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Structure and phase composition of the superalloy on the basis of Ni-Al-Cr alloyed by Re and La

E L Nikonenko[1,2,4], N A Popova[1,3], N A Koneva[1] and E V Kozlov[1]
[1]Tomsk State University of Architecture and Building, 2, Solyanaya Sq., 634003, Tomsk, Russia
[2]National Research Tomsk Polytechnic University, 30, Lenin Ave., 634050, Tomsk, Russia
[3]Institute of Strength Physics and Materials Science SB RAS, 8/2, Akademicheskii Ave., 634021, Tomsk, Russia

[4] E-mail: vilatomsk@mail.ru

Abstract. Qualitative and quantitative studies of the structure, phase composition, morphology of phase of the high-rhenium alloys additionally doped with La were carried out by TEM and SEM methods. The alloy was obtained by directional solidification method. It was shown that introduction of Re and La to an alloy leads to formation of new phases: β and χ, which bring serious irregularities in the structure of qvazicuboids of γ′-phase.

1. Introduction

Level requirements for materials with the required performance characteristics constantly increase. One of the promising areas of the search for new high-temperature materials is creation of alloys containing intermetallic phases [1,2]. Superalloys on the basis of (γ+γ′) are example of phases where γ-phase is the disorder solid solution with fcc structure and γ′ is the ordered phase with superstructure of $L1_2$. Now superalloys are created on the basis of the Ni-Al alloy alloyed by various elements. Lately, rhenium and lanthanum have been used in alloying superalloys. This work presents investigations of the composition, morphology, and particles size of phases formed due to these chemical elements. Localization of new phases and their distribution in the superalloy is also described in this paper.

2. Material and methods

The purpose was to qualitative and quantitative studies of the structure, phase composition, morphology complex alloyed rhenium alloy additionally doped by La. The alloy was obtained by directional solidification. The main elements of the alloy: Ni – ~70 at.%, Al – ~17 at.% Cr and ~5 at.%. Mo, W, Ta, Ti, Co, Co were the main alloying elements with total elemental content ~ 7 at.%. Re content was 0.4 at.% and La – 0.006 at.%.

The main methods of research of the alloy structure were TEM and SEM [3,4].

3. Results and discussion

The superalloy phases can be classified into primary and secondary phases observed by TEM. This classification is based on the volume fraction of the phases, their role in the alloy [2,5,6]. As we see from Table 1, γ′- и γ are the main phases. As a rule, they form the main structure of an alloy practically in all super alloys. In this alloy they are as quasi cuboids of γ′-phase divided by γ-phase layers. Other phases are secondary. Volume fractions of all phases in the alloy also are given in the Table 1 below. From the table is clearly that the volume fraction of γ′-phase is high. The volume fraction of γ-phase is following in size. β-phase is next (table 1). This symbol is defined β-NiAl phase with a lattice parameter a = 0.288 nm having the CsCl structure, which it can transform into a tetragonal phase type $L1_0$ [7]. The following phase is χ-phase (Table 1). It is topological close-packed phase or in other words it is Franck-Casper's phase [8]. It occurs due to the Re presence in the alloy. Actually, interaction of Re with Mo and W as well as with Co and Al leads to appearance of χ-phase. This phase is formed at annealing.

Table 1. The phase composition of the alloy and quantitative characteristics of the phases

Phases	Type of crystalline lattice	Space group	Crystalline lattice parameters, нм	Volume fractions of phases, ±1%
γ′	cubic lattice.	Pm3m	a = 0.3568-0.3575	85.60
γ	cubic lattice	Fm3m	a = 0.3569	8.00
β	cubic lattice	$Pm\bar{3}m$	a = 0.288	5.00
χ	cubic lattice	$I\bar{4}3m$	a = 0.957-0.960	1.40

It is known that the structure of superalloys is the mixture of (γ+γ′)-phase [2,5,6]. This mixture has morphologically correct crystallographic orientation and generates quasi monocrystalline structure. Part of β-phase and χ-phase completely is formed due to presence of these active phases. Formation of these two phases brings serious changings in structure of quasi cuboid of γ/γ′. Because La and Re are presented only in the local areas and they are not allocated uniformly in the whole volume of the alloy, the alloy was broken only a part of the quasi cuboids. The studies allowed to submit a scheme of the test sample of the alloy in Figure1.

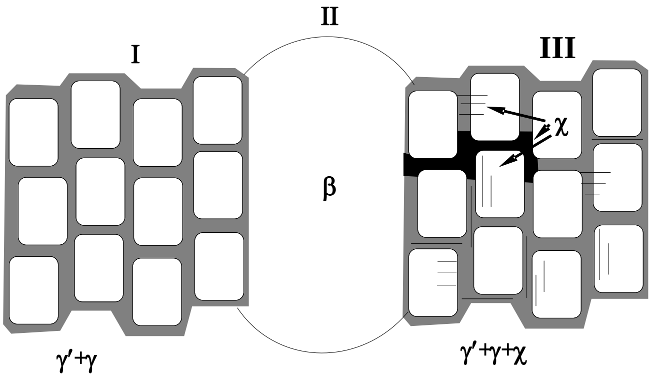

Figure 1. Schematic imagination of the structure of the alloy. Three morphologically-phase states: I - ideal structure of qauzi cuboids (γ′+γ); II-section II of β -phase; III - qauzi cuboids (γ′+γ), containing layers χ-phase

Table 2. Structure –phase state of investigated alloy

State	Volume fraction of state	Phase composition	Sizes of quazi cuboids, nm	Particles size of χ- phase, nm
I	0.65	γ′+γ	320 × 440	-
II	0.05	β	-	-
II	0.30	γ′+γ+χ	320 × 440	30 × 240

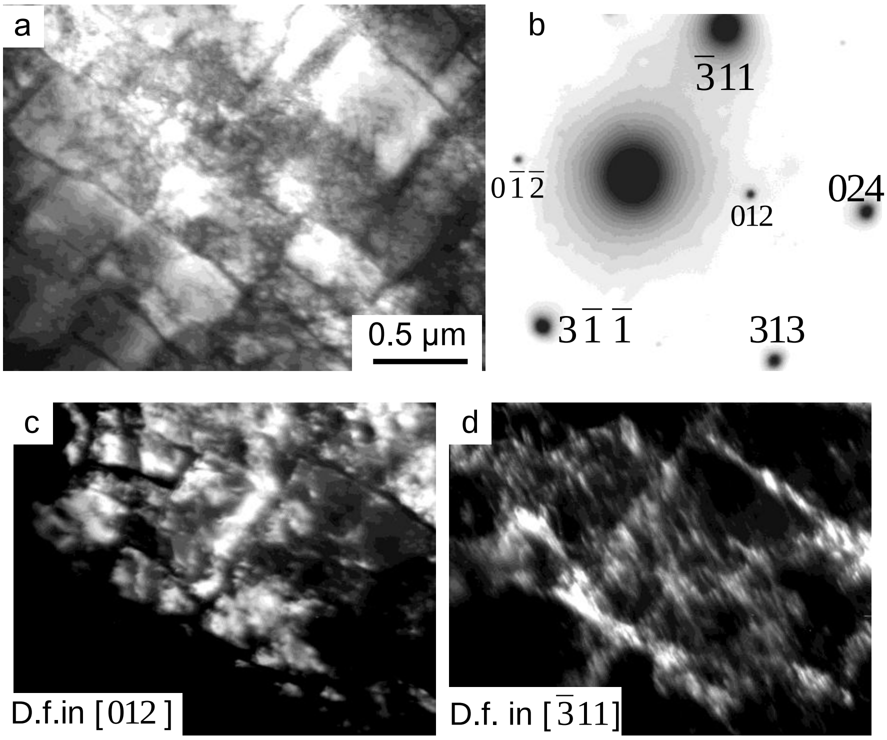

Figure 2. TEM image of quasi cuboid structure (γ′+γ) in alloy (structure-phase state I): a – bright-field image; b – microdiffraction patterns; c,d – dark-field images, obtained correspondingly in superstructure reflex [012] and main reflex [$\bar{3}11$]

It clearly shows three different morphologically-phase states: I, II and III. They are also shown in Table 2. The scheme of Figure 1 clearly shows that the state I is an ideal structure (γ+γ′) with a slightly anisotropic deformation. State III along with quasi cuboids layer contains χ-phase, which can be located in γ′-, and in γ-phase. The orientations of these layers are parallel to the cubic directions of γ′ and γ-phases, as well as the orientation of layers γ-phase, its volume fraction is close to 5%. In state III quasi cubbies are anisotropny also. Figure 1 and 2 shows results of TEM of I and III state their microdiffraction patterns and dark field. Dark field imagers are obtained in the main (Fig. 2d) for the first state and superstructure reflexes (Figure 2c). It is possible to identify γ and γ′-phases: the first layers in Figure 2d, the second it is quasi cuboid (in Figure 2c can see that layers are in unreflection position). In state III local volume fraction of γ-phase is closed to 5%.

State II is characterized by absolutely destroyed structure of quasi cuboid. There is tree component solution of $NiAl_2Re$ in the volume of part II. The last expression it is chemical formula of three component of β-phase. In Figure 3 we can see that layers of γ′ and χ are parallel. These phases have cuboid crystalline lattice but some size effects lead to crystallography disorientation. The lattice parameters of these phases differ enough [9] (a_γ = 0.3569 nm; a_χ = 0.9570 nm). We can see that direction [002]γ′ is almost parallel to [$32\bar{3}$]χ direction. In other words, the fact that the difference in the lattice parameters of these phases, the tendency to minimize of the elastic energy led to the formation of crystallographic orientation with the above orientation relationship and parallel layers χ- and γ-phases. In this case, the elastic stress fields are missing. This is indicated by absence on TEM mages of the extinction contours bending-torsion. Thus, γ- and γ′-phase coherently and almost stress-free contact with the χ-phase.

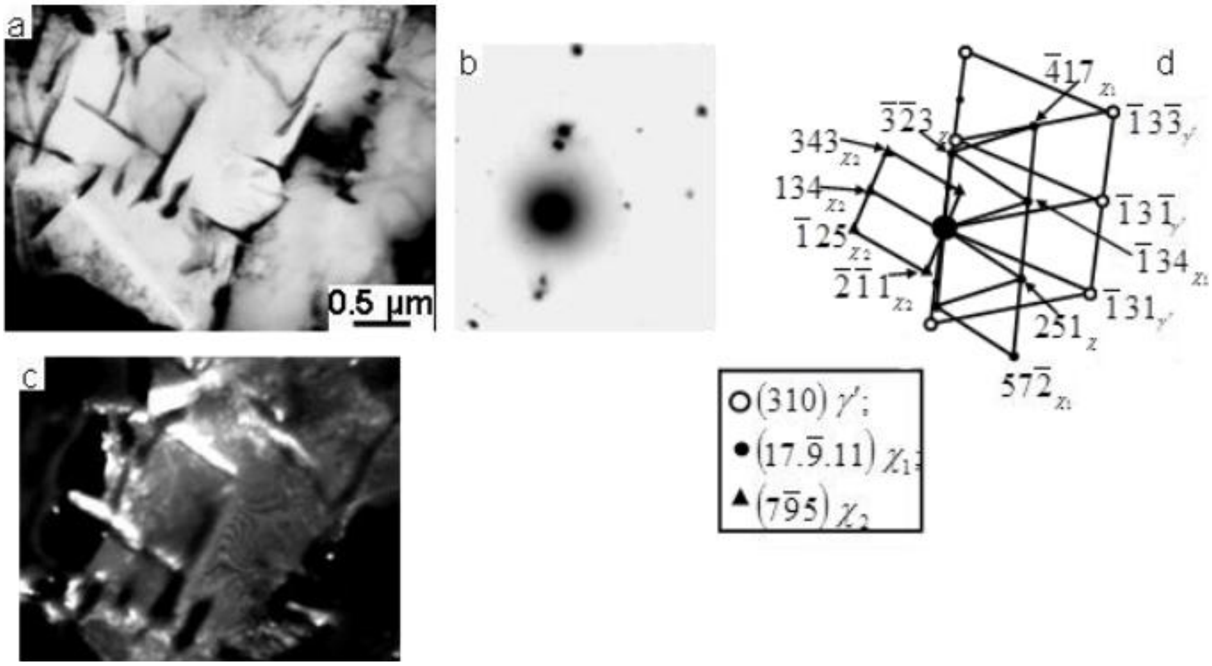

Figure 3. TEM image of structure-phase state III: a – bright-field image; b – microdiffraction patterns; c – dark-field images, obtained in reflex [$\bar{3}\bar{2}3$]$_\chi$ and d - scheme indexing (b)

We will consider contact of β-phase and the massive block of γ/γ′-phases (Figure 4) now. The interface unit and β-phase flows toward the [011] γ′-phase. Orientation ratio β-phase and γ/γ′-phase: $[110]_\beta$ II $[111]_{\gamma'}$. This typical ratio for mutual phase transformation of fcc → bcc, for example, in the steels. It is characteristically, the extinction contours bending-torsion near the β – γ/γ′ not observed (see Figure 4a). This means that β-, γ- and γ′-phase coherently related.

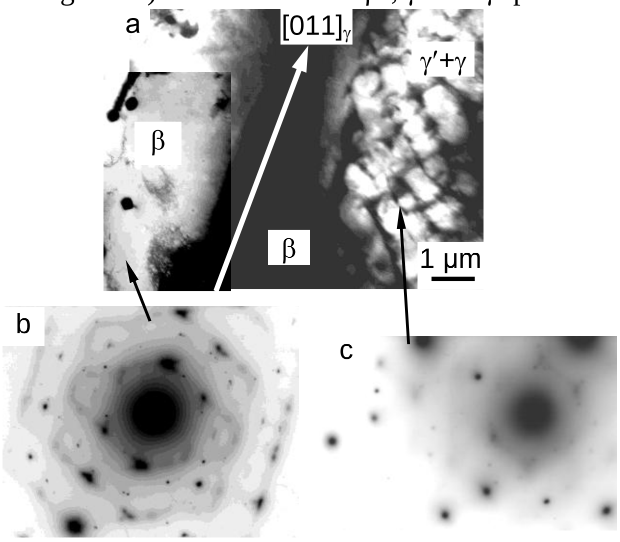

Figure 4. TEM image of fine structure of alloys: a – junction of two structurally-phase states (γ′+γ) and (β): b – micro diffraction pattern obtained from state II (there are only reflexes β-phase); c – micro diffraction pattern obtained from the state I (there are only reflexes γ/γ′ mixture)

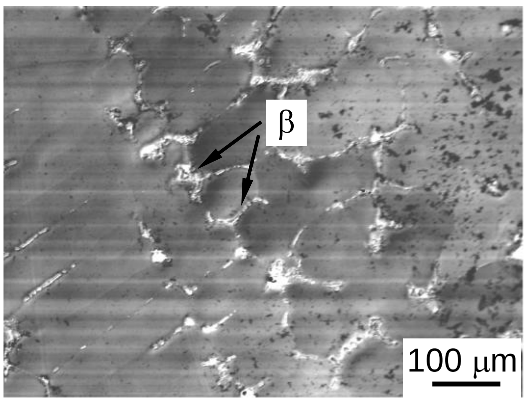

Figure 5. Image of the structure of the alloy obtained by SEM. Black arrows indicate examples of β-particle phase, a white arrow on the (b) - direction of periodicity

The microdiffraction pattern presented in Figure 4b, attract special attention. It characterizes structure of β-phase. Characteristic bands stretching between reflexes indicate micro segregation in this phase [6]. Recall that the chemical formula of this phase is close to the composition of $NiAl_2Re$. Presence of diffuse bands connecting reflexes could indicate firstly, about a nonstoichiometric composition against formula indicated above, secondly, about the presence of micro- segregation in them. It is not surprising that after annealing this phase disappears. The image of structure of an alloy obtained by the SEM method at smaller magnitude is submitted in Figure 5. Most of the volume of the alloy is quasi cuboids, whole and broken, the contrast from which due to the relatively small magnitude is different. Stratification on Re is well visible thanks to precipitation of β-phase which is mainly stabilized by this chemical element. As ratio

$$\frac{P_{V_{Al}}}{P_{V_{Ni}}} = 0.23,$$

(where P_{V_i} – volume fraction of the corresponding element), it indicates nearly stoichiometric composition A_3B (A – Ni, B – Al. This means that the amount of β-phase should be few, and that takes place actually. Particles of β-phase are well visible in Figure 5. The total share of γ-phase in an alloy makes the size equal 0.08, γ′-phase – ~0.86, ratio Δγ/Δγ′ = 0.09. It is close to the ratio of the components B and A (A = 0.82, B = 0.18). This is the sum of the ratio of the elements forming γ′- and γ-phase in the alloy under study.

Thus, we note that quasicuboides of g and g¢-phase form 95% of its volume, while 65% are ideal quasicuboides and 30% are those containing the c-phase. Finally, 5% of the volume takes the bcc-based b-phase that is an ordered ternary $NiAl_2Re$.

Acknowledgments

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