ON CRYSTALLIZATION OF A METAL MELT INOCULATED WITH NANOPARTICLES [1]

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To obtain a fine and uniform grain structure upon solidification of metals and alloys, it is possible to use particle-nucleants which are specially introduced into the melt or, in other words, inoculated. On such particle heterogeneous nucleation will occur the course of which depends on the shape of the substrate, its wettability, dimensions and conjugation of atomic lattices of the substrate and the nucleus [1-3]. To understand the mechanisms of structure formation during solidification of inoculated metals and alloys, it is necessary to study the features of nucleation of crystallization centers on activated nanoparticles, depending on their dimensional, morphological and capillary properties.

In the present work the process of crystallization of a binary alloy modified by refractory wettable nanoparticles. A small volume of the melt is chosen for the study and its internal thermal resistance is negligible compared to the external ones. In this case the temperature distribution in the volume can be considered homogeneous and the rate of its cooling is given. This alloy contains highly activated wettable refractory nanoparticles. As follows from the results of work [4], homogeneous nucleation in the process of solidification of such a melt is practically not observed, and the nucleation and growth of the crystalline phase occurs only on seeds, so homogeneous nucleation is not taken into account here.

In this paper, a mathematical model of the nucleation and growth of a solid phase in a nanomodified alloy with a eutectic-type phase diagram proposed earlier in [5] is developed. Here is a kinetic equation for describing the crystallization of a binary system of a eutectic composition after cooling the melt to the eutectic temperature. As a result, we obtained analytical expressions for the formation energy and the rate of nucleation of crystallization centers on cubic nanoseeds (nanoparticles), taking into account the dimensional and capillary effects. Equations are proposed for describing the macroscopic growth of the primary phase during the continuous cooling of the binary alloy to the eutectic temperature and the growth of the fraction of the solidified eutectic with further cooling of the alloy.

To verify the mathematical model, a comparison is made with an experimental study of the crystallization process of an aluminum alloy in a cylindrical form. During the solidification of the sample, its temperature was recorded, for this purpose a high-speed thermocouple was located in its center. The experimental and calculated values coincided with a sufficiently high degree of accuracy, the error is of the order of 1%.This indicates that the proposed model satisfactorily describes the actual physical process of crystallization of the inoculated alloy with the adopted values of the kinetic growth constants and the wetting angle.

Based on the results of numerical experiments, the value of the maximum supercooling of the melt, the maximum nucleation rate and the characteristic grain size of the ingot were estimated. As follows from the calculations performed, an increase in the number of seeds themselves leads to an insignificant (~ 5%) decrease in grain size by an order of magnitude. The greatest influence is exerted by the wetting angle of nanoseed surface by the nucleus substance. This causes the need to clad substrate surfaces with metals.

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