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CONTRIBUTION TO COMPUTATIONS OF TEMPERATURE FIELD OF ALUMINIUM CASTING

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Summary: *The interest of contemporary casting production is directed to the aluminium base alloys. The research starts with the pure aluminium casting where the process of solidification influences the quality of the product. For this goal one must know the temperature fields of the casting and the mould. The contact resistance is analysed. It is necessary to know the space shape of the temperature fields and the history of changes including the total time of solidification. This contribution contains the brief description of the numerical model which has been used by the authors. The model is based on the finite volume heat balance (i.e. the first and the second laws of the thermomechanics). The temperatures were evaluated from a voltage reading on thermocouples. A comparison with measured temperatures as the change in time is presented.*

1. INTRODUCTION

As a continuation of previous research works altogether in scientific branches of applied thermomechanics, thermokinetics and technological heat processes a next step is presented here. The basic goal of this work is to achieve a more precise knowledge about the heat processes during solidification of aluminium base alloys. For this purpose it has been chosen the pure aluminium casting of the desk shape solidifying in the steel form also of the desk shape. Both the desks are insulated from the upper and downer sides. The system consisted from the casting and the mould and it was vertical.

The research work is a combination of the numerical computations and their experimental verifications.

2. THE INITIAL EQUATION OF THE TEMPERATURE FIELDS SOLUTIONS

The basic equation of the solution is the Furrier's partial differential equation, written for 2D solution

$$\rho c \frac{\partial t}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial t}{\partial y}\right) \tag{1}$$

where ρ [kgm^{-3}] is the density, c [$Jkg^{-1}K^{-1}$] is the specific heat, λ [$Wm^{-1}K^{-1}$] is the conductivity. As can be seen from the equation (1) the conductivity is dependent on the temperature which is variable value inside the solved system. So the conductivity cannot be written in front of the

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2^{nd} derivative. The equation (1) describes the temperature field of the system in the differential shape. τ [s] specifies time.

In previous works the authors have applied the parameter e_v (the specific volume enthalpy in Jm^{-3}) to be able to simulate the latent heat of solidification when the temperature field of the casting is solved. The equation (1) was used for the temperature field of the mould.

The formulation of the boundary and the initial conditions will be explained in the next chapters. A special attention must be devoted to the contact between the casting and the mould.

3. THE BRIEF DESCRIPTION OF THE PHYSICAL AND MATHEMATICAL MODELS

The basic equation of the physical and mathematical models in the difference shape is

$$\Delta e_n = \frac{\Delta\tau}{a^2}\begin{bmatrix} \lambda(t_{nxl}, t_n).(t_{nxl} - t_n) + \lambda(t_{nxp}, t_n).(t_{nxp} - t_n) \\ +\lambda(t_{nyl}, t_n).(t_{nyl} - t_n) + \lambda(t_{nyp}, t_n).(t_{nyp} - t_n) \end{bmatrix} \quad (2)$$

for the temperature field of the casting. The enthalpy of the nodal point n is calculated from the heat fluxes from the neighbouring points as is seen from the fig.1. The conductivity is introduced for the average temperature between the nodal points. For example $\lambda(t_{nxl}, t_n)$ is the average conductivity at the temperature

$$t_{averagge} = \frac{t_{nxl} + t_n}{2}$$

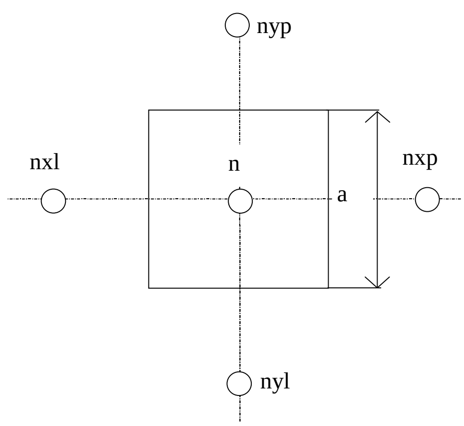

Fig.1 The square shape element

From the enthalpy of the nodal point it is calculated the temperature. The enthalpy and the temperature is drawn at the graph at Fig.2 for pure aluminium.

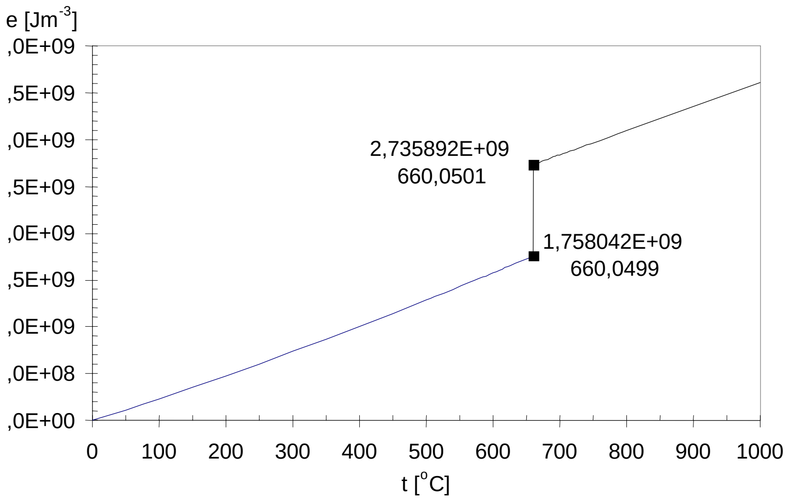

Fig.2 The enthalpy of the pure aluminium as the function of temperature

For the temperature field of the mould it is

$$\Delta t_n = \frac{\Delta\tau}{(\rho c) a^2}\left[\begin{array}{l}\lambda(t_{nxl}, t_n).(t_{nxl} - t_n) + \lambda(t_{nxp}, t_n).(t_{nxp} - t_n) \\ +\lambda(t_{nyl}, t_n).(t_{nyl} - t_n) + \lambda(t_{nyp}, t_n).(t_{nyp} - t_n)\end{array}\right] \tag{3}$$

where the temperature instead of the enthalpy is calculated.

4. THE MAIN DIMENSIONS OF THE SYSTEM AND THE BOUNDARY CONDITIONS OF SOLUTION

The object is symmetrical so only one half of the casting is calculated (see Fig.3). The positions of the thermocouples are seen in the casting and the mould (No. 1 up 7). The measured temperatures frequency was 0,1 s.

The casting: h_o = 10 mm 1st specimen, height v_o =. 125 mm, material pure aluminium 99,9%
h_o = 18 mm 2nd specimen, the height and the material are the same.
The mould: h_f = 15 mm steel 0,23%C

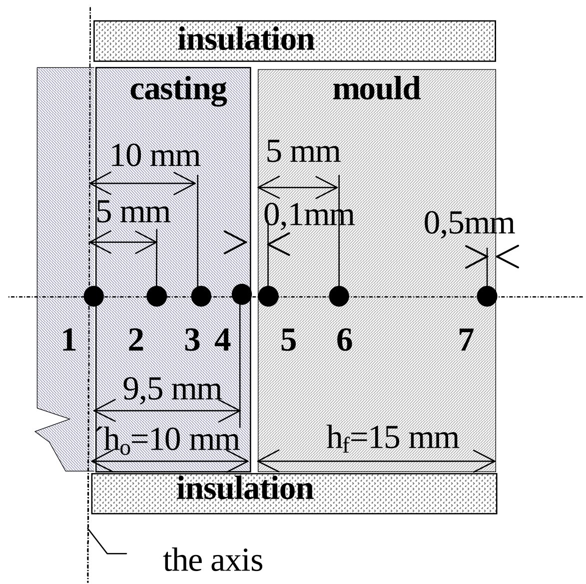

Fig.3 A schematic view on the casting and the mould and the thermocouples positions.

In effort to approximate to real casting it is necessary to take into account the gap between the casting and the mould. The gap changes with the temperature of the aluminum. The linear contraction coefficient influences the thickness of the gap. The conduction heat transfer through the gap is influenced by the gas within the gap. So the determination of the heat transfer between the casting and the mould is very complicated.

The linear contraction coefficient has been taken from the previous work and one of its relations on the temperature is drawn on fig.4.

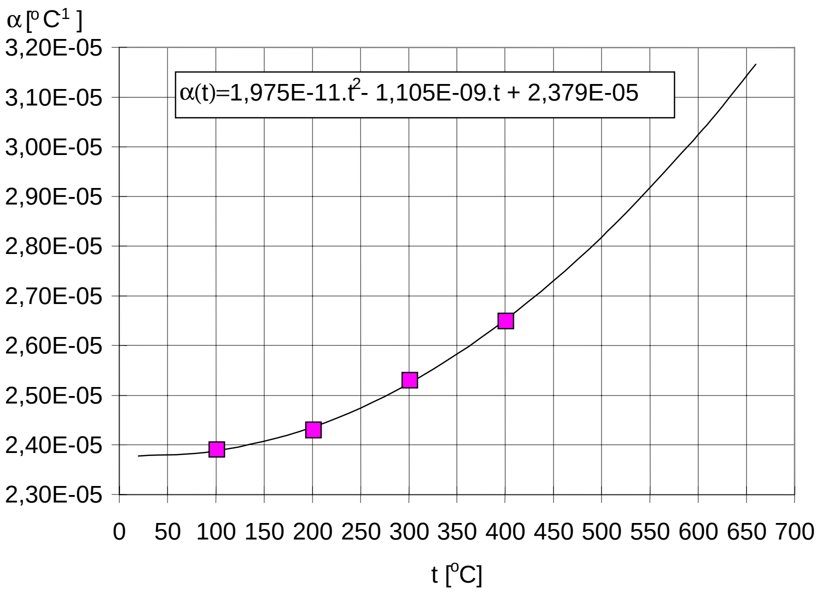

Fig.4 The linear contraction coefficient according to Smithells

The contraction coefficient is defined as

$$\beta = \frac{1}{\Delta h_o} \frac{d(\Delta h)}{dt} \tag{4}$$

where Δh_o [m] is the initial thickness of the plate.
While the temperature is falling down the thickness of the plate is diminishing to

$$\Delta h = \Delta h_{sol} \left[1 + 0{,}658e - 11\left(t^3 - t_{sol}^3\right) - 0{,}553e - 9\left(t^2 - t_{sol}^2\right) + 2{,}375e - 5\left(t - t_{sol}\right)\right]$$

The gas conductivity also changes the conditions of the heat transferred through the gap. The influence of the temperature changes must be taken into account.

5. THE RESULTS OF COMPUTATIONS

At the fig.5 one can see the calculated results when the contact was supposed to be ideal. In this case the casting solidifies quicker then in real situation i.e. the results of measurements. In the case when we supposed then the contact is covered by the layer of soot, the total time of solidification prolongs. The line t_{cr} = 660°C is the temperature of crystallisation.

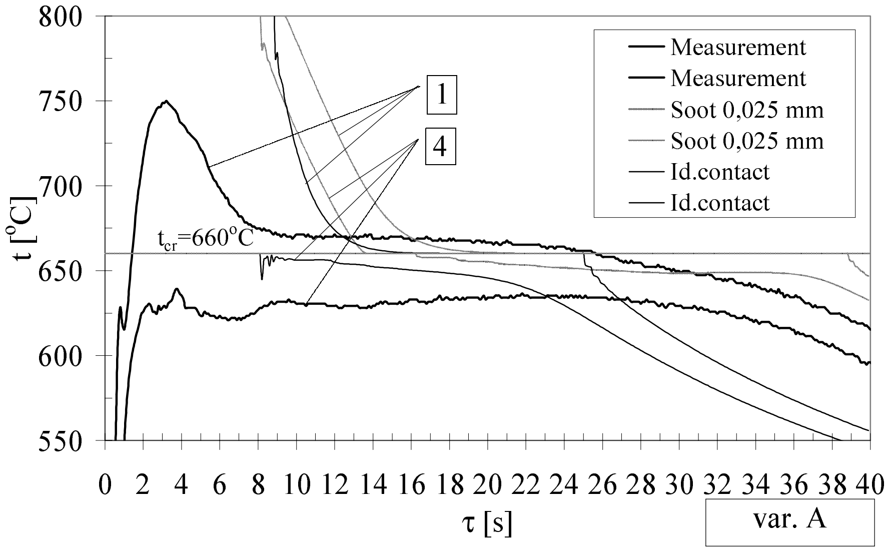

Fig.5.The comparison of two variants of calculation with measurements

6. THE MEASUREMENTS RESULTS AND THEIR COMPARISON WITH CALCULATIONS

The results of computation had been compared with measurements. At the fig.6 there are the temperature curves at the axis (point 1 acc.to fig.3) and at the contact surface (point 4 acc.to fig.3). The curves were obtained numerically for various boundary conditions at the contact:

line t_{cr}	the temperature of crystallisation,
Rinit	the constant hear resistance between the casting and the mould
Smith.	the gap with the changing thickness calculated according to Smithells' contraction coefficient
Ražnj.	the gap with the changing thickness calculated according to Ražnjevič' contraction coefficient
e	the total time of solidification obtained experimentally
s	the total time of solidification obtained numerically with the gap thickness changing according to Smithells' contraction coefficient
r	the total time of solidification obtained numerically with the gap thickness changing according to Smithells' contraction coefficient

As it is seen from the fig.6 the total time of solidification differs. It depends on the value of contraction coefficient according to various authors. This parameter could be ascertained experimentally. These measurements were not included into our research.

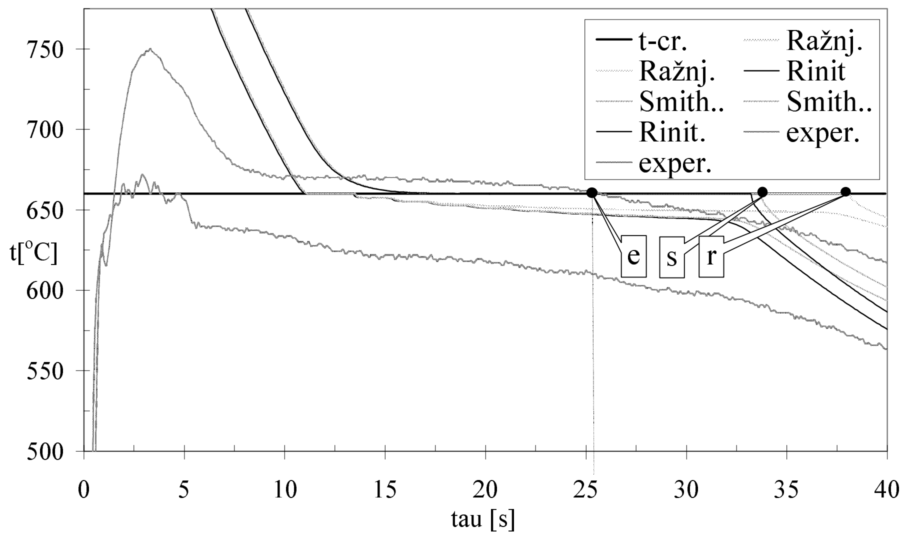

Fig.6 The comparison of measurements and calculations for various boundary conditions.

At the fig.7 there are plotted the temperatures of the mould (points 5, 6, 7 see to fig.3).

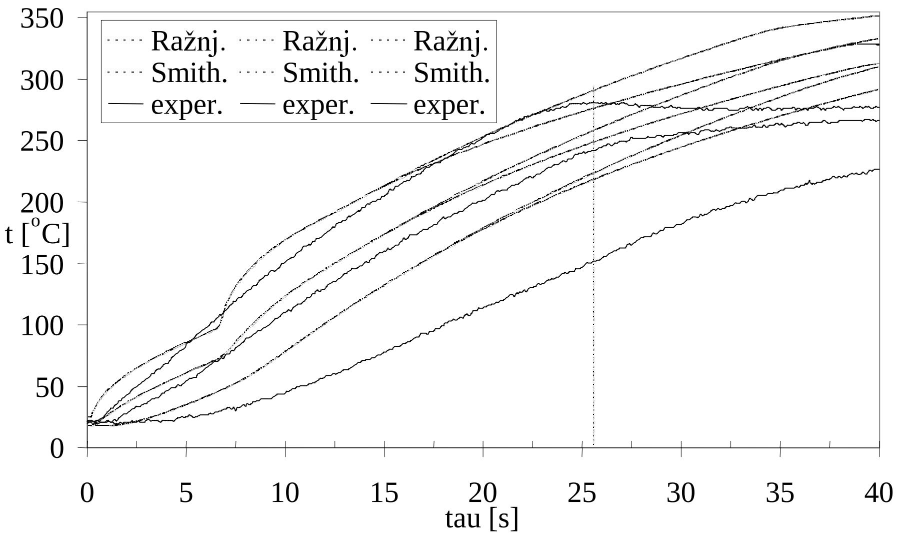

Fig.7 The temperatures against time at the mould (points 5, 6, 7)

From the fig. 7 it is seen that the changes of temperatures obtained numerically start to differ from measurement after 25 s approximately. The analysis of the temperature course in the mould will be done in future research.

May be that the causes of this phenomenon could be found in the process of the technology of the experiment. The experimental device according to fig. 3 is vertical. The liquid metal is poured from the upper opening. So the liquid level heighten in the mould from the bottom upward. The proper casting time was 27 s, while the process of solidification was 33 s. These time periods superimpose each other. So the next programs for calculation of temperature fields must involve the time period of pouring.

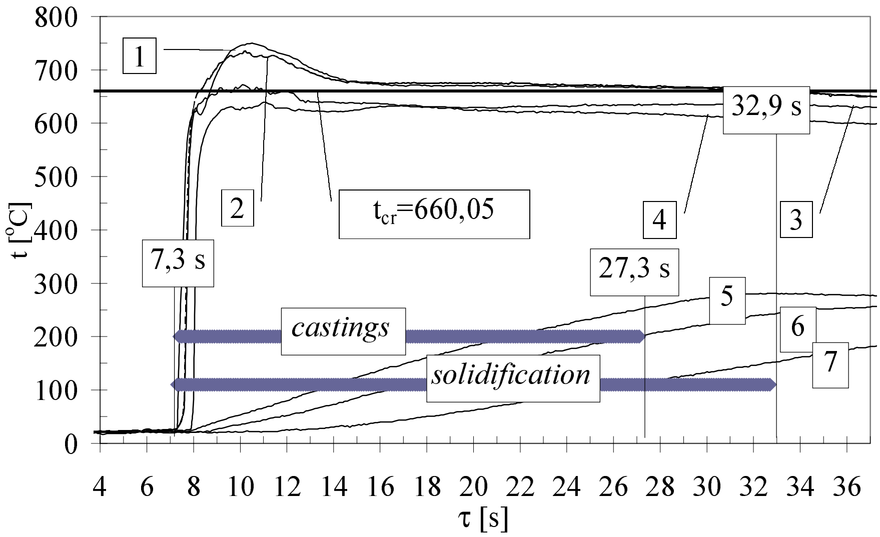

Fig.8 The overlapping of the casting and solidification periods.

7. CONCLUSION

The presented contribution contents only small part of the research that started in last year. The research continues in this year. It is necessary to state the main goals for the year 2001. The first problem is the continuation of the gap analysis with respect to the influence of the beginning resistance at the contact the casting and the mould. The second goal is to find more precise contraction coefficients of the pure aluminium. Then the process of pouring will be taken into account in new computational program construction. The research will continue with analysis of the aluminium alloys. The process of die casting and casting under vacuum will continue later on.

At the end of our contribution the authors allow to say thanks to the main collaborates Doc.Ing. Jan Lukeš, CSc, and Ing.Jiří Veselý.

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