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# HEAT TRANSFER SIMULATION IN MOLD DURING DIE CASTING OF STEEL

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ABSTRACT: The heat transfer in the melt-mold system during die casting process is made through conduction, convection and radiation. So, during pouring of melt into the mold, interface heat transfer is through forced convection and radiation. After the melt filled the mold, the interface heat transfer depends on the contact between melt and mold. Temperature evolution in mold wall during die casting of steel was analyzed by a finite element simulation and the results were compared with experimental data. The simulation consists in solving a conduction heat transfer problem with appropriate initial and boundary conditions.
KEYWORDS: die tool steel, die casting, K-type thermocouple, finite element analysis

## INTRODUCTION

The die casting process consists in pouring a molten material (metal or alloy) into the mold cavity and pressing it under high pressure. The cavity mold is filled in a few seconds. After the melt has solidified, the casting is removed [1].

The heat transfer in the melt-mold system during die casting process is made through conduction, convection and radiation [1-5]. So, during pouring of melt into the mold, interface heat transfer is through forced convection and radiation. After the melt filled the mold, the interface heat transfer depends on the contact between melt and mold.

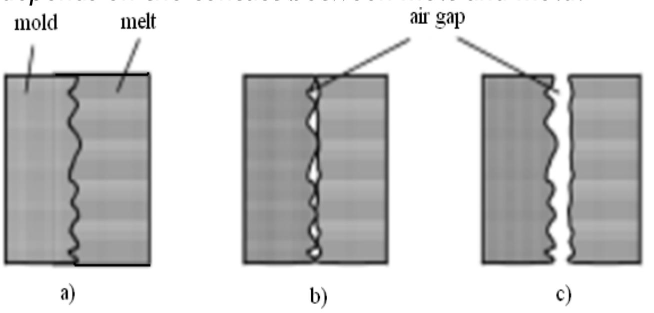



Figure 1. Possible contacts at the melt-mold interface:
full (a), partial (b) and no (c) contact [1]

The melt-mold contact is expected to be formed during three stages, which are summarized in figure 1 [1]:

- In stage I, at the beginning of solidification, the contact between molten metal and mold can be assumed good (figure 1a). Heat transfer is made through conduction from molten metal to mold wall;
- As a solid layer forms, the metal will shrink away from the mold and a discontinuous air gap will result (stage II). So, the mold and solid metal will have partial contact (figure 1b). Heat transfer is made now through solid metal/mold conduction at the contact surface and through radiation at the air gap.
- In stage III the solidified metal will pull away completely from the mold wall and the heat transfer will be made only through the gap (figure 1c).

Also, heat transfer by free convection and radiation at the mold exterior surface in contact with the environmental air, have a profound influence on temperature gradient inside the mold [4]. Figure 2 shows the expected temperature distribution during die casting process [1].

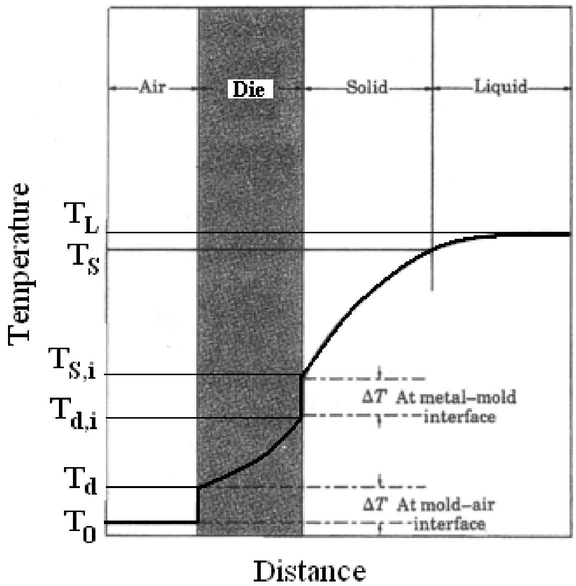



Figure 2. Temperature gradient during die casting process in the melt-mold system [1]

The temperature subscripts used in figure 2 are: L - liquidus, S – solidus,
i - interface, d - die, 0 – ambient.

*Both analytical and numerical models were developed to treat the heat transfer during solidification process, mainly based on the finite difference method [2, 4, 6, 7] and Beck's nonlinear estimation method [8, 9].*

*Also, several commercial software packages, based on finite element analysis, were used to simulate this process, such as: ProCAST [5], Ansys [10] or Abaqus [11].*

*In this study, the Comsol Multiphysics 4.2 software is used to simulate the conduction heat transfer in the mold wall during die casting processing. The simulation results are compared with experimental data obtained by K-type thermocouples measurements taken from [12].*

## MATERIALS AND EXPERIMENTAL METHOD

*The experimental details were described widely elsewhere [12].*

*The mold material is 55MoCrNi16 die tool steel grade (corresponding to AFNOR 55NCDV7 or EN 1.2714), with the following chemical composition: 0.5-0.6 %C, 0.1-0.4 %Si, 0.5-0.8 %Mn, 1.4-1.8 %Ni, 0.5-0.8 %Cr, 0.15-0.3 %Mo, max. 0.03 %S, max. 0.03 %P.*

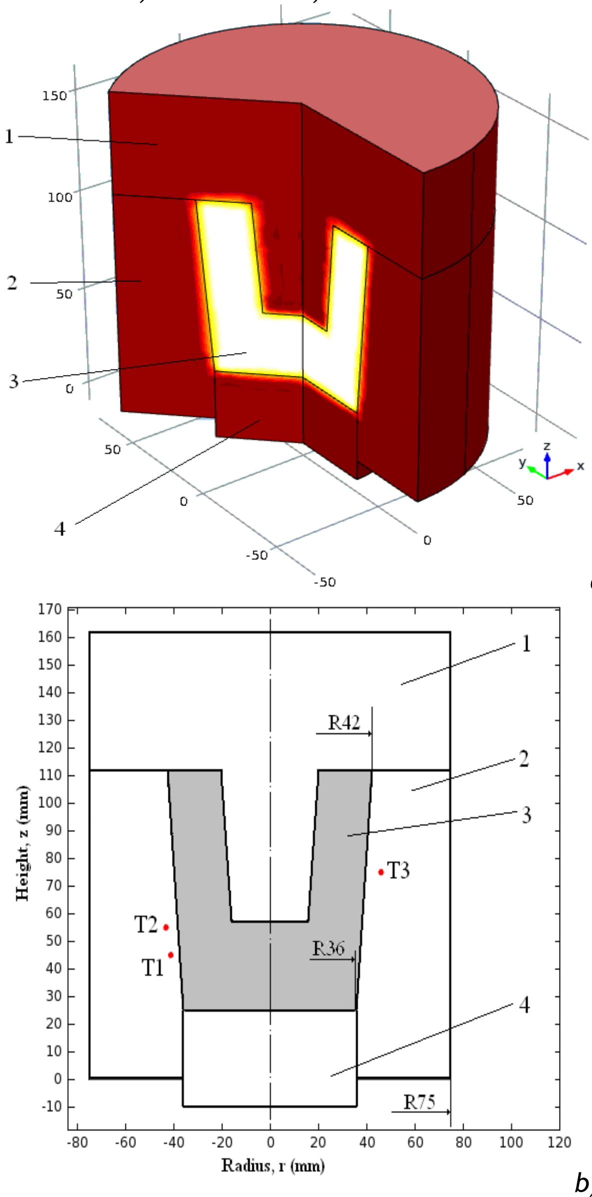



*Figure 3. Mold assembly (a) and T1-T3 thermocouples position (b): 1-upper die, 2-mold, 3-melt, 4-lower die*

*In order to evaluate the temperature changes in the mold wall, three K-type thermocouples were inserted in holes drilled to different depths around the mold diameter. The whole assembly is 162 mm height and 150 mm diameter. The mold has a glass shape with a height of 112 mm and wall thickness of 39 mm at the bottom and 33 mm at top.*

*Figure 3 shows the geometric shape of mold assembly (a) and the thermocouple position in the mold wall (b).*

*The thermocouples position coordinates are given in table 1.*

*Table 1. Thermocouple position coordinates*

| Thermocouple | Radius, r (mm) | Height, z (mm) |
|---|---|---|
| T1 | 41 | 45 |
| T2 | 43 | 55 |
| T3 | 46 | 75 |

*Experimental measurements with the three temperature sensors were recorded simultaneous with a computer aided data acquisition system [12].*

## MODEL FORMULATION

*To simulate the temperature evolution in mold wall during die casting of steel, the Comsol Multiphysics 4.2 software is used. In the Heat transfer module of the program, the space dimension was selected as 2D axisymmetric and the study was selected as time dependent. The time step was fixed at 10 seconds, for a total period of 90 seconds. This period coincides with the total experimental processing time (purring the melt into de mold and die casting [12]).*

### Heat conduction in mold wall

*The program determines the temperature changes in the mold wall, in function of processing time, as a conventional heat conduction problem governed by the Fourier law.*

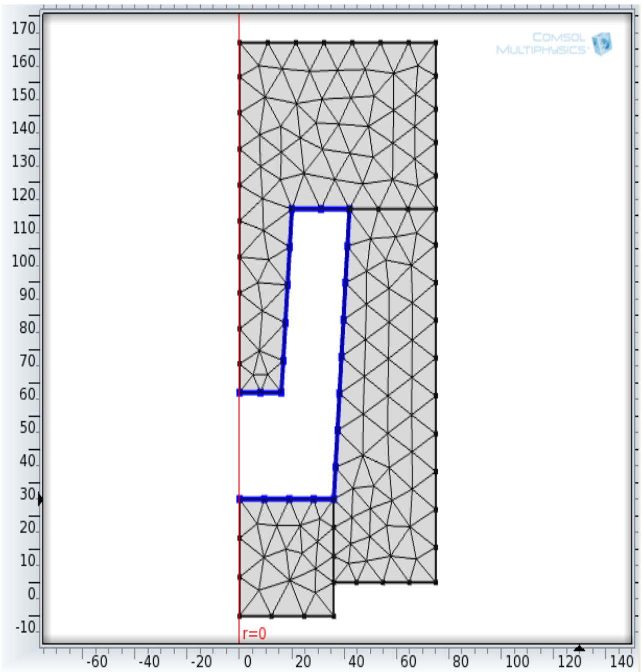



*Figure 4. Mesh of the mold assembly consisting of 265 elements*

*The upper die, mold and lower die were modeled together as one piece because they are made of the same steel grade. The complete assembly mesh consists of 265 elements and is presented in figure 4.*

*The input parameters for the heat conduction problem were the thermo-physical properties of the die tool steel (thermal conductivity $\lambda = 50\ W/m\cdot K$; density $\rho = 7833\ kg/m^3$; heat capacity at constant pressure $c_p = 465\ J/kg\cdot K$ [3]) and mold initial temperature experimentally determined ($T1_i = 125\,°C$, $T2_i = 117\,°C$ and $T3_i = 126\,°C$).*

*By the simulation were obtained values of the temperature in the same points in the mold wall where thermocouples were mounted (see table 1).*

## *Heat flux transmitted at melt/mold interface*

*The heat flux coming from the melt through the mold wall area is calculated with the following formula:*

$$q_0 = \alpha\left(T_{ext.} - T_i\right)\left[W/m^2\right] \qquad (1)$$

*The program input parameters are: the heat transfer coefficient $\alpha\left[W/m^2\cdot K\right]$ and the melt temperature, which was experimentally measured by an infrared thermometer after purring the melt in the mold $T_{ext} = 1541\ °C$ [12].*

*The most important factor affecting the rate of heat transfer at melt/mold interface is the heat transfer coefficient $\alpha\left[W/m^2\cdot K\right]$. Its value depends on the thickness of the air gap at the interface. Once the air gap forms, the heat transfer across the interface decrease rapidly and a relatively constant value of α is attended [2].*

*In the simulation the value of α was changed until the temperature values were overlapping the experimental ones.*

## *Mold exterior surface to ambient radiation*

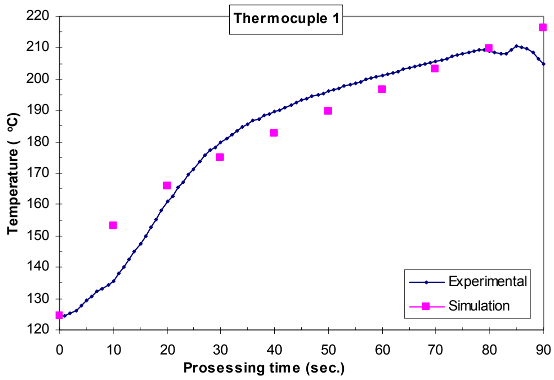
*The input parameters are: mold surface emissivity $\varepsilon = 0.9$ and the ambient temperature $T_{amb.} = 20°C$.*

*Also, the following major assumptions were considered in the simulation:*

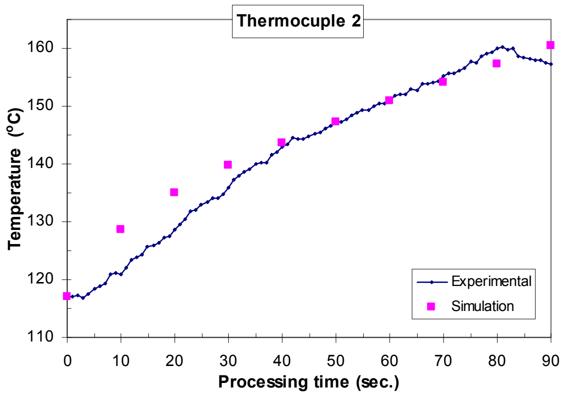
- ☐ *the heat flow is unidirectional;*
- ☐ *the thermo-physical properties of the mould material are uniform (throughout the bulk) and remain constant over the processing time;*
- ☐ *the melt is in complete contact with the mould surface (no air gap is formed);*
- ☐ *the melt/mould interface temperature remains constant from the start to*
- ☐ *end of die casting processing.*

## *RESULTS AND DISCUSSIONS*

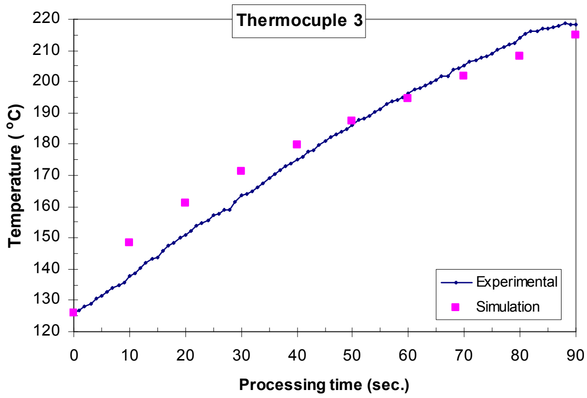
*The temperature values of the heat conduction simulation were verified by comparison with the experimental measurements. The results are given in figure 5a-c).*




*a)*




*b)*




*c)*

*Figure 5. Experimental and simulation temperature values*

*For matching the experimental and simulated temperature values, the following values of the heat transfer coefficients were used: $\alpha_1$ and $\alpha_3 = 130\ W/m^2\cdot K$, $\alpha_2 = 60\ W/m^2\cdot K$.*

## *CONCLUSIONS*

*The Comsol Multiphisycs 4.2 software package was used to simulate the heat transfer through the mold wall during die casting of steel.*

*The simulation by the finite element method was done to solve the conduction heat transfer problem inside the mold body. Boundary conditions and initial values were set before starting.*

*Among initial temperatures of the melt and mold, the heat flux at melt/mold interface and the radiation heat transfer at the external mold surface, were taken into account. The most important parameter was the heat transfer coefficient $\alpha\ [W/m^2\cdot K]$ used to find the match between the simulation results and the experimental ones.*

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