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NUMERICAL SIMULATION OF THE TUNGSTEN INERT GAS PROCESS

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SUMMARY

In the paper the numerical model of heat treatment of the casting superficial layer using the TIG method is presented. The external heat source shifts with a constant rate. Its influence on the casting surface causes the effect of the heat treatment. Such technology is called the tungsten inert gas process. In the region of heat source action one can observe the partial melting of the superficial layer. In the paper the 3D problem is analyzed. The thermal processes in the domain considered are described by the energy equation written in the form corresponding to the one domain method. The influence of external heat source is substituted by the Neumann boundary condition. The problem has been solved using the finite difference method and the results have been compared with the solution obtained by means of the commercial code MARC/MENTAT. It turned out that the results are practically the same. They will be presented in the final part of the paper.

key words: numerical simulation, solidification, tungsten inert gas process.

1. GOVERNING EQUATIONS

We consider the 3D object oriented in Cartesian co-ordinate system. The thermal processes proceeding in this domain (we assume only conductional heat transfer) are

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described by the following energy equation:

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + \sum_m q_{Vm} \tag{1}$$

where $c=c(T)$ is the volumetric specific heat, $\lambda=\lambda(T)$ is the thermal conductivity, $q_V^{(m)}$ are the capacities od internal heat sources, in particular

$$q_{Vm} = L_V^{(m)}\frac{\partial f_S^{(m)}}{\partial t} \tag{2}$$

where $L_V^{(m)}$ are the latent heats corresponding solidifying phase (in the case of cast iron $m = 1$ identifies the austenite and $m = 2$ the eutectic phases), $f_S^{(m)}$ are the solid state fractions of these phases at the neighborhood of the point considered. We assume that the successive phase changes proceed one after the other and we introduce to the considerations the substitute thermal capacity defined as the derivative of enthalpy function H with respect to temperature (the one domain approach [1]). In this way the equation (2) takes a form

$$C(T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) \tag{3}$$

where $C(T)=\mathrm{d}H(T)\mathrm{d}T$. The course of enthalpy function for the material considered is presented in [2]. Because of the discontinuity of enthalpy function for the eutectic temperature T_{eu}, the real course of $H(T)$ must be substituted by the continuous function for which the parameter $C(T)$ can be defined. In this place we use the zero order smoothing procedure introducing the certain interval $[T_{eu}-\Delta T,\ T_{eu}+\Delta T]$ - as in [2]. In this way the substitute thermal capacity of cast iron is determined by the piece-wise constant function. So, the function $C(T)$ is defined as follows

$$C(T)=\begin{cases} c_S & T < T_{eu}-\Delta T \\ c_{eu} & T_{eu}-\Delta T \le T < T_{eu}+\Delta T \\ c_{aus} & T_{eu}+\Delta T \le T < T_L \\ c_L & T \ge T_L \end{cases} \tag{4}$$

where T_L is the liquidus temperature. The values of c_S , c_{eu} , c_{aus} and c_L correspond to slopes of straight lines being the approximation of enthalpy-temperature diagram [2].

The following boundary-initial conditions supplement the mathematical model of the process:

– for the region of casting surface subjected to the external heat source (Fig. 1)

$$-\lambda\,\partial T(x,y,z,t)/\partial n = q_b(x,y,z,t) \tag{5}$$

where q_b is the known boundary heat flux, while $\partial T/\partial n$ is the normal derivative,

– on the remaining part of the casting surface

$$-\lambda \frac{\partial T\left(x,y,z,t\right)}{\partial n} = \alpha\left(T\right)\left[T\left(x,y,z,t\right) - T^{\infty}\right] \tag{6}$$

where $\alpha(T)$ is the heat transfer coefficient, T^{∞} is the ambient temperature,

– for time $t=0$

$$T\left(x,y,z,0\right) = T_0\left(x,y,z\right) \tag{7}$$

where T_0 is the initial temperature.

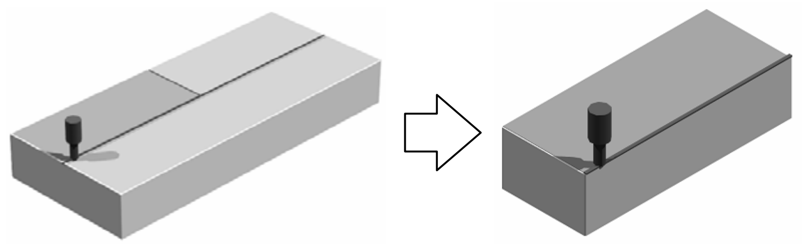

Fig. 1. The domain considered
Rys. 1. Rozpatrywany obszar

The interaction of external heat source which thermal power is equal to Q has been assumed in the form of the 2D Gauss distribution. The parameters of the function has been fit in this way in order to assure the emission of $0.95Q$ on the surface of radius R - Figure 2.

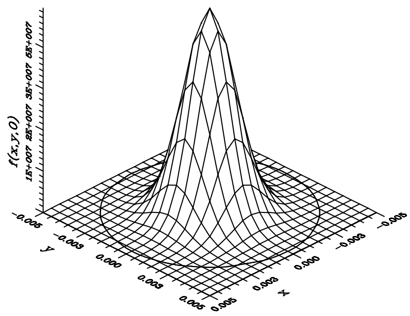

Fig.2. Function $f(x, y, 0)$
Rys.2. Funkcja $f(x, y, 0)$

2. THE METHOD OF SOLUTION

In order to solve the problem above discussed the finite difference method has been used. The domain has been covered by the rectangular mesh. The points resulting from the discretization correspond to the nodes for which the unknown temperatures are searched. The FDM algorithm (an explicit scheme) has been constructed in the form described in [3, 4]. The FDM approximation of the equation (3) is of the form

$$C_0^f \frac{\left(T_0^{f+1} - T_0^f\right)}{\Delta t} = \sum_{e=1}^{6} \frac{T_e^f - T_0^f}{R_e^f} F_e \tag{8}$$

where C_0^f is the specific heat of central node 0, R_e^f are the thermal resistances between node considered '0' and the adjacent ones 'e' (e = 1, 2, ..., 6), $F_e = 1/h_e$ are the shape functions, h_e is the mesh step, $\Delta t = t^{f+1} - t^f$ is the time step, f, $f+1$ are the two successive time levels. The thermal resistance R_e^f are defined as follows [3, 4]

$$R_e^f = \frac{0.5h_e}{\lambda_0^f} + \frac{0.5h_e}{\lambda_e^f} \tag{9}$$

while in the case of boundary nodes (in the direction of external boundary)

$$R_e^f = \frac{0.5h_e}{\lambda_0^f} + \frac{1}{\alpha\left(T_0^f, T^\infty\right)} \tag{10}$$

Finally the equation (8) takes a form

$$T_0^{f+1} = \sum_{e=0}^{6} A_e T_e^f \tag{11}$$

where

$$A_e = \frac{F_e \Delta t}{C_0^f R_e^f}, \quad e = 1, \ldots, 6, \quad A_0 = 1 - \sum_{e=1}^{6} A_e \tag{12}$$

The condition of differential scheme stability reduces to $A_0 > 0$ for each grid point.

3. THE RESULTS OF COMPUTATIONS

The cubicoid of dimensions 190×80×25 [mm] has been analyzed. Along the axis of symmetry of upper wall the external heat source moves with a constant rate

$v = 100$ [mm/min]. Arc voltage $U = 13$ [V], welding current $I = 70$ [A], thermal efficiency $\eta \in [0.4,\ 0.65]$ [5]. The thermophysical parameters of the material can be found in [6]. Figure 3 shows the temperature distribution in the domain considered.

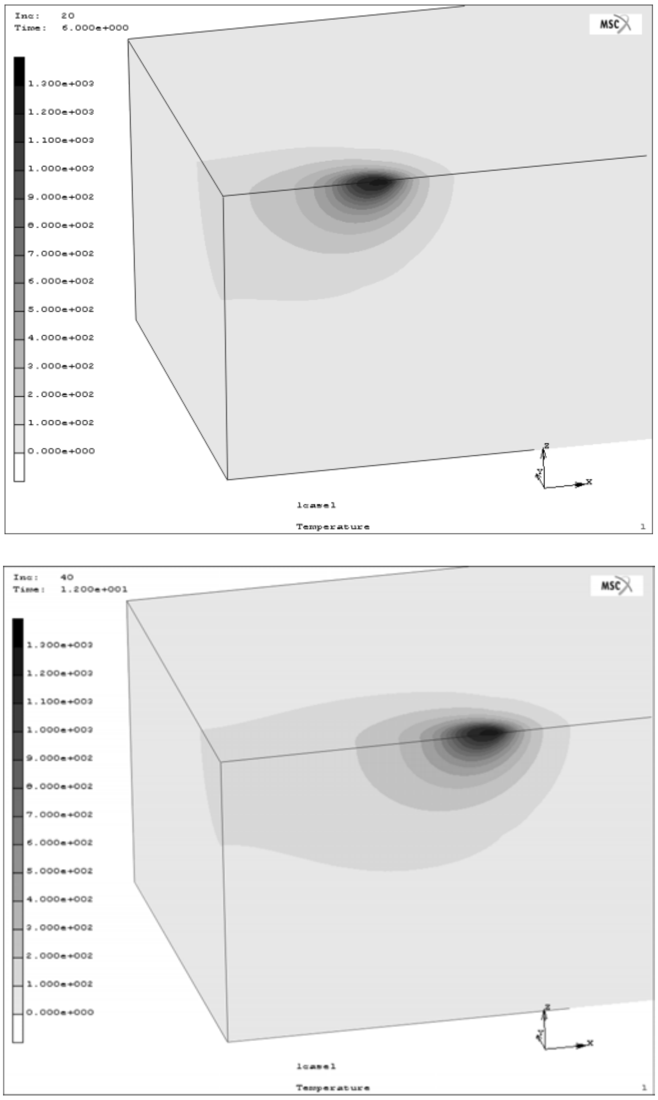

Fig.3. Temperature distribution ($t = 6$, 12 sec.)
Rys.3. Rozkład temperatury ($t = 6$, 12 sec.)

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SYMULACJA NUMERYCZNA PROCESU TIG

STRESZCZENIE

W pracy przedstawiono model numeryczny obróbki powierzchni odlewu metodą TIG. Zewnętrzne źródło ciepła przemieszcza się ponad powierzchnią odlewu ze stałą prędkością. Jego oddziaływanie na powierzchnię daje efekt obróbki cieplnej. W rejonie oddziaływania źródła można zaobserwować silne nagrzanie i nadtopienie warstwy wierzchniej odlewu. W pracy rozważano problem przestrzenny (3D). Zadanie opisuje równanie Fouriera-Kirchhoffa (zapisane w konwencji metody jednego obszaru) uzupełnione odpowiednimi warunkami jednoznaczności. Wpływ źródła zewnętrznego zastąpiono warunkiem brzegowym Neumanna. Problem rozwiązano metodą różnic skończonych, a wyniki porównano z rozwiązaniem uzyskanym przy wykorzystaniu programu narzędziowego MARC/MENTAT. Okazało się, że rozwiązania są z praktycznego punktu widzenia takie same. W końcowej części pracy przedstawiono wyniki symulacji numerycznych.

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