Advances in Science and Technology
ISSN: 1662-0356, Vol. 170, pp 101-108
doi:10.4028/p-5tvB1d

Submitted: 2025-04-07
Accepted: 2025-04-19
Online: 2025-11-10

Predicting the Geometric Shape of the Cross-Section of Fire Retardant Wooden Beams under Conditions of Fire

POZDIEIEV Serhii[a], NOVHORODCHENKO Alina[b*], ZMAHA Mykola[c] and NOVHORODCHENKO Vitaly [d]

National University of Civil Defence of Ukraine, 8, Onoprienka str., Cherkassy, Ukraine, 18034

[a]pozdieiev_serhii@nuczu.edu.ua, [b]novhorodchenko_alina@nuczu.edu.ua, [c]zmaha_mykola@nuczu.edu.ua, [d]v.novgorodchenko@nuczu.edu.ua

Keywords: wooden beams, fire-retardant cladding, OSB plates, fire-retardant plywood.

Abstract. The article presents the results of the depth of charring of wooden beams with fire-retardant cladding with OSB plates and fire-retardant plywood during fire tests under standard temperature conditions. The aim of the work was to identify changes in the geometric parameters of the charring zone of a wooden beam as a basis for calculating the design data for the strength of these beams. To achieve the aim, the following tasks were set: to determine that the contours of the charred zone in the cross-sections of wooden beams with fire-retardant cladding can be described using isotherms with a critical temperature of charring initiation; to develop a method for mathematically describing the geometric shape of the charring zone in the cross-section of the beam by approximating the contour lines of this zone using Bézier lines.

1 Introduction

According to the European standards Eurocode5 [1] there are requirements for fire-resistant cladding, in particular, such as plasterboard and mineral wool boards. Asbestos-cement plates, gypsum concrete, perlite and asbestos-vermiculite plates are also often used as fire-resistant cladding. However, insufficient attention has been paid to such materials widely used in construction as OSB chipboard and plywood, which, due to their characteristics, can serve as fire-resistant cladding for wooden structures. These boards are easy to install and have sufficient thickness to prevent the flame from reaching wooden elements.

2 Main Part

Given the assumption that the contour of the charred zone can be described by an isotherm with the temperature is critical θ_{cr}=200 °C, it can be reproduced using a curve with parametric data. In research [2–4], a method based on the use of parametric Bézier curves, the configuration of which depends on the coordinates of five key points located on the isotherm, was developed. The disadvantage, because such methods have insufficient research accuracy of the isotherm approximation. To eliminate this disadvantage, it was proposed to change the position of these points by placing three points at the vertices of the rectangle defining the isotherm, and the last two between them on the sides of this rectangle. The layout of these key points is shown in Fig. 1 [5].

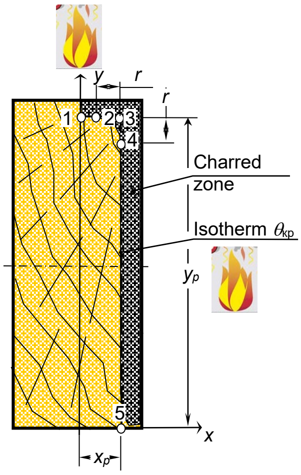


Fig. 1. Scheme of determining key points for determining the parametric function of the Bézier curve and approximating the critical charring temperature isotherm

By the coordinates of five points, the parametric function of the Bézier curve is written, which is given in implicit form using the expression [4, 5]:

$$\mathbf{P}(u) = \sum_{k=1}^{n} \mathbf{p}_k B_{k,n}(u),\ 0 \le u \le 1 \tag{1}$$

where n=5 – number of control points;
$B_{k,n}(u)$ – Bernstein polynomials for constructing Bézier lines;
p_k – vector of control point coordinates for constructing Bézier lines.

The Berstein polynomials have the following form:

$$B_{k,n}(u) = \frac{n!}{k!(n-k)!} u^k (1-u)^{n-k}, \tag{2}$$

Vector equation (1) in this case it represents is a system of two parametric equations:

$$x(u) = \sum_{k=1}^{n} x_k B_{k,n}(u), \quad y(u) = \sum_{k=1}^{n} y_k B_{k,n}(u). \tag{3}$$

These equations denote the coordinates of the vectors:

$$\mathbf{x} = \begin{cases} (0 \quad x_c - r \quad x_c \quad x_c \quad x_c)^{\mathrm{T}}; x_c > r \\ (0 \quad 0 \quad x_c \quad x_c \quad x_c)^{\mathrm{T}}; x_c \le r \end{cases}; \ \mathbf{y} = (y_c\ y_c\ y_c\ y_c - r\ 0)^{\mathrm{T}};\ 0 \le r \le y_c. \tag{4}$$

The components of the coordinate vectors (3) are determined according to the scheme shown in Fig. 1. In this case, for the parameterization of these curves, the assumption is made that the parameter r is dependent on the largest overall size in dimensionless relative notation as $r=f(y_c/h)$. This notation is effective when describing other cross-sections, including square ones.

Materials. For testing, samples-fragments of wooden beams were used. The beam consisted of glued pine timber measuring 70×50×350 mm, to which glued plywood measuring 350×350×16 mm was attached. Samples with fire-retardant cladding (with one and two layers) were tested. For fire protection, OSB chipboard and impregnated plywood were used.

a) b) c)

Fig 2. General view of experimental specimens with fire-retardant cladding made of OSB board and impregnated plywood: a) wooden beam without fire protection; b) wooden beam with 1st layer of fire-retardant cladding; c) wooden beam with 2nd layer of fire-retardant cladding

Experimental fire tests to study the fire protection effect of wooden beams with and without fire-retardant cladding were carried out in a thermal chamber for fire tests of fragment samples in compliance with the standard temperature regime for 15, 30, and 60 minutes of exposure in accordance with the experimental methods program. After the fire tests, measurements of the depth of charring of these wooden beam samples were performed. After which the duration of protection of wooden beam samples without fire protection and with fire protection cladding from direct fire exposure was assessed.

Tests. Experimental fire tests are expensive, so for a simpler study of wood charring, mathematical modeling was developed using Bézier line approximations of the contour of the charred zone of structures.

Based on the use of the above-mentioned mathematical apparatus and varying the parameter r, it is possible to construct Bézier line curves that approximate the corresponding isotherms, which, according to our assumption, correspond to the contour of the charring zone of the cross-sections of the studied wooden beams. After carrying out appropriate calculations, Bézier line contours were constructed that approximate the corresponding isotherms, which are presented in Fig. 3.

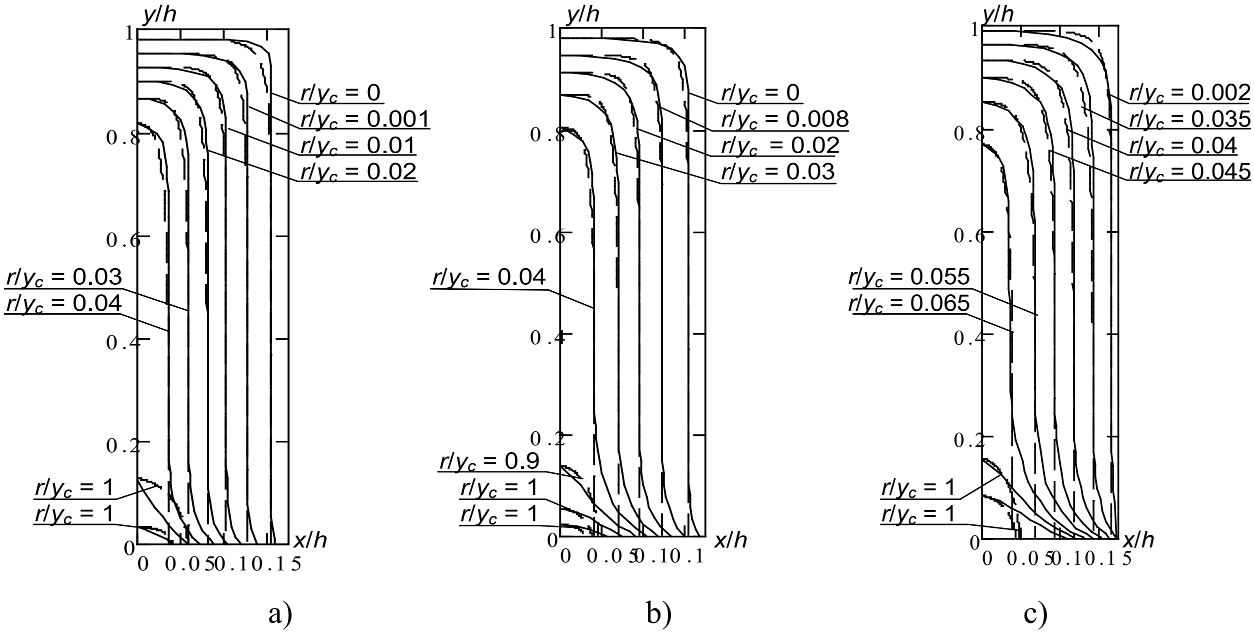


Fig 3. Bézier lines (dashed lines) that approximate isotherms (solid lines) with a critical temperature $\theta_{кр}$=200 °C, formed by varying the parameter r for wooden beams with cross section 70×200 mm: a) without fire protection; b) fire-retardant cladding w=12 mm; c) with fire-retardant cladding w=24 mm

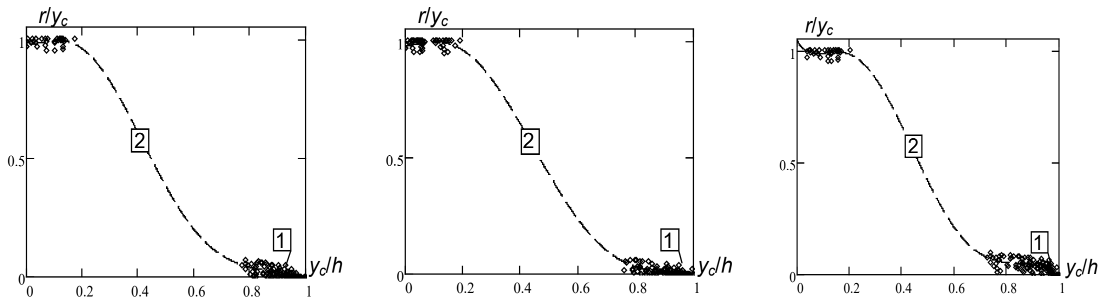
Approximation of isotherms with critical temperature by Bézier lines θ_{cr}=200 °C occurred due to variation of the parameter $r=f(y_c/h)$. In this case, the approximation of isotherms was constructed by minimizing mean square deviation by the coordinate descent method. The results shown in Fig. 6 show the high efficiency of using Bézier curves to approximate isotherms, since the constructed Bézier lines coincide with the corresponding isotherms.

Similar calculations were performed for other types of wooden beams with and without fire protection. The parameters of the considered beams are given in Table 1.

Table 1. Limits of variation of geometric parameters of the design area of cross-sections of wooden beams with fire protection based on chipboard

Cross-section width, b, [mm]	Cross section height, h, [mm]	Width of fire protection layer, w, [mm]		
19–106	200–1250	0	12	24

Using a similar algorithm to that proposed in Fig. 3, the approximation of isotherms with a critical temperature was performed. θ_{cr}=200 °C with the help of a similar algorithm to that proposed in Fig. 3, the approximation of isotherms with a critical temperature was performed. The parametr $r=f(y_c/h)$ for beams, the geometric parameters of which are presented in table 1. Fig. 4 shows the distribution of the parameter $r/y_c=f(y_c/h)$ for different geometric characteristics of wooden beams with different thicknesses of fireproof cladding. The parameter of the Bézier lines is given in dimensionless form so that it can be used for cross-sections of different geometric configurations [6, 7].



a) b) c)

Fig 4. Parameter distribution $r/y_c=f(y_c/h)$ based on the results of thermophysical calculation (1) and according to the constructed regression polynomial dependence of the 6th order (2) for different geometric characteristics of wooden beams with different thicknesses of fire-retardant cladding: a) without fire-retardant cladding; b) with fireproof cladding with a thickness w=12 mm; c) with fire-retardant cladding with thickness w=24 mm

Analysis of the given parameter distributions $r/y_c = f(y_c/h)$ for constructing Bézier lines proves that they are similar for different configurations of wooden beams and different thicknesses of fireproof cladding using OSB plates [8]. This means that it is possible to construct a single distribution of this parameter for any beam cross-section for a given thickness of fireproof cladding. Using regression analysis, regression polynomial dependencies of the 6th order were constructed, which reproduce these distributions. This mathematical modeling, which is performed by approximating isotherms with a critical temperature, is shown in detail. θ_{cr} = 200 °C by Bézier lines, with the help of varying the parameter $r = f(y_c/h)$ for wooden beams. To describe the distribution of the parameter $r/y_c = f(y_c/h)$ and constructing Bézier lines to reproduce the contour of the charring zone of cross-sections of wooden beams with different thicknesses of fireproof cladding, the following expression was used:

$$r/y_c=0.979+0.064p+3.6p^2-32.339p^3+59.242p^4-41.82p^5+10.273p^6 \quad (5)$$

where $p=y_c/h$ – dimensionless largest size of the rectangular quadrant into which a Bézier curve fits.

As a result of the application of the developed mathematical apparatus, it is possible to construct contours of the charred zone for different sizes of wooden beams without fire protection and with fire protection cladding of different thicknesses. Table 2 shows the parameters of wooden beams for which the contours of the charred zone were constructed according to the time corresponding to different fire resistance classes. Calculations were carried out to determine the accuracy of the results obtained using the proposed method of constructing contour lines of the charred zone of beams using Bézier lines [8, 9].

Table 2. Structural elements of cross-sections of wooden beams with fire protection made of OSB plates and plywood cladding

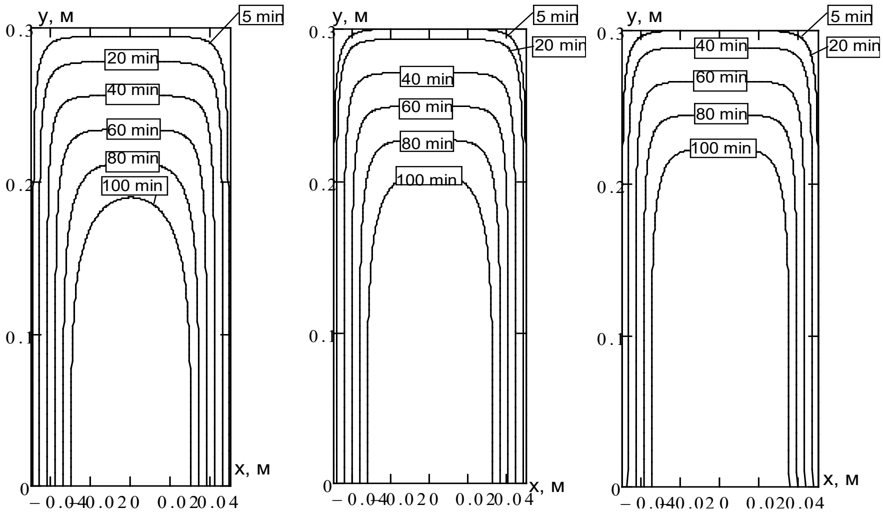
№	Cross-section width, *b*, [mm]	Section height, *h*, [mm]	Width of fire protection layer, *d*, [mm]		
With fireproof cladding made of OSB board					
1	100	300	0	12	24
With fire-retardant impregnated plywood cladding					
1	200	400	0	10	20

The time of charring onset is determined according to calculations in accordance with Eurocode 5, information on the time of charring onset is provided in Table 3.

Table 3. Time of charring initiation of wooden beam cross-sections with and without existing fireproof cladding

Of OSB plate			Of impregnated plywood		
Width of fire protection layer, *d*, [mm]	Initial time of lateral charring t_{0s}, [min]	Initial time of end charring t_{0e}, [min]	Width of fire protection layer, *d*, [mm]	Width of fire protection layer t_{0s}, [min]	Initial time of end charring t_{0e}, [min]
0	0	0	0	0	0
12	14	13	10	15	11
24	30	26	20	25	20

The contours of the resulting charring zone are shown Fig. 5 for a wooden beam of size 100×300 mm without fire protection and with fire-resistant cladding with OSB plates with a thickness of *w*=12÷24 mm.



a) b) c)

Fig. 5. Contour lines of charring zones in a cross-section of a wooden beam 100×300 mm approximated by a Bézier curve, with fire protection with OSB plates of various thicknesses: a) without fire protection; b) with fireproof cladding thickness *w*=12 mm; c) with fireproof cladding thickness *w*=24 mm.

The contours of the resulting charring zone are shown in Fig. 6 for a wooden beam of size 200×400 mm without fireproof cladding and with fireproof plywood with a thickness of *w*=10÷20 mm.

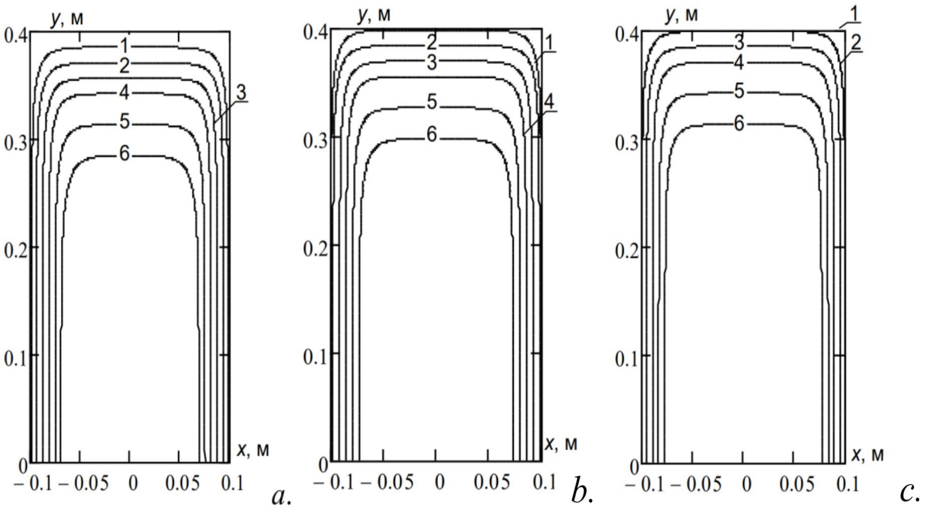


Fig. 6. Contour lines of charring zones in a cross-section of a wooden beam 200×400, approximated by a Bézier curve with fire protection made of impregnated plywood of different thicknesses: a) without fireproofing; b) with fireproofing of thickness w=10 mm; c) with fireproofing of thickness w=20 mm. At different points in time of exposure to the standard temperature regime of fire: 1 – 15 min; 2 – 30 min; 3 – 45 min; 4 – 60 min; 5 – 90 min; 6 – 120 min.

From Fig. 5–Fig. 6 it is seen that a mathematical model has been developed for constructing time-dependent charring zone at standard temperature of fire allows to effectively predict the geometric configuration of the charring zone of wooden beams without fire protection, with fire-retardant cladding based on OSB plates and impregnated plywood [10, 11].

After mathematical modeling, the average relative error of reproducing the contour of the charred zone of a wooden beam with and without fireproof cladding was determined, shown in Table 4.

Table 4. Error of the method for predicting the fire resistance of wooden beams with fire-retardant cladding

Type of wooden beam	Absolute deviation, [mm]	Relative deviation, [%]	Average relative deviation, [%]
Without fire protection	8	11.4	9.533
1-layer cladding	6	8.6	
2-layer cladding	6	8.6	

The data in Table 4 show that the accuracy of the proposed method for predicting the charred zone in cross-sections of wooden beams with fire-retardant cladding is sufficient, since the largest relative deviation of the results obtained using this method is no more than 11.4 %.

3 Conclusion

It was determined that the contours of the charred zone in the cross-sections of wooden beams with fireproof cladding can be described by isotherms using Bézier lines with a critical charring initiation temperature. A method has been developed for constructing contour lines of the charred zone of wooden beams with fireproof cladding with OSB plates and cladding with impregnated plywood at any time of exposure to the standard temperature regime of fires. This is the basis for calculating the strength of these beams. This method allows us to accurately determine the geometric characteristics of their reduced curved cross-sections due to charring.

Analysis of the constructed charring contour lines in cross-sections of wooden beams without fire protection and with fire-retardant cladding with OSB plates and impregnated plywood of different thicknesses shows the fire-retardant effect of this cladding. Analytical description of the contour lines of the charred zone allows obtaining geometric characteristics of the cross-sections of the remaining intact part of this beam cross-section, which can be used to calculate the strength of the corresponding wooden structures.

References

[1] EN 1995-1-2:2004. Eurocode 5: Design of timber structures. Part 1-2: General-Structural fire design.

[2] Feshchuk, Yu., Geometry of the charring zone of wooden columns with and without fireproof cladding under fire conditions. Scientific Bulletin: Civil Protection and Fire Safety. **1** (5) (2018) 4–12.

[3] Feshchuk, Yu., Pozdieiev, S., Zmaga, Ya., Novhorodchenko, A., Estimation of Credibility of the Results of Measuring Temperature within Specimens of Wood Columns Obtained During Fire Tests. International Journal of Engineering & Technology. **7** (4.3) (2018) 284–287.

[4] Pozdieiev, S., Zmaga, Ya., Novhorodchenko, A., Novhorodchenko, V., Research of temperature distributions in the cross-sections of wooden beams with fireproof facing. Emergency situations: prevention and elimination. **8** 1 (2024) 83–90.

[5] Pozdieiev, S., Zmaga, Ya., Novhorodchenko, A., Novhorodchenko, V., Shnal, T., Mathematical modeling for the description of the contour lines of the charred zone of wooden beams with fireproof facing. Emergency situations: prevention and elimination. **8** 2 (2024) 94–103.

[6] Medved, I., Rashkevich, N., Otrosh, Yu., Tomenko, V., Analysis of Experimental Studies of Titanium Alloy. Materials Science Forum. **1141** (2024) 35–42.

[7] Kovalov, A., Purdenko, R., Otrosh, Yu., Tomenko, V., Rashkevich, N., Shcholokov, E., Pidhornyy, M., Zolotova, N., Suprun, O., Assessment of fire resistance of fireproof reinforced concrete structures. Eastern-European Journal of Enterprise Technologies. **5/1** (119) (2022) 53–61.

[8] Nekora, V., Pozdieiev, S., Nekora, O., Fedchenko, S., Nizhnyk, V., Novhorodchenko, A., Shnal, T., Determining the behavior of a glass panel under heating conditions during a fire. Eastern-European Journal of Enterprise Technologies. **1** (1 (133) (2025) 52–61.

[9] Hearn D., Baker M. Computer graphics and the OpenGL standard. Williams, 1168 p.

[10] Pozdieiev, S., Zmaha, Y., Nekora, O., Zmaha, M., Nizhnyk, V., The Method of Interpolation of the Charred Zone in the Cross-Section of Wooden Beams with Fire-Resistant Cladding Based on Impregnated Plywood. In International Scientific Conference on Woods & Fire Safety. (2024) 36–44.

[11] Zmaha, M., Pozdieiev, S., Zmaha, Y., Nekora, O., Sidnei, S., Research of the behavioral of the wooden beams with fire protection lining under fire loading. IOP Conference Series: Materials Science and Engineering. **1021** (2020) 01203.