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# RESEARCH OF BEHAVIOR OF WOODEN BEAMS WITH FIRE BIO PROTECTION IN FIRE

*The article is devoted to the behavior of wooden beams with fire protection in case of fire. The results of calculations of the rate of charring fragments of wooden beams with fire protection.*

***Key words:*** *fire resistance, fire bio protection, scheme of measuring geometric parameters of the charred zone of samples.*

**Introduction.** Researches [1; 2] show that wooden beams in buildings with wooden structures are one of the most crucial elements to which special requirements for fire resistance are needed. According to the building codes of Ukraine [3] the limits of fire resistance of wooden beams in many cases should correspond to classes R45 and R60. Considering the combustibility of wood to provide these classes of fire resistance, it is necessary to use fire protection. Among the most common means of fire protection of wood, the most widespread are fire and bio protecting impregnations [4, 5]. The mechanism of such means is based on slowing down of burning processes on the surface of elements of wooden structures. Nevertheless, over time the thermal effects of fire-treated layer is subjected to decomposition and charring process extends to the unprotected layers, whereby the beam is still destroyed. Considering this, the parameters for predicting the charring zone, which is one of the main parameters for calculating fire resistance limits of wooden beams according to the standard must be indicated [6].

**Raising the problem and its solution.** The aim of this article is to develop a calculation technique for predicting geometric configuration of the zone of charring of wooden beams with fireproof impregnation when exposed to fire with a standard temperature regime. To achieve this goal, we have set following tasks:

- carry out experimental researches of fragments of wooden bearing beams with integrated protection against heat and fire, biological damage to the wood and determine the temperature in the inner layers of samples and the thickness of the charred layer;
- on the basis of the test results, to reveal the regularities of growth of the thickness of the charred layer;
- to develop a methodology for calculating geometric configuration of the charred zone.

**Results.** To study the behavior of wooden beams, their fragments were used, the scheme and the form of which are shown in Fig. 1. Test samples were made of pine bars with dimensions of 200*65*400 mm, and plywood with dimensions of 400*400*16 mm. The manufactured samples were impregnated in accordance with Table. 1.

For the tests, a heating installation, which is a steel chamber with dimensions of 500 × 500 × 500 mm was used. On the back side, the chamber has a hole which diameter is 60 mm for installing the burner nozzle. On the inside, the walls of the chamber are protected with a layer of non-combustible insulation "Conlit 150" produced by Rockwool company with thickness of 100 mm to minimize heat loss, which also protects it from high temperatures. General view of the installation for fire tests of fragments of wooden beams with fireproof impregnation under the standard temperature regime is shown in Fig. 2.

After the experiment, the samples are charred, the typical condition of the sample after the test is shown in Fig. 3.

To conduct the tests, we measured the charring layer, according to the scheme in Fig. 4.

Using the measurements, the average lateral thickness and the average end thickness of the charred layer were calculated, the graphs of the dependences on exposure time of which are shown in Fig. 5.

In Fig. 6 Graphs of the rate of charring of samples are shows.

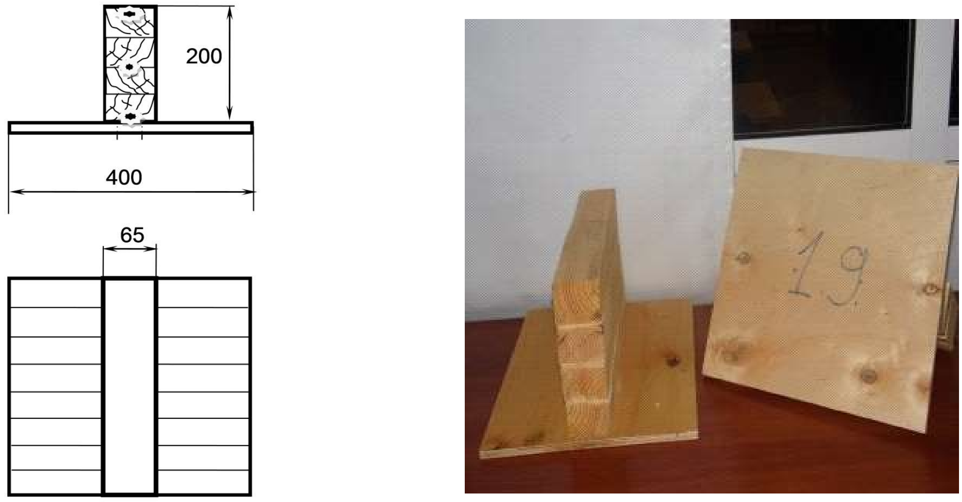



Figure 1 – Fragment of a Wooden Beam for Testing with Location of Thermocouples.

Table 1 – Nomenclature of Test Samples

| № | Sample Number | Type of Impregnant | Exposure Time, Minutes. |
|---|---|---|---|
| 1 | 1.1.-1.3. | Bio fire protection «Neomid 450-1» | 15 |
| 2 | 2.1.-2.3. | Bio fire protection «Senezh» | 15 |
| 3 | 3.1.-3.3. | Bio fire protection «Strazh-2 (BS-13)» | 15 |
| 4 | 4.1- 4.3. | Without impregnation | 15 |
| 5 | 1.4.-1.6. | Bio fire protection «Neomid 450-1» | 30 |
| 6 | 2.4.-2.6. | Bio fire protection «Senezh» | 30 |
| 7 | 3.4.-3.6. | Bio fire protection «Strazh-2 (BS-13)» | 30 |
| 8 | 4.4.- 4.6. | Without impregnation | 30 |
| 9 | 1.7.-1.9. | Bio fire protection «Neomid 450-1» | 60 |
| 10 | 2.7.-2.9. | Bio fire protection «Senezh» | 60 |
| 11 | 3.7.-3.9. | Bio fire protection «Strazh-2 (BS-13)» | 60 |
| 12 | 4.7.-4.9. | Without impregnation | 60 |

Fig. 2 – Heating Installation for Testing.

*a)* *b)* *c)*

Fig. 3 – Photo of Samples without Impregnation after Fire Tests , a) Charring of the Sample after 15 Minutes of Exposure; b) Charring of the Sample after 30 Minutes of Exposure; в) Charring of the Sample after 60 Minutes of Exposure.

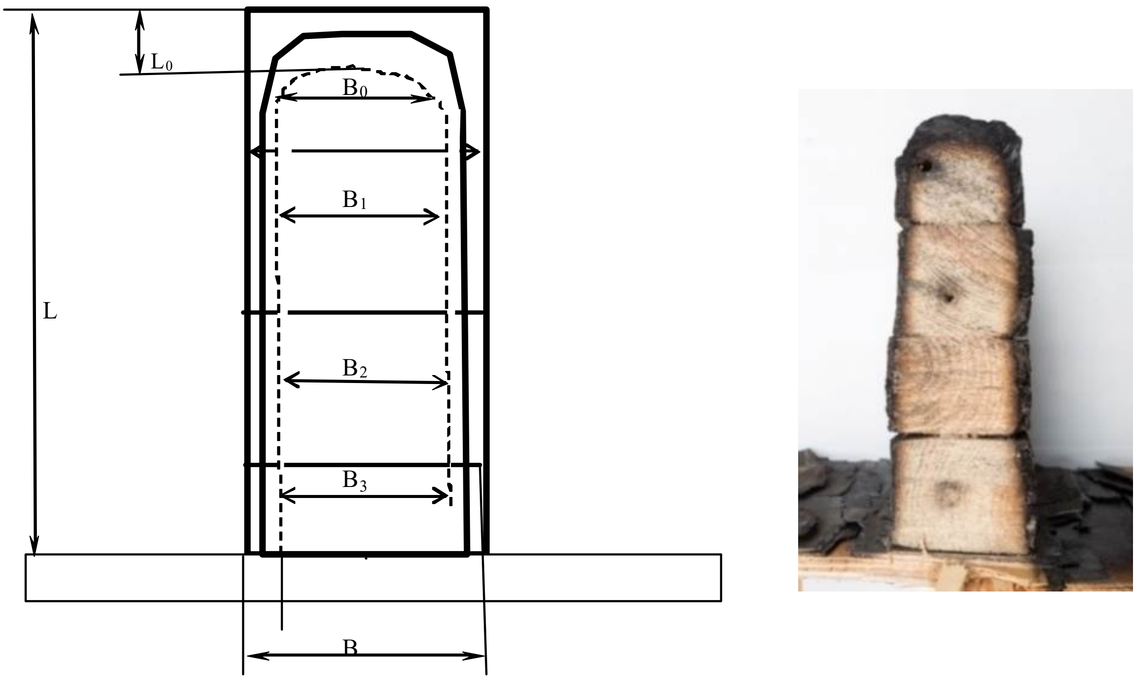
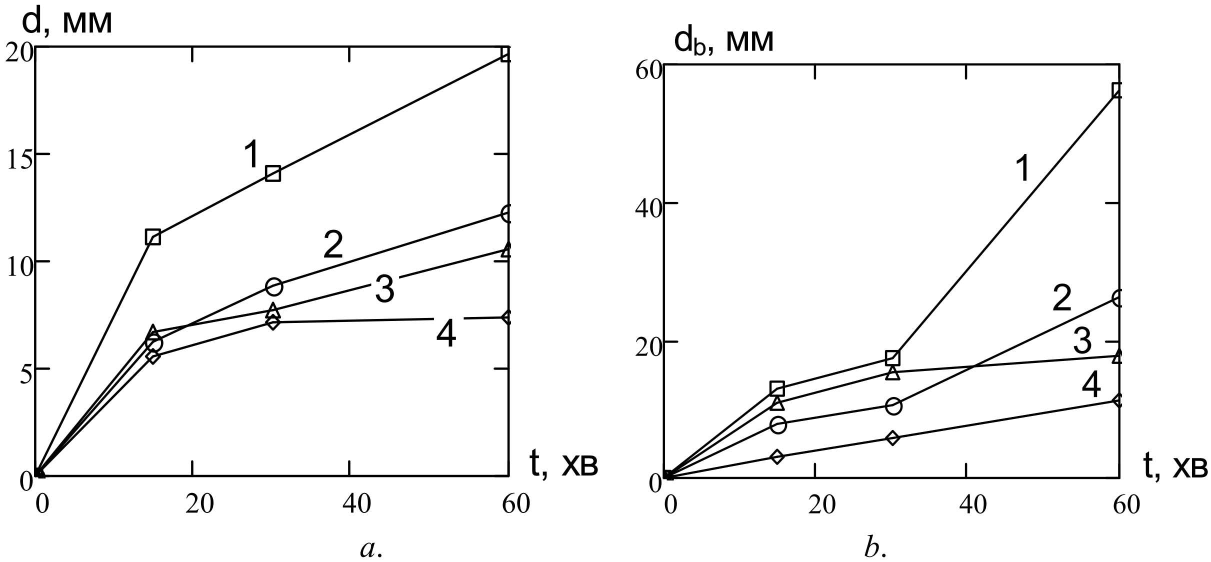
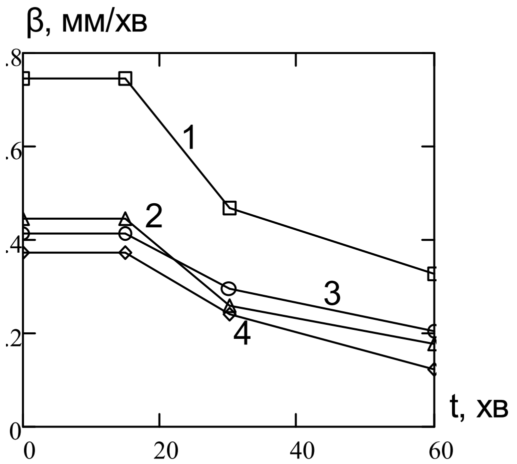



Fig. 4 – Scheme of Measuring Geometric Parameters of the Charred Zone of Samples

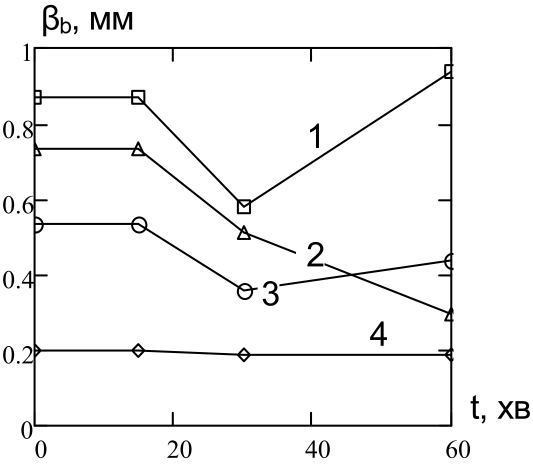



*a.* *b.*

Fig. 5 – Dependencies of Side (a) and End Thickness (b) of the Charred Layer on Exposure Time of Sample: 1 – Without impregnation; 2 – With Impregnation Neomid 450-1; 3 – With Impregnation Senezh; 4 – With Impregnation Strazh -2 (BS-13)




*а.*




*б.*

Fig. 6 – Dependencies of side (a) and end (b) Rates of Charring on exposure time of sample: 1 – без 1 – Without impregnation; 2 – With Impregnation Neomid 450-1; 3 – With Impregnation Senezh; 4 – With Impregnation Strazh -2 (BS-13)

Analyzing the graphs in Fig. 5 and Fig. 6, it can be seen that the dependencies of the thicknesses of charring on time are similar. Charring of wood with impregnation occurs much more slowly. Impregnation of the type 4 has the best indicators for the rate of charring.

When predicting geometric configuration of the charred zone there was a hypothesis the idea of which was an assumption that, when the charring behavior depends on temperature, the charring zone must be limited to a certain isotherm. To implement this hypothesis, it is necessary to construct isotherms in the cross section of the fragment. In this case, two methods can be used: by solving a heat conduction equation, or by approximating isotherms by means of interpolation functionals. To solve the heat conduction problem, the thermophysical characteristics of wood with fire protection which are unknown are required therefore, the second method was used.

To approximate the isotherms, we used a functional of the form:

$$y(x) = y_0\left(1-\left(\frac{x}{x_0}\right)^p\right)^{1/p} \qquad (1)$$

where $x_0$ and $y_0$ – coordinates on the axes $x$ and $y$ at their intersection by an approximating curve;
$p$ – exponent determined by approximating curve.

In fig. 7 a flock of curves set by the expression is shown (1).

Using this approach and measurements of temperature at the reference points of the section during the tests (fig. 1), interpolation of temperature distributions was carried out. The result is shown in fig. 8.

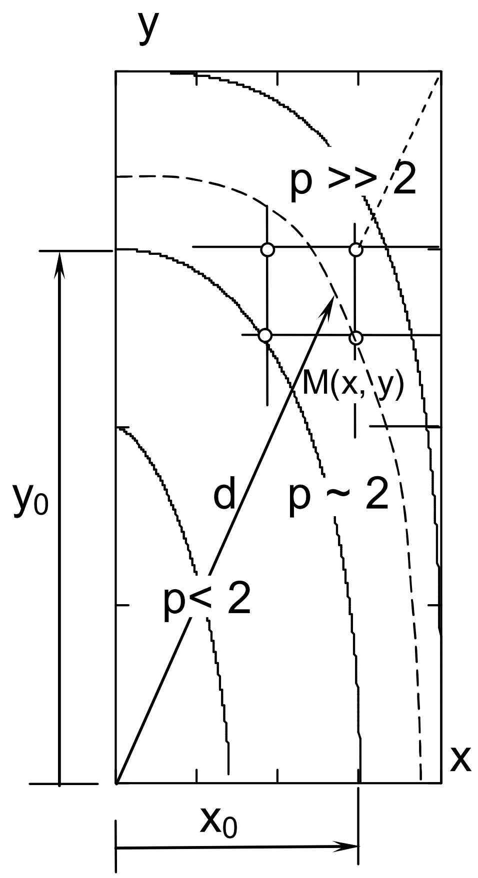
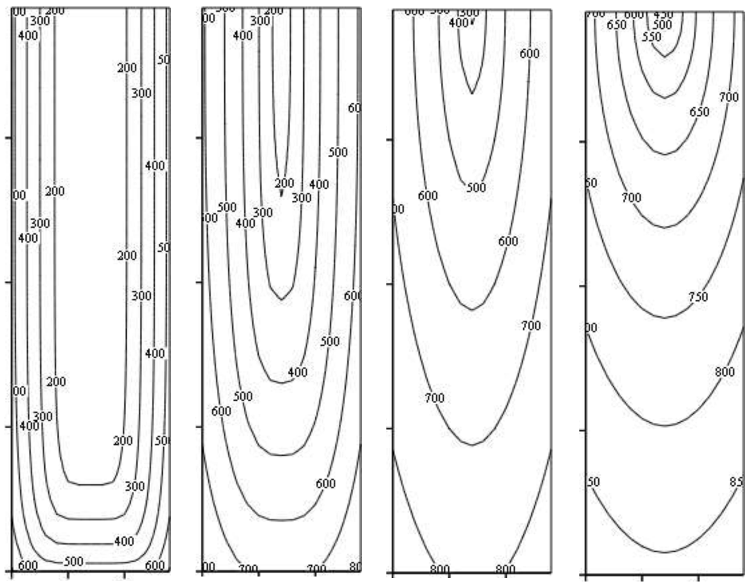



Fig. 7 – Scheme of approximation of isotherms in the section of a fragment of a wooden beam



15 хв 30 хв 45 хв 60 хв

Fig. 8 – Temperature Distributions in the Section of a Fragment of a Wooden Beam without Impregnation.

For prediction of the charred zone of the beam fragments, measurements of the charring thicknesses shown in Fig. 5. Comparing the measured thicknesses of the charred layer and found temperature distributions, critical charring temperatures were determined using the formula:

$$T_{\text{кр},i} = T_{0i} + (T_{gi} - T_{0i})\left[\frac{0{,}5a - d(i)}{0{,}5a}\right]^{Q_{gi}} \quad (2)$$

where $T_{0i}$, $T_{gi}$ – the temperature of the first and last points of the control section line in $i$ moment of time; $a$ – section width; $Q_{gi}$ – exponent of approximating parabola in $i$ moment of time; $d(i)$ – dependence of lateral thickness on exposure time.

Dependencies of the thickness of charring on time were obtained on the basis of regression analysis. The parameters of regression dependences are given in table 2.

The dependencies of rate of the side charring on time were obtained by differentiating the regression dependences described in Table 2. The parameters of the obtained dependences are given in Table. 3.

Using the data of Table 2 and the developed calculation method, charring zones for the tested fragments were set. The results are shown in Fig. 9.

Table 2 – Parameters of Regression Dependences of the Side Thickness of Carbonization on the Exposure Time

| Regression Coefficients $d(i) = b_1 + b_2 i + b_3 i^2 + b_4 i^3$ | $b_1$ | | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|---|
| Sample without impregnation | 0 | | 1,153 | -0,032 | $2{,}997 \cdot 10^{-4}$ |
| Sample with impregnation «Neomid 450-1» | 0 | | 0,585 | -0,013 | $1{,}111 \cdot 10^{-4}$ |
| Sample with impregnation «Senezh» | 0 | | 0,725 | -0,022 | $2{,}126 \cdot 10^{-4}$ |
| Sample with impregnation «Strazh-2» (BS13) | 0 | | 0,561 | -0,014 | $1{,}145 \cdot 10^{-4}$ |

Table 3 – Parameters of the Regression Dependences of Rate of Side Charring on the Exposure Time

| Regression Coefficients $\beta = \frac{d}{dt}d(i) = b_2 + 2b_3 i + 3b_4 i^2$ | $b_2$ | $2b_3$ | $3b_4$ |
|---|---|---|---|
| Sample without impregnation | 1,153 | -0,064 | $8,992\cdot10^{-4}$ |
| Sample with impregnation «Neomid 450-1» | 0,585 | -0,026 | $3,333\cdot10^{-4}$ |
| Sample with impregnation «Senezh» | 0,725 | -0,044 | $6,379\cdot10^{-4}$ |
| Sample with impregnation «Strazh-2» (BS13) | 0,561 | -0,028 | $3,436\cdot10^{-4}$ |

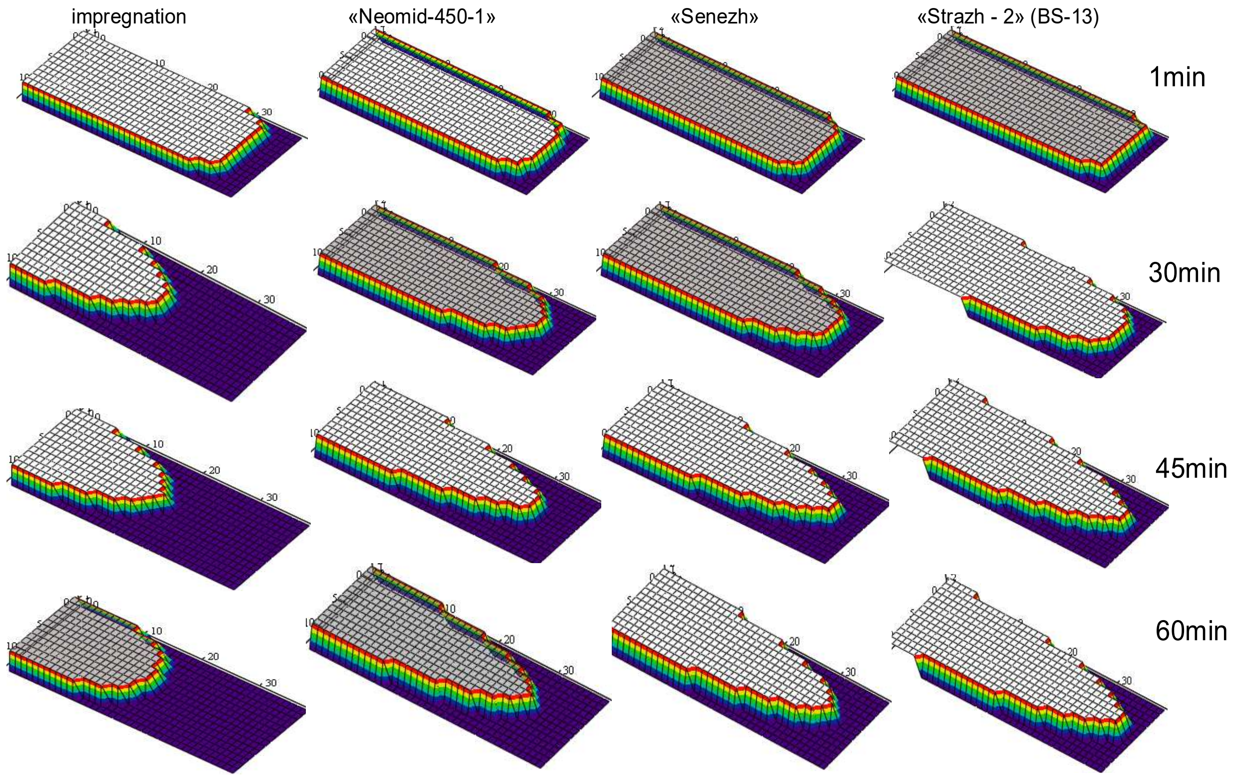



Fig. 9 – The Results of the Construction of the Zone of Charring of Samples-Fragments of Wooden Beams.

According to the received data fire-retardant impregnation «Strazh-2» (BS-13) is the most effective.

**Conclusions.**

1. Fire tests of samples of wooden beams fragments were conducted with and without the fire retardant impregnation. As a result the temperature of inner layers and the thicknesses of their charred layer were determined.

2. On the basis of the measurements made, regularities in the configuration of the charred zone have been established in the form of regression polynomial dependencies.

3. A method for interpolation of temperature distributions in the cross section of fragments subjected to tests based on specially selected functionals approximating isotherms was developed.

4. A technique for constructing a charred zone in the fragments under study is developed on the basis of its restriction by an isotherm corresponding to the critical temperature, which is determined on the basis of a comparison of the temperature distributions and the thickness of the charred layer is developed.

5. Using the developed technique, the configurations of charred zones for the studied fragments at intermediate instants of time were investigated, on the basis of which the most effective flame retardant composition was established, it turned out to be «Strazh-2» (BS-13).

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## ИССЛЕДОВАНИЕ ПОВЕДЕНИЯ ДЕРЕВЯННЫХ БАЛОК С ОГНЕБИОЗАЩИТОЙ ПРИ ПОЖАРЕ

Статья посвящена исследованию поведения деревянных балок с огнезащитой в условиях пожара. Представлены результаты расчетов геометрии зоны обугливания фрагментов деревянных балок с огнезащитой.

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## ДОСЛІДЖЕННЯ ПОВЕДІНКИ ДЕРЕВ'ЯНИХ БАЛОК З ВОГНЕБІОЗАХИСТОМ ПРИ ПОЖЕЖІ

Стаття присвячена дослідженням поведінки дерев'яних балок з вогнезахистом в умовах пожежі. Висвітлені результати розрахунку геометричної зони обвуглювання фрагментів дерев'яних балок з вогнезахистом.