OPTIMIZATION OF DIRECTIONAL SOLIDIFICATION OF HEAT-RESISTANT ALLOYS FOR CRITICAL CASTINGS

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The study investigates the influence of directional solidification rate on the structural formation of the CM88 heat-resistant alloy intended for gas turbine engine (GTE) blades. An automated control system for process parameters was developed and implemented in the UVNK-8P unit. It was established that increasing the solidification rate to 10 mm/min improves the microstructure and mechanical properties, reduces losses, and enhances the quality of castings.

Keywords: nickel-based superalloys, gas turbine engine (GTE), blade, directional solidification

Improving the efficiency and reliability of gas turbine engines for aviation and power applications requires the advancement of manufacturing technologies for critical components made from heat-resistant alloys. The most heavily loaded elements of GTEs are turbine working and nozzle blades, which operate under high temperatures, vibration, aggressive environments, and abrasive wear. Under such conditions, structural materials must meet high standards of mechanical strength, thermal stability, and corrosion resistance.

Significant potential for improving the durability and performance of GTE blades is associated with the application of specialized nickel-based superalloys alloyed with refractory elements (rhenium, tantalum, ruthenium), as well as with the development of directional solidification technologies [1–4]. Optimization of the casting process, including automated control of thermal and kinetic solidification parameters, ensures the formation of a homogeneous microstructure with minimal defects and stable operational characteristics of finished components.

The objective of this work is to improve the technology for producing GTE blades using directional solidification with the application of an automated process control system, which enables reduced production losses, improved casting quality, and compliance with technical requirements.

To evaluate the influence of technological parameters of directional solidification on the structural characteristics of the CM88 alloy, a series of experiments was carried out using the UVNK-8P unit, which implements the Bridgman–Stockbarger method. Melting and pouring were performed in a vacuum furnace with solidification rates of 5 and 10 mm/min. The pouring temperature ranged from 1550 to 1570 °C. The temperature distribution within the casting was monitored using tungsten–rhenium thermocouples installed at five points along the longitudinal axis.

To ensure efficient control of the technological process, an automated system for managing directional solidification was developed. The software enables real-time monitoring of key process parameters, including the melt chamber temperature, the temperature of the liquid aluminum coolant, the temperature gradient within the casting, and the velocity of the solidification front. All technological parameters are set before the melting begins, and during the entire process, the operator can monitor the progress of directional solidification in real time.

The application of the automated control system stabilized the directional solidification process, reduced material and energy consumption, and improved the quality of castings by increasing the precision and reproducibility of the thermal regime [5, 6].

Experimental results showed that increasing the solidification rate from 5 to 10 mm/min promotes the formation of a finer dendritic structure and an increased volume fraction of the strengthening γ'-phase. This is accompanied by a decrease in the particle size of the γ'-phase and in the average cross-sectional area of γ/γ' eutectic islands. Moreover, the amount of dispersed MC-type carbides in the interdendritic regions increases. It was determined that the optimal solidification front velocity for forming a regular directional structure lies within the range of 10 to 12 mm/min.

Mechanical testing of heat-treated samples confirmed that the obtained mechanical properties meet the technical specifications for both short-term and long-term strength. The proposed automated solution, implemented on the UVNK-8P unit, ensures the stability of the temperature field and controllability of the structure formation process, contributing to reduced production losses and enhanced service life of critical components made of heat-resistant alloys.

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