УДК 614.841.415
DOI: https://doi.org/10.31731/2524.2636.2021.5.2-119-127

Mykola Zmaha *(ORCID:0000-0003-3601-2929)*
Cherkasy Institute of Fire Safety named after Chornobyl Heroes
of National University of Civil Defense of Ukraine

ANALYSIS OF RESEARCH METHODS FOR DETERMINING THE FIRE OF WOODEN BEAMS WITH LINING OF FIRE PROTECTIVE PLYWOOD

Until now, scientists have considered only situations in which the ambient temperature has not changed over time. In the conditions of a fire, especially at its initial stage, such approximation is far from reality. Therefore, it is necessary to consider the process at non-stationary ambient temperature. This task is extremely difficult. Its solution was obtained by a number of Ukrainian scientists, and foreign studies have been developed for the case of heating wooden structures with an environment with a temperature that varies according to the standard temperature regime. In this article, we have analyzed all existing experimental and calculation methods for calculating the limit of fire resistance of wood-beam-lined wood. The analysis took into account the features of each method to achieve the most accurate estimates of possible research errors and the range of possible parameters of the specified indicators needed to determine the limit of fire resistance of wooden structures, taking into account the hygroscopicity of the material. In addition, the thermal and strength characteristics were calculated for the standard temperature curve, as well as for the real fire model. The developed algorithms are implemented in the software environment of the computer system MathCAD. For the decision the method of half division which was realized by algorithm which is offered at restrictions which are imposed on the received roots by a range of possible temperatures of heating of samples was used. According to the obtained results, the errors of the obtained researches in different methods for determining the limit of fire resistance for wooden beams with fire-retardant cladding with fire-retardant plywood were determined.

Key words: *fire resistance, research methods, experimental and calculation methods, thermal conductivity, heat capacity.*

Formulation of the problem. Emergencies, including fires, are a serious problem for many countries around the world, including Ukraine. Due to the great damage caused by fires, especially in the residential sector, as these buildings use wooden structures and wood-fiber materials. Ensuring the increase of fire resistance of such materials to this day remains a relevant study. The reason for the failure of wooden structures is the reduction of their working cross-section as a result of charring during combustion. In the process of fire exposure, when the working cross-section of the wooden structure is reduced, the stress from the normative load increases, when they reach the strength limit of the wood, the structures are destroyed.

Analysis of recent achievements and publications. According to a number of regulations, the design of wooden structures should provide protection against moisture, bio-damage, corrosion and fire ignition. The data on the study of fires abroad show that most foreign researchers divide the fire into three stages: ignition, advanced combustion and extinguishing, and argue that the fire resistance of building structures is influenced by the stages of advanced combustion and extinguishing [1-3]. The development and extinguishing of fires have been widely studied by foreign scientists, in particular Lie T.T, WhiteR.H., SilcockG.W.H., ForauterA., Bartelemi B., KruppaG., HarmathyT. believed that increasing the surface area of combustible materials and decreasing the area of the slots increases the duration of the combustion phase through ventilation [3]. The results of his research showed that a fire with a duration of the active combustion phase of less than 1 hour is extinguished with decreasing temperature at a rate of about 10 ° C / min, and a fire with a duration of active combustion phase of more than 1 hour - about 7 C / min. For more accurate modeling of fire, it is possible to use more complex physical models, which are implemented in complex computer programs [4]. Modern numerical methods are embedded in the algorithms of these programs.

At the moment, calculated and experimental studies of indoor temperature during the fire are known to researchers from the USA, France, Sweden, Great Britain, Germany, Poland, Ukraine and other countries [5 – 11]. All these studies considered non-stationary thermal conductivity in application to fire safety problems. Scientists were mainly interested in heating building structures or equipment in a fire. Of course, these tasks are directly related to fire prevention in construction and technological processes. But leaves the need to study experimental and computational methods for the presence of research errors.

To solve this problem it is necessary to consider the following issues:

- analysis of experimental and computational methods for studying the limit of fire resistance of wooden beams;
- processing of the obtained experimental data of fire tests of wooden beams lined with fire-retardant plywood;
- processing of the received calculated data of tests of wooden beams lined with fire-retardant plywood.

The results obtained. Two methods of transition from real fire regimes to a single "standard" fire regime have been developed [4, 5, 12]. One of the methods of transition from real to standard fires is the method of equality of areas under the curves "temperature-time". Another method of bringing real fires to standard is carried out by the method of achieving in any design critical temperatures that determine its fire resistance. Therefore, for the experimental determination of the limits of fire resistance of wooden beams, it is possible to use only the standard temperature regime. Because the test for fire resistance of new wooden beams is carried out according to the mode that corresponds to the temperature curve of the "standard" fire mode, both in our country and abroad.

Thus, due to the advantages, all over the world in determining the fire resistance, preference is given to the experimental method, but along with this, the experimental method has a number of significant disadvantages. The disadvantages of the experimental method primarily include the high cost and significant complexity of the study, as well as the lack of a sufficient test base in Ukraine. Because of this, calculation methods are increasingly being used to determine the fire resistance of wooden beams.

The essence of the calculation methods is to determine the time after which the beams lose their load-bearing capacity under the influence of high temperatures in a fire [13, 14]. The loss of load-bearing capacity of beams is influenced by many factors: heat load, temperature and duration of fire, load effect, mechanical and the rmophysical characteristics of materials, as well as heating conditions of structures [9, 10, 12].

The limit of fire resistance of beams occurs in connection with the reduction of the working cross-section of wood to the values at which the limit of fire resistance on the basis of "R" [4].

The method of calculating the limits of fire resistance of load-bearing building structures consists of two parts: thermal and static.

For given periods of time, the thermal field determines the temperature field in the cross section of the beam. Then perform a static calculation, the results of which build a curve to reduce the load-bearing capacity of the structure during heating. The time after which the bearing capacity of the structure will decrease to the level of the working load acting on it, is taken as the calculated limit of fire resistance of the beams.

The purpose of modeling the thermal effect on wooden beams of building structures is to determine the temperature distribution in the inner layers of the elements at any time during the development or extinction of the fire. This uses the Fourier thermal conductivity equation (1.). With the introduction of certain assumptions [4- 7, 12, 15, 16].

$$C_v(T)\frac{\partial T}{\partial t} = div\left(\lambda(T)\, grad(T)\right) \tag{1}$$

where C_V is the volumetric heat capacity, which depends on the temperature *T, J/(m3 • K)*; *λ (T)* is the coefficient of thermal conductivity, which depends on the temperature *T, W/(m • K).*

Then the Fourier equation will be written in linearized form:

$$\frac{\partial H}{\partial t} = \frac{1}{r}\cdot\frac{\partial}{\partial r}\left[r\cdot k\left(H(T)\right)\cdot\frac{\partial H}{\partial r}\right] \tag{2}$$

$$k\left(H(T)\right) = \lambda\left(H(T)\right) / Cv\left(H(T)\right) \tag{3}$$

Thermal conductivity problems for wooden structures in fire conditions have certain characteristics. To solve them, it is necessary to consider the thermal processes occurring in the room during a fire, the conditions of heat exchange on the surface of structures and thermophysical parameters in the inner layers of structures. All these factors are complex and lead to the fact that the analytical solution exists only for problems in a simplified formulation, which negatively affects the accuracy of the results.

Normative calculation methods [14, 17] recommend using a standard fire temperature curve to determine the fire resistance of wooden beams [13, 16].

The dynamics of fire development and extinguishing indicates the non-stationary heating of structures during a fire, and therefore the boundary conditions of the third kind are used to solve the Fourier equation [4, 16]:

$$-\lambda(T)\frac{\partial T}{\partial x}|_w=\alpha(T)(T_{ext}-T) \quad (4)$$

In already existing researches of search of the decision for definition of experimental researches, as a rule, are assumed: first of all the simple form of designs, stationary boundary conditions. The latter requirement means constancy at the body boundary (depending on the type of boundary conditions) or temperature, or heat flux, or temperature of the medium in contact with the heating medium. When solving the problem of the limit of fire resistance (heating time to critical temperature), the calculation procedure is as follows:

1) the average characteristic temperature is determined;

2) the average temperature determines the required values of physical parameters: heat capacity, material density, thermal conductivity and thermal conductivity; if necessary, the heat transfer coefficient is calculated.

Next, the calculation method is divided into two options: the first - for the case of a fixed surface temperature of the plate (1st row) or for the standard temperature; the second - for the case of a fixed ambient temperature (3rd kind).

First, consider the first option. According to the known critical value of temperature, based on the type of calculation equation for determining the temperature (1st row, stationary conditions) or (standard temperature regime), is the value of the error function argument; knowing the argument of the error function and the distance, calculate the required time: for stationary heating; at standard temperature.

In the second case (ie in the case of the problem of the 3rd kind and a fixed ambient temperature) in the calculations have to use approximation methods. The following technique is described on the example of the method of linear interpolation.

The first two points remain the same, and then: two values of time are set, based on which four values are calculated; according to the calculation equation or nomogram in the figure, the relative excess temperatures are determined, respectively.

Along with experimental and computational methods in Ukraine in the works of Krukovsky PG, Novak SV, Dovbysha AV, Pozdeeva SV, Tsvirkuna SV, Nekory OV, Novgorodchenko A.Yu. . [3, 10, 18, 19] became widespread calculation and experimental method. The proposed method has a number of advantages over experimental and computational. To formulate the main idea of the method of determining the fire resistance of wooden beams lined with fire-retardant plywood, the principle of dividing their sections into end regions, for which current stresses and strains can be determined, as well as the parameters of boundary conditions occurring in these elements. Using the criteria obtained by summing these characteristics over the entire discretized section, determine the bearing capacity of the element as a whole [13 – 15, 17, 19, 20].

The results of calculations of the limit of fire resistance were obtained using the calculation-experimental method in comparison with the results of the calculation and experimental methods in [16].

Thermal conductivity problems for wooden beams in fire conditions have certain characteristics. To solve them, it is necessary to consider the thermal processes occurring in the room during a fire, the conditions of heat exchange on the surface of structures and thermophysical parameters in the inner layers of structures. All these factors are complex and lead to the fact that the analytical solution exists only for problems in a simplified formulation, which negatively affects the accuracy of the results.

Heat transfer at the interface is modeled using the heat transfer coefficient, which takes into account the action of convection and infrared radiation.

Taking into account the specifics of the experimental implementation of the heating modes of the wooden beams of the samples, it is necessary to provide such a heating mode of the muffle furnace chamber that the middle of a certain sample is heated according to the mode calculated for it. Thus, again there is a need to address OST, but in a different setting. In this case, OST is formulated as a task of heat source control. The result of solving this problem is the restoration of GU III kind according to the known heating mode of the middle point of the sample, which coincides with the previously calculated mode. This problem is also mathematically incorrect [4, 15, 16]. The experiments carried out in Section 3.2 allow us to simplify the problem and solve it for GU I kind. Then the problem turns into a quasi-inverse problem of recalculation of GU of the I kind in GU of the III kind [12]. This problem is easily solved by determining the heat transfer coefficient at each step based on the results of experimental data.

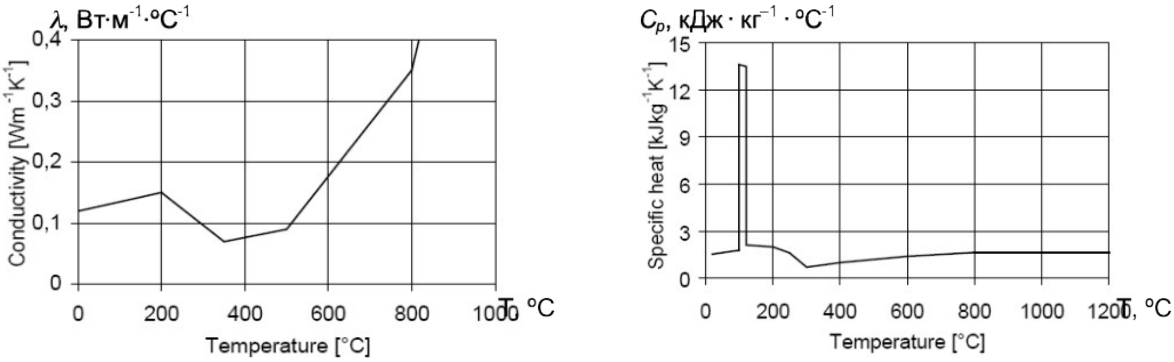
Table 1 – **Sources of errors in the process of conducting fire tests**

№	**Sources of error**	**Error,%**
1	Non-compliance of the test temperature with the standard temperature.	15 [4]
2	Thermocouple error due to heat exchange between the gaseous medium in the furnace chamber and their surface.	6 [4]
3	The mismatch of the geometry of the test sample geometry of the real element.	15 [4]
4	Non-compliance of the boundary conditions of loading and fastening of the sample with the boundary conditions of the real element.	10 [4]

The developed algorithm is implemented in the software environment of the computer system MathCAD 13 Pro.

Thermophysical characteristics of wood are accepted according to the recommendations [4].

The coefficient of thermal conductivity and the specific heat of wood are temperature dependences, the form of which is given in figure 1.



a) b)

Fig. 1 – Thermophysical characteristics of wood: thermal conductivity (a); specific heat (b).

The density of wood when it is heated is determined by the dependence of its reduction factor on the temperature shown in Fig. 2.

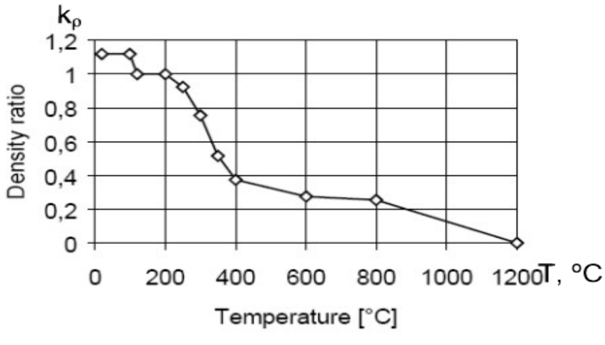


Fig. 2 – Temperature dependence of the coefficient of reduction of wood density on the temperature of its heating.

Equation (3) can be solved by the finite element method (FEM) [6]. For a nonlinear stationary problem (if the matrix of derivative temperatures is equal to zero) (T= 0), we can write a solvable system of nonlinear equations in matrix form:

$$[K(T)]\,\{T\} = \{Q(T)\}, \qquad (5)$$

where [K (T)] is the thermal conductivity matrix; {Q (T)} - vector of nodal heat fluxes due to external heat load. In a more general form, you can write:

$$\{P(T)\} = \{Q(T)\}, \tag{6}$$

where {P (T)} is the vector of internal nodal heat fluxes due to the heat flux density of the element.

This system of equations is solved by an iterative method known as the Newton-Rafson method. When using this method, decoupling is minimized:

$$\{\Phi\} \equiv \{Q(T)\} - \{P(T)\} \quad \rightarrow \{0\} \tag{7}$$

The Newton-Rafson method is based on the application of truncated Taylor series to the residual decoupling vector.

This achieves the linearization of the system of equations (6) in the form:

$$[K_T^{(i-1)}]\{\Delta T^{(i)}\} = \{Q^{(i)}\} - \{P^{(i-1)}\} . \tag{8}$$

Equilibrium iterations are performed (i = 1, 2, 3, ...), and new values of temperatures at each iteration are determined from the expression:

$$\{T^{(i)}\} = \{T^{(i-1)}\} + \{\Delta T^{(i)}\} \tag{9}$$

The iteration process continues until an acceptable convergence is reached.

In equation (8), written above, the matrix [KT] is called the tangent matrix or Jacobian. The coefficients of the tangent matrix are determined by the expression:

$$[K_T^{(i-1)}] \equiv \left(\frac{d\{\Phi\}}{d\{T\}} \right)_{i-1} \tag{10}$$

The decomposition of the vector {F} into a truncated Taylor series has the form:

$$\{\Phi^{(i)}\} \cong \{\Phi^{(i-1)}\} + \left(\frac{d\{\Phi\}}{d\{T\}} \right)_{i-1} \{\Delta T^{(i)}\} , \tag{11}$$

In nonlinear nonstationary analysis, the Newton-Rafson method is combined with the method of integration over time, which leads to the following system of solvable equations:

$$[\bar{K}^{(i-1)}]\{\Delta T^{(i)}\} = \{Q^{(i)}\} - \{\bar{P}^{(i-1)}\} \tag{12}$$

where is the equivalent thermal conductivity matrix; - equivalent vector of internal heat flux.

According to modern ideas, to consider the conditions of the boundary state, it is necessary to study the behavior of structures in general [7, 8, 17]. Thus, the loss of fire strength of statically indeterminate reinforced concrete structure occurs in several stages. At the first stage there is a loss of bearing capacity of a certain element, as a result the plastic hinge is formed. In the second stage, after the formation of plastic hinges in several elements, the statically indeterminate structure loses stability, or becomes geometrically variable and collapses. Thus it is necessary to consider separately the onset of the first limit state loss of strength of an individual element, and the second limit state - the loss of stability of the whole structure.

Recently, the calculation methods for determining the bearing capacity of individual elements of reinforced concrete structures in a fire are well developed and intensively developed. The main methods that are substantiated by numerous experimental studies are the method of VNDIPO [14], the method described by Eurocode [4] and the method of Fomin-Grigor'yan [9, 19].

According to the method developed in [14], the actual bearing capacity of heated reinforced concrete columns can be calculated by the formula:

$$N_{p,t} = \phi \left(F_я R^{н_{пр}} + F_a R_{a^н} \gamma_a \right) \tag{13}$$

where R_{an} - standard resistance of the working (longitudinal) reinforcement; γa - coefficient of reduction of normative resistance of armature; *Fa*- cross-sectional area of the working armature; φ - coefficient of longitudinal deflection; *Ran*- normative prismatic strength of concrete; Fя is the cross-sectional area bounded by an isotherm with a critical temperature Tcr.

This technique allows to determine the onset of the first limit state for the columns at the stage of fire development, but when cooling it can not be used.

The method presented in the standard [17] provides two ways to calculate the actual load-bearing capacity of heated reinforced concrete columns - isothermal and zonal.

The isothermal method is similar to the method [14] and concerns the overall reduction of the cross-sectional size taking into account the temperature of the damaged zone of the surface layer of concrete.

The zonal method involves the division of the cross section into several zones. This method, although more time consuming, is more accurate than the isothermal method, especially for columns. The method is suitable only for standard temperature. A fire-damaged cross-section is a reduced cross-section that does not include the thickness of the damaged area.

When the given cross section is found, and the strength and modulus of elasticity of concrete during fire is determined, the calculation of fire resistance is performed by the method of calculation at normal temperatures using the values of material reliability during fire (γM, fi).

Another method of calculating the fire resistance for compressed elements was developed in the works of Fomin and Grigoryan. They obtained a formula that determines the load-bearing capacity: central (14) centrifugal (15) and compressed wooden beams [16]:

$$N_{ut}=\sum_{i}^{n}\sum_{j}^{m}\sigma_{bij}\cdot A_{bij}+\sum_{i}^{k}\sum_{j}^{p}\sigma_{sij}\cdot A_{sij}\ ; \qquad (14)$$

$$N_{ut}=\phi\left(\sum_{i}^{n}\sum_{j}^{m}\sigma_{bij}\cdot A_{bij}+\sum_{i}^{k}\sum_{j}^{p}\sigma_{sij}\cdot A_{sij}\right), \qquad (15)$$

where σbij is the ultimate stresses of concrete elements to which the cross section is sampled, σsij is the ultimate stresses of the elements corresponding to the reinforcement, Abij is the cross-sectional area of the concrete elements, Asij is the cross-sectional area of the steel reinforcement element.

Consideration of the work of structures in a fire can be found in [4]. Almost all calculations are performed using the finite element method (FEM). This method has recently become widespread [10, 11] and is implemented in special multi-numerical software packages called FEM-systems.

Given the above, we can conclude that the modeling of boundary conditions in the elements of structures and structures in general in case of fire is sufficiently developed and takes into account the phenomenology of deformation of concrete at elevated temperatures. At the present stage, the priority is to consider modeling the limit state of the entire structure, taking into account the joint work of its elements. At modeling the problem of stability in nonlinear statement that causes application of the computer at calculation of durability of designs at a fire is considered. The method of finite elements is the most convenient for describing the work of structures and elements.

The moment in the cross section of the beam at the current time according to the applied approach is determined by the formula:

$$M_{d,fi}=\sum_{i}\sum_{j}\sigma_{i,j}A_{w}Y_{i,j}\ , \qquad (16)$$

where σi, j - stresses in the zone into which the section is divided;

Aw - area of the zone into which the section is divided;

Yi, j is the coordinate of the zone into which the section is divided, in the direction of the vertical axis relative to the center of gravity of the section with the rejected charred zone.

The center of gravity of the section after the rejection of the charred zone at the current time, determined by the formula:

$$Y_c = n^{-1} \sum_i \sum_j y_{i,j}, \tag{17}$$

where yi, j is the coordinate of the center of the current zone, into which the section is divided;
n is the number of zones into which the section is divided.

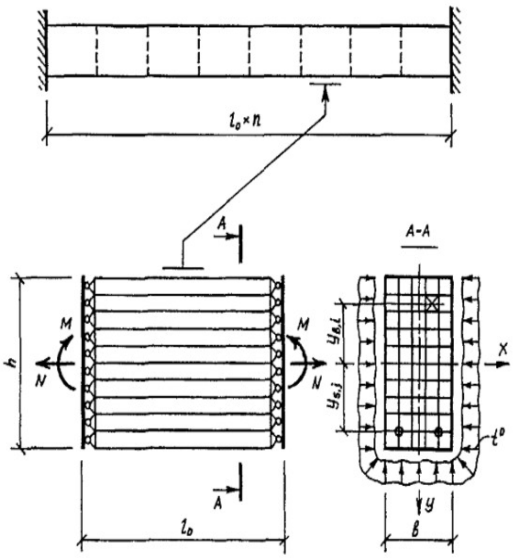


Fig. 2 – The scheme of work of section of a wooden beam in the conditions of fire for the decision of a strength problem by a method of increase of deformation.

To perform calculations according to formula (17), the calculation scheme presented in Fig. 3.

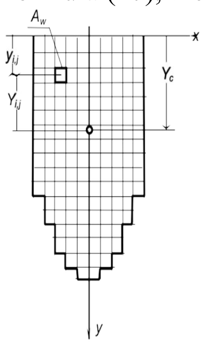


Fig. 3 – The scheme of determining the coordinates of the center of gravity of the cross section of the beam without a charred zone.

The moment acting in the dangerous section of the beam when exposed to fire is determined by the formula:

$$M_{Ed,fi} = 0.125 Q_{0d} l_z^2 \tag{18}$$

To solve the strength problem using the relationship between stresses and strains of a certain zone, into which the cross section of the beam is divided (see Fig. 4). In this case, stress-strain diagrams such as Prandtl diagrams are used.

To build such diagrams, it is necessary to know the dependence of the strength of wood and its modulus of elasticity on temperature.

A typical function for plotting the deformation of wood as a function of temperature is as follows:

$\sigma(\varepsilon) = -n_{wc}f_w$ at $\varepsilon \leq -n_{wc}f_w/(n_{Ec}E_w)$
$\sigma(\varepsilon) = -n_{Ec}E_w\varepsilon$ at $-n_{wc}f_w/(n_{Ec}E_w) < \varepsilon \leq 0$ (19)
$\sigma(\varepsilon) = n_{Et}E_w\varepsilon$ at $0 < \varepsilon \leq n_{wt}f_w/(n_{Et}E_w)$
$\sigma(\varepsilon) = n_{wt}f_w - 10^4 \cdot n_{wt}f_w(\varepsilon - n_{wt}f_w/(n_{Et}E_w))$ at $n_{wt}f_w/(n_{Et}E_w) \leq \varepsilon < n_{wt}f_w/(n_{Et}E_w) + 10^{-4}$

When determining the relative deformation of a certain layer by the curvature of the beam, the hypothesis of flat sections is used. According to this hypothesis, the relative deformation is determined by the formula:

$$\chi_{\max} = \frac{48\,D}{5\,L^2} = 24 \cdot 10^{-3}\,b^{-1} \tag{20}$$

Table 2 – Comparative data on the accuracy of methods for determining fire resistance wooden beams

	Calculation method	Computational and experimental methods	Natural fire tests
Fire resistance limit, min.	31	35	25
Deviation,%	23	12,7	1,1

Analysis of the obtained data showed that the calculation-experimental method is 10,.3% more accurate than the calculated one. That is, the calculation-experimental method is almost twice as accurate as the calculation.

Conclusion. Therefore, it can be concluded that with limited financial and material resources and taking into account new developments in the field of determining the fire resistance of wooden beams, preference should be given to the experimental method of calculation. However, it is necessary to establish the adequacy and correctness between large and small samples. Having conducted a number of studies of the fire effect on wooden beams with fire-retardant cladding with fire-retardant plywood at standard temperature and exposed to calculation methods based on certain temperature dependence of thermal conductivity, heat capacity, density.

This article presents the results of our study of various methods for determining the limit of fire resistance based on the calculation of fire resistance time. The analysis of the obtained data showed that the calculation-experimental method is 10.3% more accurate than the calculated one, and the natural tests are 21.9% more accurate than the calculated ones. That is, the calculation-experimental method is almost twice as accurate as the calculation.

REFERENCES

1. CFAST Technical Reference Manual, Natl. Inst. Stand. Technol. Spec. Pub. 1026, 126 pages (December 2005).

2. Analysis of existing mathematical models of heat transfer in cells firing furnace installations for fire resistance testing load-bearing walls / Nuyanzin OM Pozdeyev SV, Sydney S. [et al.] // Fire safety: theory and practice: zb. Science. wash. - Cherkasy: APB, 2015. - № 18. - P. 91 - 100.

3. Kuzmin D. Course: Introduction to Computational Fluid Dynamics / D.Kuzmin. – Institute of Applied Mathematics University of Dortmund.

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

5. Kramer G. Mathematical methods of statistics / G. Kramer.– M .: Mir Publishing House, 1975. - 648 p.

6. Finite element method in the mechanics of solids / [Sakharov AS, Kislookiy VM, Kirichevsky VV, etc.]; under ed. AS Sakharov, IA Altenbach. - К.: Вища школа; Leipzig: FEB Fachbuchferlag, 1982. - 480 p.

7. Perelmuter AV Calculation models of structures and the possibility of their analysis / AV Perelmuter, VI Slivker. - К .: Publishing House "Steel", 2002. - 600 p.

8. Pozdeev SV Experimental and computational method for constructing diagrams of concrete deformation at high temperatures: Sb. scientific Proceedings of the Donbass State Technical University / SV Pozdeev. - Donetsk: DonSTU. - 2011. - № 31. - P. 275–284.

9. Makarov EG Engineering calculations in Mathcad. Training course / Evgeny Georgievich Makarov. - St. Petersburg. : Peter, 2003. 448 p.

10. Porshnev SV Numerical methods based on Mathcad / SV Porshnev, IV Belenkova. - St. Petersburg. : BHV-Petersburg, 2005. - 464 p.

11. Manz H. Modelling smoke and fire in a hotel bedroom / H. Manz, W. Xu, M. Seymour. – Swiss Federal Laboratories for Materials Testing and Research, Section Applied Physics in Building, Duebendorf, Switzerland.

12. Thoeman H and Humphrey P E, Modelling of the physical processes relevant during hot pressing of wood-based composites: Part 1 – Heat and mass transfer. Holz Roh Werkst, 64(1), pp. 1-10, 2006.

13. Harmathy T Z, Properties of building materials – Section 1 Chapter 26, The SFPE Handbook of Fire Protection Engineering, NFPA, Boston, pp.388-391, 1988.

14. Strakhov VL Fire protection of building structures / Strakhov VL, Krutov AM, Davydkin NF; under ed. Yu. A. Koshmarova. - Moscow: Information and Publishing Center "TIMR", 2000. - 433 p.

15. British Standards Institution, BS 6399-1: 1996, Loading for buildings – Part 1: Code of practice for dead and imposed loads, BSI, London, 2002

16. Romanenkov IG Fire resistance of building structures from effective materials / IG Romanenkov, VN Siegern-Korn, 1984. - 240 c.

17. American Wood Council, National Design Specification For Wood Construction,American Forest & Paper Association, Washington, DC, 2001.

18. DSTU BN EN 1995-1-2: 2012 Eurocode 5 (IDT)

19. Gorbachenko Ya. V. Research of behavior of wooden beams with fire protection under the influence of fire / Gorbachenko Ya. V., Tishchenko OM // Fire safety: theory and practice: collection of scientific works of CHIPB named after Heroes of Chernobyl NUTSZU, −№ 17. - p.4-11. (Series KV № 17574-6424 PR).

20. Nekora OV Calculation-experimental method for determining the fire resistance of compressed elements of reinforced concrete building structures: dis. ... Ph.D. Sciences: 21.06.02 / Nekora Olga Valerievna. - Cherkasy, 2008. - 147 p.

Микола Змага,

Черкаський інститут пожежної безпеки імені Героїв Чорнобиля Національного університету цивільного захисту України

АНАЛІЗ МЕТОДІВ ДОСЛІДЖЕНЬ З ВИЗНАЧЕННЯ ВОГНЕСТІЙКОСТІ ДЕРЕВ'ЯНИХ БАЛКІВ З ВОГНЕЗАХИСНИМ ОБЛИЦЮВАННЯМ З ВОГНЕЗАХИСНОЮ ФАНЕРОЮ

Досі науковці розглядали тільки ситуації, у яких температура навколишнього середовища з часом не змінювалася. В умовах пожежі, особливо на початковій її стадії, таке наближення далеке від реальності. Тому необхідно розглядати процес за нестаціонарної температури середовища. Така задача надзвичайно складна. Її рішення удалося одержати рядом українських науковців так і опрацьовано закордонні дослідження як для випадку обігрівання дерев'яних конструкцій середовищем з температурою, що міняється за стандартним температурним режимом. Нами в даній статті було проаналізовано всі існуючі експериментальні та розрахункові методи розрахунку межі вогнестійкості облицьованих вогнезахисною фанерою дерев'яних балок. В аналіз бралися особливості кожного методу щодо досягнення ним найбільш точних оцінок можливих похибок досліджень та спектр можливих параметрів заданих показників необхідних для визначення межі вогнестійкості дерев'яних конструкцій, з урахуванням гігроскопічності матеріалу. Крім того було обраховано теплотехнічні та міцнісні характеристики для стандартної температурної кривої, а також для моделі реальної пожежі. Розроблені алгоритми реалізовані в програмній середі комп'ютерної системи MathCAD. Для рішення використовувався метод половинного ділення, який було реалізовано по алгоритму, який запропонований при обмеженнях, які накладені на отримувані корені діапазоном можливих температур нагріву зразків. За отриманими результатами визначено похибки отриманих досліджень в різних методиках при визначенні межі вогнестійкості для дерев'яних балок з вогнезахисним облицюванням вогнезахисною фанерою.

Ключові слова: *вогнестійкість, методи дослідження, експериментальні та розрахункові методи, коефіцієнт теплопровідності, теплоємність.*