

Structural relaxation at plastic deformation of two-dimensional polycrystals with fcc-lattice

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Structural relaxation processes at plastic deformation of two-dimensional copper and aluminum polycrystals have been studied. In experiments, various types of rotational effects — broken, through, and collective reorientation bands have been observed as well secondary rotations being formed near the previously appeared bands. A particular part played by special and close to special grain boundaries in plastic rotations formation has been established.

В работе иследованы процессы структурной релаксации при пластической деформации двумерных поликристаллов алюминия и меди. Экспериментально обнаружены различные виды ротационных эффектов — оборванные, сквозные и коллективные полосы переориентации, а также вторичные ротации, возникающие в области ранее появившихся полос. Установлена особая роль специальных и близких к специальным границам зерен в образовании пластических ротаций.

Recently, concepts of plastic deformation as a process occurring at different scale levels in two complementary and competing channels: translational and rotational ones [1–3] are developed. Under plastic deformation of polycrystals, stress concentrators arise at the grain boundaries due to difference between shear and rotation strain components of adjacent grains; these concentrators may be relaxed in various manners. The variety of stress condition relaxation manners found out in experiment causes an interest in studies of relaxation phenomena in polycrystals.

As the research objects, characteristic types of fcc metals with low and high stacking fault energy have been chosen, namely, copper and aluminum samples. The working part size of the specimens was $100\times20\times0.15$ mm^3, the grain size 3 to 15 mm. The desired specimen structure was provided by selection of preliminary strain and of recrystallization annealing regime. All specimens obtained were two-dimensional polycrystals, that is, contain the through grain boundaries. On the one hand, in such samples various relaxation processes should be manifested clearly enough because there are no constraints in the direction perpendicular to the sample surface. On the other hand, it is easy to obtain such samples with controlled density of grain boundaries. The specimens were strained under active tension conditions at a constant straining rate $\dot{\varepsilon} = 10^{-5}$ s^{-1}. Such straining rate allowed us to observe in situ the structural changes accompanying the specimen plastic deformation using a metallurgical microscope or a digital video camera connected with a computer.

It is shown in experiment that in two-dimensional aluminum and copper polycrystals, the main way to the stress state relaxation is the origination of rotational effects [4, 5]. At the first stage of research, the number of any rotations arising in various aluminum polycrystal areas (grain body, grain boundary) during plastic deformation has been determined. These results are presented in Fig. 1. Rotational effects in grain boundaries are appeared already at early plastic deformation stages. So at the speci-

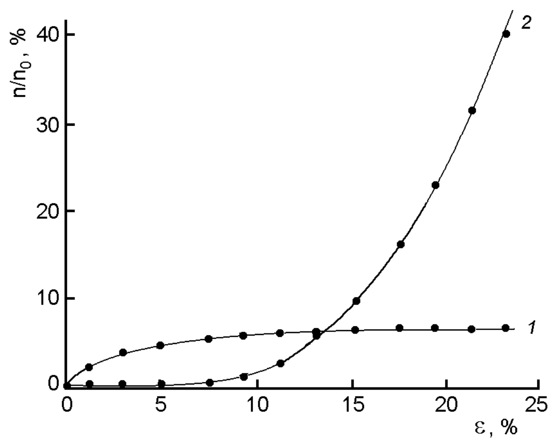
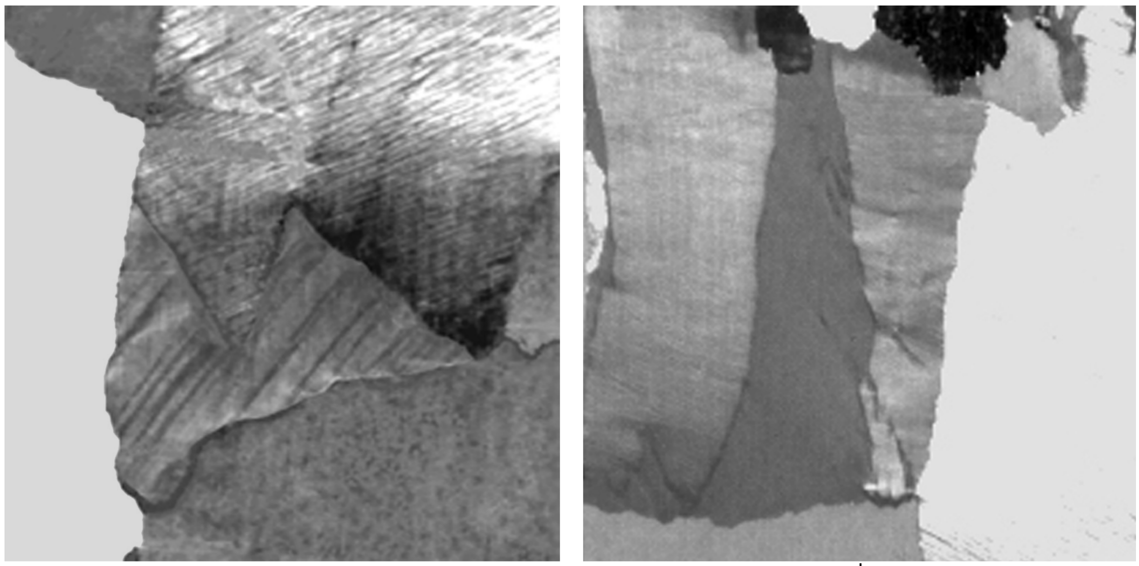


Fig. 1. Change of relative share (n/n_0) of different areas in a two-dimensional aluminum polycrystal subjected by rotational effects at plastic deformation: grain boundaries (*1*), grain body (*2*).

men deformation $\varepsilon \approx 1$ %, the relative share of rotations in boundaries makes about 2 % and it increases insignificantly with the deformation reaching about 8 % to the moment of specimen failure. At the specimen deformation not exceeding $\varepsilon \approx 10$ %, rotational effects in the form of reorientation bands (RB) in grain body are not observable essentially. Under the further straining, the reorientation bands arise in bodies of various grains, their number being increasing. The relative share of reorientation bands to the specimen failure moment amounts about 40 %.

Thus, the experimental data obtained testify that under plastic deformation of two-dimensional aluminum polycrystals, rotational effects in grain body are manifested most clearly. In the aluminum samples deformed, as a rule, the following types of RB are found out: through bands (Fig. 2a) crossing the whole grain body from one boundary to another one, broken ones (Fig. 2b) with obtuse-angular or wedge-shaped tops, and also collective RB with length exceeding their width considerably. Research of relaxation processes by means of digital camera recorder which permitted to trace rotational effects appearance and development at a period of 0.01 s has allowed to find out a new type of rotations, that is, the secondary ones (Fig. 3). These rotations appear within the body of reorientation bands arisen earlier. A source of primary and secondary rotation is the same grain boundary.

The X-ray examinations have shown that grain boundaries near which the occurrence of RB was revealed as well as the all boundaries of deformational origin ("RB-grain body") appeared, in view of Brandon criterion, close to special ones. Besides, all reorientation bands arising within the bounds of one grain had identical crystallographic orientation and have been oriented favorably for development of shear deformation therein. Thus, at the initial plastic deformation stages of two-dimensional aluminum polycrystals, the stress state relaxation occurs by formation of ro-



a b

Fig. 2. Different types of plastic rotations in two-dimensional aluminum polycrystals: (a) broken RB; (b) through RB; ×5.

tational effects as RB of various forms and sizes in the areas of grain boundaries close to special ones. Under further deformation, reorientation bands arise oriented in such manner that the further relaxation occurs therein by the dislocation sliding.

The experimental results obtained testify the specific role of special and close to special grain boundaries in relaxation processes accompanying the polycrystal plastic deformation. To check this assumption, plastic deformation was studied in two-dimensional copper polycrystals where all grain boundaries are special ones due to low stacking fault energy. The stress state relaxation in copper samples occurs by formation of rotational effects in the form of sample separate area rotations perpendicular to the sample surface in essentially all grains. The maximum plastic deformation in such samples exceed 60 %.

Thus, the experimental results obtained show, that the structural relaxation in two-dimensional copper and aluminum polycrystals occurs by rotational effects arising in the special and close to special grain boundary areas. Such relaxation way not only reduces effectively the stress concentration in the sample but also raises essentially its plasticity, since rotational deformation plays not only accommodation role but also contributes substantially to sample plastic deformation.

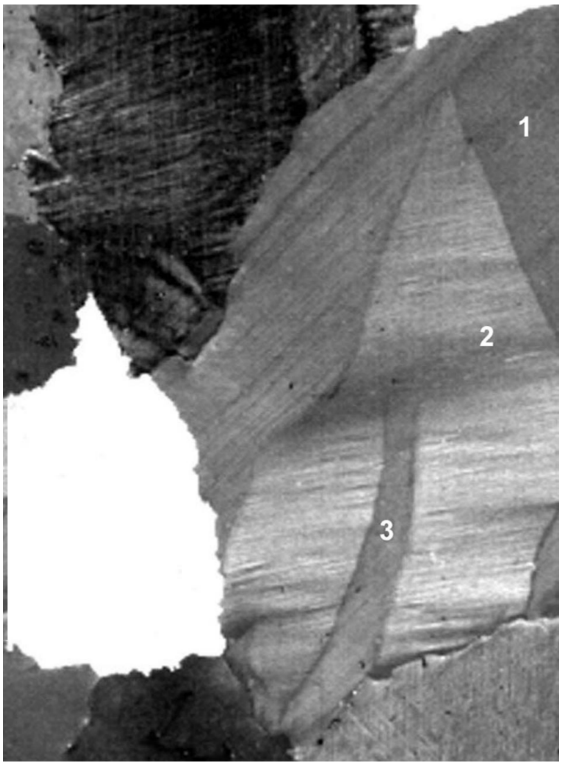


Fig. 3. Two-dimensional aluminum polycrystal after straining ($\varepsilon = 15$ %): grain (1), primary rotation (2), secondary rotation (3); ×5.

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Структурна релаксація при пластичній деформації двовимірних полікристалів з ГЦК-решіткою

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У роботі досліджено процеси структурної релаксації при пластичній деформації двовимірних полікристалів алюмінію та міді. Експериментально знайдено різні види ротаційних ефектів — обірвані, наскрізні та колективні смуги переорієнтації, а також вторинні ротації, яки виявляються в області раніш виниклих смуг. Встановлена особлива роль спеціальних та близьких до спеціальних меж зерен у формуванні пластичних ротацій.