Wydział Inżynierii Mechanicznej i Informatyki
Faculty of Mechanical Engineering and Computer Science

Applications of Physic in Mechanical and Material Engineering APMME 2021
Częstochowa, 19 luty 2021 rok

Department of Mechanics and Fundamentals of Machinery Design from Częstochowa University of Technology

# Numerical modeling of basic physical phenomena during the creation process of a casting-riser system

***Leszek Sowa***

## Mathematical model

The heat conductivity equation:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T(x_i,t)}{\partial x_j}\right) + \dot{Q}$$

where the volumetric efficiency of the internal heat source is follows:

$$\dot{Q} = \rho_S L \frac{df_S(T(x_i,t))}{dt}.$$

Finally, the heat conductivity equation is in a without-source form:

$$\rho C_{ef} \frac{\partial T}{\partial t} = \frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T}{\partial x_j}\right)$$

The effective specific heat (Cef) for each phase is determined as follows:

$$C_{ef}(T) = \begin{cases} c_L(T), & T > T_L, \\ c_{LS}(T) - L\dfrac{\partial f_S}{\partial T}, & T_S < T < T_L, \\ c_S(T), & T < T_S. \end{cases}$$

Additionally, assuming a linear function of the solid phase fraction ($f_s$), we obtain the following $C_{ef}$ form for the mushy zone:

$$f_s = \frac{T_L - T}{T_L - T_S} \qquad C_{ef} = c_{LS} + \frac{L}{T_L - T_S}$$

where: $T$ is the temperature [K], $t$ is the time [s], $\rho(T)$ is the density [kg/m$^3$], $\lambda(T)$ is the thermal conductivity coefficient [W/(m·K)], $T_L$,$T_S$ are the temperature of liquids and solids line, respectively [K], $c_L$, $c_{LS}$, $c_S$ are the specific heat of liquid phase, mushy zone and solids phase, respectively [J/(kg·K)], $L$ is the latent heat of solidification [J/kg], $x_i$ are the coordinates of a node position [m], $T_{in}$ - the initial temperature [K], $T_a$ - the ambient temperature [K], $\alpha_M$ - the heat transfer coefficient between the ambient and the mould [W/(m$^2$K)], $\lambda_M$ - the thermal conductivity coefficient of mould [W/(m·K)], $n$ - the outward unit normal surface vector.

## Results of numerical simulations

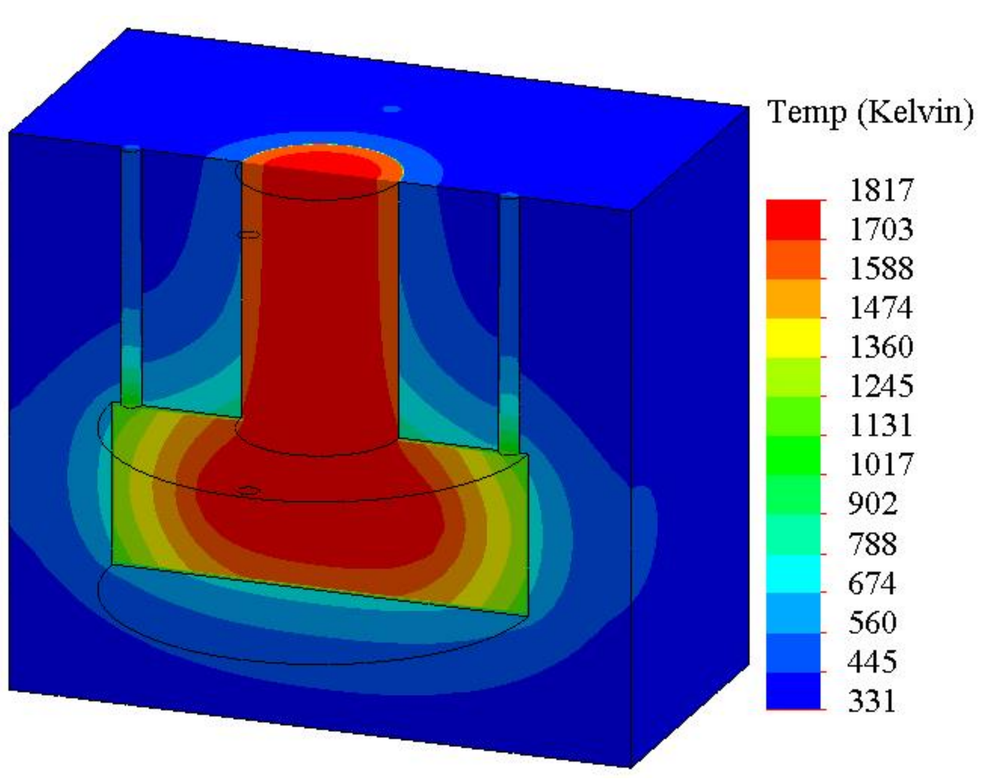


Fig.2.Temperature distribution at $t$=200 s, I variant

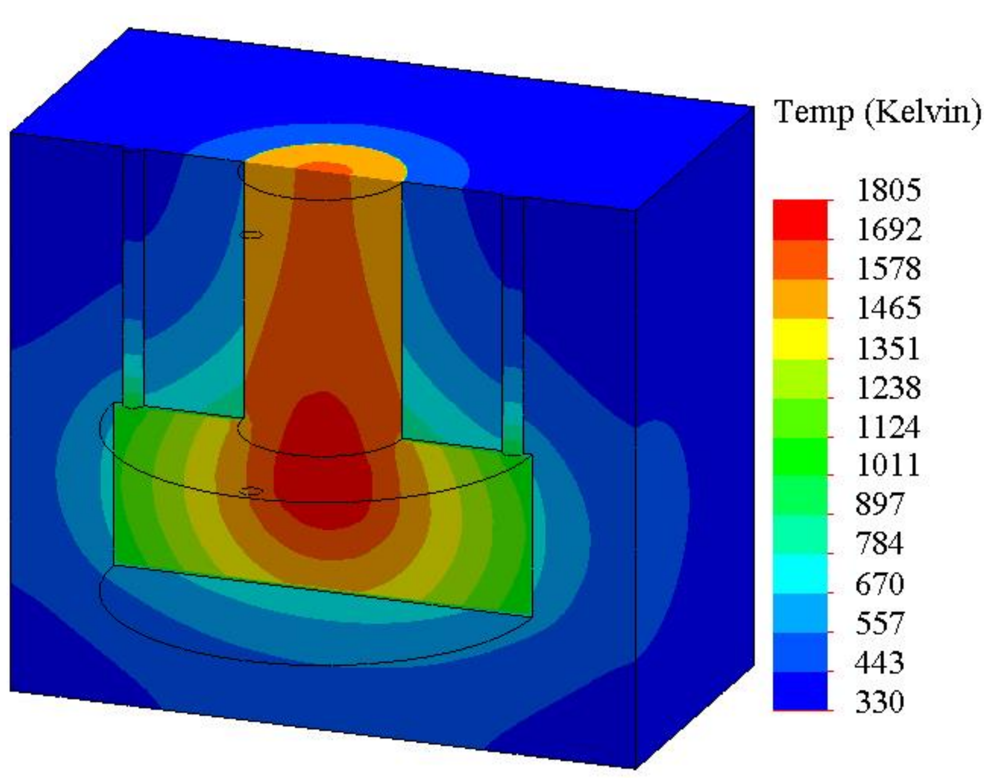


Fig.3. Temperature distribution at $t$=325 s, I variant

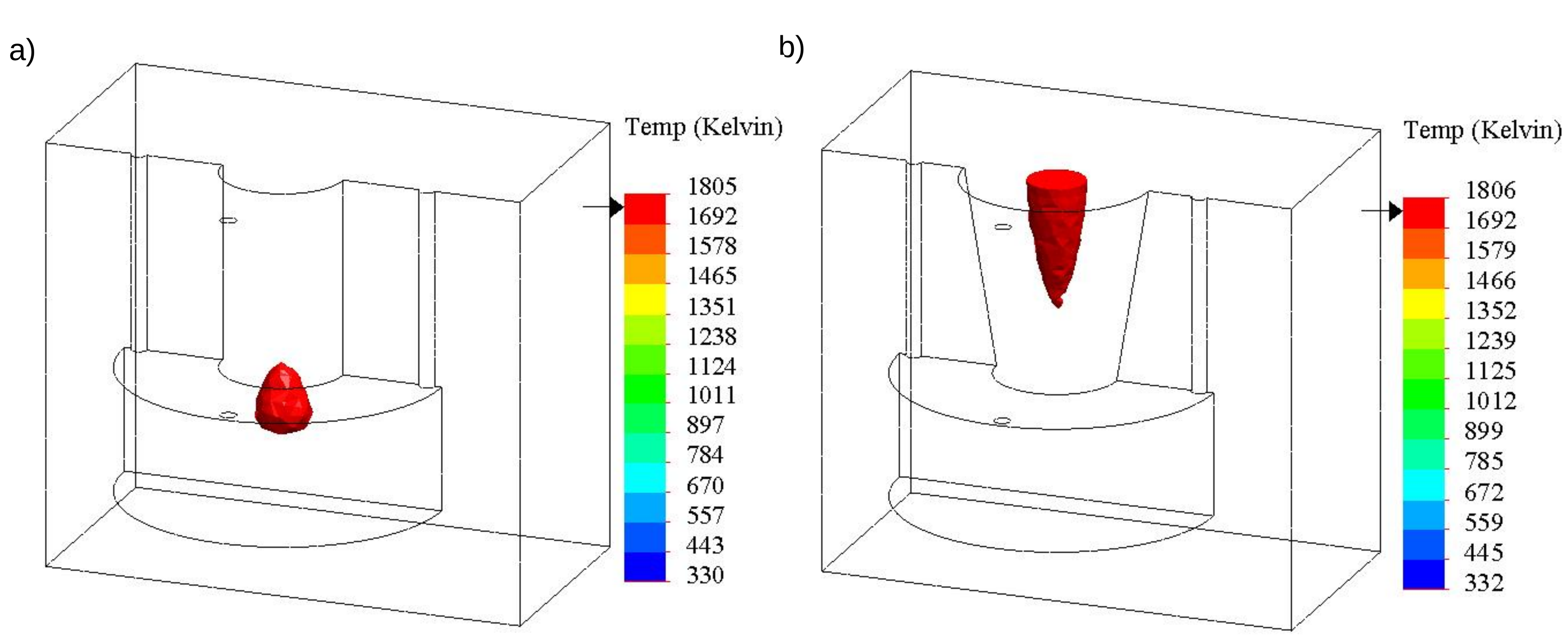


Fig.4.Temperature field above the solidus temperature at: a) $t$=325 s, I variant, b) $t$=375 s, II variant

## Numerical calculations

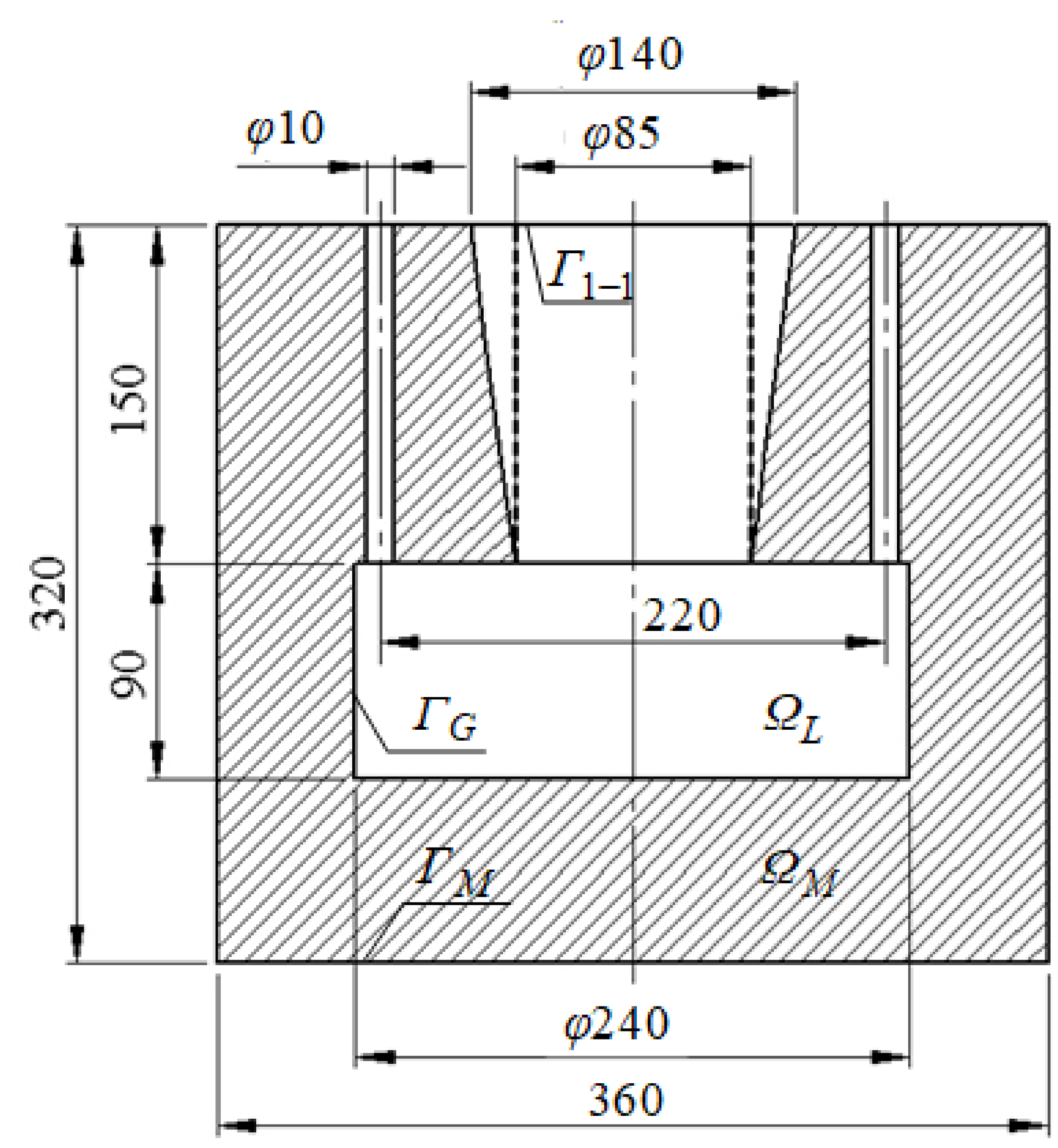


Fig.1. The cross-section of the casting-mould system and identification of sub-regions of the considered region

Material properties used in the calculations for other regions

| Material property | Mould | Protective coating |
|---|---|---|
| $\rho$ [kg/m$^3$] | 7200 | 1600 |
| $c$ [J/(kgK)] | 600 | 1670 |
| $\lambda$ [W/(mK)] | 42 | 0.6 |

The initial conditions for temperature fields

$$T(x_i,t_0) = T_0(x,y,z) = \begin{cases} T_M & \text{on } \Gamma_G \\ T_{in} & \text{in } \Omega_L \\ T_M & \text{in } \Omega_M \end{cases}.$$

The boundary conditions

$$\left.\frac{\partial T}{\partial n}\right|_{\Gamma_{1\text{-}1}} = 0, \qquad \lambda_M \left.\frac{\partial T_M}{\partial n}\right|_{\Gamma_M} = -\alpha_M\left(T_M|_{\Gamma_M} - T_a\right),$$

$$\lambda_S \left.\frac{\partial T_S}{\partial n}\right|_{\Gamma_{G-}} = \lambda_G \left.\frac{\partial T_G}{\partial n}\right|_{\Gamma_{G-}}, \qquad \lambda_G \left.\frac{\partial T_G}{\partial n}\right|_{\Gamma_{G+}} = \lambda_M \left.\frac{\partial T_M}{\partial n}\right|_{\Gamma_{G+}},$$

Parameters of the casting process

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $T_{in}$ [K] | 1850 | $T_M$ [K] | 350 |
| $T_a$ [K] | 300 | $\alpha_M$ [W/(m$^2$ K)] | 200 |

Material properties of the casting - cast steel

| Material property | Liquid phase | Solid phase |
|---|---|---|
| $\rho$ [kg/m$^3$] | 7300 | 7800 |
| $c$ [J/(kgK)] | 830 | 644 |
| $\lambda$ [W/(mK)] | 23 | 45 |
| Additional parameters | | |
| $T_L$ [K] | 1810 | |
| $T_S$ [K] | 1760 | |
| $L$ [J/kg] | 270000 | |

## Final remarks and conclusions

- This paper presents the mathematical model and the numerical simulations results of solidification of the three-dimensional casting-riser-mold system. The influence of the riser shape on the location of the solidification end of the casting-riser system was assessed. Numerical calculations were performed for two shapes of the riser: cylindrical (I variant ) and conical (II variant), estimating their suitability for feeding the shrinking casting during the solidification process.
- It was observed that in the final stage of the casting-riser solidification process, a solidus line closed in the upper part of the casting is visible in the case of a cylindrical riser. This suggests the formation of internal defects at this place in the form of a shrinkage cavity (Figs. 3 and 4a). Such a situation was not observed in the case of using a cone-shaped riser (Fig. 4b). In this case, the end of solidification took place in the riser which is desirable as the riser can be cut off and reused. It also proves that the inverted cone-shaped riser fulfilled its task and the casting was made without internal defects.