VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Mečislavas Griškevičius

HIGH TEMPERATURE EFFECT ON RESISTANCE OF TIMBER STRUCTURES

SUMMARY OF DOCTORAL DISSERTATION

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Introduction

Topicality of the problem. Nowadays timber is often used for various structures such as roof load bearing ones, walls, beams, columns etc. In case of fire, charring of timber elements (parts of the structures) is the most visible feature in such buildings. It is very important for designers, builders, firemen and fire investigators to relate this process with particular effects of a fire, e.g. the duration or temperature of the fire, in order to assess influence of high temperature on the strength of different kinds of timber. During the fire, timber undergoes many physical-chemical processes which have a huge influence on the fire-resistance of the whole structure. In order to carry out these researches and analyse the results one needs the knowledge of different disciplines. Many respectable specialists think that too little attention is paid to the rate of charring and its evaluation particularly when the effect of heat does not correspond to the standard fire curve. Formerly and presently used versions of standard documents (prEN 1995-1-2:2000; LST EN 1995-1-2:2005) present generalized timber charring rates, discuss their effect on the mechanical resistance of timber elements in case of a standard fire. The theoretical and computer-based methods for calculation of fire-resistance are also presented in these documents, however, temperature effect on elements of small cross-section when the heat effect irregularly spreads over the outline of the cross-section and when it does not correspond to the standard fire curve is not considered. Total decrease of timber elements' cross-section due to the charring and wastage and the decrease in timber strength when the temperature is rising are also not taken into account.

The behaviour of a structure in fire is most accurately defined by the distribution of temperature in the cross-section. During a fire, building structural materials heat up and most of them change their thermal properties due to the rise of temperature. This change in thermal properties have already been partly investigated, however, the differences in timber properties depend not only on their kind but on the climatic conditions of the tree growth as well. Therefore it is important to know not only the generalized timber characteristics given in standard documents but also the properties under normal conditions of the wood which grew up in Lithuania and its changes because of fire.

Identification of the factors having effect on the distribution of temperature in timber structures and their elements during the fire is essential for getting a reliable final result of load bearing capacity of timber elements.

Subject of research. The object of the research is the identification of changes in the properties of broadleaf and conifer wood growing in Lithuania affected by rising temperature, experimental analysis of the behaviour of slender timber elements under axial compression affected by the heat and the comparison of these results with the calculated results of timber elements behaviour affected by the heat.

Aim and tasks of the research. The aim of the present work is to define the thermal relationships within the changes of timber properties and the effect of fire temperature on the load bearing capacity of slender timber elements under axial compression. On the ground of obtained results, to verify whether the calculated values of fire-resistance of timber elements under compression, in case when they are exposed to fire not due to the standard its curve, but due to the other relationships between heat changes and its duration, conform with design assumptions. The aim is also to find down the methods in applying which one could evaluate not only an actual effect of heat on the structure but also consider temperature distribution in element's cross-section as well. To achieve this goal, the following tasks were performed:

1. Undertake literature review. Survey the following issues: the resistance of load bearing structures related with the classifications of their fire-resistance, the peculiarities of behaviour of timber exposed to higher temperatures and the analysis of load bearing capacity of timber structures in case of fire.
2. Obtain the experimental data concerning high temperature effect on the properties of natural wood – pine and oak – growing in Lithuania were.
3. Make the comparison of relationships between the temperature and timber properties and analyse their similarities and differences on the ground of the results of this foreseen research, the findings of foreign researchers and the material given in databases and reference books.
4. Formulate the methods of the experiment were and, after constructing peculiar furnace with the bending, tension and compression equipment, carry out the investigation on decrease of timber strength affected by the heat with the evaluation of the density, humidity and heat flow density of the wood.
5. Formulate the methods of the experiment and construct the furnace and loading equipment in order to carry out a research on the behaviour of slender timber elements under axial compression exposed to fire.
6. Obtain the experimental results and compare its with the calculated results of fire resistance of timber elements.
7. According to the more realistic heat effect under research fine down the design methodology of compressed timber elements given in LST EN 1995 1-2 in order to evaluate fire resistance of slender timber elements under compression more accurately.

Methodology of research. On the ground of standards being in force in Europe and developed substandard testing methods the investigation of changes in timber properties and the behaviuor of slender timber elements under axial compression exposed to fire was performed. The methodology of estimation of load bearing capacity of the slender timber elements under axial compression was specified applying standard methods of timber constructions design and mathematical analysis.

Scientific novelty

1. Up-to-date data of the change in properties of timber made from pine and oak trees growing in Lithuania because of the effect of high temperature were obtained additionally. Having these data, one may compare similarities and differences between the properties of timber from trees growing in various areas of the world and Lithuania in terms of high temperature effect on them.
2. The peculiar methods of the experiment were prepared, the equipment for investigation of the change of timber properties affected by high temperature and for a more realistic study of slender timber elements under axial compression exposed to fire was constructed.
3. The peculiarities of the behaviour of slender timber elements under axial compression exposed to fire and their influence on the design principles were specified.
4. Suggestions for the analysis of the behaviour of timber elements in fire were provided in applying advanced methods according to the provisions of EC5 1-2.

Practical value. The novel result for the science of civil engineering was received during the preparation of the dissertation: new relationships between temperature and decreasing strength of timber from pine and oak trees growing in Lithuania which were compared with relationships given in EC5 1-2. The recommendations how to estimate quite precisely the reserve of load bearing capacity of fire-affected slender timber elements according to the dimensions of residual cross-section, what is very important for starting the strengthening or cleaning of fire-affected timberstructures, are given.

Defended propositions

1. Suggested relationships between the higher temperature and strength changes of conifer and broadleaf timber together with methodology of their estimation.
2. The methodology of the investigation of behaviour of timber elements under axial compression exposed to fire.
3. The results of the analysis of calculated and experiment-based values of the behaviour of exposed to fire the timber elements under axial compression.

The scope of the scientific work. The scientific work consists of the general characteristic of the dissertation, 5 main chapters, conclusions, list of references, and list of author’s publications. The total scope of the dissertation: 132 pages without annexes, 39 numbered formulas, 62 pictures and 10 tables.

1. Properties of timber and its behaviour in fire situation

This chapter is an overview of timber burning process, the change of timber properties at high temperatures. During a fire timber elements, distinctly from others, undergo double effect: the first one, which is typical only for timber elements, is charring and the other one – decreasing the strength of the material due to the temperature. The latter is also common for other building materials; however the extent to which timber elements are affected by temperature is not only related with the intensity of temperature and the duration of its exposition but it is also highly connected to the dimensions of timber element's cross-section. The bigger cross-section of a timber element, the smaller is an effect of temperature on timber in deeper layers.

An influential factor for the behaviour of timber elements in fire is the application of fire protection products. Considering the materials and means for fire protection, one may increase the fire-resistance of timber members; however it is impossible to protect timber structures 100% by impregnating or lubricating with fire protection substances. The majority of impregnating substances have an impact on the strength of timber.

As the reference review revealed, there have been practically any investigations done on the change of timber from the decidouos and coniferous trees growing in Lithuania strength properties at elevated temperatures. The fire effect on compressed elements of a small cross-section has also been a very little analysed.

2. Research method of timber strength at elevated temperatures

The aim of the research is to define the effect of elevated temperatures on the change of bending, tension and compression strength for pine and oak timber used underconstruction.

To achieve this goal, three different furnaces were constructed. One of them was used for the testing of timber under statical bending, the second was used for the testing of timber under compression along and across its fibres and the third was used for the testing of timber under tension along its fibres.

Hulls of the furnaces were made of 50 mm and 42 mm diameter metal tubes; for heating the specimens the device GHG 650 LCE with the ability to control the temperature was applied. The equipment for a statical testing with furnaces was designed and installed in the standard universal testing installation (testing machine) FPZ100 which allows tension and compression of the specimens. Devices for load and temperature measuring were connected to the portable computer recording system.

The temperature 20°C was chosen as a basic one for the experiments; it is often called as room temperature or as normal temperature. The highest temperature chosen was 230°C which is very close to the average temperature of charring.

The essential temperature for the research is 100°C because evaporation of the water in timber starts at this point. Rapid release of volatile substances in timber starts at 200°C, due to this fact this temperature was also chosen for the research. The temperatures of 50°C and 150°C were chosen as intermediate stages to highlight the tendencies of change in timber strength.

The statical experiments of the changes in timber strength were carried out at temperatures 20°C, 50°C, 100°C, 150°C, 200°C and 230°C.

To measure the changes in strength the specimens from timber without any defects or imperfections such as split were prepared. The specimens were taken from seasonal pine and oak tree sapwoods within the period of 4 years. The specimens are shown in Fig. 1.

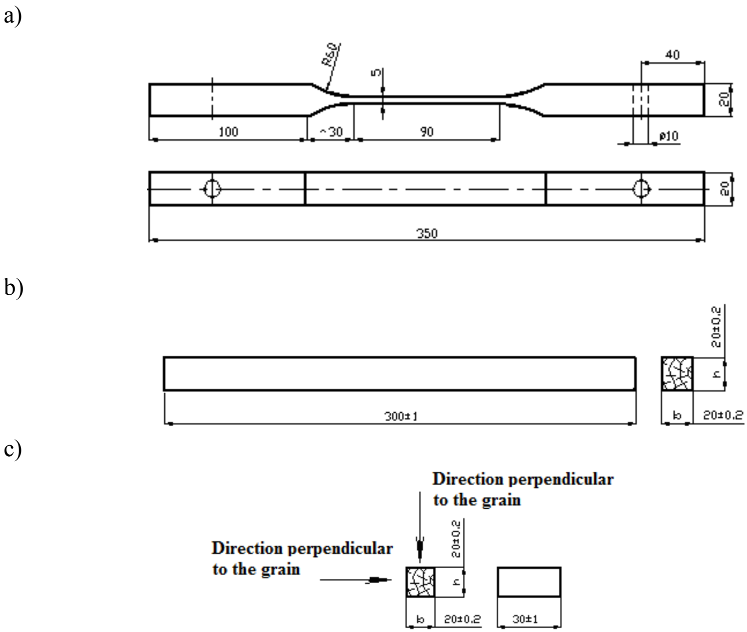

Fig. 1. Dimensions of specimens designed for the research of strength properties
a) Specimen subjected to tension; b) Specimen subjected to bending;
c) Specimen subjected to compression

The equipment for static experiments was constructed in such a way which allowed measuring the temperature of the specimen during the period of loading and heating by two thermo-couples adjusted outside the cross-section of the specimen.

3. Research method of slender timber elements under axial compression exposed to fire

The research programme on the behaviour of slender timber elements under axial compression exposed to fire was prepared according to the established testing principles and corresponding provisions of standards (LST EN 1363-1:2000; LST L ENV 1363-3:2000) for the furnace, loading equipment, thermo-couples, the devices for measuring load and displacements and also regulating character of temperature increasing considering desirable fire effect.

A special heating chamber was constructed for the research of the behaviour of compression timber elements exposed to fire (Fig. 2.). The heat in the chamber is produced by a gas fuse; a special force frame allows fastening specimen pin-ended at all possible directions and loading it with load of suitable value and, if needed, to maintain the value of the applied load.

a) b)

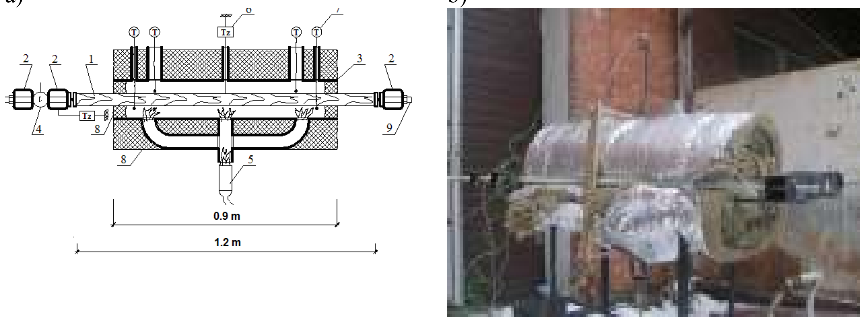

Fig. 2. The furnace for research of the behaviour of timber elements under axial compression exposed to fire
a) Schematic representation of the furnace; b) Common view of the furnace

The hull of the furnace is an open-ended steel tube the outside diameter of which is 159 mm and the length is 0.9 m. It is isolated with 150 mm layer of stone wool which withstands the heat of 1100°C.

The three holes in the lower part of the hull are used for an equal distribution of flame and heat in the furnace. Force frame used for a loading of specimen is attached along the axis of the chamber. The outside temperature of the surface of the specimen was measured by means of thermo-couples attached to the top and the bottom of it.

Having assembled the specimen in the force frame, it was loaded by (6 kN and 7.5 kN) axial load. Remissive coefficients of load during the fire are 0.4 and 0.5.

The experiment was started by inflaming the gas fuse with maximum ratings. The temperature of the chamber on the side of the flame (the lower plane of the specimen) and over the specimen (the upper plane of the specimen) was measured by thermo-couples attached to recording device 'ALMEMO' every 10 seconds. The amount of the load was monitored constantly and, if needed, it was sustained. The temperature and the indication of displacement sensors were recorded at the same rate. All the specimens were tested till failure – buckling.

4. Analysis of the fire temperature effect on the strength of timber

This chapter gives the evaluation of experimentically determined tension, bending, and compression across and along the fibre timber strength results using statistical methods.

Results of distinct timber strength investigations and strength decrease tendencies are graphically presented in Fig. 3. and Fig. 4.

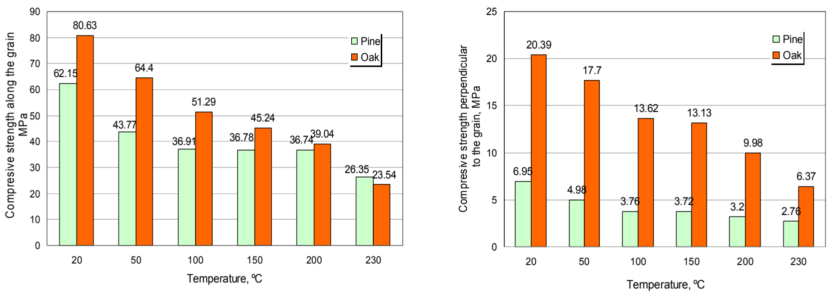

Fig. 3. Values of compression strength of timber along the grain and perpendicular to the grain at differing temperatures

The obtained results are compared with the data given in the works of Benichou and Mohamed (2000), König ir Walleij (2000) along with the values given in EC5 part 1-2. Comparisson of the values of compression strength of timber determined by research with the experimental data of other authors and regulating values of standards are presented in Fig. 5. The obtained results in Fig. 5. are called "Pine compressed along the fibre" and "Pine compressed across the fibre".

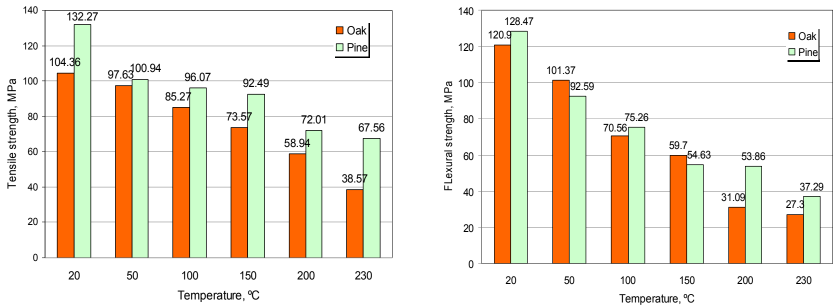

Fig. 4. Values of tensile and flexural strength of timber at different temperatures

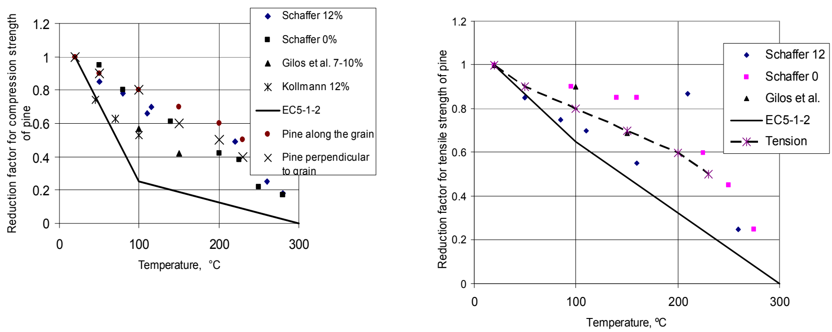

Fig. 5. Comparison of obtained results with the data provided by other authors

As it is visible from the picture, the obtained values of the strength of timber compressed along the fibre are slightly more considerable in comparison with ones of other authors; however, the difference is not great. If compared with the values given in EC5 1-2 (presented by blank line in Fig. 5.), the obtained values of all the authors differ significantly. It means that in using standard document of structural timber fire design EC5 1-2 and evaluating the decrease of strength because of rise in temperature, the fire-resistance of timber elements should be smaller than in applying obtained experimental relations.

5. Analysis of slender timber elements under axial compression exposed to fire

The average value of fire-resistance of the specimens loaded by 6 kN axial compression is 14.6 min, i.e. the criterion of the end of the experiment was reached after this time from the very beginning of it and the average value of fire-resistance of the specimens loaded by 7.5 kN axial compression is 13.9 min. The average duration of fire-resistance of all the specimens is 14.3 min. The results of fire-resistance are presented in Fig. 6.

Having performed the experiment of axially compressed timber elements it was deduced that the mode of elements failure is buckling.

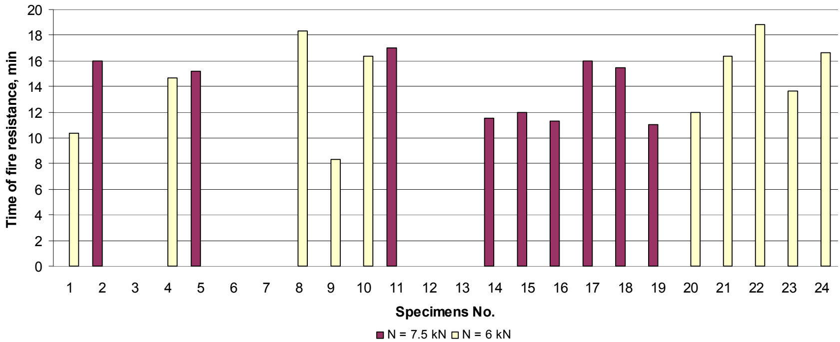

Fig. 6. Time of fire resistance of the specimens

All the elements buckled in direction of higher temperature action. The same mode of timber elements buckling is presented in the works of Young, S. A. (2001); Clancy, P. (2002); Richardson, L. R. (2002). The results of these authors are obtained in analyzing the behaviour of wall studs, protected by the layer of plaster-cardboard, in timber framework houses when studs are heated from the protected side.

Such phenomenon when the compressed timber elements buckle in the direction of the heat action could be explained by uneven shrinkage (wastage) of timber, the decrease in dimensions of cross-section and strength properties in a heated side. Due to the given reasons, the element at some phase becomes eccentrically compressed because of the displacement of cross-section axis.

The obtained inflection of axially loaded elements in fire conditions, measured during the experiment, practically in all cases was larger than after the experiment. The only exceptions were the specimens which not only buckled in one plane but also warped due to the branches or roes of tree-rings. The results of comparison of absolute values of inflections are presented in Fig. 7.

The measurements of thickness of carbon layer in mostly charred cross-sections presented in Table 1 showed that the bottom surface of the element, which was directly affected by flame is mostly charred.

In order to properly compare the exerimental and calculated, while applying standard methodologies, results real values of specimens' timber characterstics – density, humidity, compression and bending strengths, elasticity modules were estimated.

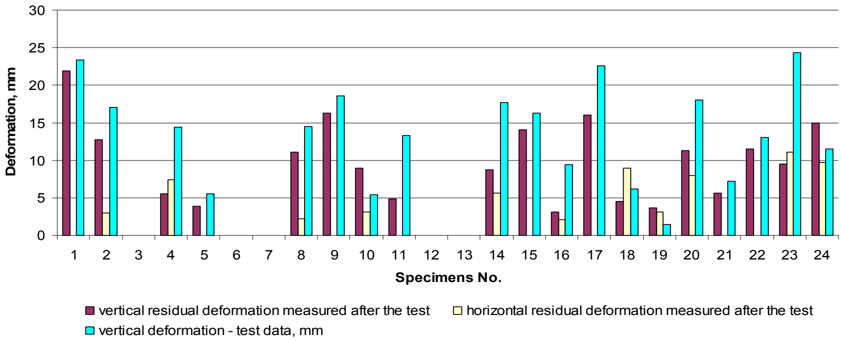

Fig. 7. Comparison of deformations

Bending strength and elasticity module are very important characteristics in analysis the elements which are under action of axial compression and bending moment.

Table 1. Dimensions of the cross-section of specimens and data of the measuring of charring depth

Specimens No.	Dimensions of initial cross-section		Dimensions of residual cross-section		Charring depth of cross- section surface			
	plotis. *b* mm	aukštis. *h* mm	b_r. mm	h_r. mm	Bottom	Top	Side P1	Side P2
1	49.4	47.5	42.3	33.85	5.9	0	0.9	1.6
2	48.4	49.35	42.1	32.5	9.7	1.1	3.9	1.9
4	50.1	48.2	44	32.6	7.4	0	1.6	0
5	50	45.5	38.65	27.35	7.2	1.9	3.1	4.1
8	48.4	49.7	38.95	28.9	13.2	0.9	3.7	3
9	47.5	49.9	34.45	29.25	6.4	4.7	4.7	4.2
10	47	46.7	41.05	35.975	5	0.3	3	1.2
11	49.4	48.2	37.6	30.45	7.2	1	2.2	3
14	49	49.8	42.2	37.7	6.7	0.3	3.3	0.6
15	49.7	50.2	43.25	38.65	3.3	0	0	1.7
16	49.8	47.8	46.25	40.35	8.5	0	0.7	1.1
17	49.7	46.8	42.85	30.55	9	0.8	1.9	2.7
18	46.4	49	37.85	28.05	1	0.6	4.4	2.1
19	49.8	49.2	36.25	31.15	7.2	1.6	4.4	3.8
20	49.2	48.8	38.7	30.25	8	0.7	1.6	3.5
21	49.8	48.9	38.6	28.95	10.9	1.3	2.4	4.5
22	48.8	50.3	35.9	28.1	11	1.1	3.5	3
23	46.4	49.4	37.25	35.1	6.4	0	3.4	1.2
24	49.4	49.1	36.2	28.1	12.6	0.7	3.3	4.1
				Mean value:	7.7	0.9	2.7	2.5

Analysis of timber element under action only of axial compression and under action of axial compression and bending moment together was done considering the residual dimensions of the specimen cross-section. The calculation was done in order to determine whether the eccentricities caused by uneven charring of cross-sections have an influence on timber elements' behaviour in fire. Reduced due to the fire, a load bearing capacity of cross-section was calculated according to EC5 1-1 6.3.2 provisions.

According to the provisions of EC5 1-2 3.4.2 the radii of residual cross-section roundnesswere calculated necessary for analysis of the elements under action of axial compression and bending moment based on the results of residual cross-section and the depths of charring of the specimens' planes. In order to calculate the geometrical indexes (cross-sectional area, the section moment of area, section modulus, eccentricities) of residual cross-section, the cross-section was divided into 4 parts. The radii of angles‘ roundness were calculated after having evaluated the mean values of horizontal plane and lying alongside collateral plane charred layer thicknesses. In calculations the quantity $k_0 d_0$ was not evaluated, however, the mean value of experimental inflection of the elements was assessed. It is equal to 8 mm.

Fig. 8 shows the values of the load bearing capacity of the residual cross-sections. It was calculated according to EC5 1-1 provisions and due to the before mentioned assumptions. As it is visible from the Fig. 8, the calculated load bearing capacity of specimens 1, 4, 10, 14, 15, 16 and 22 has not been out-going yet even though the experimental capacity with such dimensions of residual cross-sections has already been depleted. The average values of deplete coefficients (load bearing capacity) are as follows:

– according to EN 1995-1-1 (6.23) expression – 1,19;

– according to EN 1995-1-1 (6.24) expression – 0,80.

In order to measure the distribution of temperature field in the cross-section of compressed timber element, the widely applied finite elements programme ‘SolidWorks Simulation‘ was used. Fig. 9 represents the distribution of temperature in the cross-section determined by 60 seconds intervals in fire according to approximate fire effect curves obtained by the experiment.

The lower part (up to the horizontal main axis) of the specimen was affected by temperature according to a curve of approximate temperature change in lower part and the upper part (over the horizontal main axis) – according to a curve of approximate temperature change in upper part. Design assumptions were as follows:

- cross-section 50 mm×50 mm;
- the average density of timber 580 kg/m^3.

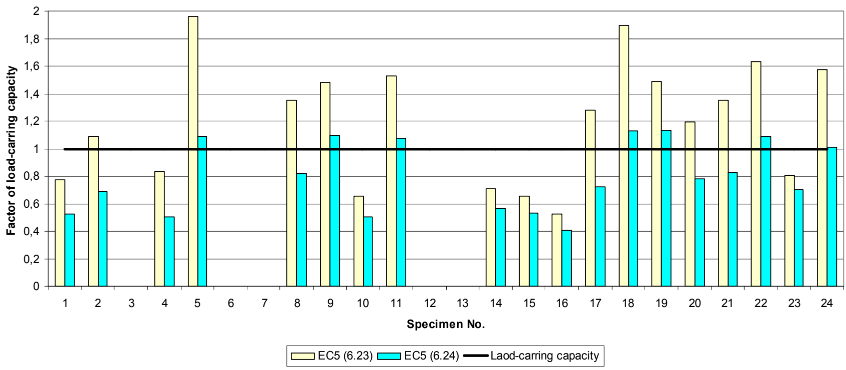

Fig. 8. Design results of the load-carrying capacity of residual cross-sections of timber elements according to EC5-1-2

This way, when only the distribution of temperature in the cross-section is defined, but behaviour of whole element during fire is not analysed, was chosen no perchance but because of complicated relationships between strength and mechanical properties of timber which are very difficult to describe because of the lack of information and also because of the limited potential in dealing with such tasks by popular computer programmes such as ‘SolidWorks Simulation‘. There were no publications found where the stress distribution and behaviour of loaded timber elements, even on natural conditions, would be analysed by employing the programmes of finite elements.

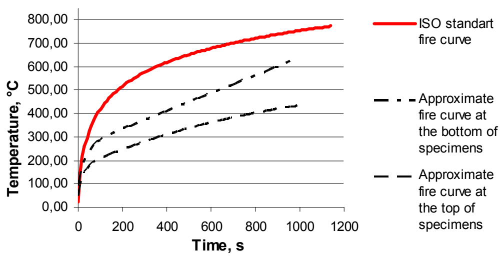

Fig. 9. Approximate relationships between fire exposed time and temperature

The distribution of temperature fields in the cross-section of timber element after 14 min of fire action is shown in Fig. 10. According to the obtained distribution of temperature in the cross-section, the limit of charring going through 300 °C isobar was determined. The calculated average value of thickness of charred layer in the lower plane, determined by the limit of charring, is 4.5 mm, while the experimental result is – 7.7 mm. The values of thickness of charred layer in the upper plane is respectivelly 1.9 mm and 0.9 mm.

Determination the values of thickness of charred layer in collateral planes is more difficult, however, from Fig. 10 (the middle of green area) is visible that the average value of thickness of charred layer will be larger than 2.7 mm. This difference the values of experimental and calculated thicknesses of charred layer may have appeared because of approximation of time-temperature relationships and conventionality of its exposure zones in defining the temperature fields.

Considering the indexes of temperature by isobar limited areas and the average values of their temperature intervals, the weighted averages of values of correction coefficients under action of heat for bending and compression strengths and elasticity moduli for area limited by 300 °C isobar were determined. The values of correction coefficients of compression and bending strengths are taken according to the experimentally-defined relations, given in chaper 4 and the value of correction coefficient of compressed timber elasticity modulus is determined according to the appendix B in EC5 1-2 because experimental research of the latter was not performed.

Table 2. Calculation results of load bearing capacity

Axial compression		
Expression according to EC5	Buckling force kN	Load bearing exlpoitation coeficient 6.0 kN – 7.5 kN
(6.23) – buckling about horizontal axis	4.25	1.412 – 1.765
(6.24) – buckling about vertical axis	4.26	1.408 – 1.761
The axial force and bending moment about horizontal axis		
(6.23)	–	1.446 – 1.810

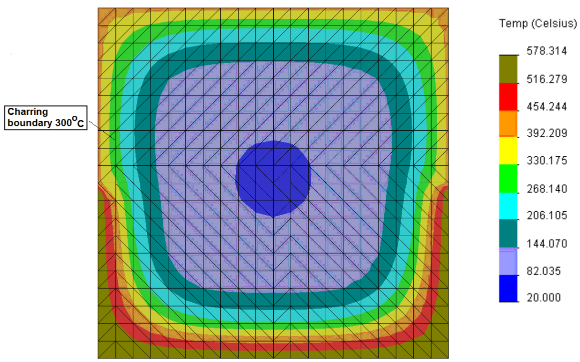

Fig. 10. Distribution of temperature fields after a 14 min. exposure to fire

As it is seen from Table 2, after estimation the values of correction coefficients of experimentally defined timber strength and the values of correction coefficients of compressed timber elasticity modulus given in EC5 1-2, having compared the experimental values, the obtained results of calculated load bearing capacity are quite conservative. It happened after having evaluated the coefficients of experimentally-measured timber strengths and in given.

General conclusions

The following results were obtained:

1. Temperature relations of the changes of properties in timber from trees growing in Lithuania were identified together with the investigation of load bearing capacity of slender compressed timber elements exposed to fire. The complience of experimental results with the analytical assuimptions was verified. The methodology of estimation the behaviour of compressed timber elements exposed to fire was revised considering temperature distribution in the cross-section when the elements are not affected by standard fire curve rather influenced by different temporal temperature relations.
2. Having compared the obtained coefficients of timber strength decrease with the findings of other authors it is possible to claim that their scattering is not large, the results are similar, however, having compared the obtained results with EC5 1-2 it is clear that the values of coefficients in standard document are more conservative.
3. It was defined that the characteristic failure of axially compressed slender timber elements which are unevenly heated from all sides is buckling in the direction of the heat action.
4. Having compared calculated and obtained results it is possible to claim that the provisions of EC5 1-2 could be applied both for the elements affected by standard fire and those affected by different time-temperature relations.
5. In applying the expressions of EC5 1-1 used for calculation the elements in bending and axial compression according to the dimensions of residual cross-section of timber element it is possible to define the reserve of load bearing capacity quite precisely. It is very important to learn this before implementing cleaning and rebuilding works of the buildings affected by fire.
6. In calculating the elements of small cross-section dimensions, which do not have any references given in EC5 1-2, it is expedient to determine the temperature distribution in cross-section by applying the provisions of EC5 1-2 appendix B and according to weighted timber properties' change in fire to determine the load bearing capacity. In applying this method the elements could be counted as axially compressed.

List of Published Works on the Topic of the Dissertation
in the reviewed scientific periodical publications

Šaučiuvėnas G.; Griškevičius, M. 2009. Medinių centriškai gniuždomų elementų elgsena ugnyje. *Statybinės konstrukcijos ir technologijos.* Vilnius: Technika, 1(1): 50–57. ISSN 2029-2317.

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Mečislavas Griškevičius was born in Vilnius, on the 4th of January,1956. He received his civil engineer degree from the Vilnius Civile Engineering Institute in 1996. Started working in Fire and Rescue Department in 1980. Since 1993 he is a lecturer at the department of Labour Safety and Fire Protection in Vilnius Gediminas Technical University. M. Griškevičius has graduated from Vilnius Pedagogical University and received the bachelor's degree in psychology and pedagogy in 2008.

AUKŠTOS TEMPERATŪROS POVEIKIS MEDINIŲ KONSTRUKCIJŲ LAIKOMAJAI GALIAI

Problemos formulavimas. Pastaraisiais metais įvairioms konstrukcijoms (stogų laikančiosioms konstrukcijoms, sienoms, sijoms, kolonoms ir kt.) gana dažnai naudojama mediena. Kilus gaisrui tokiuose pastatuose labiausiai yra pastebimas medinių detalių (konstrukcijos elementų) apanglėjimas. Projektuotojams, statybininkams, ugniagesiams ir gaisrų tyrėjams ypač aktualu susieti šį procesą su tam tikrais svarbiais gaisro poveikiais, pvz. gaisro trukme ar temperatūra, kad būtų galima nustatyti aukštos temperatūros poveikį skirtingų medienos rūšių stipriui. Gaisro metu medienoje vyksta daug fizikinių-cheminių procesų, kurie daro didelį poveikį visos konstrukcijos atsparumui ugniai. Šiems tyrimams atlikti ir rezultatams analizuoti reikalingos skirtingų mokslo šakų žinios. Daugelis specialistų mano, jog per mažai dėmesio skiriama apanglėjimo greičiui ir jo įvertinimui ypač jei kaitros poveikis neatitinka standartinio gaisro poveikio kreivės. Ankstesnėse ir dabar naudojamose norminių dokumentų versijose (prEN 1995-1-2:2000; LST EN 1995-1-2:2005) pateikiami apibendrintieji medienos apanglėjimo greičiai, aptariamas jų poveikis medinių elementų mechaniniam atsparumui būtent veikiant standartiniam gaisrui, nurodomi teoriniai ir kompiuteriniai atsparumo ugniai skaičiavimo būdai, tačiau pateikiamuose metoduose neatsižvelgiama į temperatūros poveikį mažo skerspjūvio elementams, kai kaitros poveikis nevienodai pasiskirstęs skerspjūvio apybrėža bei neatitinka standartinio gaisro poveikio kreivės, nevertinamas bendrasis medinių elementų skerspjūvio mažėjimas dėl anglėjimo ir nuodžiūvio, o taip pat ir medienos stiprio sumažėjimas kylant skerspjūvio temperatūrai.

Konstrukcijos elgseną gaisro metu tiksliausiai apibūdina temperatūros pasiskirstymas jos skerspjūvyje. Gaisro metu kylant temperatūrai statybinės konstrukcinės medžiagos įkaista, daugelis jų keičia savo šilumines savybes. Savybių pokytis dėl temperatūros poveikio yra iš dalies ištirtas, tačiau medienos savybių skirtumai priklauso ne tik nuo medienos veislės, bet ir nuo klimatinių medžio augimo sąlygų. Todėl svarbu žinoti ne tik apibendrintuosius medienos rodiklius, pateikiamus norminiuose dokumentuose, bet ir Lietuvoje išaugusios medienos savybes normaliomis sąlygomis bei jų pokyčius veikiant kaitrai.

Veiksnių, turinčių poveikį temperatūros pasiskirstymui medinėse konstrukcijoje ir jų elementuose gaisro poveikio metu, nustatymas yra labai svarbus patikimam galutiniam medinių elementų laikomosios galios rezultatui gauti.

Darbo aktualumas. Medinių konstrukcijų atsparumo ugniai klausimai yra labai aktualūs, nes mediena, kone vienintelė iš plačiai naudojamų statybinių medžiagų yra degi. Turint galvoje, kad pagal seniau galiojusias SSRS medinių konstrukcijų projektavimo normas medinių elementų atsparumo ugniai skaičiavimas nebuvo reglamentuojamas, todėl duomenų apie medienos savybių pokyčius aukštesnėse temperatūrose ir medinių elementų elgseną gaisro metu praktiškai nėra, ypač tai akcentuotina apie mūsų respublikoje augančios medienos savybes. Jei medienos stiprumінės ir fizikinės savybės natūraliomis sąlygomis yra pakankamai ištyrinėtos tai tyrimų gaisro sąlygomis praktiškai nebuvo atliekama. Ištirti Lietuvoje augančios medienos stipruminių savybių pokyčius aukštesnėse temperatūrose ir palyginti gautus rezultatus su kitų šalių mokslininkų gautais duomenimis yra pravartu siekiant nustatyti kaip gautieji sąryšiai koreliuoja su norminėmis pateiktaisiais medinių konstrukcijų projektavimo normose LST EN 1995-1-2. Tiriant liaunų centriškai gniuždomų medinių elementų elgseną gaisro sąlygomis siekiama nustatyti medinio elemento elgsenos ypatumus bei palyginti eksperimentinius rezultatus su skaičiuotiniais ir taip geriau suprasti prielaidų taikomų analitiniuose skaičiavimuose tikslingumą ir pagrįstumą. Taip pat svarbu išnagrinėti galimybę sumodeliuoti medinio centriškai gniuždomo strypo elgsena gaisro sąlygomis taikant kompiuterinę programą.

Tyrimų objektas. Darbo tyrimų objektas – Lietuvoje augančių spygliuočių ir lapuočių medienos savybių pokyčių didėjant temperatūrai nustatymas, centriškai gniuždomų liaunų medinių elementų elgsenos veikiant kaitrai eksperimentiniai tyrimai ir gautų eksperimentinių tyrimų rezultatų palyginimas su skaičiuotiniais medinių elementų elgsenos, veikiant kaitrai rezultatais.

Darbo tikslas. Šio darbo tikslas – nustatyti temperatūrinius medienos savybių pokyčių sąryšius bei gaisro temperatūros poveikį medinių liaunų gniuždomų elementų laikomajai galiai ir remiantis gautais rezultatais patikrinti atitiktį skaičiuotinėms prielaidoms skaičiuojant gniuždomų elementų atsparumą ugniai, jei elementai veikiami kaitros poveikio ne pagal standartinio gaisro kreivę, o esant kitokiam kaitros pokyčio laikiniam sąryšiui. Patikslinti metodiką, kurią taikant galima būtų įvertinti ne tik tikrąjį kaitros poveikį konstrukcijai, bet ir atsižvelgti į temperatūros pasiskirstymą elemento skerspjūvyje.

Darbo uždaviniai. Darbo tikslui pasiekti buvo iškelti šie uždaviniai:

1. Atlikti literatūros, kurioje nagrinėjama laikančiųjų konstrukcijų atsparumo klausimus susijusius su konstrukcijų atsparumo ugniai klasifikacija, medienos elgsenos veikiant aukštoms temperatūroms ypatumais bei medinių konstrukcijų laikomosios galios gaisro sąlygomis laikomosios galios analize, apžvalgą.
2. Gauti eksperimentinius duomenis apie aukštos temperatūros poveikį Lietuvoje augančios natūralios – pušinės ir ąžuolinės – medienos savybėms.
3. Remiantis darbo tyrimo, kitų užsienio šalių mokslininkų tyrimų rezultatais o taip pat duomenų bazėse bei žinynuose pateikiamais duomenimis atlikti medienos savybių temperatūrinių sąryšių palyginimą, išanalizuoti jų skirtumus ir panašumus.

4. Parengti bandymo metodus ir sukonstravus savitą kaitinimo krosnį, lenkimo, tempimo ir gniuždymo įrangą, atlikti medienos stiprių mažėjimo veikiant kaitrai tyrimus, įvertinant medienos tankį, drėgmę, šilumos srauto tankį.
5. Parengti bandymo metodus bei sukonstruoti kaitinimo krosnis ir apkrovos suteikimo įrangą skirtą centriškai gniuždomų liaunų medinių elementų elgsenos ugnyje tyrimams atlikti.
6. Gautus eksperimentinių tyrimų rezultatus palyginti su apskaičiuotaisiais elgsenos ugnyje rezultatais.
7. Atsižvelgiant į tikroviškesnį kaitros poveikį patikslinti esamą medinių liaunų gniuždomų elementų skaičiavimo metodiką, kuri leistų tiksliau įvertinti jų atsparumą ugniai.

Tyrimų metodika. Remiantis atitinkamais Europoje galiojančiais standartais ir sukurtomis nestandartinės bandymų metodikomis atlikti medienos savybių pokyčių bei centriškai gniuždomų liaunų medinių elementų elgsenos veikiant kaitrai tyrimai. Taikant standartinius medinių konstrukcijų skaičiavimo bei skaitinius analizės metodus patikslinta centriškai gniuždomų liaunų medinių elementų laikomosios galios nustatymo metodika.

Darbo mokslinis naujumas. Rengiant disertaciją gauti statybos inžinerijos mokslui nauji rezultatai:

1. Gauti nauji papildomi Lietuvoje augančios pušinės ir ąžuolinės medienos savybių pokyčių veikiant aukštai temperatūrai duomenys, leidžiantys palyginti įvairiuose pasaulio regionuose ir Lietuvoje augančių medžių medienos savybių veikiant aukštoms temperatūroms panašumus ir skirtumus.
2. Gauti nauji Lietuvoje augančios pušinės ir ąžuolinės medienos savybių pokyčių veikiant aukštai temperatūrai duomenys, leidžiantys palyginti įvairiuose pasaulio regionuose ir Lietuvoje augančių medžių medienos savybių veikiant aukštoms temperatūroms panašumus ir skirtumus.
3. Patikslinti liaunų centriškai gniuždomų elementų elgsenos ypatumai ir jų poveikis skaičiavimo principams.
4. Pateiktos rekomendacijos medinių elementų elgsenos analizei, taikant sudėtingesnius metodus pagal EC5 1-2:2005 nuostatas.

Darbo rezultatų praktinė reikšmė. Rengiant disertaciją gautas statybos inžinerijos mokslui naujas rezultatas – nauji Lietuvoje augančios ąžuolo ir pušies medienos stiprių mažėjimo temperatūriniai sąryšiai, kurie palyginti su LST EN 1995-1-2:2005 pateiktais sąryšiais. Pateiktos rekomendacijos kaip gana tiksliai nustatyti gaisro paveiktų liaunų medinių elementų laikomosios galios rezervą pagal likutinio skerspjūvio matmenis, o tai yra svarbu prieš pradedant gaisro paveiktų pastatų konstrukcijų stiprinimą ar valymą.

Ginamieji teiginiai

1. Pasiūlytieji spygliuočių ir lapuočių medienos stiprio pokyčių aukštesnėse temperatūrose sąryšiai ir pasiūlytoji jų nustatymo metodika.
2. Medinių centriškai gniuždomųjų elementų elgsenos ugnyje tyrimo metodika.
3. Medinių centriškai gniuždomųjų elementų elgsenos ugnyje eksperimentinių ir skaičiuotinių reikšmių analizės rezultatai.

Darbo apimtis. Disertaciją sudaro įvadas, penki skyriai, bendrosios išvados, du priedai, literatūros ir publikacijų sąrašai. Darbo apimtis yra 132 puslapiai be priedų, tekste panaudotos 39 numeruotos formulės, 62 paveikslai, 10 lentelių ir 130 bibliografinių šaltinių sąrašas.

Įvadiniame skyriuje nagrinėjamas problemos aktualumas, formuluojami darbo tikslai ir uždaviniai, aprašomas darbo mokslinis naujumas, pristatomos autoriaus publikacijos ir pranešimai.

Pirmasis skyrius skirtas literatūros apžvalgai. Jame pateikta darbų, kuriuose nagrinėjamas aukštesnės temperatūros veikiamos medienos stipruminių savybių mažėjimas ir kuriuose pateikiami gaisro sąlygomis gniuždomų medinių elementų laikomosios galios tyrimų rezultatai bei nagrinėjami jų ypatumai ir medinių konstrukcijų apsaugos nuo ugnies poveikio būdai, apžvalga. Skyriaus pabaigoje formuluojamos išvados ir tikslinami disertacijos uždaviniai.

Antrajame skyriuje pateikta medienos stipruminių savybių aukštesnėse temperatūrose tyrimo metodika ir sukurtų nestandartinių bandymo įrenginių schemos.

Trečiajame skyriuje pateikta liaunų centriškai gniuždomų medinių elementų elgsenos gaisro sąlygomis tyrimų metodika bei tam tikslui sukurtų nestandartinių bandymo įrenginių schemos.

Ketvirtajame skyriuje pateikta aukštesnės temperatūros poveikio medienos stipriams bandymo rezultatų analizė ir palyginimas su kitų autorių analogiškų tyrimų rezultatais.

Penktame skyriuje pateikta centriškai gniuždomų liaunų medinių elementų elgsenos ugnyje bandymo rezultatų ir šių elementų atsparumo ugniai skaičiavimo rezultatų, taikant analitinius metodus ir skaitinį temperatūros modeliavimą baigtiniais elementais, palyginamoji analizė.

Darbo rezultatai ir išvados.

Darbo metu gauti šie rezultatai:

1. Patikrintas bandymų rezultatų atitikimas skaičiuotinėms prielaidoms bei patikslinta medinių gniuždomų elementų, atsižvelgiant į temperatūros pasiskirstymą elemento skerspjūvyje, elgsenos ugnyje, kai elementai veikiami kaitros ne pagal standartinio gaisro kreivę, o esant kitokiam kaitros pokyčio laikiniam sąryšiui, vertinimo metodika.
2. Palyginus darbe gautus medienos stiprių mažėjimo koeficientus su kitų

autorių gautais duomenimis galima teigti, kad jų sklaida yra nedidelė, rezultatai yra panašūs, tačiau palyginus gautuosius rezultatus su EC5 1-2 matyti, kad norminiame dokumente pateiktosios koeficientų reikšmės yra su daug didesne atsarga.

3. Nustatyta, kad būdinga centriškai gniuždomų medinių liaunų elementų, netolygiai kaitinamų iš visų pusių, irtis – jų kluptis išlinkstant kaitros poveikio kryptimi.
4. Palyginus gautuosius bandymų ir skaičiavimo rezultatus galima teigti, kad EC5 1-2 dalies nuostatas galima taikyti ne tik standartinio gaisro veikiamiems elementams, bet ir esant kitokiems laikiniams temperatūros poveikio sąryšiams.
5. Taikant EC5 1-1 išraiškas, skirtas elementams, veikiamiems gniuždomosios jėgos ir lenkiamojo momento, skaičiuoti pagal medinio gniuždyto elemento likutinio skerspjūvio matmenis, ir ekscentricitetus galima gana tiksliai nustatyti laikomosios galios rezervą, kurį yra labai svarbu žinoti prieš vykdant gaisro paveiktų pastatų, valymo ar atstatymo darbus.
6. Skaičiuojant nedidelio skerspjūvio matmenų elementus, kuriems eurokodo 5 1-2 dalyje nepateikta jokių nuorodų, tikslinga nustatyti temperatūros pasiskirstymą skerspjūvyje taikant EC5 1-2 B priedo nuostatas ir pagal pasvertinius medienos rodiklių pokyčius veikiant temperatūrai apskaičiuoti jų laikomąją galią. Taikant šį metodą elementus galima skaičiuoti kaip centriškai gniuždomus.

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HIGH TEMPERATURE EFFECT ON RESISTANCE OF TIMBER STRUCTURES

Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)

Mečislavas GRIŠKEVIČIUS

AUKŠTOS TEMPERATŪROS POVEIKIS MEDINIŲ KONSTRUKCIJŲ LAIKOMAJAI GALIAI

Daktaro disertacijos santrauka
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