Simulation of crystallization of the surface layer of track castings in the region of holes

Tsotsko V., Peleshenko B.
Dnipropetrovsk State Agrarian and Economic University, Dnipro, Ukraine

The results of analysis of phase transformations in the surface layer of track castings during surface alloying in the casting process [1] indicated a pronounced limitation of the alloying depth. The task was to simulate a nonstationary temperature field of the surface layer of castings during their manufacture to find the relationship between the obtained data and the dynamics of surface crystallization of castings.

Simulation of a casting crystallization on a simplified one-dimensional model reduces to the formulation of the problem of phase transition (Stefan problem), which can be easily solved analytically using the similarity method **[2, p. 255, 261]**. It follows from the solution that the coordinate of the crystallization front ξ moves with time *t* according to the following law:

$$\xi = \alpha\sqrt{t}\,, \qquad (1)$$

where the constant α, according to the model parameters (110G13L steel melt for manufacture of track castings), was obtained numerically and was 0.216 mm/s$^{1/2}$.

Simulation of the crystallization process on a real casting (surface layer of tracks in the region of holes) necessitates solution of the Stefan problem using the heat-conduction equation in cylindrical coordinates:

$$\frac{1}{a^2}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}, \qquad (2)$$

where T is the temperature, a^2 is the thermal diffusivity coefficient of the phase, r is the distance from axis of the moulding core.

The initial temperatures of the moulding core and the melt were taken as additional conditions of the problem, as well as the boundary conditions imposed on the temperature gradients such as equal to zero gradients on the axis of the moulding core and in the melt core, the condition of their conjugation at the phase boundary taking into account the absorption of the latent heat of the phase transition during crystallization of the melt.

All attempts to obtain a solution of this equation using the similarity method did not produce the desired result. The use of similarity method is impossible due to the heterogeneity of the system along coordinate $z = \frac{r}{2\sqrt{t}}$. In contrast to the initial conditions, the boundary conditions with a finite nonzero value r do not correspond to the similarity transformations.

The problem was solved numerically using finite-difference method with the use of direct and reverse sweep schemes (factorization method) **[2, p. 591-592]**. In this case, the temperature at the axis of the moulding core, with the condition of zeroing the temperature gradient on the axis, served as the reference temperature setting the values of the design temperatures at the nodes.

The dependence of movement of the crystallization front Δr^* on the time t, measured from the moment of reaching the crystallization temperature at the boundary of the moulding core and the melt, is shown in Fig. 1.

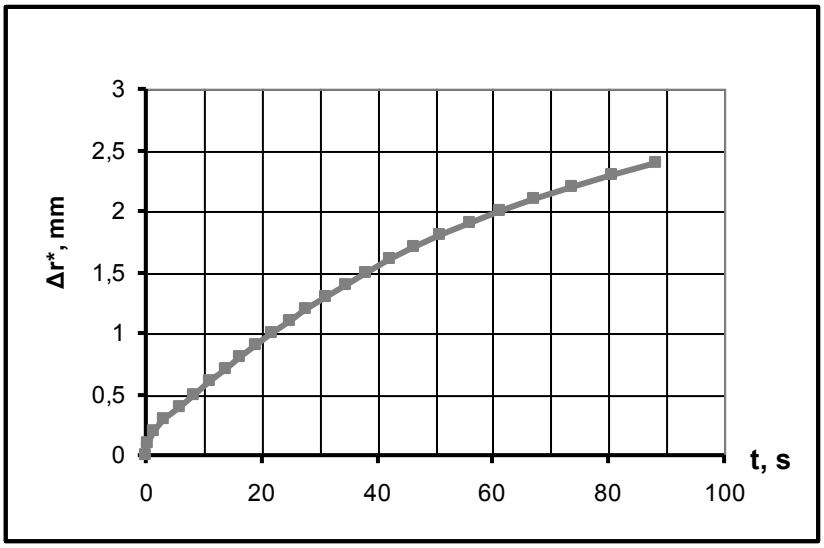

Fig. 1. Dependence of movement of crystallization front Δr^* on time t

Adjustment of the numerical experiment data on the exponential curve using the least-squares method resulted in the following empirical formula relating Δr^* to t:

$$\Delta r^* = \alpha \cdot t^{\beta} \qquad (3)$$

(with dimensions $[\Delta r^*]$ = mm and $[t]$ = c, α = 0,149 i β = 0,623).

The difference between value β and value β = ½ (1) is due to the violation of homogeneity of the boundary conditions in comparison with the semi-infinite model, which causes inapplicability of the similarity method for solving the posed problem. Deviation of the exponent β in formula (6) from the value ½ can be treated as a change with time of the constant α in the law (3) of the crystallization front motion at β = ½.

The obtained information on the temporal location and velocity of the crystallization front makes it possible to control the temperature field of the metal surface layer, make the best use of it and change it and, thus, control the process of structure formation to form the required physical properties.

[1] Tsotsko V.I., Peleshenko B.G., Melnyk P.I. Alloying of the surface layer of a cast blank during casting. // Metallurgy and metal processing. No. 2 (2009). P. 27-30.
[2] Tikhonov A.N., Samarskiy A.A.. Equations of mathematical physics. – M.: Nauka. - 1972. - 736 p.