Orientation of nickel-based alloy after thermal treatment

Conference or Workshop Item

Orientation of Nickel-Based Alloy after Thermal Treatment

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Abstract. The paper presents transmission electron microscopy investigations of Ni-Al-Co alloy with γ′- and γ -phases obtained by directional crystallization. The main alloying elements are Cr, Ta, and Re in the amount of no more than 3.5 at % each. W and Mo are present in a smaller amount. The alloy structure is investigated in two states: (1) original (after directional crystallization and long-term homogenezation which includes a series of annealing ranging from 1285 to 1340°C) and (2) original state subjected to subsequent annealing within 900–1000°C temperature range during 105–1143 h. The experiments show that the annealing process causes the fracture of the ideal quasi-cuboid structure of the γ′-phase and modifies its preferable orientation. The increase in the annealing temperature modifies the morphology of the γ′-phase that, in turn, changes the grain orientation in the alloy.

INTRODUCTION

In superalloys containing (γ + γ′)-phases, a full orientation correlation is usually observed between these phases [1–10]. One of the methods to obtain such superalloys is a method of direct crystallization [11–21]. Such a superalloy is expected to possess a well-ordered [001] orientation. However, a superalloy alloyed with a great amount of various elements and its annealing has a modified orientation [22–26]. The paper mainly focuses on this very issue.

MATERIALS AND METHODS

A superalloy obtained via the directional crystallization technique and composed of 69 to 59 at % Ni, 12–15 at % Al, and 10–13 at % Co was used in this experiment. The main alloying elements are Cr, Ta, and Re in the amount of not over 3.5 at % each. W and Mo are observed in a smaller amount.

Two states of the Ni-Al-Co alloy structure were investigated: (1) after directional crystallization (original state) and prolonged homogenization in the form of a series of annealing within the temperature range 1285–1340°C and (2) after directional crystallization (original state) and annealing at 900 and 1000°C during 105 and 1143 hours, respectively. It was expected that the superalloy would possess a well-ordered [001] orientation in both states.

The transmission electron microscopy (TEM) investigations of thin foils are carried out in the experiment. Observations of thin foils are carried out on an EM-125 transmission electron microscope with 125 kV accelerating voltage.

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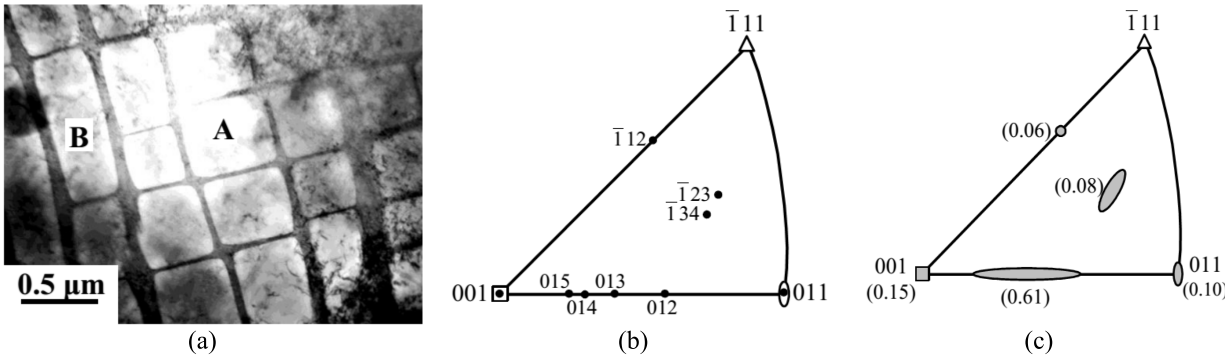

FIGURE 1. Original state of the Ni-Al-Co superalloy: (a) TEM image of the quasi-cuboidal structure (*A*—isotropic quasi-cuboids; *B*—anisotropic quasi-cuboids); (b) standard stereographic triangle with the indication of orientations; (c) orientations in the superalloy (dark regions) and their specific weight

Structural investigations are performed on specimens cut normally to the crystal growth axis. The obtained diffraction patterns allow us to detect stereographic components for each state of the alloy. With respect to the specific weight of orientations, their distribution is plotted on a standard stereographic triangle, and orientations are then analyzed.

RESULTS AND DISCUSSION

According to the results obtained, the major phase of both states of the alloy is the γ'-phase whose crystal system is a face centered cubic (FFC) ordered Ni-based solid solution having an $L1_2$ superstructure. In different specimens, the amount of this phase differs from 0.58 to 0.83 of the material bulk. The γ'-phase morphology represents quasi-cuboids with a sufficiently clear cut (Fig. 1a). Quasi-cuboids are surrounded by relatively thin layers of the γ-phase whose crystal system is a face centered cubic (FFC) disordered solid solution.

The TEM investigations allow us to classify quasi-cuboids of the γ'-phase. Thus, in the original state they are homogeneous as shown in Fig. 1a. These cuboids have practically the same size *L*, i.e. the dispersion of *L* does not exceed 0.005±0.001 µm. Homogeneous cuboids can be both isotropic ($K \approx 1$,) and anisotropic ($K >> 1$), where $K = l/d$ is the ratio for the transverse size of quasi-cuboids (see Fig. 1a, *A* and *B*).

The analysis of diffraction patterns obtained for different regions of the superalloy structure shows that already in the original state it possesses a significant dispersion of orientation (Fig. 1b). The quantity of the [001] orientation in the superalloy is merely 0.15. The quantity of the [011] orientation is 0.10 and the quantity of side [$\bar{1}$11]–[001] and the center of the stereographic triangle is 0.14. A huge proportion (0.61) of orientations falls on side [001]–[011] of the stereographic triangle (Fig. 1c). Thus, already in the original state the material structure has a 'soft' orientation [011] besides a 'hard' one in the center of the stereographic triangle [27].

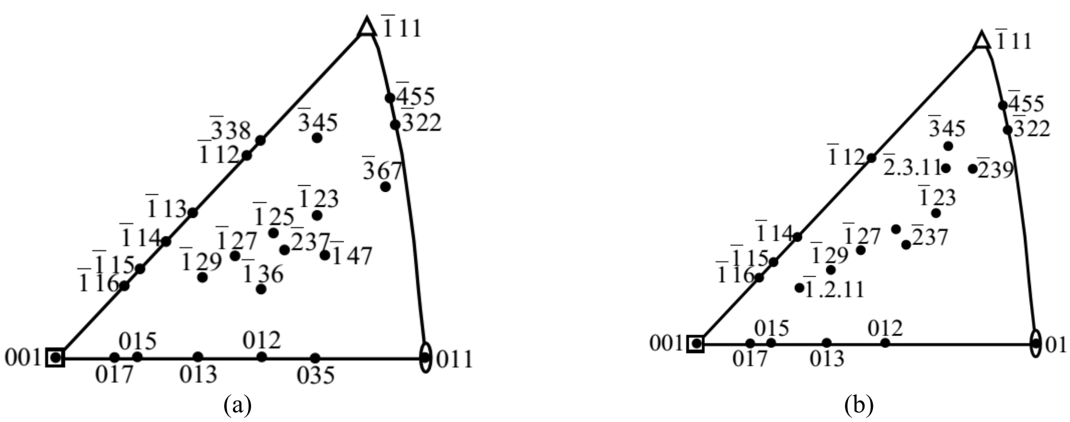

FIGURE 2. Plots of stereographic triangles with orientations in the Al-Ni-Co alloy: 900 (a) and 1000°C annealing (b)

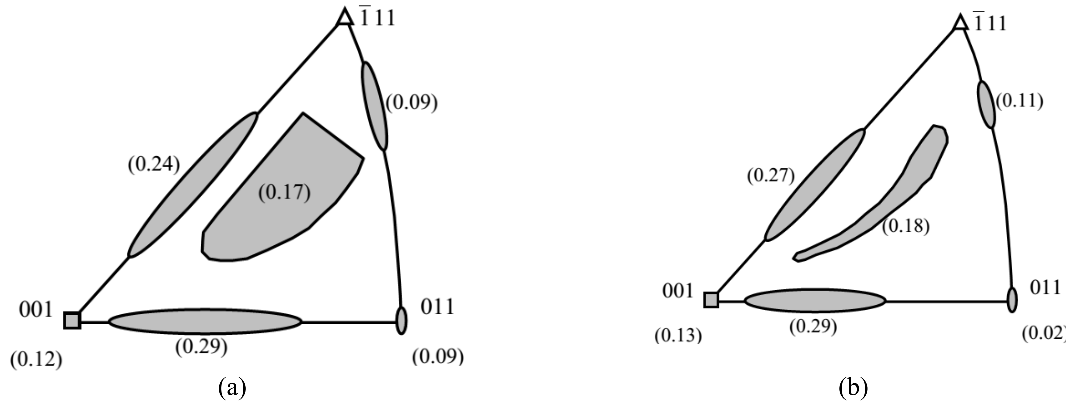

FIGURE 3. Orientations in the superalloy (dark regions) and their specific weight in the Al-Ni-Co alloy: 900 (a) and 1000°C annealing (b)

A 900°C annealing results in a sharp dispersion of orientation (Fig. 2a). As can be seen from this figure, a large number of new orientations are observed along all sides of the stereographic triangle. Additionally, a lot of various orientations are also present within the stereographic triangle.

The quantitative analysis of the specific weight of the observed orientations (Fig. 3a) shows that 900°C annealing results in almost uniform dispersion of orientation both along the sides and in the center of the stereographic triangle. At the same time, the amount of [001] and [011] orientations hardly changes.

The analysis of TEM images of the superalloy shows that 900°C annealing results in a considerable morphological change of its quasi-cuboidal structure. Thus, now it consists of not only homogeneous quasi-cuboids similar to those shown in Fig. 1a but also heterogeneous quasi-cuboids with a distorted structure (Fig. 4b).

Heterogeneous quasi-cuboids are characterized by their different size L. Its dispersion in the regions with such quasi-cuboids is >0.2 μm. The shape of quasi-cuboids that have different sizes and are found side by side can differ from a cube. Similar to homogeneous ones, heterogeneous quasi-cuboids can be both isotropic and anisotropic.

The distorted structure of quasi-cuboids includes torn boundaries (see Fig. 4b, *C*), irregular shape, and absence of one or more walls (see Fig. 4b, *D*).

An increase in annealing up to 1000°C results in further morphological modifications in the γ′-phase. First, the amount of quasi-cuboids with a distorted structure increases. Second, a new kind of quasi-cuboids appears in the alloy structure, namely, distorted quasi-cuboids as presented in Fig. 4c. This kind of quasi-cuboids represents regions in which only individual walls of a quasi-cuboid are retained (Fig. 4c).

The modification of the quasi-cuboid morphology at 1000C annealing results in a change in the material structure. These changes are as follows. Firstly, the dispersion of orientation lowers (see Fig. 2b). However, the [001] orientation of the γ- and γ′-phases is low-grade as before (0.13). At the same time, the amount of the [011] orientation decreases down to 0.02. Secondly, the amount of orientations over all sides of the triangle decreases and becomes closer to the [001] orientation, but their specific weight grows. Thirdly, all orientations elongate along bisector [001] of the stereographic triangle (Fig. 3b).

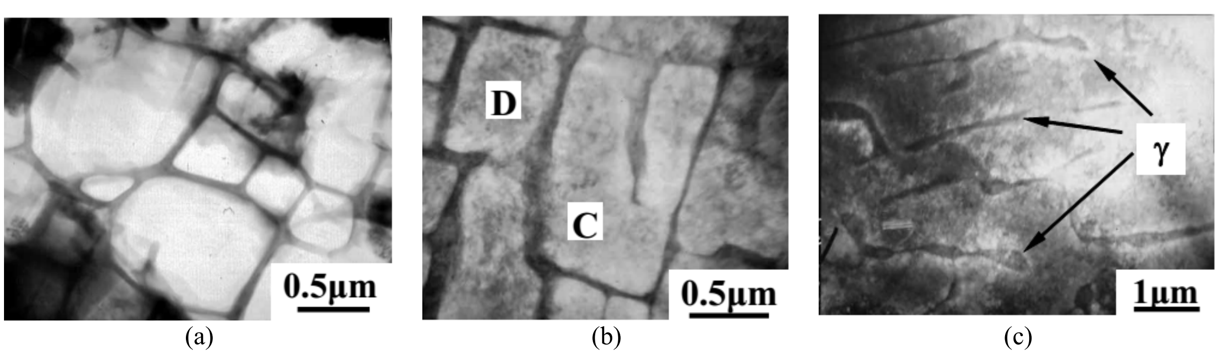

FIGURE 4. Quasi-cuboid morphology of the γ′-phase: (a) heterogeneous structure; (b) distorted structure (C—torn boundary, D—without a wall); (c) destructed (black arrows indicate individual walls)

CONCLUSIONS

Summing up the results, it can be concluded that the introduction of alloying elements in the nickel-based superalloy did not disturb the quasi-cuboidal structure of the γ'-phase but significantly changed its preferred orientation. The process of annealing, firstly, modifies the quasi-cuboid morphology in the γ'-phase and, secondly, leads to the dispersion of orientation. An increase in the annealing temperature from 900 to 1000°C resulted in the following: (a) dispersion of orientation was observed both in the qualitative and quantitative sense; (b) quasi-cuboid morphology in the γ'-phase is strongly distorted.

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