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Research paper

Estimation of Credibility of the Results of Measuring Temperature within Specimens of Wood Columns Obtained During Fire Tests

Yurii Feshchuk[1]*, Serhii Pozdieiev[2], Yana Zmaga[2], Alina Novhorodchenko[2]

[1]The Ukrainian Civil Protection Research Institute,
[2]Cherkassy Institute of Fire Safety named after Chernobyl Heroes of the National University of Civil Protection of Ukraine
**Corresponding author E-mail: feshchuk2810@ukr.net*

Abstract

Analysis of the results of experimental studies of wood columns mode of behaviour both having fire retardant coating based on OSB slabs and without any coating under standard time – temperature curve fire conditions was realized. An assumption was made that thermocouple wires could be positioned along isotherm at a distance of at least 50 mm from measuring thermojunctions (otherwise disturbance of the structure of isotherm itself possible). Due to specific features of thermocouples positioning within the specimen, this assumption calls in question of credibility of the obtained results of temperature indices measuring. Bearing this in mind we prepared calculation scheme of the specimen of wood column under study. We have composed finite elements scheme of specimen under study for heat engineering calculations. We simulated temperature distributions within the wood column specimen section at various moments of time and substantiated the obtained results. It was revealed in the course of the study conducted that the obtained results were adequate for relative error was as small as ca. 4.5% and Fisher test did not exceed appropriate tabulated value. Thus, assumption made does not affect in general credibility of the results of measuring thermal values within the layers of specimens obtained during fire tests.

Keywords: *fire resistance; isotherm; results credibility; temperature; wooden column*

1. Introduction

Bearing wooden constructions stand for significant potion in building engineering. Various statistical analyses confirm that tendency to use wood in building constructions will remain. But wood is a combustible material and thus represents fire hazard. Ensuring required fire resistance class of wood constructions is a significant task for designers. Various impregnating agents and slab materials including OSB are used as fire retardant materials. Due to this necessity arises in the development of appropriate calculation methods of designing similar constructions. But proper experimental results are necessary for such methods, the former are obtained by conducting full-fledged fire tests. In practice such tests cannot always be realized according to some generally accepted rules. This can call in question credibility of the results derived when performing tests.

2. Literary Review

A number of papers are dedicated to the problems related to fire resistance of building structures [1, 2] and fire hazards [3 – 6]. Studies [7, 8] show that under fire conditions the worst consequences occur as result of loss of bearing performance by columns or bars. This accentuates actuality of the sphere of the studies chosen. Behaviour of bearing wood construction elements under fire conditions was studied in detail in papers [9, 10]. In particular, some methods for the determination of fire resistance rating of wood bars and slabs were developed based on conduction of appropriate experimental studies. Studying wood has been conducted by the following foreign scientists: White, Frangi et al. [11]. But up to now specific features of wood columns having been subjected to fire retardant treatment were not considered to the full, and no method of full value exists for the determination of fire resistance rating of wood columns with fire retardant coating based on OSB slabs, in particular, the one to use tabulated values. Taking this into consideration, necessity in complementing existing normative base with some method of full value based on using tabulated values arises.

3. Purpose, tasks and Results

Purpose of this paper lies in the check-up of credibility of the results obtained when measuring temperature within specimens of wood columns when performing full-scale fire tests in a special furnace. It was necessary to solve the following problems in order to reach the purpose set:
– to perform working through of the experimental data [12] obtained while performing fire tests in a special furnace under standard time-temperature curve according to method [13];
– to prepare calculation scheme of the wood column specimen under study;
– to compose finite element scheme of the wood column specimen under study for heat engineering calculation;
– to simulate temperature distributions within the section of the wood column specimen at various moments of time and to substantiate the results obtained.

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We worked through experimental data [12] obtained during fire tests of wood column specimens in a special furnace under standard time – temperature curve (Figure 1) in accordance with method [13] in order to solve the problems set.

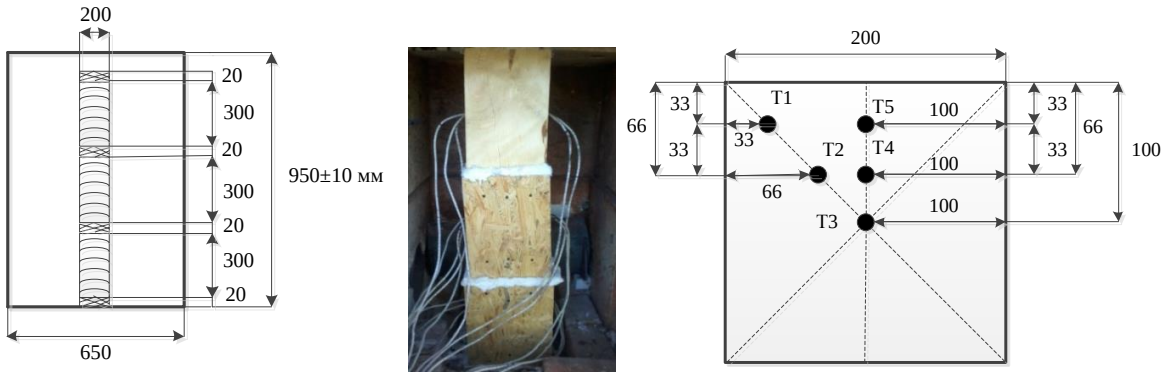


Fig. 1: a) Scheme of positioning test specimens in a special furnace, b) photo of positioning test specimens in a special furnace, c) layout of thermocouples (T1 – T5) within the specimen's section.

Measuring temperature within the wood column specimens was realized using five chromel-alumel thermocouples (CAT) positioned as specified by the layout and photo (Figure 1). Such the positioning of the thermocouples is explained by impossibility of drilling bores alongside the wood column specimen. Whereas, an assumption exists that thermocouple wires can be positioned alongside the isotherm at a distance of at least 50 mm from measuring thermojunctions (otherwise disturbance of the structure of isotherm itself possible). Such an assumption calls in question credibility of the results derived when measuring temperature values within the layers of wood column when performing fire tests. Temperature trends within the layers of section of wood column both having been subjected to fire retardant treatment in the form of single or two 10 mm thick layers of OSB slabs and without them vs. duration of fire influence are shown as graphs (Figure 2).

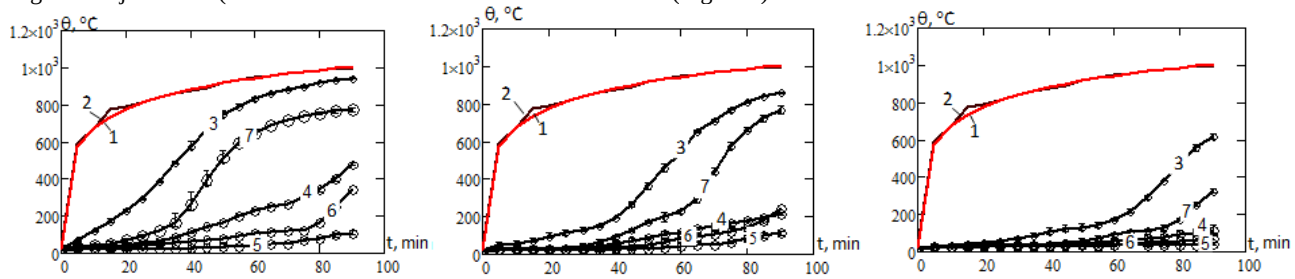


Fig. 2: Graphs of 90 minutes duration tests: a) specimens without any protection, b) specimens protected with single layer of OSB slabs, c) specimens protected with two layers of OSB slabs; 1 – standard time – temperature curve, 2 – average temperature in the furnace, 3 – average value for thermocouple No. 1, 4 – average value for thermocouple No. 2, 5 – average value for thermocouple No. 3, 6 – average value for thermocouple No. 4, 7 – average value for thermocouple No. 5; θ - temperature, t – time.

Because of this necessity arises in performing heat engineering calculation for the wood column specimen.
According to preset regulations and assumptions heat conductivity equation shall be put down as follows:

$$c_p(\theta)\rho(\theta)\frac{\partial\theta}{\partial t} - \nabla(\lambda(\theta)\nabla\theta) = 0\,, \qquad (1)$$

where $\rho(\theta)$ stands for density,
$c_p(\theta)$ stands for specific heat content,
$\lambda(\theta)$ stands for thermal conductivity coefficient depending on temperature.

Conventionally III type boundary conditions are used when setting boundary-value problem:

$$\lambda(\theta)\frac{\partial\theta}{\partial r} + \alpha(\theta_P - \theta_W) = 0\,, \qquad (2)$$

where θ_P stands for temperature in the space of the fire room,
θ_W stands for temperature of the surface of the element,
α stands for actual heat exchange coefficient.

According to [13] the specimen shall be installed in the furnace together with proper measuring equipment, including the one inside it (Figure 1). Figure 3 shows universal layout of construction elements of specimens being fragments of wood columns for fire tests.

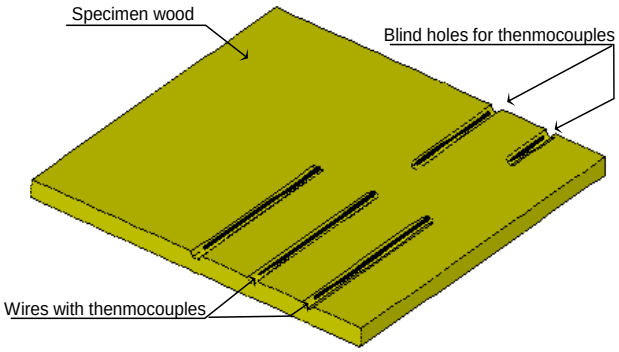


Fig. 3: Layout of construction elements positioning within the test specimen.

When performing calculations we prepared calculation scheme for the solution of heat engineering problem shown on Figure 4.

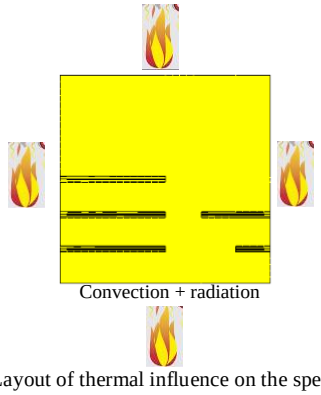


Fig. 4: Layout of thermal influence on the specimen.

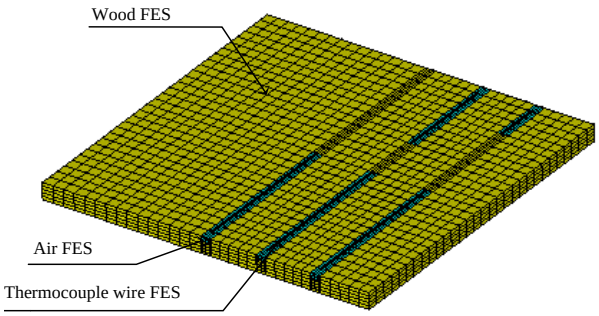


Fig. 5: Finite element scheme of the test specimen when solving heat engineering problem.

We chose hexahedral Lagrangian type finite element [14] in order to solve thermal conductivity problem as well as problem according to mode of deformation by finite elements method.
Finite element scheme of wood test specimen in accordance with Figures 3 and 4 is shown on Figure 5.

This Figure shows types of materials of which it was fabricated in various colours.
Temperature distributions derived as result of solving heat engineering problem [15] are shown on Figure 6.

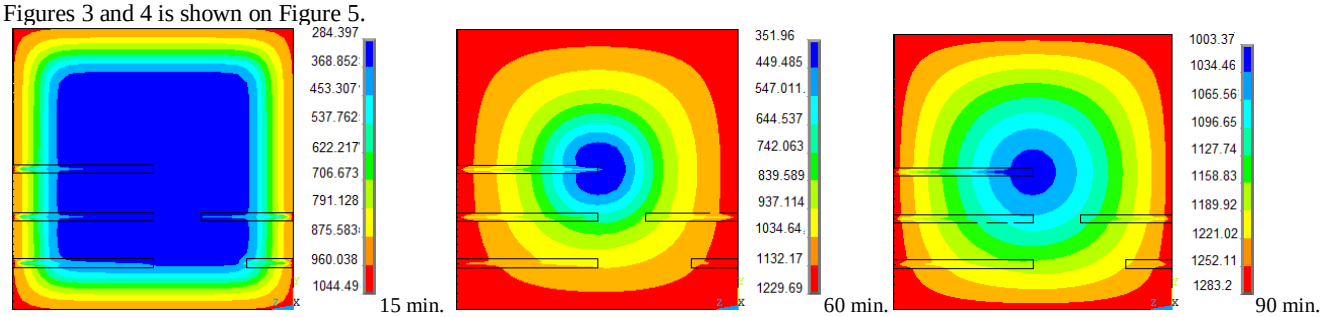


Fig. 6: Results of the heat engineering problem solution: temperature distributions in a portion of the section of wood column specimen at various moments of time.

You can see from distributions on Figure 6 that availability of blind holes distorts lines of isotherms to some extent; nevertheless, such a distortion remains local one. When analyzing temperature distributions through cross-section of the specimens one can see that the isotherms distortion does not affect general picture and temperature distributions are symmetrical in general and reflect real image of the temperature distributions within the present specimen. Value of the temperature reached due to warming-up exceeds to some extent those ones derived when conducting experiment; however, such the exceeding is insignificant and is due to different structure and properties of the specimens subjected to the tests relative to averaged properties of wood used as reference one for heat engineering properties recommended in DSTU B. N. EN 1995-1-2:2012 Eurocode5 (IDT).
In order to realize more detailed analysis we studied modes of heating of test specimens with appropriate construction elements derived in the course of the tests as well as warming-up modes in the same reference points with no construction elements. Results of calculation of these temperature modes are shown on Figure 7.

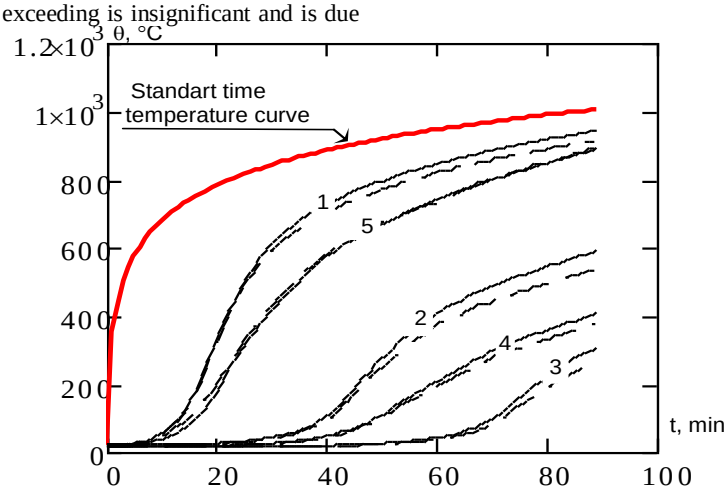


Fig. 7: Graphs of temperature modes of warming-up the specimen having not been subjected to any fire retardant treatment calculated for a specimen with appropriate construction elements (solid line) and without them (dotted line): 1 – at thermocouple No. 1 reference point, 2 – at thermocouple No. 2 reference point, 3 – at thermocouple No. 3 reference point, 4 – at thermocouple No. 4 reference point, 5 – at thermocouple No. 5 reference point; θ - temperature, t – time.

Graphs on Figure 7 show that the differences between temperature values within the specimen with real constructional specific features and values of temperature within the ones with no similar specific features differ from each other by not more than 30 °C at maximum deviation.

In order to study adequacy of the results derived when measuring temperature in the course of experiment in more detail we analyzed proper statistical criteria. We used values of relative and root-mean-square deviations as well as Fisher test as such criteria.

Calculation of Fisher test was performed by the following equation:

$$F_C = \frac{S_{ad}^2}{S_{\text{cp}}^2} \le F(\nu_1, \nu_2, \alpha), \quad (3)$$

where S_{ad}^2 stands for dispersion of adequacy,

ν_1 stands for d stands for number of degrees of freedom for numerator,

ν_2 stands for $n - 1$ stands for number of degrees of freedom for denominator,

S_{cp}^2 stands for dispersion of reproducibility of experimental data,

$\alpha = 0.05$ stands for significance level.

Here n is the number of measurements during single experiment, d is the number of experiments.

Dispersion of adequacy is determined by the following equation:

$$S_{ad}^2 = \frac{d}{n-1} \sum_{k=1}^{n} \left[\frac{\bar{y}_k^e - y_k}{\min\left(\left| \bar{y}_k^e \right|, \left| y_k \right| \right)} \right]^2, \quad (4)$$

where $\bar{y}_k^e$ stands for average value of the measured property for the sampling,

y_k = current calculated value.

Dispersion of reproducibility of experimental data is determined by the following equation:

$$S_{\text{cp}}^2 = \frac{1}{d(n-1)} \sum_{k=1}^{n} \sum_{j=1}^{d} \left[\frac{y_{kj}^e - \bar{y}_k^e - \delta_m}{\bar{y}_k^e} \right]^2, \quad (5)$$

where $\bar{y}_{kj}^e$ current experimental value,

δ_m = permissible measurement error.

Results of the analysis of statistical criteria performed are shown in Table 1.

Table 1: Statistical parameters derived when studying adequacy of the results of calculation of temperature within the specimens

Number of degrees of freedom of numerator, ν_1	Number of degrees of freedom of denominator, ν_2	Number of experiments, d	Number of measurements in an experiment, n	Dispersion of reproducibility, S_{cp}	Dispersion of adequacy, S_{ad}	Calculated value of F-test	Tabulated value of F-test	Average relative deviation, %	Root-mean-square value, °C
5	90	5	450	0.17	0.09	0.55	1.01	4.5	11.9

Data submitted in Table 1 show that the results having been obtained are adequate for relative error is as small as 4.5 % and Fisher test does not exceed appropriate tabulated value.

4. Conclusion

It was established upon conducting analysis of adequacy of the results of temperature measuring within the specimens of this construction that the results obtained were adequate for relative error was as small as ca. 4.5 % and Fisher test did not exceed appropriate tabulated value. Thus, assumption made that thermocouple wires could be positioned alongside isotherm at a distance of at least 50 mm from measuring thermojunctions (otherwise disturbance of the structure of isotherm itself possible) does not affect in general credibility of the results of measuring thermal values within the layers of specimens of wood column obtained when conducting fire tests.

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