PhD DISSERTATION

Investigation of structural defects during solidification of single crystal turbine blades superalloy

by

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Abstract

The critical components of aircraft gas turbine work under high mechanical loads at temperatures near their melting point and aggressive corrosive environment. These elements, such as high pressure turbine blades, are obtained in single crystal form by directional crystallization from nickel-base superalloys. The microstructure after solidification process shows parallel dendrites with uniform crystallographic orientation. Turbine blades after crystallization process possess structural defects such as low angle boundaries, random grains or strain areas. These defects can not be removed during heat treatment, and their presence decreases mechanical properties. It is therefore of great importance to know the mechanisms of defect formation during the crystallization process of key elements of aircraft engines and power turbines.

In the dissertation the characteristics of the structural defects and the mechanisms of their formation were described during solidification of single crystal turbine blades from CMSX-4 superalloy.

It has been shown that during the directional crystallization process of the blades the macroscopic low-angle boundaries can form along the axis of dendrite growth. As a result of the formation of these boundaries, macroscopic subgrain structure is formed. Subgrains consist of dendrites with similar crystallographic orientation. It has been found that the significant widening of the crystallization front is conducive to the formation of low-angle boundaries. They are located in the interdendritic regions in the γ phase and consist of a dislocation grid located near the γ' phase precipitation. The presence of the subgrain boundary also results in disarrangement

of the dendritic structure in its vicinity. In addition, it has been shown that dendrites which growth was blocked by the mold walls can cause local strain. In the thin-walled area of the airfoil, crystallization proceeds with the successive growth of secondary dendrite arms due to the continuous constrain of dendrites growth on the mold walls. Such mechanism of dendrite growth causes gradual increase in defect formation and gradually change the crystallographic orientation along the direction of crystallization.

The present quality control techniques used in industry are based on the previous generation casting technology, such as etching of whole surfaces of the blades supported by crystallographic orientation determination at several points on the surface of the element. However, recent years have described a number of structural defects associated with the local changes in crystallographic orientation that have a significant impact on strength. For this reason, new research methods are still being developed to allow more accurate and comprehensive investigation of the single crystal casting quality.

X-ray topography methods, in particular with Auleytner geometry, are one of the few methods using conventional X-ray sources, which has been successfully used for investigation of the dendritic single crystal superalloys. It has been shown that this method can successfully detect even the subtle defects of the crystalline structure of such castings.

One of the aims of the work was use of the EFG prototype diffractometer to characterize single crystal turbine blades and to compare the results obtained with the Auleytner X-ray topography method. In addition, the use of electron microscopy allowed the proper interpretation of the X-ray topography results and the microscale characterization of the low-angle boundaries. New ways of visualizing defects for different diffraction methods have been developed which reveal the correlation between misorientation defects and images of dendritic microstructure.

The paper presents new ways of using X-ray diffraction methods, adapted to investigation of dendritic single crystal nickel-base superalloys, which can be successfully applied in the industry.