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Anastasiia PAVLENKO
Dniprovskii state technical university, Ukraine

CALCULATION OF PROCESSES OF MELTING METAL PARTICLES (INOCULATOR) IN A ONE-DIMENSIONAL PROBLEM STATEMENT

Abstract: *The article presents the results of research of thermophysical peculiarities obtaining volumetric amorphous structures in metals and alloys. This technology differs mainly the realization internal heat removal by means of local heat sink (inoculator). A mathematical model of melting inoculator in melts for optimizing the process of obtaining massive amorphous structures, which allows to reduce time of experimental research and material resources to create massive amorphous structures. Mathematical modeling of processes heat and mass transfer inoculator in melts allows you to identify peculiarities of the technological process, and establish influence inoculator on the degree of amorphization melt. The results provide an effective assessment of the intensity of heat transfer during the casting process, which makes it possible to estimate and predict the ability of alloys to the amorphization of the structure.*

Keywords: *heat and mass transfer, amorphous structure, inoculator, thermal conductivity, mathematical model, cooling, melting*

Introduction

Consider the process of melting solid inoculator having a melting point t_L^T, completely immersed in molten metal with a given temperature t_p. In reality, the initial temperature inoculator t_0 always less temperature of solidification metal t_S^p and therefore, initially formed on its surface shell of solid metal. Further progress depends on the melting of the relationship between temperature values t_L^T, t_S^p, t_p [1]. In I inoculator period when immersed in the molten metal at its surface formed shell of solid metal. The heat coming from the melt by convection and solidification of metal on the surface, is spent on heating and melting inoculator shell melt. End of period determined by moment of complete melting of the shell. In the II period the solid inoculator heated to the melting point t_L^T and direct contact with the liquid alloy. In III period inoculator begins to melt and liquid phase body dissolved in the melt.

Mathematical model

On the surface inoculator the formation of solid metal shell with further melting of the shell. This period is described melting heat conduction equations for two-layer body, which includes the equation for the material body ($0 \le r < R_i$) and for shell melt ($R_i \le r < Z_m$) at $\tau > \tau_1 + \tau_2$:

$$\begin{cases} c_i(t)\rho_i(t)\dfrac{\partial t_i(r,\tau)}{\partial \tau} = \dfrac{1}{r}\dfrac{\partial}{\partial r}\left[r\lambda_i(t)\dfrac{\partial t_i(r,\tau)}{\partial r} \right], & 0 \le r < R_i \\ c_m(t)\rho_m(t)\dfrac{\partial t_m(r,\tau)}{\partial \tau} = \dfrac{1}{r}\dfrac{\partial}{\partial r}\left[r\lambda_m(t)\dfrac{\partial t_m(r,\tau)}{\partial r} \right], & R_i \le r < Z_m \end{cases} \tag{1}$$

Boundary conditions at $\tau > \tau_1 + \tau_2$:

- on the axis of symmetry of the body ($r = 0$) given the symmetry condition [1]:

$$\frac{\partial t_i(0,\tau)}{\partial r} = 0 \tag{2}$$

- at the interface between the material inoculator and the shell melt ($r = R_k$) given boundary conditions IV:

$$\lambda_i(t)\frac{\partial t_i\left(R_i,\tau\right)}{\partial r} = \lambda_m(t)\frac{\partial t_m\left(R_m,\tau\right)}{\partial r}$$
$$t_i\left(R_i,\tau\right) = t_m\left(R_i,\tau\right) \tag{3}$$

- of heat exchange condition on the boundary of frozen shell melt – melt ($r = Z_m$):

$$-\rho_m(t)Q_m\frac{dZ_m(\tau)}{d\tau} = \alpha_m\left(t_p(\tau) - t_V\right) - \lambda_m(t)\frac{\partial t_m\left(Z_m(\tau),\tau\right)}{\partial r}$$
$$t(z(\tau),\tau) = t_L,\quad 0 \le z(\tau) \le z_0,\quad \tau > \tau_2,\quad Z_m(\tau) > R_i \tau > \tau_1 + \tau_2 \tag{4}$$

The initial conditions:

$$\begin{cases} t_i\left(r,\tau_1\right) = \varphi_i\left(r,\tau_1\right), & 0 \le r < R_i \\ Z_m\left(\tau_1 + \tau_2\right) = R_i \end{cases} \tag{5}$$

where $\varphi_i\left(r,\tau_1 + \tau_2\right)$, a solution to the problem of heat conduction material inoculator at $\tau = \tau_1 + \tau_2$.

Three period ends when the shell melts completely melt, formed on the surface of the body. Duration of the third period – τ_3.

Mathematical model

Process melting material inoculator begins after heating its surface to the melting point. Thus, we solve the problem of heat conduction for a body with III kind boundary conditions at the outer edge ($r = Z_i$) for calculated area. Heating the body surface is described by the heat equation for the material inoculator at $\tau > \tau_1 + \tau_2 + \tau_2$:

$$c_i(t)\rho_i(t)\frac{\partial t_i(r,\tau)}{\partial \tau} = \frac{1}{r}\frac{\partial}{\partial r}\left[r\lambda_i(t)\frac{\partial t_i(r,\tau)}{\partial r}\right],\quad 0 \le r < Z_i \tag{6}$$

Boundary conditions at $\tau > \tau_1 + \tau_2 + \tau_2$:

- on the axis of symmetry inoculator ($r = 0$) symmetry conditions:

$$\frac{\partial t_i(0,\tau)}{\partial r} = 0 \tag{7}$$

- of heat exchange condition on the boundary surface inoculator – melt ($r = Z_k$):

$$\lambda_i(t)\frac{\partial t_i\left(Z_i,\tau\right)}{\partial r} = \alpha_m\left[t_p(\tau) - t_i\left(Z_i,\tau\right)\right] \tag{8}$$

The initial conditions:

$$\begin{cases} t_i\left(r,\tau_1+\tau_2+\tau_3\right)=\varphi_i\left(r,\tau_1+\tau_2+\tau_3\right), \quad 0\le r<Z_i \\ Z_i(\tau_1+\tau_2+\tau_3)=R_i \end{cases} \tag{9}$$

where $\varphi_i\left(r,\tau_1+\tau_2+\tau_3\right)$ solution to the problem of heat conduction material inoculator described in period 3, at $\tau=\tau_1+\tau_2+\tau_3$. The duration of heating of the body surface to the melting point – τ_4^n.

After heating the surface of the body begins the process of melting, which is described by the heat equation for material ingot (6) at $\tau>\tau_1+\tau_2+\tau_3+\tau_4^n$.

Conditions on the boundary of heat exchange surface of the body – melt ($r=Z_i$):

$$\begin{gathered} -\rho_i(t)Q_i\frac{dZ_i(\tau)}{d\tau}=\alpha_m\left(t_p(\tau)-t_L^i\right)-\lambda_i(t)\frac{\partial t_i\left(Z_i(\tau),\tau\right)}{\partial r} \\ t_i\left(Z_i(\tau),\tau\right)=t_L^i, \quad 0\le Z_i<R_i, \quad \tau>\tau_1+\tau_2+\tau_3+\tau_4^n \end{gathered} \tag{10}$$

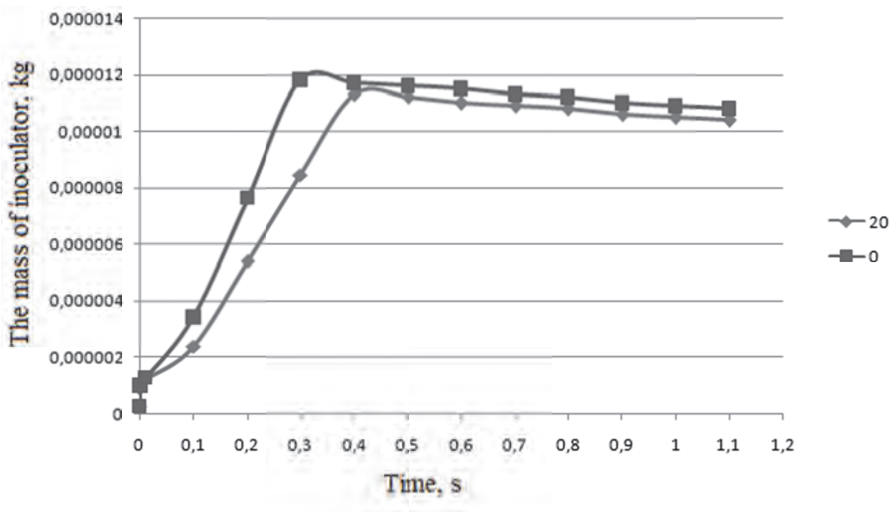
The initial conditions:

$$t_i\left(r,\tau_1+\tau_2+\tau_3+\tau_4^n\right)=\varphi_i\left(r,\tau_1+\tau_2+\tau_3+\tau_4^n\right), \quad 0\le r<Z_i \tag{11}$$

where $\varphi_i\left(r,\tau_1+\tau_2+\tau_3+\tau_4^n\right)$, a solution to the problem of heat conduction material inoculator described in the heating period surface of the material inoculator to the melting point at $\tau=\tau_1+\tau_2+\tau_3+\tau_4^n$. The duration of the melting material body – τ_4^{nl}.

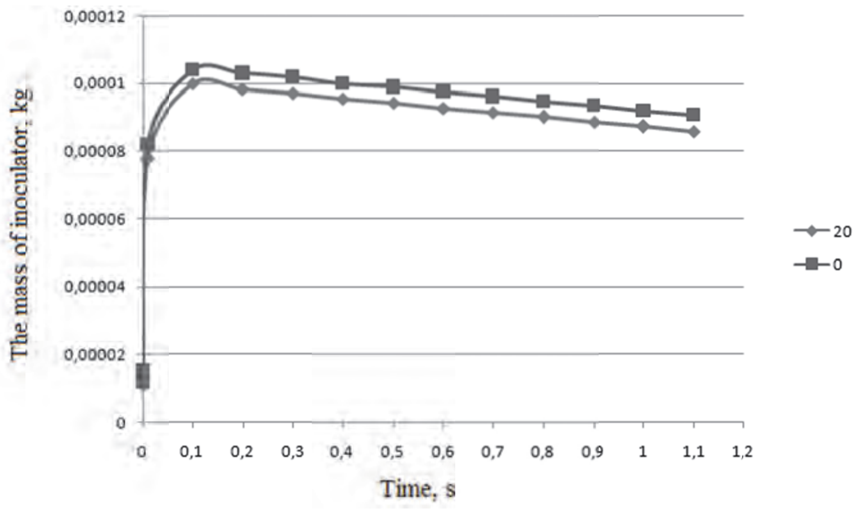
Four periods considered complete with the full melt material inoculator. The duration of the fourth period – $\tau_4=\tau_4^n+\tau_4^{nl}$.

The estimated model was made using the programming language BASIC, calculations obtained allowed to determine the impact inoculator on the degree of amorphization structure. The calculation results in graphs in figures 1-2. As a model alloy was chosen alloy that has a good tendency to amorphization due content in the element prone to amorphization, Zr [2, 3]. In table 1 are researched thermophysical properties of the alloy.



0-20 – initial temperature inoculator according 0°C and 20°C

FIGURE 1. *Graph changes mass of the alloy $Cu_{45}Ti_{35}Zr_{20}$ in the melting liquid alloy during the initial diameter of inoculator 1 mm*



0-20 – initial temperature inoculator according 0°C and 20°C

FIGURE 2. *Graph changes mass of the alloy $Cu_{45}Ti_{35}Zr_{20}$ in the melting liquid alloy during the initial diameter of inoculator 2 mm*

TABLE 1. *Thermophysical properties investigated alloy*

Alloy	The melting temperature, °C	The transition temperature in amorphous state, K	Density of the alloy, kg/m³	The heat capacity of alloy, J/(kg·K)	Coefficient of thermal conductivity, W/m·K
$Cu_{45}Ti_{35}Zr_{20}$	1090	410	6900	513.9	175

Conclusion

1. Add inoculator leads to the implementation of the internal heat removal and the formation of additional active melt crystallization centers.
2. Impact inoculator manifested in the increasing speed and preferably volume solidification. This technology differs mainly the implementation of internal heat removal by means of local heat removal.
3. At the time of solid particles inoculator contact with liquid metal melt creates local thermal hypothermia even in the event of significant overheating of total melt.

References

[1] Pavlenko A.M., Usenko B.O., Koshlak H.V., *Analysis of thermal peculiarities of alloying with special properties*, Metallurgical and Mining Industry, 2014, No. 2, pp. 15-20.