EBSD STUDY OF DEFORMATION PROCESSES IN NI-BASED HEAT-RESISTANT MONOCRYSTALLINE ALLOYS

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Abstract

Two heat-resistant monocrystalline Ni-based alloys were studied before and after series of high-temperature tensile tests. The plastic properties of the alloys were investigated using EBSD method. Schmid factor was chosen as a parameter suitable for analysis of crystal lattice orientation evolution.

Some differences of plastic behavior of the materials were discovered. Plastic insability in one of the alloys was found.

Keywords: Superalloys, EBSD analysis, plastic deformation

1. INTRODUCTION

Monocrystalline Ni-based superalloys play highly important role for aircraft industry as a material for turbine buckets. Development of the very first such alloys permitted to significantly increase working temperatures in turbines, that is one of the most important factors of engines efficiency [1].

One of the biggest problems of using superalloys is the cost, so problem of optimization quality/price ratio is arising severely [1]. A possible direction for solution is investigation of mechanisms of plastic deformation. Understanding of these mechanisms allows to take steps to improve strength characteristics.

The optimal instrument for this purpose is EBSD method that combines advantages of two popular methods: SEM (wide field of view, relatively simple sample preparation, relatively low cost) and TEM (local orientation and local crystal structure determination).

The method provides as a result map of orientations, that permits to obtain a lot of information about microstructure, like local orientation and misorientation distribution, grain and sub-grain boundaries, twins boundaries, local microdistortions etc [2]. Since deformation of crystalline materials is accompanied by rotation of crystal lattice [3], the EBSD method represents the optimal tool for analysis of deformation processes in metals.

Thus, in this study, evolution of crystal orientation during high-temperature plastic deformation in two monocrystalline Ni-based alloys was investigated for different temperatures of testing.

2. EXPERIMENTAL

Two monocrystalline Ni-based alloys were used in this study. The nominal compositions of the alloys are shown in the **Tables 1 - 2**. The samples were obtained by oriented crystallization with seed crystal. The orientation of the crystal lattice was [100] along the sample axis.

Table 1: Chemical composition of alloy 1

Ni	Al	Cr	Co	W
base	5.8-6.1	2.4-3.2	5.7-6.3	3.7-4.1
Mo	Ru	Ta	Re	Si
3.8-4.2	3.8-4.1	4.2-4.8	5.8-6.2	<0.2

Table 2: Chemical composition of alloy 2

Ni	Al	Cr	Co	W
base	5.8-6.1	4.1-4.9	8.0-9.0	5.0-6.0
Mo	Ti	Re	Ta	Si
1.8-2.1	0.6-0.9	4.0-4.5	5.7-6.5	<0.2

Five cylindrical samples were subjected to uniaxial tensile tests at different temperatures until destruction of the samples. Regions on longitudinal section close to rupture surface were studied. Five undeformed samples heated to the same temperatures also were investigated.

The conditions of the tests are presented in **Table 4**.

Table 3: Conditions of the tensile tests

Alloy	Declination of [001] direction from sample axes, °	$\frac{d\varepsilon}{dt}$	T, °C	Yield strength, MPa	Tensile strength, MPa	Relative elongation, %
1	6.27	10^{-4}	500	814	1019	5.1
1	2.29	10^{-4}	850	970	1050	17.6
2	0.56	10^{-4}	500	950	1009	6.1
2	1.45	10^{-4}	850	883	988	24.7
2	0.56	10^{-4}	975	624	660	25

Alloy 1 was not tested for T=975°C, but two orientation maps were obtained from sample of alloy 2 tested at T=850°C.

Lattice orientation analysis was carried out for each sample before and after plastic deformation using EBSD analysis. Tescan MIRA 3 scanning electron microscope with Nordlys EBSD detector was used for the analysis. The accelerating voltage was 20 kV and the scanning resolution was 2 μm.

3. RESULTS

Pole figures and orientation maps obtained from the samples didn't show significant. Hence Schmid factor was chosen to describe changes in crystallographic orientations. Schmid factor is given by eq. 1.

$$M = cos\varphi \cdot cos\lambda \quad (1)$$

where φ is the angle between the normal of the slip plane and the direction of the applied force and λ is the angle between the slip direction and the direction of the applied force [4].

Schmid factor characterizes probability for a slip system to be involved into plastic deformation process. Plastic behavior of crystal is substantially determined by the number of acting slip systems. This number in the first place depends of geometrical orientation of crystal lattice.

The lattice orientation in the studied samples ([001] axis along the tensile direction) is the most “rigid” for FCC structure as at least four slip systems have equally favorable orientation. Schmid factor for this orientation is M=0.41.

Thus evolution of crystal lattice orientation can be characterized using Schmid factor.

Fig. 1 and **Table 3** show results of Schmid factor determination. Number of channels of the histograms is 80.

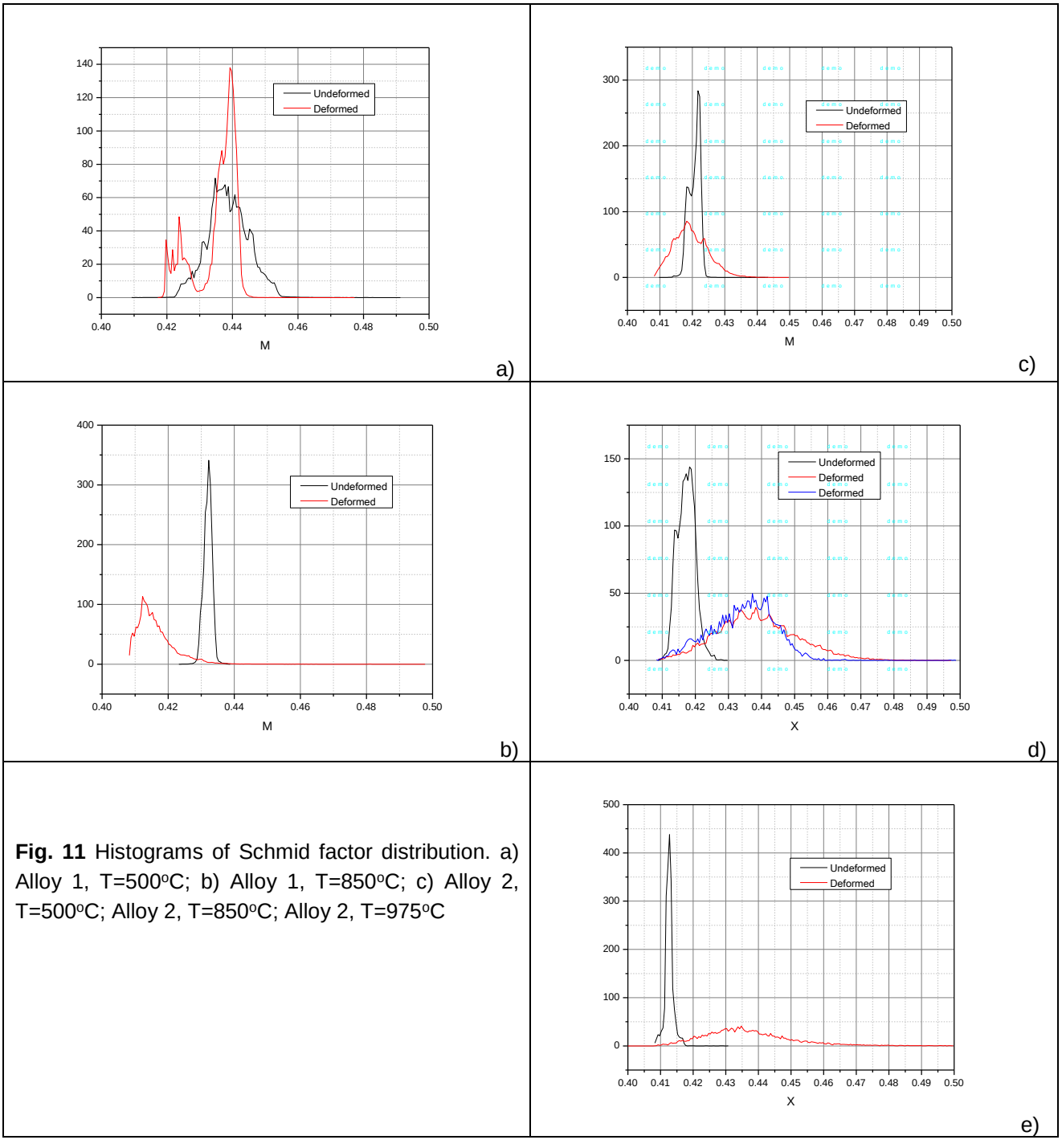

Fig. 11 Histograms of Schmid factor distribution. a) Alloy 1, T=500ºC; b) Alloy 1, T=850ºC; c) Alloy 2, T=500ºC; Alloy 2, T=850ºC; Alloy 2, T=975ºC

Centers of gravity M_{cg} of the peaks were calculated and also integral widths β and its relative variations $\Delta\beta/\beta_o$ before and after deformation.

As can be seen from **Fig. 1** histogram of alloy 1, corresponding to deformation at T=500°C, is divided into two peaks. So, integral width for this state can not be determined or, better to say, doesn't make sense.

Table 4: Results of Schmid factor histograms processing

Sample	M_{cg}	β	$\Delta\beta/\beta_o$
Alloy 1, T=500°C, before deformation	0.439	0.0140	
Alloy 1, T=500°C, after deformation peak 1 peak 2	0.424 0.438	0.0043 0.0057	-
Alloy 1, T=850°C, before deformation	0.432	0.0029	
Alloy 1, T=850°C, after deformation	0.415	0.0088	3.010577
Alloy 2, T=500°C, before deformation	0.421	0.0035	
Alloy 2, T=500°C, after deformation	0.419	0.0117	3.316879
Alloy 2, T=850°C, before deformation	0.417	0.0069	
Alloy 2, T=850°C, after deformation (1)	0.439	0.0254	3.653038
Alloy 2, T=850°C, after deformation (2)	0.434	0.0201	2.894040
Alloy 2, T=975°C, before deformation	0.412	0.0023	
Alloy 2, T=975°C, after deformation	0.437	0.0244	10.708151

4. CONCLUSIONS

As can be seen from **Fig. 1** and **Table 3**, large plastic deformation leads to changes in form and position of histogram peaks. This is an indication that lattice rotation had place. The values of the rotations that correspond to the Schmid factor changes in the studied samples are about 1°.

At the same time, some differences can be observed in the obtained distributions:

- There is splitting of histogram peak for the sample of alloy 1 tested at T=500°C. This is, probably, an evidence of some plastic instability that led to rotation of one part of the crystal relative to another. A possible reason of such instability is relatively high declination of the lattice direction [001] from sample axes.

  It should be observed that nor on orientation maps nor on pole figures this rotation was not visualized.

- With increase of deformation temperature histogram peak of deformed samples of alloy 2 dislocates to bigger values comparing with undeformed samples. For the alloy 1 the effect is opposite.

  Increase of Schmid factor during plastic deformation can be explained by the following reason: the orientation [001] along the sample axis is stable [5] and any possible rotation of lattice leads to its growth.

  The decrease of Schmid factor for alloy 1 probably can be connected with bigger declination.

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