THE DISLOCATION-GRAIN BOUNDARY INTERACTION AND ITS EFFECT ON THE BOUNDARY DYNAMIC PROPERTIES

R. Valiev, V. Gertsman

To cite this version:


HAL Id: jpa-00230015
https://hal.archives-ouvertes.fr/jpa-00230015
Submitted on 1 Jan 1990

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
THE DISLOCATION-GRAIN BOUNDARY INTERACTION AND ITS EFFECT ON THE BOUNDARY DYNAMIC PROPERTIES

R.Z. VALIEV and V.Yu. GERTSMAN

Institute of Metals Superplasticity Problems, URSS Academy of Sciences, Ufa 450001, U.R.S.S.

Abstract - The problem of the interaction of dislocations with grain boundaries is discussed on the basis of the concept of grain boundary non-equilibrium state generation and recovery. According to this concept, trapped lattice dislocations, being non-equilibrium defects, are absorbed by the boundaries as they dissociate into grain boundary dislocations which are then rearranged into equilibrium configurations. During the absorption of lattice dislocations, grain boundaries are shown to be in an non-stationary, excited state, which causes an abrupt acceleration of some of the grain boundary dynamic process such as diffusion, migration, and sliding.

The interaction of grain boundaries (GB) with lattice dislocations (LD) usually imply such processes as nucleation of LD, penetration of LD through GB and their absorption. The latter process is of special importance when structural changes and behaviour of solids at higher temperatures are studied, in particular during the solid phase reaction, recrystallization, and high-temperature deformation /1, 2/. The process of LD absorption in this case is responsible not only for the reduction of the density of dislocations in the structure, but also for significant changes in such dynamic properties of GB as diffusion, migration, and sliding. These problems have been the authors' primary concern lately and the results of their studies are summarized in this paper.

The study of the dislocation-boundary interaction and its relation to the GB dynamic properties included both the analysis of the LD absorption mechanism /3, 4/ and experiments in order to confirm the existence of this relation and to define its nature /1, 2/. Let us consider these two points in turn.

1. Our analysis of the LD absorption mechanisms is based on the concept of the GB non-equilibrium state generation and recovery /4, 5/. According to this concept, trapped lattice dislocations (TLD), being non-equilibrium defects, are absorbed by the boundaries, the boundary energy being reduced to the equilibrium state values, through rather complicated rearrangements in GB structure. The type of these rearrangements depends on the crystallogeometry of GB and conditions of the LD absorption. It should be noted that the term "recovery" used with reference to the process of LD absorption is rather conventional since in transformations of the following type: an equilibrium GB - LD entering the GB - absorption of TLD by the GB structure, the resultant equilibrium GB structure must differ from the original one /4/.

Numerous experiments /2/ prove that during heating TLD are unstable in all the GB, but the observed changes however depend on the GB crystallogeometry. In coincidence and near-coincidence GB the dissociation of TLD into perfect extrinsic grain boundary dislocations (EGBD) with the DSC-Burgers vectors or partial ones are often observed; in GB with visible intrinsic grain boundary dislocation (IGBD) networks the interaction of EGBD with IGBD and incorporation of the former into equilibrium IGBD networks were observed. In random GB it is hardly possible to see the dissociation of TLD into EGBD. The experiments on the in situ heating of foils revealed the spreading of the electron microscope TLD contrast; with heating, the TLD

(1) The non-equilibrium state of GB can be described in more detail in the framework of disclination-structural unit model proposed by the authors in /6/ and developed in /7/.
images in random GB will gradually widen and fade until the diffraction contrast disappears completely.

It should be emphasized that spreading and disappearance of the electron microscope images of TLD do not attest to the complete TLD absorption, i.e. to the recovery of the GB structure. This conclusion was drawn directly from the experiments which demonstrate that some of the GB properties remain non-equilibrium after the spreading of TLD images (see below).

The elucidation of the mechanism of LD absorption in GB implies the consideration of both the crystallogeometrical rearrangements of GB structure and energy aspects of this interaction /4, 5, 6/.

In /5, 8/ variations of the GB energy during the TLD absorption was analyzed on the basis of the model of the dissociation of TLD into EGBD. The energy of a non-equilibrium GB was represented as a total of the following components: the energy of the original equilibrium GB; the energy of elastic distortions introduced either by the TLD or by the complex of EGBD, i.e. products of TLD dissociation; the variation of the energy of original GB due to the change in misorientations provoked by the defects; the energy of the interaction of EGBD with each other; the energy of the interaction of GB regions occupied by the products of TLD dissociation with the GB regions of the original GB structure, i.e. the energy of the transition region. The energy of GB decreases during the redistribution of EGBD in GB, i.e. during the spreading of TLD dissociation products. Assuming that the elasticity theory applies to high-angle GB, the energy variation value for TLD with the Burgers vector normal to the GB will be as shown in Fig. 1. During the absorption of TLD, the GB energy does not change monotonously: there is a certain potential barrier at the beginning of the separation of TLD dissociation products. It means that TLD in GB are relatively stable and to be absorbed by the GB structure, they have to overcome the potential barrier due to thermal activation.

Fig. 1 – Dependence of the GB energy on the width of the EGBD complex (H) formed during the TLD dissociation. The energy at H/L=1 (L is the GB length) corresponds to the new equilibrium GB structure with the corresponding number, n, of TLD dissociation products.

The most important conclusion drawn from the results obtained in /8/ is that the non-equilibrium state of the GB structure may be either relatively stable (quasi-stable) if TLD are localized, or unstable if the separation of the TLD dissociation products has started and the necessary potential barrier has been overcome. A similar conclusion was made earlier on the basis of the qualitative analysis: /9/ and later /10/ and other; the corresponding states of GB structure are called non-equilibrium states of the first and second order respectively. Besides, in /2, 5/ the state of GB structure where the process of TLD absorption is in progress is called non-equilibrium or non-stationary state.

2. Let us dwell now on the relations between the TLD absorption and GB dynamic properties. The existence of such relations could be expected if we support the view that the non-equilibrium or non-stationary state of GB is formed in the course of LD absorption. To confirm this statement we have performed a series of experiments.

Grain Boundary Diffusion. The effect of the TLD absorption on the diffusion was determined on the basis of the data obtained through the study of GB precipitate nucleation and growth kinetics during the ageing of an Al-base alloy /11/. Two states of the alloy were studied: as-annealed with the grain size of 15 μm and as-annealed with subsequent 2% straining at room
temperature. Such small cold deformation provides for the running of TLD with the average density of $3 \times 10^5 \text{cm}^{-2}$ in GB. These dislocations were unstable during the heating and already at $90^\circ \text{C}$ the spreading of these TLD started. The kinetics of phase-precipitations were studied at $130^\circ \text{C}$ (see the Table).

Table - The Fractions of Grain Boundaries Containing Disperse Particles ($x$) and the Volume Fraction of MgZn$_2$ Precipitates ($f$) Depending on the Time of Annealing at $130^\circ \text{C}$.

<table>
<thead>
<tr>
<th>State</th>
<th>Time of Annealing (min)</th>
<th>$x%$</th>
<th>$f%$</th>
<th>$x%$</th>
<th>$f%$</th>
<th>$x%$</th>
<th>$f%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. As-annealed + 2% cold prestraining</td>
<td>30</td>
<td>18</td>
<td>6</td>
<td>65</td>
<td>11</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A considerable acceleration of the formation and growth of precipitates in GB in the pre-strained specimen is observed, which may be directly connected with the absorption of TLD in the course of subsequent annealing. The alloy phase precipitation kinetics is controlled by the diffusion of precipitate forming elements Mg and Zr in GB. It is well known that when precipitates are small (unities or tens of nanometers) the role of grain boundary diffusion in their formation and growth is dominating as compared to volume diffusion. Basing on this statement it was shown in /11/ that due to the absorption of TLD in the alloy, diffusion accelerates more than 10 times. It is important to emphasize that the acceleration of grain boundary diffusion during the absorption of TLD may cause abrupt changes in the kinetics and character of solid-phase reactions which proceed with the involvement of grain boundaries as it has recently been shown on the Ni-base alloy /12/.

Grain Boundary Sliding. Zinc bicrystals were used for investigation /13, 14/. This metal with an h.c.p. lattice has only one preferential slip plane (basal plane), thus the study of the deformation of these bicrystals allows to distinguish between the deformational processes in the boundary and within the grains.

![Fig. 2](image.png)

Fig. 2 - Scheme of cutting (a) and types (b) of the investigated Zn bicrystals with $90^\circ\langle1010\rangle$ tilt boundary.

It can be seen that in type I bicrystal the basal slip is banned. Thus, during the tensile straining, the "pure" sliding develops here without intragranular slip. At the same time, in type II bicrystals, simultaneous development of sliding and basal slip takes place during the deformation.

It turned out that at the same shear stress of $1.4 \text{ MPa}$ for type II specimens the GBS rate was 50-60 times as high as the rate of GBS for type I specimens. In the former case contrary to the latter one an intensive interaction of grain boundaries with the intragranular slip took place and, consequently, an active absorption of LD in GB was observed /14/. The data obtained
give direct evidence for the stimulating effect of the absorption of TLD on the development of grain boundary sliding.

This effect may be due to the acceleration of diffusion and the increase of the density of mobile grain boundary dislocations as a result of the non-equilibrium state of grain boundaries induced during the absorption of TLD.

Migration of Grain Boundaries. The grain boundary migration was assessed by the data obtained from the investigation of grain growth in the magnesium alloy with the grain size of 10 µm in the following two initial states: as-annealed and 3% prestrained at room temperature /15/.

It turned out that the annealed alloy displayed no noticeable variations of grain size with further heating and annealing at 400°C.

Fig. 3 - Dependence of the average grain size in the magnesium alloy specimen 3.3% strained on the time of annealing at 670 K.

The case was quite different with the prestrained material (Fig. 3). At the start of annealing there was an incubation period of about 10 minutes, then an intensive grain growth started, after which the grain size became stable. This grain growth cannot be explained either from the point of view of the dissolution of precipitates in the alloy or by the influence of the volume density of dislocations /15/. However, a distinct correlation was observed between the grain growth and the TLD behaviour in grain boundaries. It turned out that at the start of annealing the TLD in the boundaries were stable, but after the 10 minutes of annealing their spreading started, followed by their absorption. The investigations showed that the beginning of the TLD absorption was the main reason for an active migration of boundaries and grain growth.

Conclusions.

The absorption of TLD seems to be related to complicated rearrangements in GB during which the GB structure is in a non-equilibrium and non-stationary state.

2. The experimental data obtained indicate that considerable activation of such dynamic properties of GB as diffusion, sliding, and migration seems to take place during the absorption of TLD in GB.

REFERENCES


