DETERMINATION OF MICROSTRUCTURE OF CMSX-4 SINGLE CRYSTALS

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Extended Summary

Nickel base superalloys consisting of ordered γ’ precipitates in γ matrix are widely used for structural components of gas turbines and as blade materials for aircraft turbines. Excellent high temperature mechanical properties of these alloys are given by their specific microstructure. Both the thermal and mechanical loading in service results in microstructural changes. Different kinds of coarsening processes take place in dependence on the temperature and mechanical loading conditions, e.g. [1]. Because the changes of mechanical properties and lifetime of components are determined by the changes of initial microstructure, its proper description and evaluation is necessary to judge the condition of material. Indeed this treatment has been successfully used as a condition based assessment procedure for alloys in military gas turbines.

In this contribution experimental methods and some examples of determination of microstructure of CMSX-4 superalloy will be described.

Ni-base superalloy CMSX-4 belongs to the second generation of single crystal superalloys [2], containing 3% of Re, which is known to strengthen the γ matrix and to stabilise the γ’ phase. It consists of regularly arranged γ’ precipitates embedded in γ matrix; there is a full coherence between the γ’ precipitates and the matrix.

There are three main structural features, which have to be determined and quantified when characterizing the structure of this superalloy. First of all it is a dendrite structure reflecting the growth of single crystals and chemical inhomogeneity. Though CMSX-4 is well known by its full γ’ solutioning during heat treatment of final single crystals the remnants of the dendritic growth remain. The second and perhaps the most important feature from the point of view of high-temperature creep and fatigue properties is the distribution of γ’ precipitates and their shape. Distribution and morphology of cavities is the third important structural feature closely related to the fatigue properties, more precisely to the fatigue crack initiation.

Dendrite structure

Dendrite growth and resulting dendrite structure is related to the undesirable effects in interdendritic liquid, where inhomogeneity of concentration, cavities or freckles can appear. One of the appropriate methods for displaying the dendrite structure is the so-called colour etching. The principles of this metallographic method are well known [3]. This method has been used e.g. on cast steels or grey irons [4] or duplex steels [5].

Colour etching method was applied to reveal the dendrite structure of CMSX-4 single crystals. Primary dendrite arms are oriented in the <001> crystallographic direction, i.e. in
the direction of solidification. They penetrate the whole single crystal. Secondary dendrite arms were documented on the transversal (001) plane crystallographic sections. Tertiary dendrite arms are displayed as expansion of secondary arms into interdendritic areas. Under typical magnification (25 times) the optical micrographs can be well used for the quantitative determination of an average length of the secondary and tertiary dendrite arms. Different colours can easily detect interdendritic regions with chemical composition deviations. It was found that cavities are formed first of all in interdendritic regions.

**Morphology of γ′ precipitates in γ matrix**
The standard way to determine the parameters of γ/γ′ microstructure lies in an observation of mechanically polished and slightly etched surfaces by means of scanning electron microscopy (SEM). The typical microstructure in fully heat-treated condition consists of cuboidal coherent γ′ precipitates embedded in γ matrix. A net of vertical and horizontal channels can be displayed on sections by {001} planes. SEM enables to determine the characteristic parameters of γ/γ′ microstructure, e.g. the average dimension of γ′ cubes, the width of γ channels or the volume fraction of separate phases. The simplest way to determine qualitatively the volume fractions of both phases consists in the application of image analysis methods. The volume fraction of γ′ precipitates was found 67% and the average length of cube edges lying along {001} planes 0.47 µm.

Optical microscopy combined with colour etching methods is another way how to display the γ/γ′ microstructure. By high enough magnification the γ′ cubes and γ channels can be made clearly visible. This treatment was found to be not sufficient for quantitative estimates of the volume fraction of separate phases, but it is suitable for the inspectional verification of cuboidal microstructure and relation to the dendrite structure.

An alternative method for the determination of the γ/γ′ microstructure is an electron channelling contrast technique in SEM [6]. Application of this treatment demands well metallographically prepared surfaces and yields images well comparable with those observed by means of the standard observation methods.

Transmission electron microscopy (TEM) enables to observe the γ/γ′ microstructure at highest magnification on thin foils, e.g. [7]. This type of observation reveals details of dislocation structure and also enables to determine the volume fraction of separate phases.

**Cavities**
Standard metallographic methods and optical microscopy with small magnification can be used for the quantitative analysis of cavities in CMSX-4 superalloy. The distribution and size of cavities can be determined either by standard metallographic procedures or with advantage by means of image analysis procedures.

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References