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DYNAMICS OF CHANGING THE TEMPERATURE GRADIENT DURING TITANIUM ALLOY COOLING

***Abstract**: Description of the thermodynamic cooling process of the ingot (titanium alloy) at the time range of 0-120 s is presented in the article.*

***Key words**: cooling, the casting, titanium alloy, the temperature gradient.*

***Language**: English*

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Introduction

The wide use of titanium alloys in various industries is due to high strength and low density of material [1]. Casting is one of the ways to produce workpieces from titanium alloys [2]. Titanium alloy in the molten state is chemically active, so during the casting process, the molds must have a high inertia. Failure to comply with this requirement during titanium alloys casting leads to an uneven change in the cooling temperature of the surface layers of the crystallizing casting in contact with the mold surfaces [3-10]. This leads to the uneven structure of the casting after cooling. Let us consider the cooling phase of titanium alloy under standard conditions of the casting process based on the results of computer modeling.

Materials and methods

The mathematical calculation was performed in the Comsol Multiphysics program to determine the thermodynamic processes in the volume of the cooling casting made of titanium alloy. The casting model was the ingot with dimensions of 100×50×10 mm. The initial temperature of Ti-6Al-4V titanium alloy (UNS R56400) during cooling was adopted 1923 K. The thermodynamic processes calculation during the casting cooling was performed according to the heat transfer equation (1)

$$d_z\rho C_p\frac{\partial T}{\partial t}+d_z\rho C_p u\cdot\nabla T+\nabla\cdot q=d_zQ+q_0+d_zQ_{ted}, \quad (1)$$

where d_z is the domain thickness in the out-of-plane direction; ρ is density; C_p is heat capacity; T is the temperature; t is the time; u is the velocity field; q is the heat flux vector, $q=-d_zk\nabla T$; Q is the heat source; q_0 is inward heat flux, normal to the boundary; Q_{ted} is thermoelastic damping; k is thermal conductivity.

The cooling process time of the casting model was adopted 120 s.

Results and discussion

The cooling process of the casting model is presented by the color contours of the material temperature gradient. The results were recorded every 15 seconds from the specified casting cooling range.

The contours of the cooling temperature gradient of the casting model are shown in the Fig. 1.

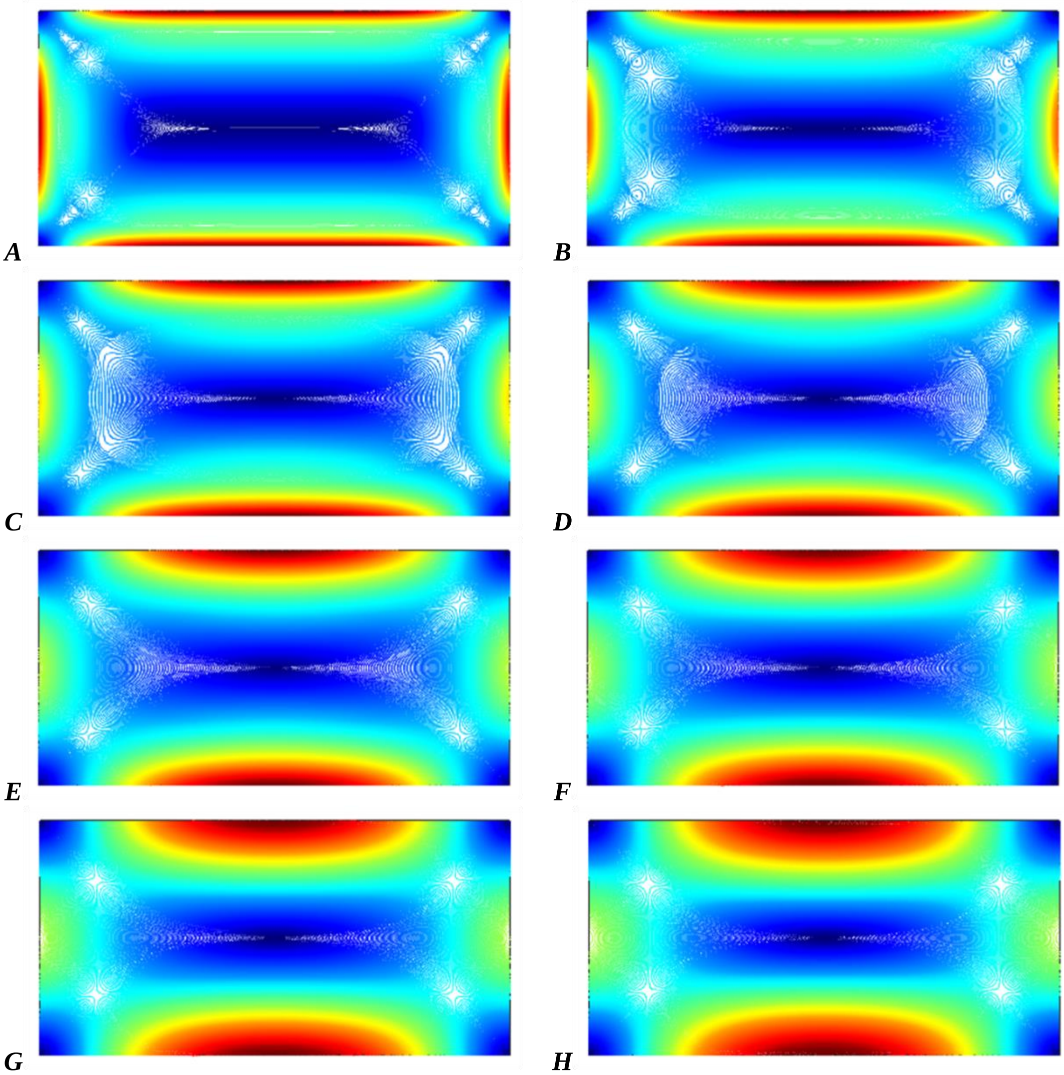

Figure 1 – The contours of the cooling temperature gradient of titanium alloy: *A* – 15 s; *B* – 30 s; *C* – 45 s; *D* – 60 s; *E* – 75 s; *F* – 90 s; *G* – 105 s; *H* – 120 s.

The dark red contours on the casting model indicate the maximum value of the temperature gradient, while the blue contours indicate the minimum value of the temperature gradient. The calculation of the spatial configuration of the thermally stressed state of the casting during cooling allows us to determine the volumes in material that will be subject to the cracks formation.

During the cooling process, the temperature gradient value in the surface layers of the crystallizing casting is more than the temperature gradient value in the inner layers. At the same time, in the surface layers distributed along the casting length, the volume of the temperature gradient will increase over time taking into account a decrease in the temperature of material. The reverse thermodynamic process is observed in the surface layers distributed along the casting width. In the middle part of the casting, the temperature gradient for the considered cooling range in the mold practically does not change and has the ellipse shape. This indicates uniform cooling rate of the given volume of the casting.

Conclusion

Thus, the cracks formation during titanium alloy cooling is predicted at the boundaries of the surface and inner layers of the casting. The movement direction of the temperature gradient contours from the diagonals to the middle part of the ingot leads to a decrease in the intensity of the temperature change in the surface layers distributed along the casting width.

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