ELECTRON-MICROSCOPIC STUDY OF CHROMIUM AND MOLYBDENUM DEFORMED UNDER HIGH-PRESSURE CONDITIONS

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Abstract

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ELECTRON-MICROSCOPIC STUDY OF CHROMIUM AND MOLYBDENUM DEFORMED UNDER HIGH-PRESSURE CONDITIONS

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During deformation under high all-round pressure, the plasticity of metals (including metals that are brittle under ordinary conditions) increases substantially ($^{1-4}$). The plasticizing effect of high pressure is associated (^{3}) with the suppression of the nucleation and growth of fracture cracks. It is also known (^{5}) that plastic deformation under high pressure can very strongly affect the residual mechanical properties of certain metals. To understand the nature of these effects, it is of considerable interest to investigate the fine structure of metals deformed under high-pressure conditions.

The experiments were carried out on chromium and molybdenum of high purity (not less than 99.99%). Cylindrical specimens of the materials under study were deformed by compression between plane-parallel anvils both at atmospheric pressure and in a liquid medium under high pressure (14–18 kbar). Some of the specimens were deformed by hydroextrusion at pressures of 16–18 kbar. The high-pressure apparatus used in the experiments has been described previously (^{5}). Deformation was carried out at room temperature (20°) and at elevated temperature (250°). Deformation heating of the specimens was practically eliminated owing to good heat removal and a low deformation rate ($\dot{\varepsilon} = 2{\cdot}10^{-3}$ sec^{-1}). Thin foils for electron-microscopic studies were prepared from the deformed specimens.

The structural studies performed make it possible to note a number of features imposed by high pressure on the process of plastic deformation.

In the case of deformation of chromium and molybdenum at atmospheric pressure, the electron micrographs (see Fig. 1a, c) show a structure typical of cold-deformed metals, distinguished by a high density of dislocations and a comparatively uniform (“homogeneous”) distribution of them throughout the

Fig. 1

Figure 1: Fig. 1

crystal volume.* Dislocations of irregular shape with a large number of bends and jogs form numerous tangles and clusters. A considerable fraction of the dislocations is blocked in these tangles.

Under deformation under pressure the picture changes sharply (Fig. 1b, c, d). First, the average dislocation density in this case decreases substantially in comparison with the dislocation density in materials deformed without pressure. The dislocation lines are noticeably straightened, and dislocation clusters are either absent (Fig. 1d) or weakly expressed and few in number (Fig. 1b, c). Secondly, under deformation under pressure the main mass of dislocations arranges itself into walls, forming a cellular substructure similar to a polygonization structure.* The cells (blocks) formed under pressure are almost free of dislocations, while the comparatively few dislocations present in these blocks are straightened and have few bends and loops (this is especially clearly seen in Fig. 1d). With an increase in the deformation temperature (Fig. 1e), the cells are almost completely freed of dislocations.

Fig. 1. Effect of hydrostatic pressure P, deformation ε, and deformation temperature T on the dislocation structure of chromium and molybdenum (electron micrographs, 20,000×).
a –chromium, $P = 1$ atm., $\varepsilon = 20\%$, $T = 20^\circ$;
b –chromium, $P = 16$ kbar, $\varepsilon = 37\%$, $T = 20^\circ$;
c –chromium, $P = 18$ kbar, $\varepsilon = 83\%$, $T = 20^\circ$;
d –molybdenum, $P = 1$ atm., $\varepsilon = 21\%$, $T = 20^\circ$;
e –molybdenum, $P = 18$ kbar, $\varepsilon = 80\%$, $T = 20^\circ$;
f –molybdenum, $P = 18$ kbar, $\varepsilon = 83\%$, $T = 250^\circ$.

In the case of deformation at room temperature (Fig. 1b, c, d), the cells are nonequiaxed, elongated along a certain preferred direction.** An increase in the deformation temperature, as was to be expected, leads to the formation of a more equiaxed cellular structure (Fig. 1e).

Electron-diffraction studies showed that between neighboring cells (both in cold and in warm deformation) there is a considerable misorientation (8–12°). In cold-deformed molybdenum (Fig. 1d) it was found that the orientation of cells located "every other one" (i.e., even or odd cells) coincides, so that the crystal consists of a large number of blocks with alternating orientation.

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* In Fig. 1, for deformation at atmospheric pressure we have confined ourselves to showing the structure of specimens deformed only by 20%, since at larger deformations the dislocation density increases so much that the foil becomes practically opaque.

It was also established that the cellular structure is formed under pressure both during compression deformation and during hydroextrusion. At the same time, no difference whatever was observed in the structures as a function of the type of deformation (at the same pressures, temperatures, and magnitudes of deformation).

It is known (9, 10) that the process of formation of dislocation walls, which form subgrain boundaries, is determined by the intensity of climb (nonconservative motion) of dislocations. The observations carried out in the present work indicate that, during deformation under high pressure, the process of dislocation climb is extremely activated, although the mechanism of such activation remains unclear.

Let us note that the phenomenon described, which we have called the "baropolygonization effect," appears very interesting also from the practical point of view. It was reported earlier (5) that, as a result of deformation under high pressure (by hydroextrusion), brittle bcc metals acquire considerable residual plasticity. On the basis of the present work it should be assumed that the plasticizing action of deformation under pressure, in addition to other factors (see (5)), is associated with the formation of an exceptionally fine (2–3 μ) grain on the basis of a strongly misoriented cellular structure, since, as discussed in (7), subboundaries with such a strong misorientation (8–12°) are in fact grain boundaries.

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* The formation of a cellular structure in chromium and molybdenum by ordinary polygonization occurs (7, 8) at substantially higher temperatures than was observed in our experiments.

** The regularity of the orientation of such cells has not yet been clarified.

Note: Figure translations are in progress. See original paper for figures.

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