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SIMULATION OF INFRARED HEATING FOR INDUSTRIAL PRACTICE

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Abstract: *The content of the upcoming article will be a presentation of the results achieved in the issue of numerical simulations of radiative heating shell moulds for the production of artificial leather. These artificial leathers have become common interior accessories in the automotive. The process of virtual heating starts with design and simulation of suitable types of reflectors of infrared emitters and their location above the model of mould. Followed by the simulation of nonstationary temperature fields containing components of temperature control. Part of simulation is also the calculation of temperature-mechanical loads of mould during the heating process.*

Keywords: ***Radiative heat transfer, simulation, artificial leather, optimization.***

1. Introduction

Heating shell moulds for artificial leather manufacturing process are realized in various ways. The forms can be heated for example by means of hot sand, oil or air. All these methods require some medium for heat up the shell mould, which could be very difficult to handle with.

Another utilizable method of heating-up the mould is based on the using a set of infrared heat emitters located above the shell mould. This heating method has several advantages. Heating using thermal radiation does not require any heating medium. The main disadvantage of this approach is the difficulty in uniformly heating of shell moulds. The uniformity must be assured by the appropriate emitters' control. Then, the considerable outcome can provide the model of heating-up the form by particular set of emitters, which is based on the understanding of single emitter contribution to the warming.

This paper concerns on two points of view in simulation radiative heat transfer model. First model is aimed on single emitter. This type of simulation is useful to study of heat flow distribution and for appropriate flow optimization. Second model is utilizable for concrete industrial situations. Second model includes shape of shell moulds and set of emitters with measured values of heat flow under each emitter. The aim of this model is to determine temperature on each point of shell moulds.

2. Theory of heat transfer

In general, every part of the system radiates continuously some electromagnetic energy. The magnitude of the energy depends on the temperature of the object and its surface properties. The amount of the radiated energy depends on the biquadrate of absolute temperature. In the case of „black body" i.e. a body, which absorbs/emittes all the incident energy without any reflection, the amount of energy absorbed or emitted per square meter e_b (Wm^{-2}) is described by the Stefan-Boltzmann's law.

$$e_b = \sigma T^4 , \tag{1}$$

where T (K) stands for absolute temperature and σ = 5.670373×10−8 Wm−2 K−4 is Stefan-Boltzmann constant. In the case of a real body („gray body") we deal with emissivity ε (-)

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$$\varepsilon = \frac{e(T)}{e_b(\lambda)} = \frac{\int_0^\infty e_\lambda(\lambda,T)d\lambda}{\sigma T^4}, \quad (2)$$

that expresses the rate of emitted energy against black body emission. In the term (2) λ (m) is wavelength of radiating energy.

Supposing all the parts of the system are in thermodynamic equilibrium state, according to the Kirchhoff´s law [4] everybody emits as much energy, at each direction and each wavelength, as it absorbs. In general, monochromatic emittance ε_λ (-) and monochromatic absorptance α_λ (-) depend on absolute temperature T (K) and the direction of radiation. For non-black diffusive body is possible to simplified angle independent term

$$\varepsilon(T) = \alpha(T). \quad (3)$$

For more details see [4]. Amount of radiated energy (radiosity) B (Wm^{-2}) is determined as sum of reflected energy and energy emitted by self. It can be expressed by

$$B = \rho H + \varepsilon e_b. \quad (4)$$

where H (Wm^{-2}) stands for irradiance (i.e. flux of energy that irradiates the surface per square meter), ρ (-) stands for reflectivity of the surface of the considered body.

Next we perform partition of surface of all parts of the system into a set of particle surfaces A_i. For arbitrary two particle surfaces A_i, A_j ($A_i \neq A_j$) we introduce view factor F_{i-j} (-), which quantifies the fraction of energy that leaves surface A_i and reach the surface A_j, , so way

$$F_{i-j} = \frac{1}{A_i}\int_{A_i}\int_{A_j}\frac{\cos\beta_i\cos\beta_j}{\pi r^2}dA_i dA_j \quad (5)$$

where r (m) stands for the join of particular points A_i and A_j and β_i (rad) is the angle between the join and outer normal of A_i in the particular point of A_i. Eventually, heat flux Q_i (Wm^{-2}) of particular surface A_i in the direction of outer normal due to radiation can be expressed as

$$Q_i = \frac{e_b - B_i}{(1-\varepsilon)/(\varepsilon A_i)}. \quad (6)$$

3. Production process of artificial leathers

The process of manufacturing of artificial leathers is called "Slush moulding". The base of this method is a shell mould. The mould is usually made of nickel. The inner face of the mould has to be formed so that it gives the corresponding shape and surface relief suitable to the final product. It is covered with thermoplastic powder based on PVC or PU. Outer surface is heated by infrared emitters up to the temperature of approximately 220 °C. Infrared emitters are clamped into a special structure located above the mould. The whole process of heating is carried out under the temperature regulation. When the mould is cooled down by water, melted powder becomes a compact mass representing artificial leather. The final leather is subjected to the strict quality control when removed from the mould. For example, in the case of artificial leather for dashboard is checking the thickness in the airbag area [2].

4. Process of infrared heating design

The process of heating design is shown in the fig. 1. The chart is divided into three main parts. It is the simulation of infrared emitters, simulation of heating and the heating on the real production line. The simulation of emitters is used for design of suitable reflector shape to achieve the appropriate shape of heat characteristic. These simulations are useful to make the particular reflector type of infrared emitters. The phase heating simulation is based on positioning emitters around a model of the mould. After that the FEM analysis in CAE software follows in order to calculate the final temperature dependant on time. In case of a positive result, the necessary data are exported for physical installation of infrared emitters into the production line. The phase of heating in the real process begins with the installation of the emitters on the production line. Correctness of the installed heating is tested on the first samples of the artificial leather.

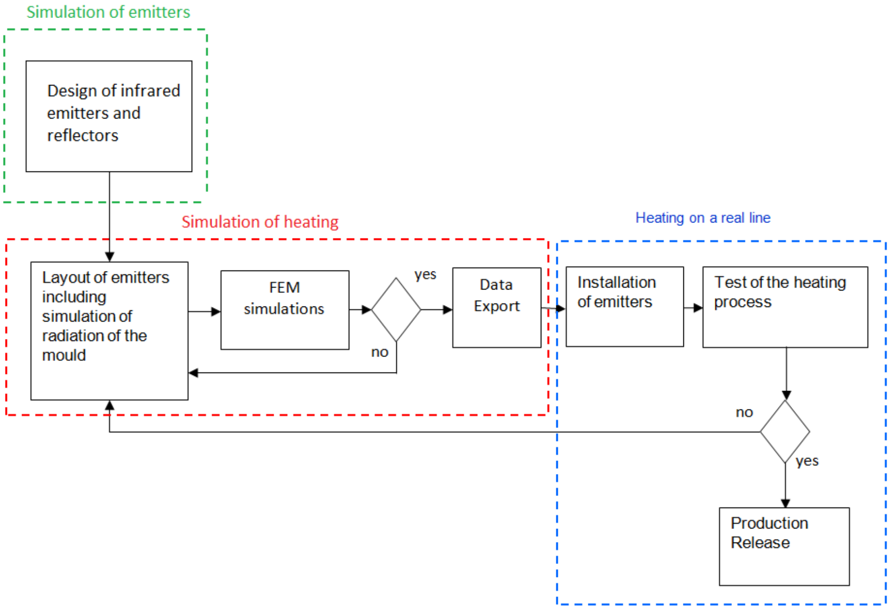

Fig. 1: Process of design of infrared heating

5. Numerical model of infrared emitter

Model of infrared emitter is designed to be able to figure heat flux distribution (6) over any surface in two-dimensional space. Model is composed of set of straight particle surfaces, whereas every particle surface has given particular properties (location, emittance and temperature). Model uses Hottel´s crossed-strings rule to determine view factors between particle surfaces of the whole system.

5.1 IRE Designer

The model was implemented in simulation tool named IRE Designer. In this tool the concrete simulated system is divided into two logical parts. The first part is the irradiated surface. The second part supplies emitters functionality. As it was already mentioned, the numerical model supposes partition both these parts into a set of straight partial surfaces i.e. segments. Difference between irradiated surface and emitter segments is at access to those single surfaces. In case of irradiated surface segment, the main demand is to point out numerical outputs of particular simulation. Every emitter segment has implemented several functions, which supply the manipulation with shapes, position and other emitter properties. Fig. 2 shows sample screen of IRE Designer user interface.

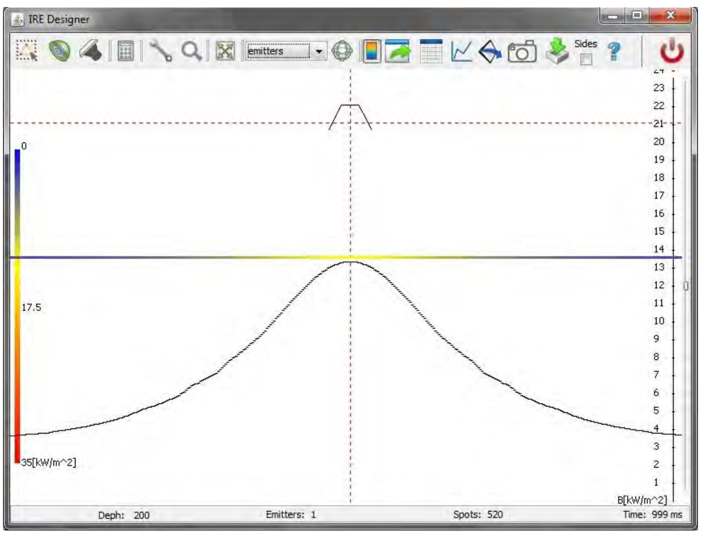

Fig. 2: Sample simulation in IRE Designer tool

5.2 Calibration

To determine accuracy of values given by particular simulation, we need to compare values with real measured ones. The IRE Designer tool has implemented functionality for importing measured values in specific text format.

For testing, we selected the Phillips IRZ500 emitter. Fig. 3 shows the side view of the emitter. Real measurement was realized by Hukseflux SBG01 heat flux sensor. The comparison between measured values and values obtained by the numerical model is shown in fig. 4. There, the gray line on the right half figures out the measured values, the black curve points out the numerical simulation results. Due to symmetry of heat flux trace, the measurement is performed under only a quarter of irradiated surface.

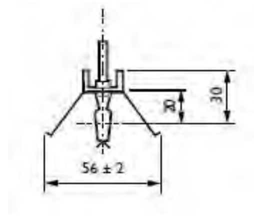

Fig. 3. Side view of Phillips IRZ500.

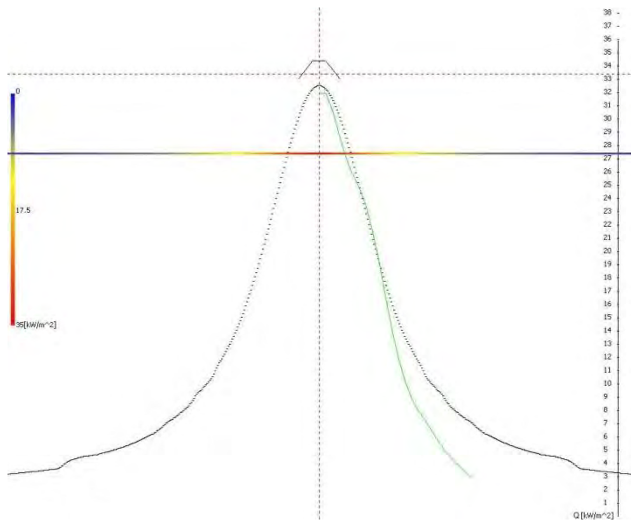

Fig. 4: Comparison of measured values and the simulated ones.

5.3 Optimization

As mentioned, described numerical model is able to use for example for new emitter configuration design. In general, it is not possible to solve the problem analytically. So it is appropriate to use automated optimization. For the purpose, the tool implements gradient descent algorithm. The algorithm supposes that there is specified required tracing. Then, the algorithm gradually manipulates the reflector points and compares the simulated results to the demanded track. The best partial result is the basis for the next step of the algorithm. Fig. 5 shows four different model situations which differ only in reflector shapes. The properties of all surfaces are the same for all configurations.

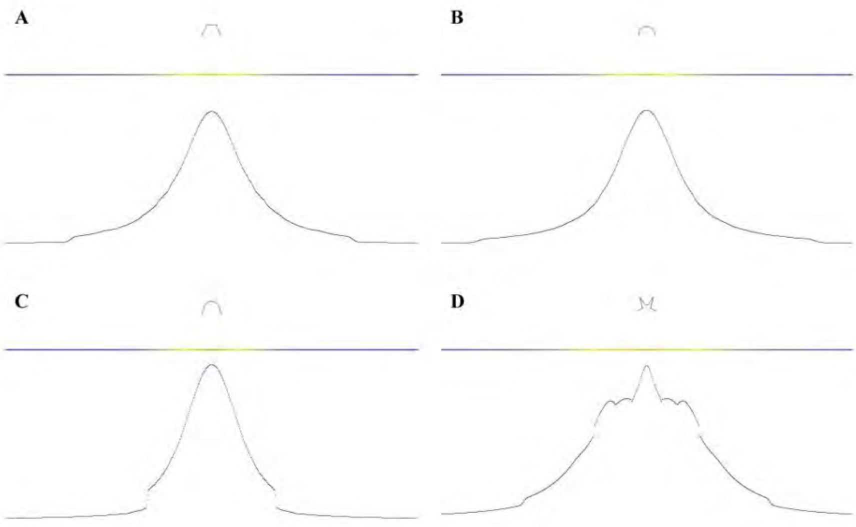

Fig. 5: Comparison of four different reflector shapes with the same properties

6. Simulation of shell mould heating

The simulation phase of heating begins in simulation tool named IREview Blender. Application was created in Blender software. With the use of the appropriate functions, the emitters are placed around a model of the mould and heat flux loading of the surface is simulated. The final temperature is calculated in the CAE software. The result of modeling is expected uniform temperature distribution on the mould surface.

6.1 IREview Blender

In this case the heat flux is obtained from the database of the characteristics of emitters created by means of experimental measurements in the laboratory. The required types of emitters are selected by the user from the database of emitters, see fig. 6. The fig. 6 shows various types of emitters. There are single emitters or double emitters with or without reflectors. The most used emitters are 1.6 kW and 2kW. The complete model is shown in fig. 7. The model contains shell mould, infrared emitters and frame for fixing of special holders of emitters.

Fig. 6: IREview Blender - database of emitters [2]

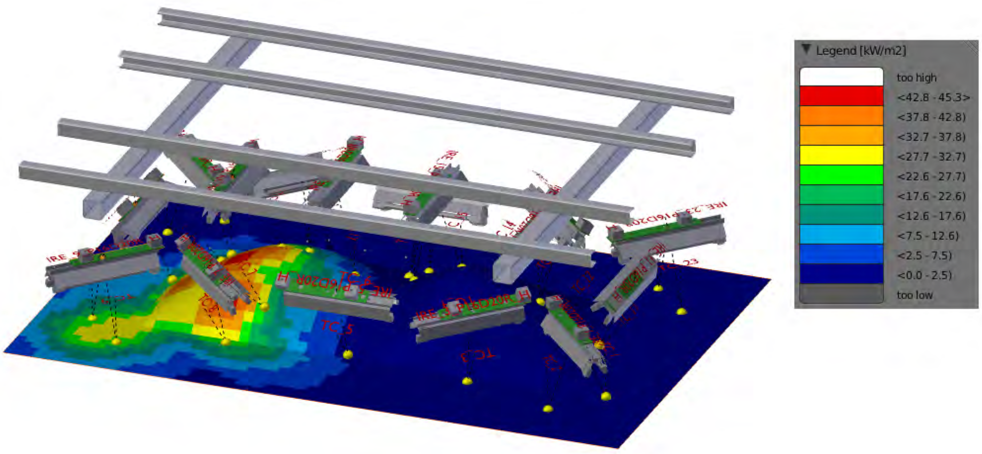

Fig. 7: IREview Blender - distribution of heat flux [2]

6.2 Calculation of the temperature

Final temperature of the mould surface is possible to calculate in the CAE software by means of special exports from the IREview Blender tool, see fig. 8. These analyses are time dependent. Suitable combination CAE software and IREview Blender tool allows to realize regulated heating which is necessary for real heating on the production line.

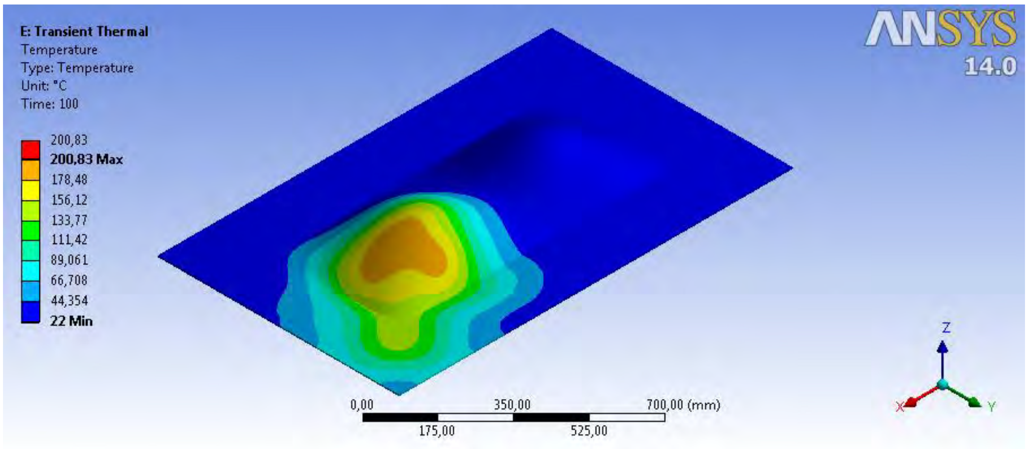

Fig. 8: ANSYS - distribution of temperature [2]

7. Conclusions

Represented numerical model is based on radiation heat transfer theory and its utilization for two-dimensional case. Such model enables to use optimization algorithm, which finds alternative reflector shape. Actually, the model does not include dynamical processes such as heat transfer by conduction or gradual heating of model components. Numerical model implemented in IRE Designer tool can be used as tool for a design of demanded reflector configuration. For heating of shell moulds is used IREview Blender tool and CAE software for temperature calculation. Further development is focused on linking IRE Designer tool with IREview Blender tool to simulate infrared heating using new emitters types with various shaped reflectors. With suitable virtual model of emitter with reflector will not be necessary the experimental measurements of infrared emitters for simulation of temperature field.

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