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STRESSED STATE NEAR A WEDGE-SHAPED TWIN WITH A DISBALANCE OF DENSITIES OF TWINNING DISLOCATIONS

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The influence of disbalance of densities of twinning dislocations at the boundaries on the stressed state inside a wedge-shaped twin, near its top, and in external regions adjoining the twinning boundary is studied using a dislocation model.

1. The interest in the stressed state in the vicinity of mechanical wedge-shaped twins is caused by the fact that the character of twin development, interaction of twinning dislocations with total ones, and distribution of admixtures and vacancies near the twin are largely determined by the magnitude and localization of stresses generated by the twinning boundary.

At the same time, in studying strength and plasticity of solids, it is very important to know the stress fields in the vicinity of the wedge-shaped twins. The reason is that the stressed state mainly determines the character of inter-dislocation interaction and affects plastic deformation [1, 2].

At present, the theory of twinning is not adequately developed; therefore, it is advisable to formulate the problem for calculation of stress fields close to the wedge-shaped twin and to investigate the influence of the number of twinning dislocations at two twinning boundaries on the configuration of stress fields.

2. Let us proceed from the assumptions on the dislocation structure of the twinning boundaries [1, 2]. Hirth and Lothe noted [3] that twinning dislocations are partial Shockley dislocations with the Burgers' vector $\boldsymbol{b} = \boldsymbol{b}_{\rm ed} + \boldsymbol{b}_{\rm scr}$ ($\boldsymbol{b}_{\rm ed}$ and $\boldsymbol{b}_{\rm scr}$ are the edge and screw components of the Burgers' vector of the twinning dislocation, respectively).

Let the twinning dislocations be distributed along straight-line twinning boundaries so that the vector $\boldsymbol{b}_{\rm ed}$ is directed along twinning, and the vector $\boldsymbol{b}_{\rm scr}$ is perpendicular to the twinning plane. Then, the stress fields near such a twin can be determined by superposition of the stresses generated by each twinning dislocation.

Measuring the geometrical parameters of the wedge-shaped twins, for example, in the case of deformation of the crystal surface by a concentrated load [4, 5], one can determine the twin length L and width H near the mouth.

3. The above problem can be solved as follows. Determining the dislocation densities at the twinning boundaries ρ_1 and ρ_2 and the length of the twin L from experimental data, and knowing the inter-plane distance a for the material investigated, we determine the numbers of dislocations N_1 and N_2 on each boundary of the twin and the distances d_1 and d_2 between the twinning dislocations along the twinning direction. The values of ρ_1 and ρ_2 are calculated by the formulas

$$\rho_1 = H_1/(aL), \qquad \rho_2 = H_2/(aL). \tag{1}$$

Let a twin of length $L = 10^{-4}$ m and width $H = 5 \cdot 10^{-6}$ m near the mouth be formed in a bismuth single crystal in the vicinity of a stress concentrator. For bismuth, $a \leqslant 3.3 \cdot 10^{-10}$ m [5] (the twinning occurs in the planes $\{110\}$). In the example considered, we have $H_1 = 3 \cdot 10^{-6}$ m and $H_2 = 2 \cdot 10^{-6}$ m. Calculation by formulas (1) yields $\rho_1 = 0.9 \cdot 10^8$ m^{-1} and $\rho_2 = 0.6 \cdot 10^8$ m^{-1}. It is easy to show that $N_1 = 9 \cdot 10^3$, $N_2 = 6 \cdot 10^3$, $d_1 = 1.1 \cdot 10^{-8}$ m, and $d_2 = 1.7 \cdot 10^{-8}$ m. Substituting these values into relations for calculating the stress fields near the wedge-shaped twin, which were obtained by superposition, we determine the stresses in the vicinity of the twin considered.

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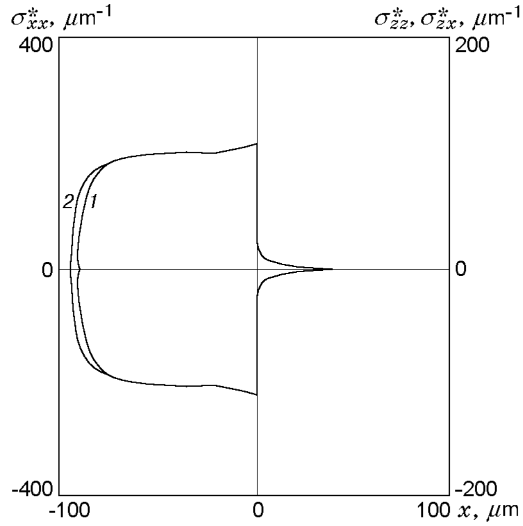

Fig. 1. Calculation results of the stressed state near the wedge-shaped twin [$\sigma^*_{xx}(x,0) = 0$ and $\sigma^*_{zz}(x,0) = \sigma^*_{zx}(x,0) = 0$ for $\rho_1 = \rho_2$]: curve 1 refers to $\sigma^*_{xx}(x,0)$ for $\rho_1 \neq \rho_2$ and curve 2 refers to $\sigma^*_{zz}(x,0)$ and $\sigma^*_{zx}(x,0)$ for $\rho_1 \neq \rho_2$.

For physical analysis, in these relations where the spatial coordinates x and y are used as variables, it is more convenient to accept one of these variables (x or y) equal to zero or to an arbitrary constant. Of interest are the values $x = L$, $L/2$, and 0, which allow one to evaluate the stresses near the mouth, in the middle of the twin, and in the vicinity of the twin top, respectively, by changing the coordinate y. Taking $y = 0$, one can follow the change in the stress inside the twin along the twinning direction.

Figure 1 shows the calculation results of some components of the stress tensor. Note that the figure presents not the dependences $\sigma_{ij} = f(x,y)$ (for given x or y) but the functions similar in form $\sigma^*_{ij} = f(x,y)$, where $\sigma^*_{xx} = -\sigma_{xx}/A$ [$A = \mu b_{\rm ed}/(2\pi(1-\nu))$], $\sigma^*_{zz} = -\sigma_{zz}/B$ [$B = \mu b_{\rm ed}\nu/(\pi(1-\nu))$], and $\sigma^*_{zx} = -\sigma_{zx}/C$ [$C = \mu b_{\rm scr}/(2\pi)$] ($\sigma_{ij}$ are the components of the stress tensor, μ is the shear modulus, and ν is Poisson's ratio). This allows one to avoid calculation of the constants A, B, and C without the loss of generality of results.

4. The result obtained is of great importance for analyzing the character of evolution of the wedge-shaped twin, because the twin develops under conditions of a constant disbalance of densities of twinning dislocations at the twinning boundaries. It is stipulated by defectiveness of the regions where the twins develop and by inconsistency of operation of sources of twinning dislocations at different twinning boundaries.

5. Thus, by means of numerical simulation of the stress fields near the wedge-shaped twin with different densities of twinning dislocations at the twinning boundaries, the role of disbalance of densities of twinning dislocations in the formation of the stressed state in the vicinity of a wedge-shaped mechanical twin have been determined for the first time. It has been found that the stresses near the twin top play the governing role in twin development.

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