Macroscopic localization of plastic deformation in single crystals Ni$_3$Ge with $L_{12}$ superstructure

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Abstract. The dislocation structure forming in the single crystal Ni$_3$Ge alloy during the deformation is studied in this paper. It is established that plastic deformation leads to the uniform strain stability loss in the Ni$_3$Ge alloy at increasing the temperature. The homogeneous dislocation structure loses its stability in local places, which are situated close to the zone of localization. The internal structure of the localization band of deformation consists of cleaned from dislocations fragments in size about 1$\mu$m that are disoriented from each other to 10-60º. Then the polycrystalline local band is formed, in which the plastic deformation reaches hundreds of percents.

1. Introduction

One of the main features of intermetallic compounds with the superstructure $L_{12}$ is a rather homogeneous slip [1]. Homogeneous sliding is stable to the definite strain. Two channels of the loss stability of the uniform strain can be considered. The first is the catastrophic growth of cracks and the fracture of the material. The second one is connected with accumulating antiphase boundaries in slip bands and changing the type of deformation carriers from motion of superstructure dislocations to motion of single dislocations. It leads to appearance of rough slip traces [2]. It should be noted that the both channels are not mutually exclusive. Deformation of the intermetallic alloys, as a rule, is completed by brittle fracture but plasticity of alloys increases when the rough slip appears.

In this paper results of studying the macroscopic localization of plastic deformation and the uniform strain stability loss in the Ni$_3$Ge alloy are presented.

2. Experimental

A single crystal of the Ni$_3$Ge alloy was grown by the Bridgeman method in an argon atmosphere from Ni and Ge of 99.99% purity. Specimens shaped as parallelepipeds 3.0 $\times$ 3.0 $\times$ 6.0 mm$^3$ in size were cut by the electric spark method from single crystal ingots. Samples were compressed on a test machine with a rate of 2%min$^{-1}$ at different temperatures (T=293, 523, 673, 873 K). Before tests specimens were homogenized for 40 h at T=1228 K. The directions of the compression axes of the investigated single crystals coincide with the [001] direction. The dislocation structure and the relief of the surface were studied by transmission electron
The orientation of crystal faces was determined by the Laue and X-ray diffraction methods.

3. Results and Discussion

The alloy Ni$_3$Ge belongs to group of alloys with the $L_1^2$ ordered structure and exhibits strongly expressed positive temperature dependence of mechanical characteristics [3, 4]. In certain temperature interval, increasing temperatures causes an increase of shear stresses, yield stress, and work-hardening rate.

The analysis of slip traces has shown, that sliding is homogeneous in orientation of the deformation axis [001] up to temperature $T=873$ K. The shift in lines of sliding reaches 50-100 Å. Lines of sliding 10000 - 15000 Å in length are distributed in regular intervals on a surface of a crystal. The distances between them are 300 – 400 Å. Roughening the slip, which is typical for severe deformation in alloys with the $L_1^2$ superstructure, is not observed in the Ni$_3$Ge alloy.

Formed to the moment of fracture the dislocation structure is homogeneous as well. The dislocations are situated uniformly within the deformed crystal. They are combined mainly into dipole and multipole configurations. Measured characteristics of the dislocation structure and following statistical treatment have shown that the dislocation structure is described by the lognormal distribution.

At $T=873$ K the deformation is realized homogeneously as before by means of the fine slip up to $\varepsilon \approx 3 – 4 \%$. The dislocation structure, which is formed at mentioned strains, is also homogeneous and described by the lognormal function. However the qualitative differences are observed in the homogeneous dislocation structure at different temperatures. It should be noticed that the dipole configurations and the rectilinear dislocations are absent at $T=873$ K.

![Figure 1. An initial stage of forming a band of superlocalization](image)

The increase in temperature has displayed that plastic deformation is non-uniform beginning from $\varepsilon \approx 5 \%$ at the temperatures exceeding $T=893$ K. On the surface of the crystal there is a band passing through all crystal of width about $10^2$ mm, in which deformation is localized. Originally, the band is formed from set of rough slip traces (figure 1).
The evolution of the band caused by increase in the strain leads to even greater localization of deformation and displacement of parts of a crystal relative to each other on the localization deformation band. The single crystal is divided into two parts shifted along planes close to \{111\}. The further deformation develops along the division plane of parts of the crystal (figure 2).

Newly created surface has a complex rough structure, which consists of many fragments (figure 3a, b). Local deformation in the band, defined as $\Delta l/l \cdot 100\%$, where $\Delta l$ – a value of displacement, $l$ – a width of the band, is hundreds of percents.

The drop in stresses in curve of strengthening corresponds to development of this process. To study the dislocation structure, foils have been prepared from different parts of the crystal: a) far from the band of localization, where deformation is homogeneous; b) near the zone of localization; c) the zone of localization. It turned out that the homogeneous dislocation structure with the high density of dislocations ($2-3 \times 10^{10}$ sm$^2$) is formed in parts are placed far from the localization band. The homogeneous dislocation structure loses its stability close to the zone of localization. There appear areas of the disorientated band structures with 1-2° disorientations. Polycrystalline substructure, composed of the fragments with the low density of dislocations bounded by the high-angled boundaries, is detected directly in the band of localization. Disorientation between the fragments in this zone goes up to 10-60° (figure 4).

Sizes of observed fragments in the localization area fall into the interval $10^{-3} - 10^{-4}$ mm. The same sizes have roughness of the newly appearing surface that points to possible unity of their nature.

Raising the temperature leads to changing the shape of the localization band. The band of localization gets diffuse losing the sharp outline (figure 5).
4. Conclusions
The investigation and the analysis of the deformation relief and dislocation structure for the single crystal Ni$_3$Ge, oriented along the [001] axes at the temperatures 893 - 973 K carried out in this work make it possible for the authors to offer the following stages of plastic deformation development. There are several stages of macroscopic localization process of the deformation.

1. The initial stage observed before deformations of 3-4 %, is the stage of the homogeneous slip. Dislocations are accumulated very fast up to density $(2-3) \times 10^{10}$ cm$^{-2}$.

2. The stage with zero coefficient of hardening is the stage of the homogeneous slip too; however the density of dislocations at this stage remains at constant level. The balance of processes of multiplication and annihilation of dislocations is observed at this stage.

3. The stage with negative coefficient of work-hardening is a stage of superlocalization of deformation. The density of point defects, dislocations, the level of the stress and the temperature are sufficient to form the localization band of deformation, which internal structure consists of fragments in size about 1 µm that are disorientated from each other to 10-60 º. Internal areas of these fragments are cleaned from dislocations, and the polycrystalline local band is formed, in which the plastic deformation goes up to hundreds of percents.

References
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