation of the veneer with the use of a flame retardant using the process line a 10 mm and 20 mm thick fireproof plywood was manufactured.

As the value of the level of fire resistance of wooden beams with fireproofing plywood coating is determined by testing by standard methods of fire resistance test, and the indicator of the class of fire resistance is determined by the onset of the limiting state in the loss of bearing capacity and according to [7-9, 13] it is equal to 60 minutes, so the fire tests were conducted wooden beams according to the standard temperature of the fire.

For the tests, a heating installation was used, which is a $500 \times 500 \times 500$ mm steel casing. On the back, the chamber has a 60 mm diameter hole to install the burner nozzle. To minimize heat loss, the camera is protected inside by a 100 mm layer of non-combustible Conlit 150 insulation made by Rockwool that protects metal structures against high temperatures for up to 3 hours. Four TXA-VIII thermocouples were also used, three of which were installed in the sample and one was installed in the unit to determine the standard temperature mode complete with Digital multimeter DT 700C and Digital multimeter DT 838C (Figure 1).



Figure1. TXA-VIII thermocouples (0 to 1100)°C.

The experimental samples were made of pine blocks measuring $250 \times 70 \times 350$ mm and plywood 250×100 mm in the amount of three pieces for every three intervals of 15, 30 and 60 minutes for two types of thickness, i.e. in total there were twenty-four samples that are shown (Figure 2). Figure 3 shows a photo of the experimental sample with the indicated locations for thermocouples.

General view of the experimental installation for testing the fire resistance of samples - fragments of wooden beams lined with fire-retardant plywood with 10 mm and 20 mm thickness and indicating the location of thermocouples in the samples, according to the standard temperature curve is shown in Figure 4.

Thus, the installation presented in Figure 4 has high performance characteristics, a wide range of materials used for research and a small error in the results.

This experimental setup was used in the study of scientists A.V. Shvidenko, O.V. Nekora, V.M. Nuyanzina, S.O. Sydney for fire resistance of reinforced concrete structures of various configurations, as well as wooden beams and wood products – by Y.V. Zmaha, A.Yu. Novgorodchenko.

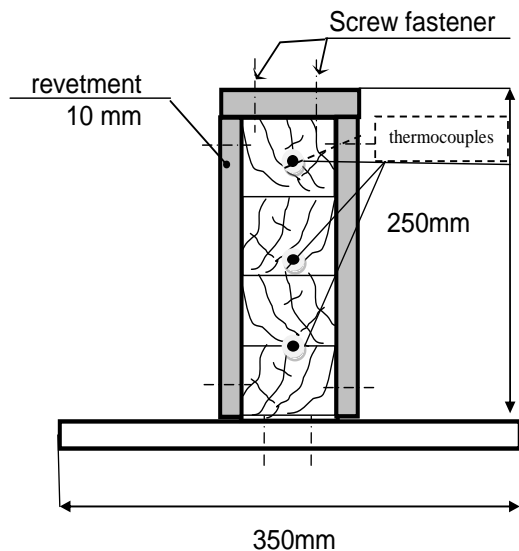


Figure 2. View of the test sample at 10 mm thick fire-protective plywood.



Figure 3. A photo of the sample with placement of thermocouples.

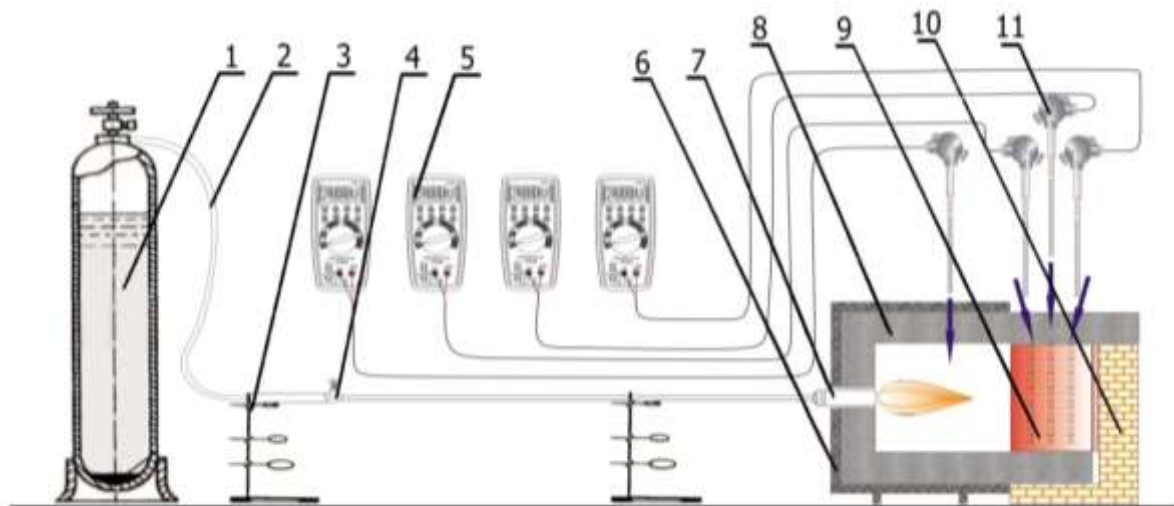


Figure 4. Installation diagram: 1 - cylinder filled with gas; 2 - sleeve; 3 - tripod; 4 - valve with injector; 5 - multimeter; 6 - steel body of the furnace; 7 - gas burner; 8 - thermal insulation of the chamber of thermal influence of the furnace; 9 - sample for research, installed in the body infusion chamber; 10 - brick body of the furnace; 11 - thermocouples.

The thermocouple element position allows the temperature readings to be recorded from the surface inner layers of the sample. The sample is set to the outlet of the experimental setup. When heating the specimens, a mode corresponding to the “standard” fire mode was used in the test setup chamber. The mode of heating the space of the chamber was determined by the thermocouple installed in the chamber. The thermocouple readings according to [6] were recorded from the graduated combined measuring device every 1 minute.

The temperature in the samples was recorded for 15, 30, 60 minutes, then recording stopped and the test and description of the sample was carried out.

During the complex of 15 minutes fire tests, the following behavior of the samples was observed:

- Samples with fireproof plywood lining with a single layer of 10 mm during fire tests did not emit smoke temperature rise was gradual, while the cells of self-ignition were observed.
- Samples with fireproof plywood lining with a single layer of 20 mm in a 15-minute time interval did not emit smoke, temperature rises were gradual and moderate, cases of self-ignition were not observed, which in turn can characterize the effect of the thickness of the layer on the effectiveness of protective properties.

The complex of 30 minutes fire tests gave a clearer idea of the behavior of fragments of wooden beams with fireproofing coating material during the fire, as can be seen in the graphs namely:

- Wood samples without impregnation behaved similarly to experimental studies in a 15 minute interval. The change in temperature occurred with an equally rapid increase.
- Specimens with one layer of 10 mm flame retardant were not subjected to significant fire effects during the experiment, the temperature rise was gradual and had a maximum at the first thermocouple of 160 degrees, without self-ignition, and no thick, odorless smoke was released.
- The most refractory specimens were those with a 20 mm flame retardant coating layer. They did not emit smoke, the temperature rise was slow and reached a 107-degree mark on the first thermocouple, with the specimens only charred by a few millimeters.

The following phenomena were observed in the 60 minute block of tests: specimens with lining fireproof plywood with one layer of 20 mm, characterized by high flame retardant and flame retardant properties. Collected and analyzed the actual results of measurements of the thickness of the depth of charring of samples of wooden beams allows to illustrate in (table 1), certain observations of the dependences of the geometric parameters of the thickness of fire-retardant plywood.

Table 1. Parameters of charring depth from the thickness of the facing layer and exposure time

Samples of fire-retardant plywood	Sample number	Time exp, min	B, mm	B0, mm	B1, mm	B2, mm	B3, mm	L, mm	L0, mm
10 mm	1.	15	70	0	0	0	6	250	243
	2.		70	0	0	0	8	250	244
	3.		70	0	0	0	8	250	245
20 mm	4.	15	70	0	0	0	0	250	250
	5.		70	0	0	0	0	250	250
	6.		70	0	0	0	0	250	250
10 mm	7.	30	70	14	16	20	25	250	231
	8.		70	14	15	16	26	250	236
	9.		70	14	15	17	27	250	235
20 mm	10.	30	70	3	4	5	8	250	240
	11.		70	2	4	6	8	250	243
	12.		70	1	2	3	5	250	245
10 mm	13.	60	70	19	22	26	28	250	206
	14.		70	21	24	28	27	250	208
	15.		70	18	21	25	29	250	207
20 mm	16.	60	70	15	20	24	44	250	227
	17.		70	17	19	22	26	250	215
	18.		70	17	20	23	28	250	215
Without impregnation	19.	15	70	16	18	21	27	250	187
	20.	30	70	22	24	28	31	250	165
	21.	60	70	32	41	43	53	250	132

4. The method of determining the carbonation depth.

The following procedures should be followed to determine the carbonation depth of wooden beams:

- Determine the performance of the sample.
- The obtained sample is subjected to one of the methods of fire protection of wooden structures.
- Conduct fire tests on a standard temperature curve for 15, 30, 60 minutes.
- After the end of the experimental part, measurements of the depth of charcoal using the caliper according to figure 2 are made.
- Conclusions are drawn as to the effectiveness of the fire retardant method for wooden structures and the depth of charcoal of wooden beams.

5. Conclusions

In this article, flame-retardant substances were analyzed and one substance was selected for further experimental study which is the most used within our country. The method of fire testing of wooden beams with fireproof plywood lining at standard temperature is also given, and the results of this experiment are published. At intervals of 45 to 60 minutes, as a rule, there is a rapid increase in temperature, and in some cases, self-ignition of the samples. This changes the structure of the wood, which in turn correlates with the change in the strength properties of the wooden beams.

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