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# Criterion of optimal infra-heating of moulds in production of artificial leathers

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**Abstract:** The paper presents research, development and implementation itself of methods and methodologies, designed and realized in connection with innovation of the technology of artificial leathers production in the company Magna Bohemia. The application of the designed experimental procedures, both physical and virtual, contributed to acceleration and improvement of the stage of technical preparation of thin-walled galvanomoulds and finally to increase of the product quality. The product is an elastic foil – artificial leather, applied in softened interior parts of vehicles in order to improve comfort of passengers. The discussed problems were part of the development activities realized within the project MPO TIP 2009, registered under the number FR-TI1/266.

**Keywords:** Experimental; Thermal, Heat Flow Measurements, Analysis

## 1. Introduction

Within the development of artificial leather production technology in the company Magna Exteriors & Interiors Bohemia, s.r.o., where processes of thin-walled moulds heating and consequent cooling dominate, heating by a regulated system of infra-red emitters appeared as economically the most advantageous way of thermal excitation.

Considering the layout of infrared emitters above generally complicated in-shape mould is a complex optimisation task, the company LENAM, s.r.o. developed within its innovative activities a sw product called IREviewBlender that significantly contributes to speed and quality of technical preparation of infrared heating of moulds [1, 2].

One of the important inputs into the virtual simulation of infrared heating of moulds by means of this sw tool is the information concerning real intensity of the heat flux into the corresponding area of the mould, which represents a radiation effect of each individual emitter or a group of emitter on a concrete mould area.

To be able to predict, by means of the simulation, the state when the total intensity of the heat flux of the emitters for the given mould is sufficient throughout the whole process of the artificial leather production, it was necessary to better specify

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the criterion of sufficient heat. The procedure of identification of this criterion by means of the experiments designed to that purpose is the theme of the present paper.

## 2. Experimental workplace

For the needs of the above-mentioned identification of the sufficient heat criterion, two experimental workplaces have been used. The first workplace serves for measuring heat flux densities of the emitters [3], which are quantities used by the software IREviewBlender for the respective numerical simulations of the mould heating.

The second workplace is a so called test line; see Fig. 1, which is approximately a quarter size version of the real flow line. It has been designed for needs of special tests, in order not to restrain the operating mode on the flow lines.

**Fig. 1.** Test line for artificial leather production

For experimental work on the test line, a mould with such shapes has been designed so that various situation of infrared-heating could be simulated by physical experiments, that would allow better specification of the criterion of sufficient heat in real production process, see Fig.2.

**Fig. 2.** Experimental galvanomould with defined geometric shapes

### *2.1. Selection of criterion of sufficient infra-heat*

To define the correct criterion, it was necessary to consider number of crucial requirements and available information, e.g.:

1. Price requirements on the realised product (quality and quantity of the products).

2. Physical laws and technical limits of the present means of production.
3. Empirical knowledge and experience of the team of workers from the production processes on the current lines (one prototype and one beta batch line).
4. Comments of the team of workers who are engaged in the regulation of the infra-heating of the moulds in interaction with unmanned line regulation throughout the whole work cycle of the artificial leather fabrication.
5. Requirements of the colleagues who have designed and verify application of genetic algorithms for the second level of layout optimisation of the infrared emitters placed above complicated-in-shape surfaces of moulds [4].

As showed during the innovation activities, the common factor of the experience, knowledge and requirements is the need of sufficient available amount of energy from the optimally placed infrared emitters. The time of the mould heating should be as short as possible ($0 \leq \tau \leq t_{max} < 5\ min$), the mould material must not be overheated ($T_{max} < 230\ °C$) and maximum quality of the product, i.e. thin artificial leather (***foil 0.7 to 1 mm thick***), should be reached with required colour scheme and mechanical properties all over its surface and volume. The basic estimation of the amount of energy necessary for heating the mass of the galvanomould $m_G$ by the temperature difference $\Delta T$ is given by the calorimetric equation. Hence follows the relation for the radiation intensity, or heat flux density

$$I_{mG} = \frac{h_G\, \rho_G\, c_{pG}\, \Delta T}{t_{\max}}, \tag{1}$$

where $c_{pG}$. and $\rho_G$ are specific caloric receptivity and mass density of the mould, $h_G$ is mould wall thickness..

Considering the heating process has non-stationary and random character, it is useful to take advantage of basic stochastic approaches. When heating the mould during the work cycle, a countable set of emitters is in function. Then each emitter contributes to the mould heating by its effect, i.e. by intensity of the heat flux intensity $I_j$, on every elementary surface of the mould $1 \leq j \leq N$ (***N*** is in the order of thousands and more).

Let us denominate $I_{jl}$ the radiation intensity of the ***l-th*** emitter on the ***j-th*** elementary surface $p_j$ of the mould. The total $I_j$ intensity [$W/m^2$] of the ***j-th*** elementary surface can then be expressed by the relation

$$I_j = \sum_{l \in L_j} I_{jl}\ . \tag{2}$$

Be $I_{opt}$ = ($\sim I_{mG}$) optimal value of the radiation intensity necessary for reaching required quality of the artificial leather in each moment $\tau$. As it is not possible to reach the optimal intensity value all over the whole mould surface within the allowed time of the work cycle, let us express the deviation $F_j$ on the ***j-th*** elementary surface of the mould Ij ($1 \leq j \leq N$) from optimal $I_{opt}$ as

$$F_j = \left| I_j - I_{opt} \right|\ . \tag{3}$$

Then average deviation of the heat flux intensity over the whole surface of the mould could be expressed by the relation

$$\overline{F} = \frac{\sum_{j=1}^{N} F_j s_j}{\sum_{j=1}^{N} s_j}, \tag{4}$$

where $\boldsymbol{s_j}$ means surface in [$\boldsymbol{m^2}$] of the elementary surface $\boldsymbol{p_j}$ of the mould.

The aim of the technical preparation of infrared heating is to minimise the quantity $\overline{F}$ at required value $\boldsymbol{I_{opt}}$. As mentioned above, $\boldsymbol{I_{opt}}$ is dependent on one hand on very strict economical parameters of production, which is the price of the produced artificial leather, and on the other hand on the physical and technical possibilities of the production equipment. Then it will certainly be useful to have information on other statistics (e.g. frequencies) of positive and negative deviations from $\boldsymbol{I_{opt}}$, i.e.

$$\begin{aligned} F_m &= \left(I_m - I_{opt}\right) \geq 0, \\ F_n &= \left(I_n - I_{opt}\right) < 0, \\ where\ &\left(m+n\right) = N, \end{aligned} \tag{5}$$

and/or on their average values $\overline{F}_m$ *and* $\overline{F}_n$, or other suitable statistic quantities (variances, standard deviations etc.).

Analogical considerations on deviations from the required temperature $\boldsymbol{T_{opt}}$ could be introduced for statistics of temperatures $\boldsymbol{T_j = T_j(t)}$ in a mould excited by radiation, which can easily by evaluated with the help of a virtual simulation of non-stationary thermal fields on elementary surfaces of the mould (elements, or nodes of the FEM mesh) as well as, in our case, by a physical experiment, at least at the points with installed thermocouples. Let us note that the value $\boldsymbol{T_{opt}}$ does not have to be required to the same in all the points of the mould.

### *2.2. Design of experiments (DOE)*

As mentioned in the introduction, during the innovation activities of the mentioned project, a mathematical model of infrared heating of mould had been created, which was implemented in sw tool IREviewBlender together with a possibility to predict non-stationary temperature phenomena in the mould by means of the finite element method. By means of these virtual methods, the computations of the quantities introduced in the previous chapter 2.1. can be realised including prediction of temperature non-stationary fields and temperature gradients in the mould, eventually of other quantities such as components of structural strain and stress tensors.

The real physical heating of a mould has its limits that are given namely by a number of regulation thermocouples which continuously monitor temperatures on the mould. The number of thermocouples is usually equal to that of emitters installed above the mould surface. Therefore, for the purpose of verification of optimisation heating criteria, we have to manage with comparison of physical and virtual realities of a small number of measured quantities, namely with temperatures only, that means of quantities for $\boldsymbol{N=(m+n)}$ in the order of tens instead of thousands or more, when applying numerical methods.

By means of numerical simulations, a set of suitable physical measurements has been selected and designed to be carried out on a prepared experimental mould, see Fig.1, so that the results of physical measurements could be correlated to the results of numerical simulations. As it is surely known to the reader, these are influenced by a number of physical, geometrical and topological parameters of a numerical model. In this way it is possible to better specify the quantities of infrared mould heating used in the numerical models and thus contribute to explanation of experience and knowledge gained from practice.

In order to satisfactorily identify the thermal phenomena in the mould, it is evident that the number of measurements of temperature responses of the mould, heated by radiation excitation of various configurations of infrared emitters, must be considerable. At the same time it is necessary to respect the fact that during the defined processes of heating it is possible to measure and register only time dependencies of temperatures on a countable set of thermocouples to which we then find such parameters of numerical simulations to reach a good agreement. Provided it happens, a quantity $\boldsymbol{I_{opt}}$ pro for reaching the optimal temperature $\boldsymbol{T_{opt}}$ and their statistic deviations are identified on the basis of the relations (2) to (5). The figures below illustrate selected heating situations and their presumed outputs at the given moment of running experimental measurement.

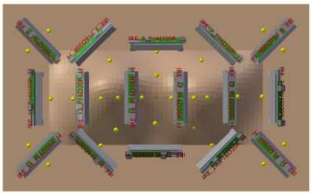

**Fig. 3.** Position of infrared emitters

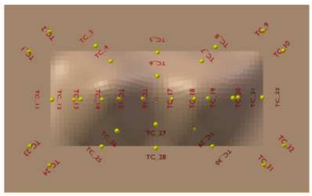

**Fig. 4.** Position of thermocouples

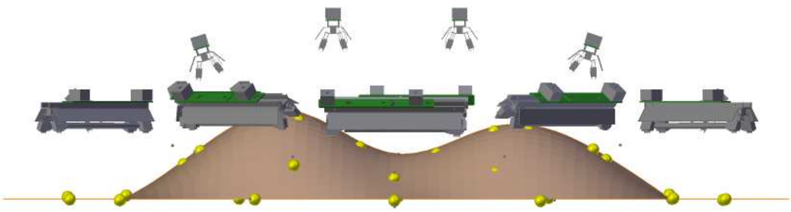

**Fig. 5.** Side view of set of infrared emitters above the experimental mould

Temperature time behaviour from individually switched emitters

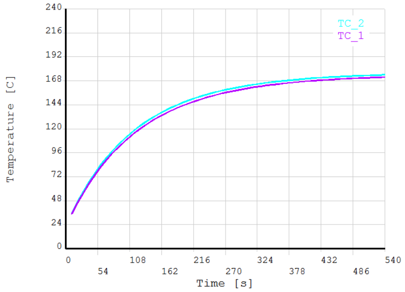


**Fig. 6.** Temperature time behaviour at points 1, 2

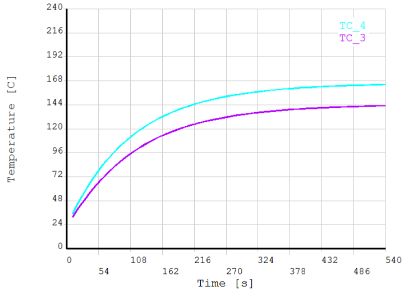


**Fig. 7.** Temperature time behaviour at points 3, 4

Temperature time behaviour in case of mould when heated without regulation

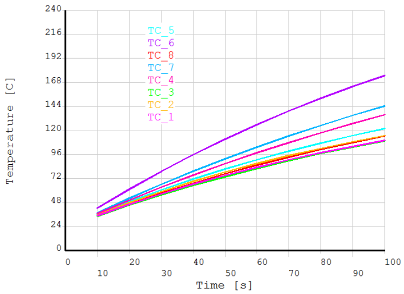


**Fig. 8.** Temperature time behaviour at points 1 to 8

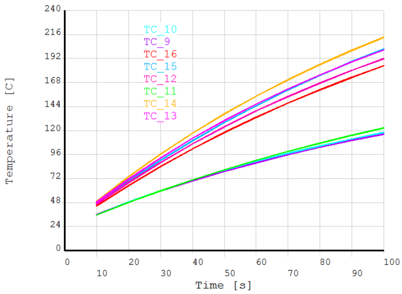


**Fig. 9.** Temperature time behaviour at points 9 to 16

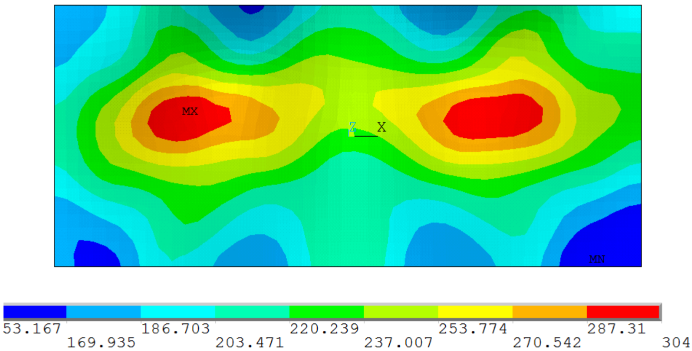


**Fig. 10.** The thermal field of the experimental mould when heated without regulation, 32 emitters, τ=100s

## 3. Example of the experimental results processing

Considering the number of designed experiments is high and the measured data files are large, let us show in this part of the paper a typical or, if you like, a model example of the result evaluation.

Let us consider two cases of experimental mould heating. In the first case the heating will be realised without regulation by all the emitters numbering 32 pieces of power-identical tubes placed by two with one reflector. In the second case let us additionally integrate the system of regulation. The calculated statistics according to the above stated relations are given in the Tables 1 and 2; numerically predicted temperature time behaviours are in Fig. 11 and 12.

**Table 1. Average deviations of Heat Flux Densities for $I_{opt}$ = 30, 35, 40 and 45 kW/m²**

| | $I_{opt}$ [kW/m²] | | | |
|---|---|---|---|---|
| Statistics | 30 | 35 | 40 | 45 |
| $\overline{F}$ | 7.9 | 7.4 | 9.1 | 12.3 |
| $\overline{F}_m$ | 9.3 | 7.9 | 7.9 | 7.2 |
| $\overline{F}_n$ | 4.9 | 6.9 | 9.4 | 13.1 |

**Table 2. Average Temperature deviations for $T_{opt}$ = 230 °C for mould heating**

| Statistics | Without regulation in time τ=100s | With regulation in time τ=180s | With regulation in time τ=360s |
|---|---|---|---|
| $\overline{\Delta T}$ | 27.7 | 27.6 | 13.1 |
| $\overline{\Delta T}_m$ | 27.1 | 6.6 | 9.7 |
| $\overline{\Delta T}_n$ | 28.1 | 29.7 | 15.1 |

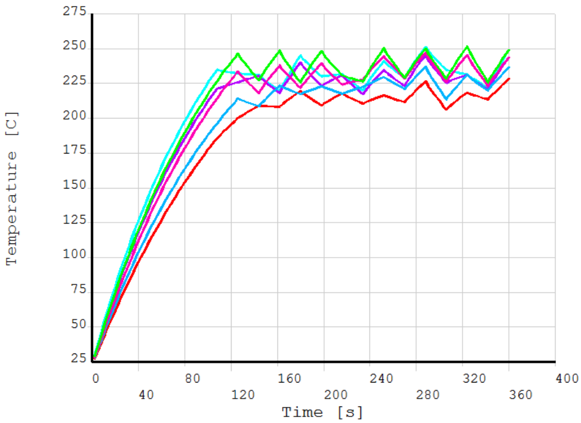


**Fig. 11.** Temperature time behaviour at regulated heating of the mould by all the emitters

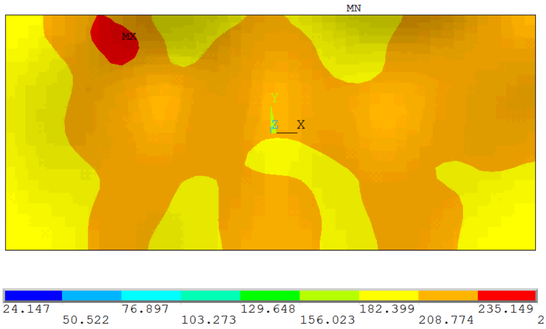


**Fig. 12.** Example of temperature field of an experimental mould at regulated heating, 32 emitters, τ=340 s

## 4. Conclusions

The paper makes the reader acquainted with the problems of specifying originally ad hoc estimated criterion for optimal infrared heating of tool, which is a thin walled mould for production of artificial leather – foil. The designed methodology, combining in itself numerical procedures and simulations together with physical experiments aims at acceleration and improvement of the stage of technical preparation of batch moulds heating in the company Magna Bohemia and in consequence at increase of the quality of the products, decrease the spoilage and thus the price of the final product, which is, e.g. softened switchboard or other softened interior parts of vehicles.

## Acknowledgements

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