THERMAL REMEDIATION OF ROOF STRUCTURE OF THE ST. MARTIN'S CATHEDRAL

SANDANUS, J. & SLIVANSKÝ, M.

Abstract:
Strain measurement of a timber roof structure of the St. Martin's cathedral chancel in Bratislava was performed during its heat remediation (i.e. thermal remediation). The thermal remediation is a modern method of the treatment of timber structures, which is focused on the elimination of biotic wood-destroying insects by the way of the increased temperature.

Key words: *thermal remediation, wood-destroying insect, strain gauge measurement*

Introduction

With regard to the above-mentioned facts, this method is relatively rarely used in Slovakia and it was also used on the historically relevant object. The experimental research monitored the behavior of the timber structure during the artificially increasing temperature to see, whether the observed changes were permanent or they were just temporary. Based on the obtained results the following conclusions and recommendations were formulated as far as further research is concerned.

Fig. 1 The roof structure and the installation of the fumigator with the hot-air pipeline

1. Thermal remediation - principle and technology

The principle of the thermal remediation is a global elimination of all forms of the wood-destroying insects in the contaminated wood material. It can be said, that the heating process is successful by achieving a minimum temperature of 55°C in the core of all timber cross sections for the duration of at least 1 hour.

Heating of the timber structure is usually realised by the blowing of hot air into the roof space through the hot-air pipeline connected to the fumigator. The average temperature of the produced hot air is from 100°C to 120°C according to dimensions of the roof structure and length of the pipeline. The thermal remediation process of the roof structure of the St. Martin's cathedral chancel was divided into 3 stages.

2. Roof structure - the system and the measurement points

The roof structure of the chancel is 4 story construction. The roof is closed on the front side by hipped end and small tower, on the other side the roof is linked to the main structure of the cathedral. In the longitudinal direction is the roof structure braced with a diagonal bracing system located between the main supporting frames situated in the sloped plane.

Fig. 2 The structural system of the roof construction

The effect of increasing temperature during the thermal remediation was monitored by the strain gauge measurement. The strain gauges were mounted on the surface of the selected structural timber members by 2-component epoxy adhesive. The measurement points were selected with regard to the expected normal stresses (compression or tension) due to the uniform heating of the roof structure and accessibility of the structural member. The strain gauges were situated either on the upper edge of the horizontal 1st floor's spanner (10 measurement points) or on the edge of the diagonal roof brace (2 measurement points). One of the strain gauges was situated separated from the roof's structural members on the independent specimen of the timber. The names and location of the strain gauges measurement points are shown in table 1.

Tab. 1 Names and location of the measurement points

Name	Stage	Member	Direction	Strain gauge
1 compensation	Stage 1	spanner midspan	parallel	compensated
2 compensation		spanner	parallel	compensated
1 resistor		separated	parallel	uncompensated
2 resistor		spanner	parallel	uncompensated
3 compensation	Stage 3	brace	parallel	compensated
4 compensation		brace	parallel	compensated
3 resistor		spanner	parallel	uncompensated
4 resistor		spanner	perpendicular	uncompensated
5 compensation		spanner	parallel	compensated
6 compensation		spanner	perpendicular	compensated
5 resistor		spanner	parallel	uncompensated
6 resistor		spanner	perpendicular	uncompensated

Notice:
- the direction parallel or rather perpendicular means the tensiometer's position relative to the direction of the wood fibres

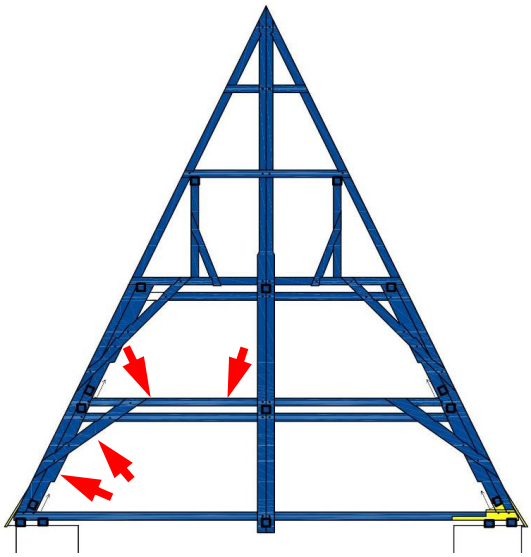

Fig. 3 A schematic view of the structural system of the roof construction and location of the measurement points

3. Measurement equipments

The effect of the increasing temperature to the normal stress in structural members was measured by the strain gauges. Two different types of strain gauges were used - the half-bridge without compensating tensiometer, and half-bridge with the compensating tensiometer. The measurement points were protected by thermal isolation against the high temperature. The course of the thermal remediation was recorded using the HBM Spider8 measuring station, and the data were stored in a PC (notebook) via the Catman utility software. The measured data were exported to a Microsoft Excel file format.

Fig. 4 The strain gauges installation and thermal isolation

4. Evaluation of the measurements

Temperature measurement

The time-history of the temperature of the roof structure was monitored by employees of the company Thermo Sanace s.r.o. during the thermal remediation for a relatively large number of the measurement points. A course of the temperature measurement for selected points is illustrated in Fig. 5.

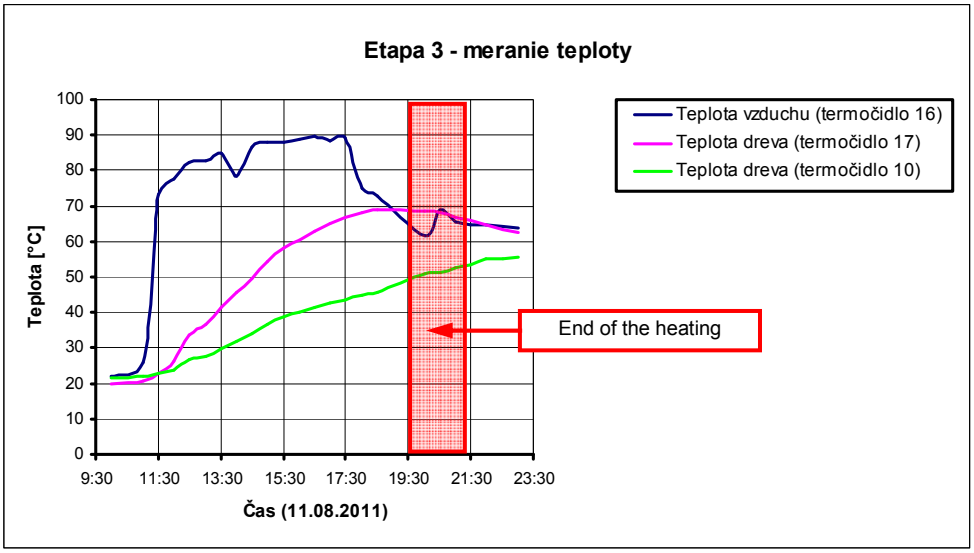

Fig. 5 A course of the temperature measurement in Stage 3

Relative deformations

The relative deformations were measured by the strain gauges located on the surface of the selected timber members. Two different types of strain gauges were used, thus the results have to be interpreted with regard to this fact.

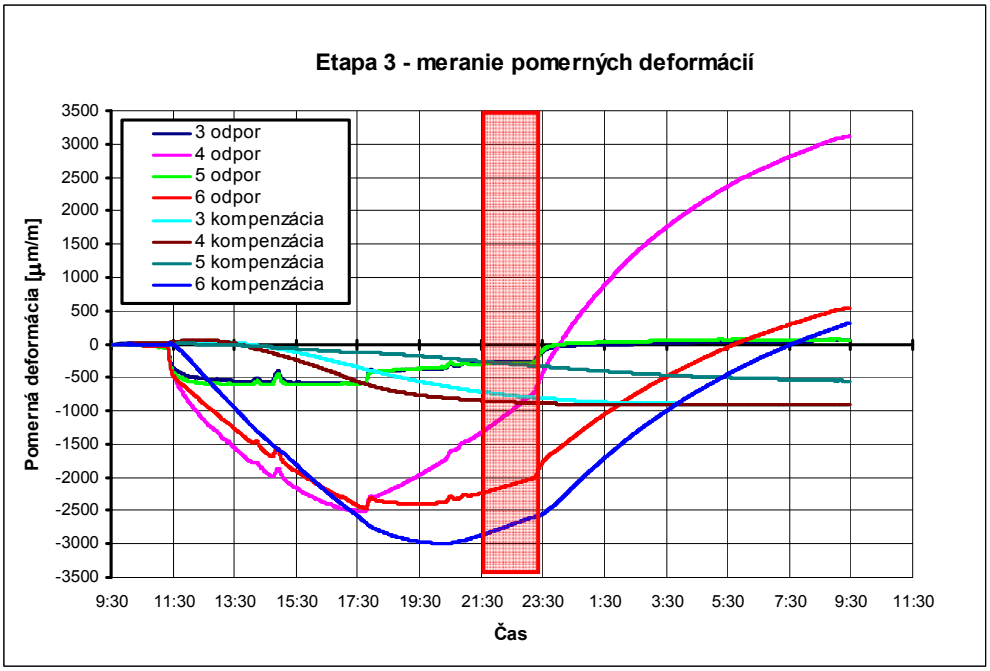

Fig. 6 A course of the relative deformations measurement in Stage 3

According to obtained results of the strain measurement (relative deformation), it can be said, that the volumetric change of the wood material at surface of the timber element due to the change of the humidity (shrinkage, swelling) is more significant than the change caused by thermal expansion of the material. We can not exactly formulate the relationship between the humidity and relative deformations from the experiment, because the humidity of the timber elements was not measured. Generally, the test results proved the theoretical physical properties of the wood as a structural material - the coefficient of the expansion caused by change of the humidity is theoretically 104 times higher than the coefficient of the thermal expansion.

The change in the volume of the wood material in perpendicular direction to wood fibres was also more significant comparing to the direction parallel to wood fibres. The experimentally obtained data of the relative deformations in perpendicular direction (4 resistor, 6 resistor, 6 compensation) were several times higher than the relative deformations in parallel direction. This trend corresponds also with the theoretical values, which is the ratio between different directions α_{Tan}: α_{Rad}: α_{Lin} = 15:10:1 generally given (approximately the identical ratio is used both to the change in volume due to humidity and thermal expansion).

The more significant volumetric changes appeared probably on the surface of the timber members, because these results of strain's measurement followed the increase and decrease of the temperature during the heating of the roof structure very strictly (increasing of the temperature = increasing of the relative deformations and vice versa), and after interruption of the heating they gradually disappeared. It is very important to notice, that the results of the strain gauges without compensation (the measurement points named "resistor") are strongly affected by the influence of the temperature on the electronic equipments (tensiometers, resistors, wires, etc.), so the trends of the results are mainly interesting, not the numerical values. Despite the fact, the error of the measurement using the strain gauges with compensation is reduced, it can not be completely ignored, because the wood is very inhomogeneous material (direction of the wood fibres, cracks, etc.).

Normal stresses

The normal stress was evaluated only in the measurement points with compensated and in the parallel direction oriented strain gauges. Due to the thermal longitudinal expansion of the wood, the increasing of the temperature produces the compressive stresses in the measured structural elements. Increasing and decreasing of the normal stresses did not follow the ambient temperature simultaneously, but a specific time delay was obvious. Even the heating of the roof structure was finished, the normal stress faded out in the time gradually (figs 7 and 8). As a result of the long-term strain gauge measurements it can be considered, that the normal stress finally reduced to the same level as before the thermal remediation in the next couple of days (fig. 8).

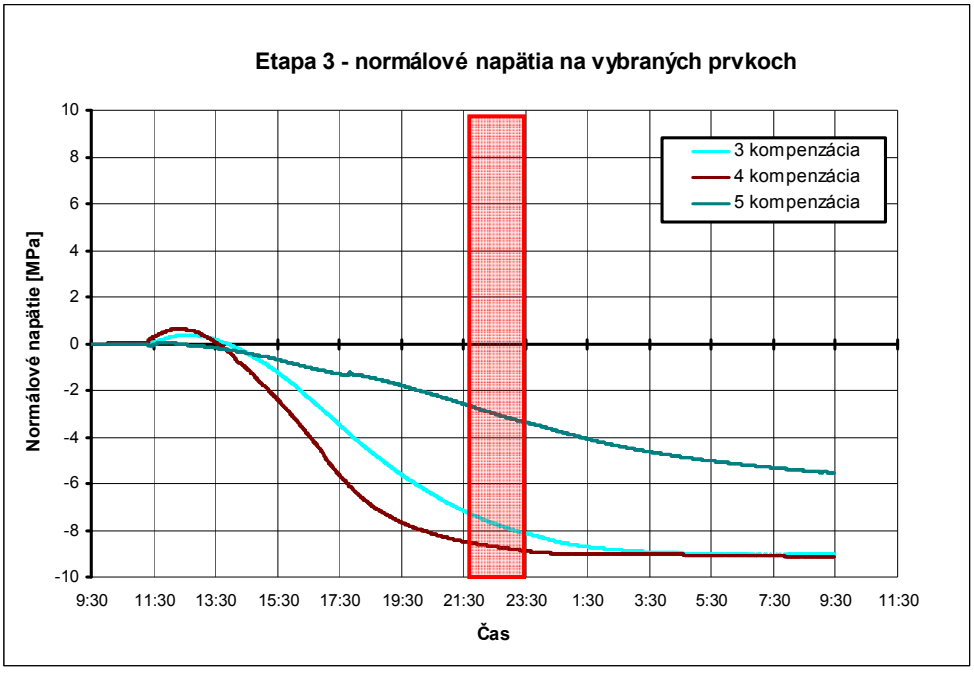

Fig. 7 A course of the normal stresses measurement in Stage 3

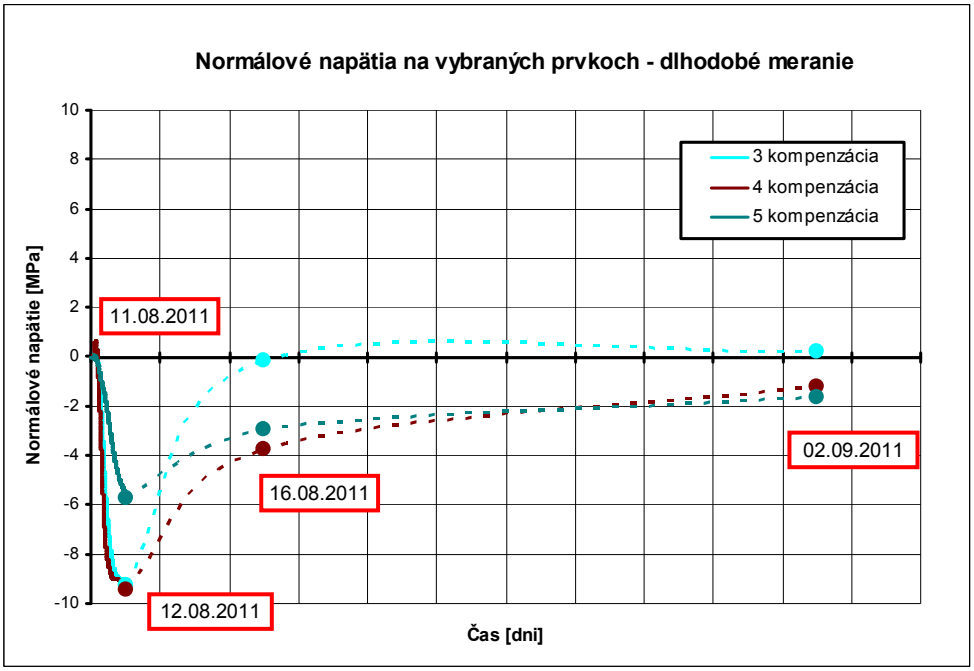

Fig. 8 A course of the normal stresses measurement, long-term results

Visual inspection of the roof structure

A complete visual inspection of the roof structure was made before and also after the thermal remediation. None defects (e.g. cracks in the wood, damaged joints, etc.), due to the heating of the structure, of the structural elements and its joints were detected. Also there were not any other indications of the damage's creation during the process of thermal remediation observed (cracking, breaking, vibrations, etc).

Conclusion

From the results of the experimental research during the thermal remediation of the roof structure of the St. Martin's cathedral chancel in Bratislava following can be formulated:
- increasing of the normal stress due to the heating of the timber structure is not permanent; the normal stress faded out in the time gradually, after interruption of the heating,
- the change in the volume of the wood material in perpendicular direction to wood fibres is more significant comparing to the direction parallel to wood fibres,
- the change in the volume of the wood material at surface of the timber element due to the change of the humidity (shrinkage, swelling) is more significant than the change caused by thermal linear expansion of the material,
- none defects (e.g. cracks in the wood, damaged joints, etc.), due to the heating of the structure, were detected.

Literature

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Mailing adress

1. doc. Ing. Jaroslav Sandanus, PhD.: Slovenská technická univerzita v Bratislave, Stavebná fakulta
Katedra kovových a drevených konštrukcií, Radlinského 11, 813 68 Bratislava
tel. 00421 2 592 74 366
e-mail: jaroslav.sandanus@stuba.sk

2. Ing. Miloš Slivanský, PhD.: Slovenská technická univerzita v Bratislave, Stavebná fakulta
Katedra kovových a drevených konštrukcií, Radlinského 11, 813 68 Bratislava
tel. 00421 2 592 74 367
e-mail: milos.slivansky@stuba.sk