MECHANISM OF GRAIN BOUNDARY SLIDING IN SUPERPLASTIC DEFORMATION

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Annotation. This article analyzes the mechanism of grain boundary sliding that occurs during deformation under superplastic conditions. The study explains scientifically how the movement along grain boundaries affects the general deformation properties of the material. The importance of interaction between grains under conditions of high temperature and low deformation rate is also considered. The effect of the grain boundary sliding process on the strength and plastic properties of the material is evaluated from theoretical and practical perspectives. As a result, the important role of the grain boundary mechanism in the process of superplastic deformation is substantiated.

Keywords: superplasticity, deformation, grain boundary, sliding, mechanism, material strength, high temperature, deformation rate, microstructure, interaction.

Annotatsiya. Ushbu maqolada o‘ta plastiklik sharoitida yuzaga keladigan deformatsiya jarayonida donalar chegarasida sodir bo‘ladigan sirpanish mexanizmi tahlil qilinadi. Tadqiqotda donalar chegarasi bo‘ylab siljish materialning umumiy deformatsiya xususiyatlariga qanday ta’sir ko‘rsatishi ilmiy jihatdan yoritilgan. Shuningdek, yuqori harorat va kichik deformatsiya tezligi sharoitida donalararo o‘zaro ta’sirning ahamiyati ko‘rib chiqiladi. Donalar chegarasida praskalzyvaniye jarayonining material mustahkamligi va plastiklik xossalariga ta’siri nazariy hamda amaliy jihatdan baholanadi. Natijada, o‘ta plastiklik deformatsiya jarayonida donalar chegarasi mexanizmining muhim o‘rni mavjudligi asoslab beriladi.

Tayanch so‘zlar: o‘ta plastiklik, deformatsiya, donalar chegarasi, praskalzyvaniye, mexanizm, material mustahkamligi, yuqori harorat, deformatsiya tezligi, mikrostruktura, sirpanish.

Аннотация. В данной статье анализируется механизм проскальзывания по границам зерен, возникающий в процессе деформации при условиях сверхпластичности. В исследовании научно раскрывается влияние перемещения вдоль границ зерен на общие деформационные свойства материала. Также рассматривается значение взаимодействия между зернами при высоких температурах и малых скоростях деформации. Оценивается влияние процесса проскальзывания по границам зерен на прочность и пластические свойства материала с теоретической и практической точек зрения. В результате обосновывается важная роль механизма границ зерен в процессе сверхпластической деформации.

Ключевые слова: сверхпластичность, деформация, границы зерен, проскальзывание, механизм, прочность материала, высокая температура, скорость деформации, микроструктура, взаимодействие.

The characteristics of the GPR have been studied in many materials, but they are most clearly evident in model superplastic alloys deformed at low temperatures and not highly susceptible to oxidation. As a result of deformation, the GPR manifests itself in the spatial displacement of scratches and the appearance of steps on the surface of specimens polished before testing (Fig. 1).

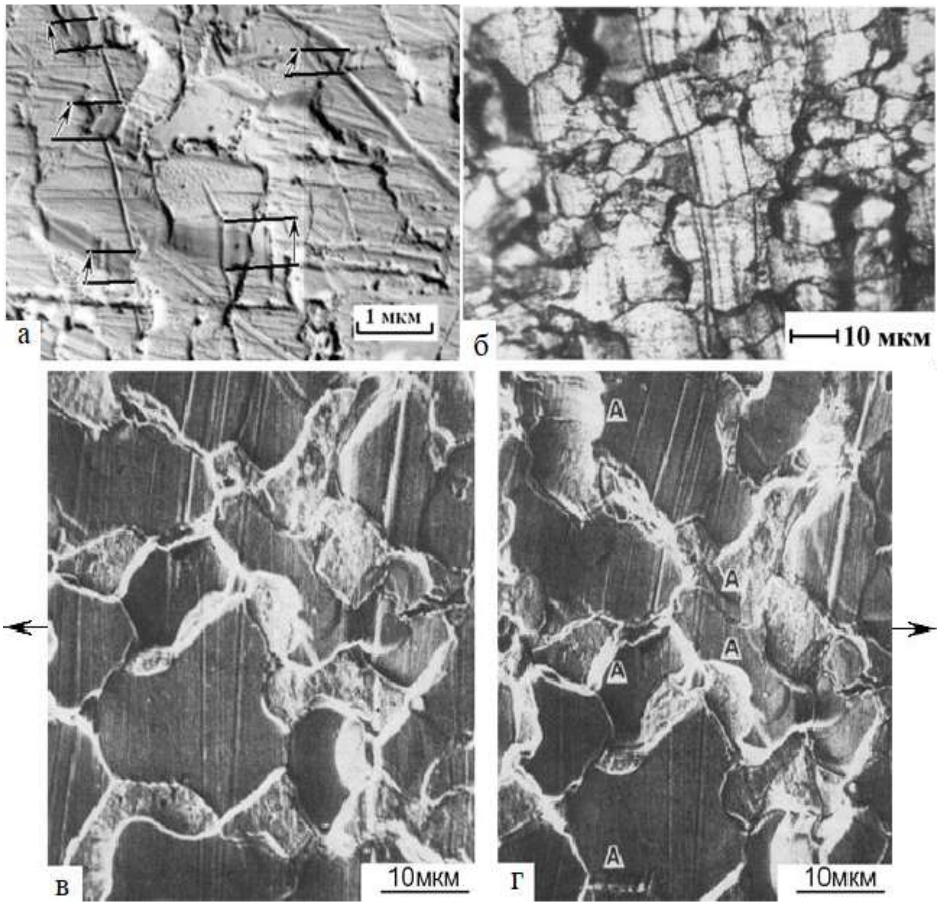

FIGURE 1. Deformation relief on the surface of samples after stretching in the second speed interval: a – Zn-0.4% Al alloy (replica method, photograph by the author); b – supral-type alloy deformed by $\varepsilon = 100 + 15\%$ (optical microscope); c and d – Pb – 62 wt. % Sn alloy, the same area, $\varepsilon =$ (c) and $\varepsilon = 100\%$ (d) (SEM, in situ) [1, 2].

The regions where grains emerged on the sample surface are marked with the letter “A” The maximum value of $\gamma = 40\%$ was obtained at the optimal strain rate [3]. At different boundaries, the direction and magnitude of the GBP can vary significantly, even to the point of being completely absent.

Thus, the listed deformation mechanisms participate in the SPD of various materials to varying degrees. Figure 2 shows the contributions of the main mechanisms at different strain rates for the MA8 magnesium alloy. The largest contribution from the

GBP is observed in the second strain rate interval. The contribution of diffusion creep, determined from precipitate-free zones, is significant only in the first strain rate interval, while VDS dominates in the third interval. The ratio of these contributions largely depends on the material type and grain size. In ultrafine-grained two-phase alloys, the contribution from the GBP can approach 100% [4, 5].

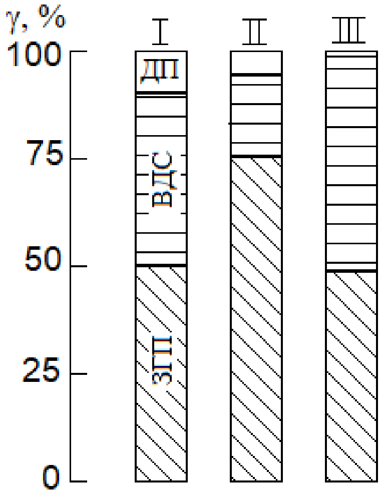

Fig. 2. Contribution of the ZGP, VDS and DP to the deformation of the MA8 alloy [3].

Another feature of the sgb is its association with the appearance of characteristic zones at actively sliding boundaries. these zones were studied in detail by i. i. novikov et al. on the zn-22% al alloy [68], and after the rejection of the diffusion creep hypothesis, they were called deformation zones (dz). the nature of dz formation has generated lively discussion in the literature, since it directly [6, 7].

The main phenomenological features of superplasticity are as follows:

– superplasticity (sp) is realized in materials with an equiaxed fine-grained structure ($d < 10$ μm), which remains virtually unchanged during deformation;

– elongations before failure δ under sp conditions reach several hundred and even thousands of percent (fig. 1);

– deformation temperature (0.4...0.8) tpl (tpl is the melting temperature of the material);

– the stresses required to deform superplastic materials are significantly lower than for the same materials in a coarse-grained state under the same external conditions;

– the maximum elongation of samples is achieved within a narrow range.

FIGURE 3. Sample of Zn-22%Al alloy before (a) and after (b) testing under superplasticity conditions

This dependence, in its simplest form, explains the stability of plastic flow, which is expressed by the equation σ = A εn εm (A is an empirical constant; n and m are material parameters that determine the dependence of strain hardening on the degree and rate of deformation), when the strain hardening exponent m- is in the range $0.3 < m < 0.8$ [8, 9].

In logarithmic coordinates, the σ-ε dependence has a sigmoidal form (Fig. 3, a), allowing us to identify three characteristic strain rate regions: low (I), optimal (I), and optimal (I). The dependences of δ and m on the strain rate are similar, with both quantities reaching a maximum in the optimal strain rate range (Fig. 3, b).

The stability of SP flow can be explained as follows. If a random narrowing (neck) appears on a tensile specimen, the strain rate locally increases at this location. At high m-values, increasing velocity causes a significant increase in stress, which hinders deformation in the neck and redistributes it to other areas of the specimen. In other words, self-regulation of the flow occurs, which is more effective the higher the m-value [10, 11].

Zn-22% Al and Zn-0.4% Al alloys have proven useful for studying the physical nature of superplasticity [3]. The former, a typical two-phase alloy with a duplex structure, exhibits superplastic properties at 250°C, while the latter, a quasi-single-phase alloy, is superplastic at room temperature. Thus, together, they allow modeling the behavior of two important classes of materials, and the superplasticity temperature significantly simplifies experimental observations.

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